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Growth and Employment Potentials of Chosen Technology Fields

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Abstract The development of European technology platforms is a valuable building block of European science and technology policy. Out of the range of technology platforms, seven technology fields were chosen and investigated for their potential impacts on selected economies of the European Union. The study is based on input-output analysis, thus enabling us to account for the complex interrelationships between the sectors related to technology fields, either as origin or as user sectors, and the other sectors of the economy. Multiplier analysis is used to quantify the impacts of demand for goods produced by the sectors related to technology fields. Key sector analysis yields suggestions as to whether these sectors play a key role within the network of intermediate inputs. By linking the input-output tables with data on business enterprise R&D technology flow matrices are calculated and evaluated with respect to the sectors related to technology fields. Subsystem minimal flow analysis (SMFA) is carried out in order to find out whether these sectors are part of growth bipols. Due to the principal difficulty to relate technologies which are not yet applied to actual economic data the results require great care in interpretation. Nevertheless, some patterns emerge from the analysis that suggest that some technology fields seem promising areas for future R&D efforts.

Keywords technology fields, input-output analysis, key sector analysis, technology flows, subsystem minimal flow analysis
JEL classification C67, O33

1. Introduction

The average growth rates of real GDP, labor productivity and total factor productivity of the European Union have fallen behind those of the United States since the mid-1990s (e.g. Mahony and van Ark 2003). In order to catch up, the European Commission launched several initiatives. In the field of European science and technology

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policy a valuable building block is the development of European technology platforms. The objective is to define and realize a common research agenda which integrates, basically in a bottom-up process, all stake-holders of a technology. Today, more than 20 technology platforms exist in various stages of development. Each of them is unique in its origin and concerning its implementation – this is also true for the underlying technology of each platform.

From the range of technology platforms, seven technology fields – *innovative medicines, nanoelectronics, embedded systems, aeronautics and air traffic management, hydrogen and fuel cells* (for these five technology fields see European Commission, 2005b), *photovoltaics* and *food for life* – have been chosen, which are especially important in the economic-policy and European context. The selection was made taking into account the strategic relevance of the subject and the evidence of a substantial long term commitment of the economy. In certain fields, the sample is identical to the issues covered by the Communication of the European Commission of 6 April 2005 (focus on six main programmes, joint European technology initiatives).

The primary aim of the study is to provide deeper insights into possible impacts of different technology fields, especially with respect to production, employment and technology flows for selected European countries. Taking into account the difficulty to relate information about technologies which are not yet applied to actual economic data, the results of this study require great care in interpretation. Recommendations for economic policy cannot be derived in a straightforward manner, but have to be indirectly deduced from assumptions on the input structure of particular industries and commodities related to new technologies. Likewise, expected changes in productivity implied by the new technologies largely depend on assumptions in the absence of reliable estimates.

The problem lies in the cross-classification of new technologies and production activities on the one hand and in the multiple dimensions of competitiveness on the other hand. Moreover, there is a lack of data on technology indicators like R&D expenditures and patented innovations in particular technology fields considered in the study. Although total R&D expenditures are available for industries, data do not exist for particular technology fields. With respect to the technology fields considered in the present study, one study dealing with the economic impact of hydrogen and fuel cells for the German economy (Erdmann and Grahl 2000) could be considered as a valuable source of information. Similar studies for other fields were not available.

Modern economies are characterized by complex interrelations between industries that need to be taken into account in analyzing the impact of different technology fields on the competitiveness of the economy. The definition of policy measures requires that beyond the separate analysis of each industry, each industry is considered as a part of a complex set of interdependencies. Input-output tables, which concern the web of intermediate inputs, encapsulate interrelations through which innovation and technology embedded in intermediate inputs diffuse throughout the economy. “Input-output analysis shows that the competitiveness of the EU economy is not the result of merely aggregating individual industries’ performance but the result of a complex network of relationships between them.” (European Commission (2005b, p. 33) In this way, the innovation or R&D spent in one sector can have repercussions in other sectors of the economy. Input-output analysis is therefore a useful tool to model the knowledge flows and transmission of economic rents that arise from R&D and was used in numerous studies (e.g. special issue of the Journal of Economic System Research in 1997 and 2002, European Commission, 2005c, and others). It also provides the methodological background for the presented study.

The remaining sections of the study are the following. The next section introduces to the chosen technology fields. Then the employed data and methods are described. Two sections present the results of the input-output analysis, the first one of the multiplier and key sector analysis and the second one of the technology flow analysis and subsystem minimal flow analysis. The last section concludes.

2. Technology fields with European perspectives

This analytical survey focuses on seven different technology fields, each of them presumably being of vital importance for the future development of the European economic area. Furthermore, knowledge and technology flows might appear between the single fields. Each single technology would deserve to be treated comprehensively in terms of content. Instead of such a detailed description, which would go beyond the scope of the present study, we provide the reader with an overview of the technology fields in Table 1.

It is not immediately clear how these technology fields can be related to economic activities, as captured in currently used classification systems. However, such a link between technology and economic sectors has to be created if an analytical tool such as input-output analysis is to be employed.

Basically, numerous technologies can neither be commonly classified nor are there any internationally accepted definitions. This lack of definitions and classifications exists for both, economic fields in which technologies are developed and for those in which technologies are applied. For a good part, the technology fields are concerned with technologies in the stage of development and of high development potential. Future capabilities and concrete fields of application might be guessed vaguely only, but not defined precisely. The dynamic aspect comes into play when one technology is combined with another one or when it serves to enable innovative activities in the first place. Against this background, an assessment can only be feasible to a certain degree.

We based the linking between technology fields and economic activities on work already done, e.g. by National Science Foundation, OECD and others, and on interviews with 35 experts from the academics and business. The results of this process, which focuses on the technology origin in a consistent sectoral classification, can be seen in Table 2. Though technologies might not be coequal in different countries, this mapping constitutes a good starting point.

As can be seen from Table 2, there are overlappings – e.g. in the electronic industry research and development are done on the field of nanoelectronics as well as on the field of information and communication technologies.

Table 1. Technology fields description

EU-level coordination	Potentials
Innovative Medicines (1) European Technology Platform on Innovative Medicines	In 2000, the market volume of the pharmaceutical sector is estimated to amount to 320 billions dollars. The market potential of technologies which recognize the effects of substances in preclinical phases vary. For example, DNA chip technology is assumed to surmount a market potential of 1 bn USD in 2005. Enormous capabilities are assigned to the pharma market, not only on the basis of demographical developments.
Nanoelectronics (2) European Nanoelectronics Initiative Advisory Council (ENIAC)	The market volume of the microelectronic and nanoelectronic value chain is estimated to be nearly 1% of the world wide gross domestic product; with high growth rates amounting to 15% annually. The weight of industries influenced directly by nanoelectronics amongst others telecommunications operators, consumers' products, internet services, constructors of vehicles, defense, space is estimated to be higher.
Embedded Systems (3) Advanced Research and Development on Embedded Intelligent Systems (ARTEMIS)	The development of embedded systems is pushed by new options, which result from increasing computing power, decreasing costs as well as networking of components. More and more embedded systems are used in order to offer services for firms and persons. In 2003, on average about 8 billion embedded systems existed worldwide. Conservative estimations forecast a doubling of this figure to 2010.
Aeronautics & Air Traffic Management (4) Advisory Council for Aeronautics Research in Europe (ACARE)	The contribution of the air transport sector to GDP will continue to grow. The sector forecasts that over the next decade, both passenger and freight traffic is expected to increase at an average of 4 to 5% p.a. ACARE expects that the sector will create between 2 and 4 million new jobs by 2020, even assuming conti-nued productivity gains at historic levels, with the GDP contribution of the air transport sector increasing from 2.6% to about 3.3%. The contribution to the wider economy through reliance effects that enable a diversity of businesses to succeed better is expected to rise from its present 8 to 10% to 11 to 13%.
Hydrogen & Fuel Cells (5) European Hydrogen and Fuel Cell Technology Platform (HFP)	If pure hydrogen could be used directly to power fuel cells, a number of environmental and engineering advantages would arise. Fuel cells in vehicles combine very high-energy efficiency with zero exhaust emissions and potentially low noise. In the medium to long term, fuel cells have a strong energy saving potential for decentralised co-generation in households and buildings and for power pro-

EU-level coordination	Potentials
	duction. In the long term, they could replace a large part of the current combustion systems in all energy end use sectors. According to the state of knowledge at present, the estimated market volume for fuel cells in 2010 for Germany can be around 3.5 bn EURO. Experts estimate the market volume of fuel cell cars for 2020 to 14 million cars world wide; this corresponds to a market share of 25% based on 1999.
Photovoltaics (6) European Technology Platform on Photovoltaics (A vision report throws light on the way ahead for the Photovoltaic Technology Platform)	Solar power is a key technology and an investment into the future. This can be demonstrated by the increasing interest of the finance industry (until 2010 the turnover is estimated to reach 30 bn USD). Japan is the world leader with a market share of 45% (notably, the Japanese government supports photovoltaics). The second largest share of the market (28%) belongs to European firms, whereby the production of the European enterprises outstrips the output of US firms. Five of the top 10 firms of this industry are European ones, four are of Japanese origin and one firm is American.
Food for Life (7) European Technology Platform on Food for Life	The European agriculture and food industry is the largest manufacturing sector in Europe. 4.1 million people in the European Union are employed in this sector predominantly in small and medium-sized enterprises. In 2004, the turnover of the food and beverage industry turned out to be 810 bn EURO; moreover, the food and beverage industry turned over 70% of the agricultural raw materials.The food and drink industry covers a market of 450 million consumers in the EU. The preferences of consumers for quality and health, and their justifiable expectations of safety, ethics and sustainable food production serve to highlight the opportunities for innovation. New products will have to fit the needs, lifestyles and incomes of consumers.

Source: ACARE (2004), ACARE (2004), Confederation of the Food and Drink Industries of the EU (2005), ENIAC (2003), EC(2005a), Group of Personalities (2001), Mahlich (2005), Nowak (2005), europa.eu.int/comm/research/energy, www.bics.be.schule.de, www.europa.eu.int, www.cordis.lu/ist/artemis, www.cordis.lu/technology-platforms/summaries.htm, www.tci.uni-hannover.de, www.fona.de, www.fumatech.com, www.solarserver.de.

In a more ambitious approach it was tried to assign statistical weights to each economic activity according to its importance for a certain technology field. But asking experts on this issue produced very heterogeneous answers and allowed a wide spectrum of interpretation. Thus these results are not taken into account in the study. However, such endeavors, possibly institutionalized in the form of expert groups consisting of statisticians, technicians, economists and business agents, could be an important first step towards impact assessment of technology fields.

Table 2. Cross classification of technology fields and economic activities (fields of origin) on a two-digit level

		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Food products and beverages	15							✓
Chemicals, chemical products (incl. pharmaceuticals)	24	✓				✓		✓
Fabricated metal products	28					✓		
Machinery and equipment n.e.c.	29					✓		
Electrical machinery and apparatus	31					✓		
Radio, TV and communication equipment	32		✓	✓			✓	
Motor vehicles, trailers and semi-trailers	34					✓		
Other transport equipment (incl. aircraft and spacecraft)	35				✓			
Electrical energy, gas, steam and hot water	40					✓		
Construction work	45						✓	
Air transport services	62				✓			
Supporting transport services and travel agency services	63				✓			
Computer and related services	72	✓		✓				

3. Data and methods

3.1 Database

There are two main sources for input-output tables on an international level: Eurostat and OECD. The former provides tables in commodity-by-commodity classification, the latter in industry-by-industry classification. Though working with the OECD tables offers some advantages[1] we use the more recent Eurostat input-output tables. The tables cover 59 product groups classified on a CPA 2-digit level.[2] We analyze the six countries listed in Table 3.

The choice of countries is motivated by the aim to have a mixture of small and big countries as well as old and new Member States situated in different geographic regions of the continent. A wide diversification of countries is beneficial because the results of the input-output analysis depend on size, economic structure and the geographic location of countries. The choice is also influenced by data availability. An important criterion is the up-to-dateness and the quality of data.

France and Germany are selected because of their large size and Austria and the Netherlands because of the small size of their economies. Additionally, Italy is chosen because it is located in the south of the European continent. Finally, Poland is included because it is a former transition country and its membership in the EU is relatively new.

[1] Since the OECD tables are in industry-by-industry classification they can be combined with other data that is also classified by industries. Furthermore, in the OECD tables pharmaceuticals (CPA 24.4) and aircraft and spacecraft (CPA 35.3) are shown separately, which is convenient for the analysis of technology fields.

[2] CPA stands for statistical classification of products by activity (CPA) in the placeEuropean Economic Community. For further details see Commission Regulation (EC) No 204/2002 of 19 December 2001 and Council Regulation (EEC) No 3696/93 of 29 October 1993.

Table 3. Data overview

Country	Year of IO-table	Year of employment data	Year of R&D data
Austria	2000	2000	2002
France	2000	2000	2000
Germany	2000	2000	2000
Italy	2000	2000	2000
Netherlands	2001	2001	2001
Poland	2000	2000	2000

The input-output tables used do not contain any information about employment. Employment data are taken from the 60-industry database of the Groningen Growth and Development Centre.[3]

In the original tables used for the simple multiplier analysis, sectors of pharmaceuticals (CPA 24.4) and aircraft and spacecraft (CPA 35.3) are aggregated in chemical products (CPA 24) and other transport equipment (CPA 35) respectively.

For the technology flow and subsystem minimal flow analyzes (SMFA) some additional aggregation and disaggregation procedures are applied to the tables. First, in order to have pharmaceuticals and aircraft and spacecraft available as separate sectors, they were isolated from their respective sectors using the best available information about the structure of the intermediate consumption of these two sectors and about the structure of the intermediate consumption of other sectors with respect to these two sectors. This information is taken from OECD input-output tables either from the same country or from France, depending on the detail of disaggregation available in the OECD tables. Some other information is introduced to verify this procedure.[4]

Second, in order to reduce the number of sectors in a way suitable for the SMFA, several sectors that are not connected to the technology fields considered are aggregated, following a scheme corresponding largely to the structure of the OECD input-output tables. The input-output tables applied have 45 sectors.

With respect to the subject of the analysis, different versions of input-output tables are used. Version B, which contains domestic input-output relations only and treats imports as separate variable, is used for the multiplier analysis and estimation of key sectors. In contrast, version A, which treats both domestic and imported intermediate goods, is used for the analysis of the technology flows and SMFA. This differentiated approach seemed appropriate because multiplier analysis deals with the impact on domestic production while SMFA is related to the technological structure regardless of the origin of inputs.

Technology flow analysis and SMFA are based on data of business R&D expenditures. Alternatively to R&D data, technology flow analysis could also be based on other indicators and methods.[5] We use the OECD Analytical Business Enterprise R&D

[3] For further details see http://www.ggdc.net/dseries/60-industry.html.

[4] More details on the procedures used for disaggregation are available upon request.

[5] In recent years, several authors have proposed different kinds of technology-specific matrices (see e.g. Economic Systems Research, vol. 9, issues 1 and 2). According to Dietzenbacher and Los (2002) it seems

database (OECD 2004) which largely corresponds to the classifications of input-output tables. Data is cross-checked (and in some cases ameliorated) with the Eurostat Business Enterprise R&D Expenditure (BERD) database (Eurostat 2004). Only for Austria, Eurostat data are used. The data are broken down by activity and reclassified by product groups applying the algorithm by Almon (2000).[6] The data are in current prices.

In order to prevent possible misinterpretation it should be made clear that no data are available on R&D carried out in specific technology fields. Thus, our technology flow and SMFA analyzes are based on the assumption that high (or low) R&D expenditures of sectors related to certain technology fields contain also high (respectively low) expenditures related to this technology field.

3.2 Multiplier analysis

In order to get a better insight into the structure and interdependencies of the economy, the standard multipliers are estimated in the first step. It is assumed that the demand for related products increases because of the introduction of new technologies (e.g., because of better position of the European industry in the international market). A rise in demand affects economies in terms of production, value added, employment, etc.

The impacts of technology fields are analyzed by using a demand-oriented open Leontief input-output model. In this model, changes in final demand are translated via the Leontief inverse matrix into corresponding changes in the production of goods which is necessary to satisfy final demand (for details see Appendix A or Miller and Blair 1985, chapters 2 and 4).

The output multiplier (production or backward linkage multiplier) measures the output in the economy that is necessary to deliver one unit of a particular commodity (e.g. EUR 1 million) to final demand.

The employment multiplier of a commodity gives us the total employment in the economy generated by one unit (e.g. EUR 1 million) of that commodity delivered to final demand. The employment multipliers take into account interdependencies between sectors in the economy on the one hand and the labor intensity in the production of particular commodities on the other hand.

Additional insights into the structure of the economy are provided by the so called *output-to-output multiplier*, which can be derived by the mixed model (see, for example, Miller and Blair 1985, chapter 9). The output-to-output multipliers reveal the output value induced in the economy by one unit (e.g. EUR 1 million) of production of a particular commodity.

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useless to apply the methodology we proposed in this section to other technology-specific materials, despite its initial attractiveness. In particular, the proportionality assumption with regard to inputs and outputs is extremely awkward in this respect.

[6] This algorithm uses the information contained in the make matrix and could not be applied to data for Poland due to a lack of the make matrix. For the Netherlands and Germany, additional corrections were necessary in two sectors.

3.3 Key sector analysis

In the framework of an input-output model, production by a particular sector has two economic effects on other sectors of the economy. If sector j increases its output, this means that there will be an increased demand of sector j (as a purchaser) on sectors whose products are used as inputs for production of commodity j. This is the direction of causation in the usual demand-side model presented above and used in this study.

The term *backward linkage* is used to indicate a connection between a specific sector and those sectors from which the inputs come. If the power of dispersion for the backward linkages is greater than 1, this indicates that a unit change in final demand of commodity j will create an above-average production increase in the economy.

The term *forward linkage* is used to indicate a connection between a particular sector and those sectors to which it sells its output. If the power of dispersion for forward linkages is greater than 1, this asserts that a proportional change in all commodities' final demand would create an above-average increase of production in sector i. The comparison of the strengths of backward and forward linkages for sectors in an economy provides one mechanism for identifying key sectors. A key sector is usually defined as one in which both indices are greater than 1 (see Sonis, Hewings and Guo 2000; the approach is described in Appendix A).

3.4 Technology flow analysis

The analysis of technology flows helps to identify technology diffusion patterns for technology fields, respectively for those sectors that are linked to the technology fields. Research and development activities within the originating sectors of a new technology lead to spillover effects in other sectors of the economy based on several possible channels. A basic distinction is made between disembodied and embodied technology diffusion. Disembodied technology transfer encompasses direct knowledge transfer through experts, literature or imitation. Embodied technology transfer comes about through the purchase of intermediate or investment goods containing a new technology.

The hypothesis of positive spillover effects of embodied technology transfers guided the research agenda in this field from the beginning (e.g. Griliches 1979). The main arguments are that the use of better intermediate and investment goods leads to productivity gains in the user industry. Because of the limited market power of the provider of the new technology, the provider can not appropriate the entire rent of the new technology and some of it is taken by the user industries. However, depending on the market power constellation, negative spillover effects may arise when sectors using new technologies are forced to pay higher prices for intermediate or investment goods, but are not able to effect the corresponding productivity gains or market prices (see Dietzenbacher and Los 2002, for a more detailed discussion). Thus, a more complete analysis of the effects of technology flows has to take account of competition.

Embodied technology transfer is usually measured by linking an indicator of the innovation activity to the input-output system of an economy. By following this approach, the present analysis links business R&D expenditures to the input-output table. As discussed in earlier contributions, a limitation of this approach is that technology flows embodied in the purchase of investment goods are omitted in the analysis. It would be desirable to include these since many investment goods are produced by R&D-intensive industries. However, including investment flows in the analysis would require an extension of the simple static input-output model. Furthermore, the database (including capital stock data) is not available in a quality that allows the comparison of the six countries chosen.

By linking the innovation indicator (e.g. R&D expenditures) to the input-output system one gets the technology flows matrix. This is a table that specifies how the R&D expenditures carried out by one sector are received by the sector itself or by other sectors through direct or indirect intermediate relationships.

In this study, we analyze two versions of the technology flow matrix (for the technical derivation of technology flow matrix see Appendix A or Schnabl 2000). The so-called actual structure incorporates information on the actual final demand and, thus, represents actual technology flows.[7] We use this matrix to calculate R&D spillover rates, defined as the sum of R&D expenditures of sector j received by other sectors divided by the total R&D expenditures of sector j.

In contrast thereto, the standard structure neglects information on the actual final demand by replacing final demand by a vector of 1 in the calculation formula. We use this matrix to calculate R&D backward multipliers according to Dietzenbacher and Los (2002). These measure the R&D expenditures that are stimulated in the economy by one unit (e.g. EUR 1 million) of final demand for a specific commodity.[8] The empirical results by Dietzenbacher and Los (2002) confirm that high-tech industries are characterized by high total backward R&D multipliers. The result is not surprising because the production of these commodities requires relatively more R&D intensive commodities produced by other sectors.

It is also possible to analyze the technology flows that come from selected sectors only. Based on the actual structure, this approach will be used to identify the main technology users of those sectors which are related to the selected technology fields as originating sectors of the technology.

3.5 Subsystem minimal flow analysis

In a next step of our analytical procedure, we apply subsystem minimal flow analysis (SMFA) to our data. This part is based on the technology flow matrices defined in the previous section. It aims at analyzing and visualizing the core of the National Innovation System (NIS). Freeman (1986) describes an NIS as the network of institutions in the public and private sectors whose activities and interactions initiate, modify and diffuse new technologies. Thus, the NIS typically includes organizations and institutions such as R&D departments, technological institutes and universities. A broader

[7] For calculating the actual structure of the technology flow matrix, the final demand for domestic goods is used. Furthermore, in order to ensure consistency of the model, a correction in the production vector used for the calculations is needed (for further details see Appendix A).

[8] There is a strong empirical correlation between R&D backward multipliers and R&D intensity, defined as the ratio of R&D expenditures of sector j to the output of sector j. This is to be expected, since the final demand for commodity j regularly stimulates R&D primarily in the sector that produces commodity j.

definition by Lundvall stresses the system aspect: “The broad definition . . . includes all parts and aspects of the economic structure and the institutional set-up affecting learning as well as searching and exploring – the production system, the marketing system and the system of finance present themselves as subsystems in which learning takes place.” (Lundvall 1992, p. 4)

SMFA (Düring and Schnabl 2000, Schnabl 2000) is an advancement of Minimal Flow Analysis (Schnabl 1995) and qualitative input-output analysis (see Appendix A for details). Like these, it is an input-output based method for finding qualitative structure in a system of interrelationships between sectors that would otherwise not be visible at a first glance. By considering only those flows that exceed a certain filter value, the complexity of the system is reduced, thereby enabling analysis. The focus is on those technological links that are relatively intensive and, therefore, provide strong impulses for growth of the NIS.

When a link between two sectors is only strong in one direction it is called a unidirectional link. A bilateral link exceeds the filter value in both directions. The sectors forming part of bilateral links are considered to be the growth core of the economy.

SMFA deals with both versions of technology-flow matrices introduced in the previous section (“actual structure” and “standard structure”). The sectors that show up as core sectors in both versions are called “growth bipols” or “bipols” and are considered as the core of the NIS. The SMFA captures the technological interrelationships of the sectors of the economic system. Thus, it encompasses an important part, but not the entire National Innovation System (NIS) since it leaves out other important parts like the education and university system. Schnabl (2000) argues that if the NIS is a “real” phenomenon, it should emerge as a consistent phenomenon, independent of the analytical approach.

4. Results of multiplier and key sector analysis

This part presents standard multipliers as well as results of key sector analysis for the selected European countries.

4.1 Standard multipliers

The results show that the values of multipliers differ significantly from country to country and with respect to the commodities related to the technology fields. These varieties are not only caused by differences in the economic structure or in labor productivity, but also by the size of countries. Like in other studies, the multipliers of big countries are systematically higher than the multipliers of small countries. These variations come from differences in the openness of countries to foreign trade. In small countries, enterprises generally use a smaller portion of domestically produced intermediate inputs than is the case in big countries. Consequently, indirect effects of their activities on their home economies are smaller than in big countries.

Let us start with a detailed description for the technology field of *innovative medicines*. The results for this technology field are summarized in Table 4, while the results for the remaining technology fields will be presented later.

Table 4. Multipliers for commodities related to innovative medicines

	Output multiplier		**Employment multiplier***			**Output-to-output multiplier**		**Key sector**
	min	max	min	max	max**	min	max	cases no.
Origin								
PHARM	1.49	**1.96**	**6.55**	36.01	10.02	1.38	1.62	3
COMPU	**1.29**	1.71	10.88	**40.85**	**19.19**	1.16	1.53	1
Users (top 5)								
HEALT	1.31	1.75	20.68	112.40	28.45	1.28	1.45	0
FOODP	1.90	2.43	11.78	151.71	22.36	1.59	1.91	4
ADMIN	1.35	1.54	15.27	44.80	20.46	1.35	1.50	0
MACHI	1.52	1.97	10.62	60.72	14.10	1.47	1.83	2
CONST	1.52	1.97	13.80	52.01	20.59	1.42	1.78	5

* Persons per 1 million EURO.
** Without Poland.

Innovative medicines has two origin sectors: pharmaceutical goods (PHARM) and computer and related services (COMPU). Looking at the first row of Table 4 related to pharmaceuticals (PHARM), the production multiplier for the six countries under consideration lies between 1.49 (for Austria), indicated in the column "output multiplier min", and 1.96 (for France), indicated in the column "output multiplier max." Increasing final demand in commodity pharmaceuticals (PHARM) by one unit (e.g. EUR 1 million) increases the production in the selected European countries by 1.49 to 1.96 units (e.g. million euro).

Multipliers for the second commodity, computer and related services (COMPU), range from 1.29 (for Germany) to 1.71 (for France). Summarizing the results, we can see that output multipliers for commodities related to *innovative medicines* lie between 1.29 and 1.96 (see figures printed in bold face). In other words, increasing final demand for commodities of this group by one unit generates additional production in the selected European countries by 1.29 to 1.96 units, depending on the proportions of both commodities in the final demand.

The top five users[9] of the goods belonging to *innovative medicines* are: health and social work services (HEALT), food products and beverages (FOODP), public administration services (ADMIN), machinery and equipment (MACHI) and construction work (CONST), indicated in the last five rows in Table 4. Analogously to the previous interpretation of the first two rows in Table 4, increasing the final demand in commodities of this group by one unit (e.g. EUR 1 million) generates an increase of production by 1.27 to 2.43 units (depending on the structure of the final demand) in the selected European countries.

The next three columns of Table 4 contain the results for employment multipli-

[9] The top five users were identified on the basis of technology flow analysis, which is the subject of the following section.

ers. They indicate the employment effect of an increase in final demand for particular commodities by EUR 1 million. As the first row related to pharmaceuticals (PHARM) shows, the employment multiplier for the six countries under consideration ranges from 6.55 (for the Netherlands) to 36.01 persons employed per EUR 1 million (for Poland). The high multiplier for Poland is caused by its low labor productivity relative to all other countries investigated in this study. The productivity of Poland is between one quarter and one fifth of the productivity in other economies of the sample. This low labor productivity results in a larger labor input for producing EUR 1 million of output compared to all other countries in the sample. If Poland is excluded, the multiplier ranges from 6.55 to 10.02 employees per EUR 1 million.

Multipliers for the second commodity, computer and related services (COMPU), lie between 10.88 (for Austria) and 40.85 persons employed per EUR 1 million (for Poland); if Poland is excluded, multipliers range from 10.88 to 19.19 persons employed per EUR 1 million (for Italy).

In summary, it can be seen that employment multipliers for commodities related to *innovative medicines* lie between 6.55 and 19.19 persons employed per EUR 1 million (see bold figures in the fifth column). Increasing final demand for the commodities of this group by EUR 1 million generates an increase of employment by 6.55 and 19.19 persons in the selected economies (excluding Poland). The employment multiplier can be interpreted in a similar way with respect to the users of *innovative medicines*.

Output-to-output multipliers in columns 6 and 7 of Table 4 describe the effects caused by an increase in the production of a specific commodity on the rest of the economy. Increasing the output of pharmaceuticals (PHARM) by one unit implies that the output will rise by 1.38 to 1.68 units in the selected European countries. The output-to-output multiplier for computer-related services (COMPU) ranges from 1.16 to 1.53. Summarizing the output-to-output multipliers over the six European countries considered, we have a range from 1.16 to 1.62. In the same way, the output-to-output multiplier for the users (the last five rows) can be provided.

The discussion of the results for the remaining technology fields summarized in Table 5 is straightforward. Considering the origin sectors, we can see that relatively higher production effects can be expected from goods related to the technology field *food for life*: The lowest value is 1.49 and the highest value reaches 2.43 (highest lower bound and highest upper bound for the output multipliers over all technology fields).

With regard to the multipliers of the user sectors of the goods related to technology fields *innovative medicines* and *aeronautics and air traffic management* might have slightly higher impacts on production than the other technology fields. An increase of final demand by EUR 1 million in commodities related to the above-mentioned technology fields can generate a value of production in the economy from EUR 1.31 to 2.43 million (due to the multiplier for food products). In comparison, the average output multiplier (output generated by one unit of final demand) lies between 1.52 and 1.77 in the six European countries under consideration.

Table 5. Multipliers for commodities related to selected technology fields (except innovative medicines)

	Output multiplier		Employment multiplier*			Output-to-output multiplier		Key sector
	min	max	min	max	max**	min	max	cases no.
Nanoelectronics								
Origin								
RADEQ	1.32	2.12	6.22	29.45	12.19	1.31	1.78	0
Users (top 5)								
MACHI	1.52	1.97	10.62	**60.72**	14.10	1.47	1.83	2
OFFMA	1.34	1.76	5.64	37.86	10.95	1.33	1.71	0
PTELE	1.46	1.86	11.26	50.46	14.02	**1.25**	1.64	2
CONST	1.52	1.97	13.80	52.01	**20.59**	1.42	1.78	5
MOTOR	**1.27**	**2.23**	**5.06**	33.15	14.06	**1.25**	**1.97**	0
Embedded systems								
Origin								
RADEQ	1.32	**2.12**	**6.22**	29.45	12.19	1.31	**1.78**	0
COMPU	**1.29**	1.71	10.88	**40.85**	**19.19**	**1.16**	1.53	1
Users (top 5)								
MACHI	1.52	1.97	10.62	**60.72**	14.10	1.47	1.83	2
CONST	1.52	1.97	13.80	52.01	**20.59**	1.42	1.78	5
ADMIN	1.35	1.54	15.27	44.80	20.46	1.35	1.50	0
MOTOR	**1.27**	**2.23**	**5.06**	33.15	14.06	**1.25**	**1.97**	0
OFFMA	1.34	1.76	5.64	37.86	10.95	1.33	1.71	0
Aeronautics and Air Traffic Management								
Origin								
AIRCR	**1.51**	2.27	8.37	58.96	12.95	1.48	1.73	1
TRAIR	1.53	2.04	**6.94**	32.65	9.77	1.49	**1.96**	0
TRSER	1.58	**2.34**	9.66	**70.09**	**19.00**	**1.15**	1.73	3
Users (top 5)								
TRAIR	**1.35**	1.54	15.27	44.80	20.46	1.35	1.50	0
ADMIN	1.53	2.04	**6.94**	32.65	9.77	1.49	**1.96**	0
TRANS	1.46	1.76	12.61	46.39	**24.01**	1.39	1.70	0
CONST	1.52	1.97	13.80	52.01	20.59	1.42	1.78	5
TRSER	1.58	**2.34**	9.66	**70.09**	19.00	**1.15**	1.73	3
Hydrogen & Fuel Cells								
Origin								
CHEMI	1.49	1.96	6.55	36.01	10.02	1.38	1.62	3
PRDMT	1.51	1.90	11.78	52.98	**16.67**	1.35	1.72	5
MACHI	1.52	1.97	10.62	**60.72**	14.10	1.47	1.83	2
EMACH	1.47	1.93	9.55	47.56	16.28	1.43	1.80	1
MOTOR	**1.27**	**2.23**	5.06	33.15	14.06	1.25	**1.97**	0
ENERW	1.48	1.91	**4.90**	45.53	11.80	**1.20**	1.77	4

	Output multiplier		**Employment multiplier***			**Output-to-output multiplier**		**Key sector**
	min	max	min	max	max**	min	max	cases no.
Users (top 5)								
CONST	1.52	1.97	13.80	52.01	20.59	1.42	1.78	5
MOTOR	**1.27**	**2.23**	**5.06**	33.15	14.06	**1.25**	**1.97**	0
MACHI	1.52	1.97	10.62	**60.72**	14.10	1.47	1.83	2
ADMIN	1.35	1.54	15.27	44.80	20.46	1.35	1.50	0
MTREP	1.45	1.74	14.63	43.83	**23.51**	1.35	1.67	1
Photovoltaics								
Origin								
RADEQ	**1.32**	**2.12**	**6.22**	29.45	12.19	**1.31**	**1.78**	0
CONST	1.52	1.97	13.80	**52.01**	**20.59**	1.42	**1.78**	5
Users (top 5)								
MACHI	1.52	1.97	10.62	**60.72**	14.10	1.47	1.83	2
OFFMA	1.34	1.76	5.64	37.86	10.95	1.33	1.71	0
ADMIN	1.35	1.54	15.27	44.80	**20.46**	1.35	1.50	0
MOTOR	**1.27**	**2.23**	**5.06**	33.15	14.06	**1.25**	**1.97**	0
PTELE	1.46	1.86	11.26	50.46	14.02	**1.25**	1.64	2
Food for Life								
Origin								
FOODP	1.90	**2.43**	11.78	**151.71**	**22.36**	1.59	**1.91**	4
CHEMI	**1.49**	1.96	**6.55**	36.01	10.02	**1.38**	1.62	3
Users (top 5)								
CONST	1.52	1.97	13.80	52.01	20.59	1.42	1.78	5
RUBBP	1.40	1.91	10.26	43.97	13.67	1.39	1.75	2
MOTOR	**1.27**	2.23	**5.06**	33.15	14.06	**1.25**	**1.97**	0
FOODP	1.90	**2.43**	11.78	**151.71**	22.36	1.59	1.91	4
HOTRE	1.59	1.88	18.61	87.47	**38.15**	1.57	1.87	0

* Persons per 1 million EURO.
** Without Poland.

Summarizing the employment multipliers for selected technology fields the results show that relatively higher employment effects can be expected from goods related to the technology *food for life* having the highest lower bound (6.55 persons per EUR 1 million) and highest upper bound (151.71 per EUR 1 million or 22.36 per EUR 1 million if Poland is excluded) over all technology fields.

As far as the users of technology fields are concerned, the lower bound of multipliers is slightly higher for goods belonging to *innovative medicines* and *aeronautics and air traffic management*. With respect to the upper bound, relatively higher employment effects can be expected from the technology fields *innovative medicines* and *food for life*. An increase of final demand in the commodities related to *innovative medicines* by EUR 1 million can generate employment in the economy for 10.62 to 28.45 persons (excluding Poland). In comparison, the average employment multipliers of final demand (employment generated by EUR 1 million of final demand) range from 14.27 to 17.66 (excluding Poland).

The results of the multiplier analysis discussed above do not take into account any innovation indicators. Therefore the analysis has been extended by technology flow analysis and SMFA. Before we proceed to this part of the analysis, useful insights can be provided by a key sectors analysis.

4.2 Key sectors

This section shows the results of the key sector analysis. Like in the previous section, the investigation focuses on domestic production. The outcome differs from country to country. Results are determined by interdependencies between sectors. Key sectors are characterized by their pronounced linkages to other sectors. They create above-average impacts on the rest of the economy generated through changes in final demand.

The results of the key sector analysis are indicated in the last column of Table 4 and Table 5. In each row of this column, the number of countries is displayed in which a sector is identified as a key sector.

In the first row for pharmaceuticals (PHARM), this sector is classified as a key sector in three countries (France, Germany, and the Netherlands). In these countries, this sector generates above-average effects on production in the rest of the economy. The second commodity, computer and related services (COMPU), is identified as a key sector in one country (Austria). In summary, we can see that commodities from originating sectors of *innovative medicines* are identified as key sectors in one to three countries. The top five users of the goods belonging to *innovative medicines* (as input) are classified as key sectors in zero to five countries. The results of the key sector analysis for other technology fields can be interpreted in the same way. The more often the sectors belonging to a technology field are identified as key sectors, the higher are its economic potentials.

By surveying originating sectors of new technology, we can distinguish two groups of technology fields. The first group consists of the fields *innovative medicines*, *hydrogen and fuel cells*, and finally *food for life* with a relatively high number of key sectors. For *innovative medicines*, pharmaceuticals (PHARM) are indicated as key sector in three countries and computer and related services (COMPU) in one country. Supposing that pharmaceuticals (PHARM) are more important for this field, above-average production impacts can be expected in the European Union. Chemical products (CHEMI), the most important commodity among the goods related to *hydrogen and fuel cells*, are a key sector in three countries. Several other goods which belong to this technology field are also key sectors in several countries. Therefore, there can be above-average economic impacts from this field. The most important sector for *food for life*, food products (FOODP), is a key sector in four countries and the second important sector for this field, chemical products (CHEMI), is a key sector in three countries. Consequently, there may be above-average impacts emanating from the sectors of this technology field.

The second group consists of the fields *nanoelectronics*, *embedded systems*, *aeronautics and air traffic management*, and finally *photovoltaics*. The goods of *nanoele-*

ctronics are products of a key sector in no country. The important sector for *embedded systems*, namely radio, television and communication equipment (RADEQ), is not a key sector in any country. The other less important sector, computer and related services (COMPU), is a key sector in one country only. For *aeronautics and air traffic management*, the most important sector, aircraft and spacecraft (AIRCR), is a key sector in one country only and the second important sector is not a key sector in any country. In the field *photovoltaics*, the more important sector is radio, television and communication equipment (RADEQ), which is not a key sector in any country. Only the less important sector, construction work (CONST), is a key sector in five countries. Therefore, an increase in the final demand of commodities belonging to these fields might induce below-average effects.

To get a complete picture of the influences of goods belonging to the technology fields, it is advisable to take into account a key sector analysis for technology users. From the point of view of technology users, the distinction between a first group of technology fields with a relatively high potential of above-average impacts and a second group with below-average effects is less clear. But in principle, the classification is similar to the one of origin sectors, particularly if the interpretation focuses on the three most meaningful users.

The first group consists of *innovative medicines*, *embedded systems*, *hydrogen and fuel cells*, and finally *food for life*. In all of these technology fields, related goods which are counted as user sectors in many countries are frequently indicated as key sectors. Therefore, from this point of view there is also some potential of above-average impacts of technology users in the economies of some countries is given.

The second group comprises *nanoelectronics*, *aeronautics and air traffic management*, and finally *photovoltaics*. The goods related to these fields are less frequently classified as products of key sectors. Thus, it is less probable that technology users generate above-average impacts in many EU countries compared with the first group.

5. Results of technology-flow and subsystem minimal flow analyses

While the results of the multiplier analysis presented in the previous section are based on interdependencies between sectors or production of commodities only, technology flow analysis takes into account R&D expenditures spent in one sector and spillover effects generated in other sectors of the economy.

The results of the technology flow analysis and the SMFA are summarized in Table 6. First, we discuss the results of the technology flow analysis. Second, the SMFA results are presented, which are based on technology flow matrices.

5.1 Technology flows

Technology flow matrices can be evaluated in many different ways. Here, we focus on three main aspects, all of which are summarized in Table 6 and Table 7:

(i) How large are the R&D expenditures stimulated by final demand for commodities produced by sectors related to technology fields? In close relation to this aspect: What technology category do the sectors belong to?

(ii) What is the fraction of R&D expenditures of technology origin sectors related to technology fields that spills over to other sectors via technology flows embodied in intermediary goods?

(iii) What are the major user sectors of the selected fields?

We will answer each of these questions separately. As in the previous chapters, we explain how Table 6 is read by using the technology field *innovative medicines* as an example first. We then proceed to the other technology fields.

The answer to the first question is provided by the R&D backward multipliers, which are to be interpreted in the following way: An increase of final demand for pharmaceutical goods (PHARM) by one unit stimulates R&D expenditures by 0.0259 (Poland) to 0.1635 (Germany) units. These values are relatively high. Most of the R&D stimulated by final demand for pharmaceuticals is, of course, carried out by the sector itself, which has a very high R&D intensity. For purposes of comparison, the OECD classification by technology category for manufacturing sectors is included in a separate column of Table 6. The pharmaceutical sector is classified as a high-technology sector. The other origin sector of *innovative medicines*, computer and related services (COMPU), has a multiplier of ranging from 0.0022 to 0.0371. Since it is not a manufacturing sector, no OECD technology classification is available for this sector.

The analysis of R&D backward multipliers for the seven selected technology fields yields results that are confirmed by the OECD classification by technology category. Besides *innovative medicines*, the group of technology fields that have a main origin sector with high R&D multipliers also contains *nanoelectronics*, *embedded systems*, *aeronautics and air traffic management, and photovoltaics*. In the technology field *hydrogen and fuel cells*, several related sectors have medium to high R&D multipliers and are accordingly classified by the OECD as medium-high technology category. Only *food for life* stands out, having a main sector with a relatively low R&D multiplier and being classified low technology by the OECD.

In order to answer the second question, we calculate R&D spillover coefficients (as percentages). Again, Table 6 contains the range of values observed for the six countries. In *innovative medicines* this means, for example: When the pharmaceutical sector (PHARM) spends 1 euro on R&D, at least 18.58 percent (in France) and at most 66.66 percent (in Italy) thereof are used by other sectors. In fact, the value for Italy is an outlier that can partly be explained by the comparatively high weight of intermediary demand for pharmaceuticals of the health sector (HEALT) as compared to final demand. Without that outlier, the maximum would be 35.57. The range of R&D spillover coefficients for the other sector related to *innovative medicines*, i.e. computer and related services (COMPU), is 54.09 to 74.94.

An overall evaluation of R&D spillover coefficients shows that the ranges of R&D spillovers are relatively narrow in most cases. This result confirms the expectation that the role of sectors within the economic system is comparable across countries. For example, the general pattern that the production of motor vehicles (MOTOR) is primarily dedicated to final demand (typically consumption, investment or exports) is

Table 6. R&D flows of selected technology fields (origin Sectors)

	R&D multiplier (x 100)		OECD categ.	R&D spillover (in %)		Growth bipols (num.)
	min	max		min	max	
Innovative Medicines						
PHARM	2.59	16.35	high	18.58	66.66	2
COMPU	0.22	3.71	-	54.09	74.94	1
Nanoelectronics						
RADEQ	2.53	23.12	high	28.78	52.33	4
Embedded Systems						
RADEQ	2.53	23.12	high	28.78	52.33	4
COMPU	0.22	3.71	-	54.09	74.94	1
Aeronautics and Air Traffic Management						
AIRCR	2.07	30.88	high	10.77	88.82	0
TRAIR	0.89	2.54	-	22.84	70.08	0
TRSER	0.26	1.00	-	31.95	70.08	0
Hydrogen and Fuel Cells						
CHEMI	0.86	6.45	med.-high	33.01	69.37	5
PRDMT	0.35	2.59	med.-low	61.41	70.08	2
MACHI	1.10	6.22	med.-high	15.77	53.66	5
EMACH	1.04	5.21	med.-high	51.64	68.75	4
MOTOR	0.84	9.44	med.-high	3.74	22.66	0
ENERW	0.27	1.38	-	51.74	83.42	0
Photovoltaics						
RADEQ	2.53	23.12	high	28.78	52.33	4
CONST	0.29	1.33	-	12.23	25.44	0
Food for Life						
FOODP	0.24	2.16	low	16.84	30.44	1
CHEMI	0.86	6.45	med.-high	33.01	69.37	5

reflected in low R&D spillover percentages (between 3.74 and 22.66 percent). On the other extreme, fabricated metal products (PRDMT) are primarily demanded as intermediate goods by other sectors, mirrored in R&D spillover percentages between 61.41 and 70.08. Though some outliers exist, patterns of R&D spillover percentages emerge quite clearly and allow the intended comparison of technology fields.

The sample of technology fields can be divided into three categories according to their R&D spillovers. The first category consists of only one field that generates rather high R&D spillovers to other sectors. The second category comprises several technology fields that induce medium R&D spillovers to sectors which receive goods

Table 7. Top 5 users (number of growth bipols in parentheses)

	Top 1	Top 2	Top 3	Top 4	Top 5
Innovative Medicines	HEALT (0)	FOODP (1)	ADMIN (0)	MACHI (5)	CONST (0)
Nanoelectronics	MACHI (5)	OFFMA (0)	PTELE (0)	CONST (0)	MOTOR (0)
Embedded Systems	MACHI (5)	CONST (0)	ADMIN (0)	MOTOR (0)	OFFMA (0)
Aeronautics & Air Traffic Management	ADMIN (0)	TRAIR (0)	TRANS (0)	CONST (0)	TRSER (0)
Hydrogen & Fuel Cells	CONST (0)	MOTOR (0)	MACHI (5)	ADMIN (0)	MTREP (0)
Photovoltaics	MACHI (5)	OFFMA (0)	ADMIN (0)	MOTOR (0)	PTELE (0)
Food for Life	CONST (0)	RUBBP (2)	MOTOR (0)	FOODP (1)	HOTRE (0)

from sectors of the technology field. Finally, a third category of fields can be identified whose related goods generate a rather low R&D spillover.

The first category contains only hydrogen and fuel cells. The most important good, chemistry products (CHEMI), as well as several other goods in this field generate more than 50 percent of R&D spillovers in the majority of countries in our sample.

The four technology fields *nanoelectronics*, *embedded systems*, *photovoltaics* and *aeronautics and air traffic management* belong to a group of fields with sectors generating medium R&D spillovers. The three technology fields *nanoelectronics*, *embedded systems* and *photovoltaics* present a similar picture since the sector radio, TV and communication equipment (RADEQ) plays a major role in all of them. This sector induces R&D spillovers between 28.8 and 52.3 percent.

For *aeronautics and air traffic management* the good aircraft and spacecraft (AIRCR) is the most important product. Only in three countries this good generates R&D spillovers of more than 30%. The other goods related to this field induce higher R&D spillovers, but they are less important.

The third category comprises *innovative medicines* and *food for life*. The technology field *innovative medicines* generates rather low R&D spillovers, taking into account the outlier mentioned above and the fact that pharmaceutical products (PHARM) form the most important sector in this technology field. The technology field *food for life* induces also rather low R&D spillovers, taking into consideration those of food products (FOODP). Though R&D is important in *innovative medicines* and *food for life*, other sectors will not receive high shares of it through technology flows embodied in intermediate goods.

The third question posed at the beginning of this section concerns major technology users of R&D carried out by sectors belonging to the selected technology fields.[10] For

[10] We do not give absolute values of received R&D on which this ranking is based on since the ranking involves summing up R&D expenditures of potentially heterogeneous sectors. In fact, a thorough procedure would require the definition of a weight for each sector depending on the ratio of the R&D specific for the technology field to the total R&D of the sector. This is a nearly impossible task since it would have to be

each selected technology field and for each selected country the top five technology user sectors are identified in Table 7.

Again, *innovative medicines* may serve as an example and is discussed in more detail. The R&D expenditures of pharmaceuticals (PHARM) and computer and related services (COMPU) are received by other sectors that purchase from them. By far the most important user sector of *innovative medicines* is health and social work services (HEALT). It is the top user sector in all six European countries selected. The other user sectors of this field vary from country to country and are less important in volume. Over all countries, the sectors most frequently found among the top five users are HEALT, FOODP, ADMIN, MACHI and CONST.[11] MACHI and CONST show up among the top five because they are mainly users of COMPU.

In technology fields *nanoelectronics*, *embedded systems* and *photovoltaics*, the same typical user sectors are listed among the top five users in many countries: Machinery and equipment (MACHI), motor vehicles, trailers and semi-trailers (MOTOR) and office machinery (OFFMA).

In *aeronautics and air traffic management*, sectors using the technology are also origin sectors. This indicates strong interrelationships within the technology field.

The user sectors of *food for life* do not seem very plausible as they are mainly determined by receiving R&D flows originating from the chemical sector, which in turn is not the most important sector in this technology field.

5.2 Subsystem minimal flow analysis (SMFA)

This part of the analysis centers on identifying the core of the National Innovation System (NIS) by means of SMFA. The core of the NIS is formed by growth bipols and comprises those sectors which are part of bilateral connections in both the actual structure and the standard structure.

Before discussing the results of the SMFA in more detail, it is therefore interesting to see whether growth bipols emerge as clear phenomena in the selected countries. Indeed, this is the case as growth bipols in the actual and in the standard structure are highly congruent in all countries. Typically, the standard structure contains two to four additional growth bipols (as opposed to the actual structure), while one or two growth bipols are contained in the actual structure (but not in the standard structure).[12]

Table 6 summarizes the results of the SMFA and of the matching of growth bipols with technology fields. For each sector belonging to a technology field either as origi-

done separately for each country.

[11] Among these are two sectors, namely MACHI and CONST, that obviously do not have much relevance as users of innovative medicines. This may be seen as a deficiency of our technology flow approach. Since technology flow analysis is based on input-output relations it is not able to account for finer structures than sectors are. However, in the case of innovative medicines it is difficult to name other sectors that would more likely be users than MACHI and CONST.

[12] This general feature of the results is as expected, since in the actual and in the standard structure technological coefficients are the same and only the final demand is different. Due to the implementation of the endogenisation of the filter used in the SMFA, the number of bilateral connections is always approximately 10, but the number of sectors forming the core can vary. More details and results in graphical form are available from the authors.

nating sector or as a top five technology user sector, the question is asked whether it is part of the core of the NIS (i.e. it shows up as part of a bipol in both the actual and the standard structure) or not.

For example, the part of Table 6 and Table 7 that covers *innovative medicines* has to be interpreted in the following way: The sector PHARM is part of a bilateral connection in two countries out of six (Italy and Germany) and the sector COMPU only in one country (Italy). Thus, the origin sectors of *innovative medicines* seem to be not very well integrated into the NIS, according to the SMFA. Likewise, the user sectors of *innovative medicines* are not frequently bipols, with the exception of MACHI, which is not a user sector of the more important origin sector of *innovative medicines*.

When summarizing the results of SMFA for all technology fields, a clear distinction between two groups can be drawn. The first group contains four technology fields that are highly integrated into the NIS. The second group contains three technology fields that seem to be less integrated into the NIS. Clearly, the results show that this distinction concerns both origin sectors and user sectors of technologies.

The first group comprises the four technology fields *nanoelectronics*, *embedded systems*, *hydrogen and fuel cells* and *photovoltaics*. Their strong integration into the NIS can be explained by important origin sectors being part of the NIS. These sectors are radio, television and communication equipment (RADEQ), identified as part of a bipol in four out of six countries, chemical products (CHEMI), which is part of a bipol in five out of six countries and electrical machinery and apparatus (EMACH), which is part of a bipol in four out of six countries.

In this first group, values for R&D multipliers and R&D spillovers are generally higher, which is not surprising. Thus, it is safe to say that the NIS of the selected European countries are well prepared for bringing forward these four technology fields.

There is a second group of three technology fields for which the SMFA yields less promising results. However, in this group, interpretation requires more care since it is possible to identify peculiarities that help explain these results and that suggest other channels that might link these technology fields to the NIS.[13]

According to the SMFA, *aeronautics and air traffic management* is very weakly integrated into the NIS. This result can be partly explained by the fact that aircraft and spacecraft (AIRCR) delivers a large part of its production to final demand and, therefore, generates not very high R&D spillovers through the channel of embodied technology flows. This is the case despite the impressing R&D intensity of the aircraft and spacecraft sector (AIRCR).

The same applies more or less to *innovative medicines*. Here, the more important origin sector, pharmaceuticals (PHARM), is part of a bipol in two countries, even though it has a relatively high R&D intensity of about 10% in many European countries.

The last technology field of the second group, *food for life*, could also be considered as NIS-integrated if its main origin sector were chemical products (CHEMI) and not food products (FOODP). FOODP is found among growth bipols in only one out of six countries. A closer look into data reveals that the generally low R&D intensity in this

[13] For example, some technology fields, such as innovative medicines, have strong ties with universities, the health sector and public administration, which are not covered by our R&D data.

sector contributes to this poor result.

As mentioned above, the results of the SMFA should not be interpreted such that technology fields in the second group are not linked at all to the NIS.

5.3 Industry growth clusters

The results of the SMFA bear some implications for growth, since they provide information for identifying the growth core of the economy. However, in this section a more direct link of the sectors related to the technology fields and their growth prospects shall be established. A study carried out by the European Commission (2005c) identifies five large industry growth clusters (Table V.2 on p. 93). By matching the technology fields to these industry growth clusters, further implications can be derived with respect to growth potentials of the technology fields.

In the European Commission study (2005c), a sector's growth is characterized by the growth of three variables, namely value added in constant prices, employment and labor productivity. The study uses time series of these three variables ranging from 1979 to 2001. A classification of sectors according to their growth profile can be obtained from a cluster analysis based on the values of these three variables. The approach is based on a hierarchical cluster analysis that has been carried out to identify groups of sectors that are similar in their growth profile.

The European Commission (2005c, p. 90–92) outlines five growth sector clusters. An overview of the five clusters is provided in Appendix B. Cluster 1 (from mining and quarrying and textiles, through building and repairing of ships) is characterized by the poorest performance in terms of both output and employment growth. The median of its growth rate in value added is slightly below zero, and its performance in terms of employment is even worse. It is, therefore, formed by industries stagnating or exhibiting very low growth rates, but undergoing a process of adjustment resulting in high increases in productivity. Cluster 2, encompassing a high number of manufacturing industries, exhibits on average relatively low, though positive, growth rates in value added, and poor performance in employment. Productivity growth is high, although on average inferior to that of cluster 1. Clusters 3 and 4 are, with two exceptions "rubber and plastics" and "telecommunications equipment" in cluster 3), formed by service sectors. Cluster 3 exhibits high growth rates in value added, positive, though relatively low, growth in employment, and consequently high increases in productivity. Cluster 4, from "hotels and catering" to "computer and related activities", exhibits high rates of growth in output and employment and the poorest performance in productivity. Finally, cluster 5 encompasses two sectors ("office machinery" and "electronic valves and tubes"), which exhibit very high growth rates in value added and productivity, and negative growth rates in employment.

The matching of the industry growth clusters with the technology fields shows that the sectors of the five technology fields *nanoelectronics*, *aeronautics and air traffic management*, *hydrogen and fuel cells*, *photovoltaics*, and *food for life* belong to industry clusters 2 or 3, which are characterized by high productivity growth. For the remaining technology fields, *innovative medicines* and *embedded systems*, the sectors are contained in cluster 2 and 4. Cluster 4 is characterized by high rates of output and employment growth and the poorest performance in productivity growth.

6. Conclusions

In this study, the impacts of seven technology fields on selected economies of the European Union are investigated. The multiplier analysis and key sector analysis focus on the interdependencies between sectors, considering only input-output data. Additionally, the technology flow analysis and the subsystem minimal flow analysis take into account R&D spent in one sector and spillover effects generated in other sectors of the economy. The main conclusions are the following.

With respect to production multipliers related to source sectors, the highest effect can be expected from the field *food for life*. *Aeronautics and air traffic management* and *hydrogen and fuel cells* may have also relatively high impacts on production. Concerning employment multipliers of goods related to source sectors, the highest effects can be expected from goods related to the technology *food for life* as well. *Innovative medicines* and *photovoltaics* may also create relatively high employment impacts. With respect to user sectors, taking into account the model assumptions and available data base, it is very difficult to derive simple implications.

With regard to key sectors, technology fields can be classified into two groups. The first group consists of *innovative medicines*, *hydrogen and fuel cells* and finally *food for live*. In all of these technology fields, related goods are frequently indicated as key sectors. Therefore, some potential of above-average impacts of increasing final demand for the commodities of this group is given.

The second group comprises *nanoelectronics*, *embedded systems*, *aeronautics and air traffic management* and *photovoltaics*. The goods related to these fields are less frequently classified as key sectors. Thus, in comparison with the first group, the expected effects of changing final demand are weaker.

Technology flow analysis provides a helpful view on R&D multipliers and spillover effects of technology fields. Since R&D multipliers turn out to be closely correlated to R&D intensities and to OECD's four technology categories (e.g. published in European Commission, 2005c, p. 136), the results can be summarized in terms of these. In all technology fields except *food for life*, the origin sectors, in particular the most important origin sector of the technology field, frequently belong to the categories high tech and medium-high tech. Among those the technology fields *nanoelectronics*, *embedded systems*, *hydrogen and fuel cells* and *photovoltaic* also contain sectors that tend to have high R&D spillover coefficients, which means that R&D carried out by these sectors generates high positive externalities in other sectors of the economy.

Results of the SMFA give a very clear picture, which also yields suggestions for policy recommendations. There is a group of four technology fields that are highly integrated into the National Innovation System (NIS) in many of the six selected countries. It may seem promising to promote future R&D efforts in these technology fields since the existing bilateral links between the related sectors create the growth core of the economy.

These technology fields are *nanoelectronics*, *embedded systems*, *hydrogen and fuel*

Table 8. Classification of goods belonging to technology fields with respect to their potential economic effects

	Output multiplier	Employ-ment multiplier	Key Sector	R&D multipli-ers and OECD classification	R&D spill-over	Growth bipol
Innovative Medicines	–	high	high	high	–	–
Nanoelectronics	–	–	–	high	high	high
Embedded Systems	–	–	–	high	high	high
Aeronautics & Air Traffic Management	high	–	–	high	–	–
Hydrogen & Fuel Cells	high	–	high	high	high	high
Photovoltaics	–	high	–	high	high	high
Food for Life	high	high	high	–	–	–

cells and *photovoltaics*. Another group of technology fields comprising *innovative medicines*, *aeronautics and air traffic management* and *food for life* seems to be less integrated into the NIS according to the SMFA. The particular reasons for this might be identified and there may be other links to the NIS that our SMFA-based approach is not able to account for. Hence, a negative judgement must be avoided.

Relating our empirical results to the industry growth clusters (European Commission, 2005c) and, in particular, to productivity growth, we can observe that the sectors of the five technology fields *nanoelectronics*, *aeronautics and air traffic management*, *hydrogen and fuel cells*, *photovoltaics*, and *food for life* belong to the industry clusters 2 or 3, which are characterized by high productivity growth. For the remaining technology fields, i.e. *innovative medicines* and *embedded systems*, the sectors are contained in clusters 2 and 4. Cluster 4 is characterized by high rates of output and employment growth and the poorest performance in productivity growth.

The merits and drawbacks of input-output analysis used in our study are well known. The study places more emphasis on qualitative input-output analysis (key sector analysis, SMFA). The results are presented in broad ranges, implying relative robustness and validity. In a previous study (Schnabl 2000), the empirical results of SMFA have shown the relative stability of NIS over time.

Taking into account the complexity of the problem analyzed and the availability of data on technologies that are not applied yet, the results provide decision support and a well-founded contribution to the discussion on the economic impact of new technologies. With great care, we tried to summarize the different economic effects for the sectors related to the technology fields under consideration.

The summary is shown in Table 8. The classification presented in Table 8 is a very rough approximation of the broad compendium of results of our study illustrating the potentials of the chosen technology fields.

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Appendix A: Theory and methods

A1. Multiplier analysis

The IO-model has the general form of $x = (I - A)^{-1}y$, where x stands for the gross production, I for the unit matrix, A for the matrix of direct inputs coefficients and y for the vector of final demand. The term $B = (I - A)^{-1}$ is called the Leontief inverse matrix. We compute this matrix directly from the input-output tables of Eurostat. The i-th element in the j-th column of matrix B, b_{ij}, indicates by how much the output of the sector i changes when the final demand of sector j changes by one unit (a final-demand-to-output multiplier).

The *output multiplier* measures the impact of a change of the final demand for sector j by 1 unit on the output of the national economy as a whole. It is defined as the production of all sectors of the economy that is necessary in order to satisfy 1 unit of final demand for sector j. Formally, the output multiplier for good j is given by $B_{\cdot j} = \sum_{i=1}^{n} b_{ij}$, where b_{ij} is the i-th element in the j-th column of the Leontief inverse matrix and n is the number of goods covered by the Leontief inverse matrix (Miller and Blair 1989, p. 103). Thus, $B_{\cdot j}$ is the column sum of the Leontief inverse matrix.

The *employment multiplier* measures the impact of a change of final demand for sector j by 1 unit on the employment of the whole national economy. It is defined as the total employment generated from 1 unit of final demand. The Leontief inverse is multiplied by the diagonal matrix $\hat{L}$ of labor coefficients l_j. The labor coefficient shows the relationship between the value of output of a sector and the employment needed in order to produce the goods of that sector (in physical and not in monetary terms). Formally, this step is shown as $E = \hat{L}(I - A)^{-1}$, where E is the matrix of the cumulative labor input coefficients. The employment multiplier is equal to the sum of elements of the column j of E, thus $E_{\cdot j} = \sum_{i=1}^{n} e_{ij}$, where e_{ij} is the i-th element of the j-th column in the matrix of the cumulative labor input coefficients.

Dividing each element in a column of the Leontief inverse by its diagonal element, the so-called *output-to-output multipliers* can be obtained (Miller and Blair 1985, p. 328). Denoting the output-to output multiplier by b_{ij}^*, we have $b_{ij}^* = b_{ij}/b_{jj}$, where b_{ij}, b_{jj} are elements of the Leontief inverse B. Multiplier b_{ij}^* indicates by how much the output of sector i changes if the output of sector j changes by one unit. The output-to-output multiplier as introduced in section 3 and used in the analysis in section 4 is defined as $B_{\cdot j}^* = \sum_{i=1}^{n} b_{ij}^*$ or as column sum of matrix B^* (which has b_{ij}^* as elements). $B_{\cdot j}^*$ indicates by how much the output of the whole economy changes if the output of sector j changes by 1 unit.

A2. Key sector analysis

The approach chosen in this study is introduced by Sonis, Hewings and Guo (2000) and combines the averaging evaluation of economic sectors together with the description of the structure of synergetic interdependencies between economic activities. The key sector analysis of backward and forward linkages may be directly related to the properties of the multiplier product mix that is derived from averaging principles that are based on minimum information about economic sectors.

Let $B_{\cdot j}$ and $B_{i\cdot}$ be the column and row multipliers of the Leontief inverse matrix. These are defined as $B_{\cdot j} = \sum_{i=1}^{n} b_{ij}$ and $B_{i\cdot} = \sum_{j=1}^{n} b_{ij}$. Thus, $B_{\cdot j}$ is the column sum and $B_{i\cdot}$ the row sum of the Leontief inverse matrix.

Let V be the global intensity of the Leontief inverse matrix $V = \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij}$. The power of dispersion for the backward linkages, BL_j, is defined as:

$$BL_j = \frac{B_{\cdot j}}{\frac{1}{n}V} = \frac{n \sum_{i=1}^{n} b_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij}}$$

The indices of the sensitivity of dispersion for forward linkages, FL_i, are given as:

$$FL_i = \frac{B_{i\cdot}}{\frac{1}{n}V} = \frac{n \sum_{j=1}^{n} b_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij}}$$

The usual interpretation is to propose that $BL_j > 1$ indicates that a unit change in final demand of sector j will create an above average increase in activity in the economy; similarly, for $FL_i > 1$, it is asserted that a unit of change in all sectors' final demand would create an above average increase in sector i. A key sector is usually defined as one in which both indices are greater than 1.

A3. Technology flow analysis

The technology flow matrix Z describes the technology transfers embodied in the intermediate relations between the sectors. For the calculation of Z, we use a method that Schnabl (2000) calls sub-system method.[14] In this approach, all R&D expenditures are projected into the input-output table, irrespective of their causation by final or intermediate demand. The formula is

$$Z = \langle r \rangle \langle x \rangle^{-1} (I - A)^{-1} \langle y \rangle, \tag{1}$$

where r is the vector of R&D expenditures, x is the vector of production, $(I-A)^{-1}$ is the Leontief inverse matrix and y is the vector of final demand.[15] Notation $\langle \cdot \rangle$ implies a diagonal matrix.

In (1) the term $(I-A)^{-1}\langle y \rangle$ forms a matrix whose columns are called sub-systems of the economy. The j-th column of $(I-A)^{-1}\langle y \rangle$ contains all production necessary to provide the final demand in sector j. By pre-multiplication with $\langle x \rangle^{-1}$, the matrix of the sub-systems of the economy is normalized, resulting in the operator $\langle x \rangle^{-1}(I-A)^{-1}\langle y \rangle$. Post-multiplying $\langle r \rangle$ with this operator performs a distribution of r that enables the allocation of r to the production system, such that the sum over all elements of Z and the sum over all elements of r is the same.

[14] The approach is connected by Schnabl to works of Sraffa (1960) and Pasinetti (1973), but other research contributions put the same approach in a different context and come up with very similar formulae for technology flow matrices, e.g. Dietzenbacher and Los (2002).

[15] To be precise, in the actual structure y denotes the final demand for domestic goods. In order to ensure model consistency, x, as used in (1), is not the actually observed production vector but the model-consistent production vector as given by $(I-A)^{-1}y$. With that modification the row-sums of Z give the vector of R&D expenditures. This modification is necessary only with the actual structure.

The technology-flow matrix Z is called the actual structure because it incorporates the structure provided by the actual final demand. Alternatively, one might neglect the available information about the final demand and substitute I for $\langle y \rangle$ in (1), resulting in

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

This matrix represents the purely technological relationships between final demand and R&D and allows one to analyze the potential effects of possible final demand. Dietzenbacher and Los (2002) obtain the same matrix from a slightly different context and interpret the sum of its j-th column as backward multiplier, giving the total amount of innovation activities (e.g. R&D expenditures) associated with a unit of final demand for product j.

The interpretation of the technology flow matrices Z and Z_s is closely linked to the notions of innovation spillover, technology providers and technology recipients.

Consider the rows of the matrix, in which we can see the providers of innovation. The sum of the j-th row are the total R&D expenditures of sector j. The diagonal element in this row specifies the R&D expenditures, that are necessary to satisfy the final demand for good j. The off-diagonal elements contain the R&D expenditures necessary to satisfy the final demand for the other goods. In that sense they show R&D provided by sector j and received by the other sectors. The sum of the off-diagonal elements in the j-th row gives the R&D spillover of R&D activities of sector j.

The columns of the matrix allow a view on the recipients of the technology flows. The sum of the j-th column are the total R&D expenditures necessary to satisfy the final demand for good j. The off-diagonal elements in the j-th column specify the R&D expenditures, that come from the other sectors.

Comparing row sums z_i and column sums z_j of Z, or Z respectively, one can classify sectors into technology providers ($z_i > z_j$) and technology recipients ($z_i < z_j$).

One may also use the concept of the technology flow matrix to see how the R&D activities of those sectors that are linked to a specific technology field are used by other sectors. In that case one applies a row filter to the matrix, thus leaving the selected rows untouched and setting to zero all elements in rows that belong to sectors not pertaining to the technology field. This method allows identifying the main users of the R&D carried out by the origin sectors of a technology field.

A4. Subsystem minimal flow analysis

SMFA applies the filter not directly to the technology flow matrix, but to its layers according to the stages of causation in the production system. To form the layers, the Leontief inverse is replaced by its geometric power series

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

Then the layers are defined as

$$Z_n = \langle r \rangle \langle x \rangle^{-1} A^n \langle y \rangle.$$

Each of these layers corresponds to another expenditure round, thus making explicit the thinning out of the technology flows with the increasing depth of the intermediate flows. Each element z_{ij} of the layer matrices is tested whether it exceeds the filter value F and for each layer an adjacency matrix W_n is constructed. The typical element w_{ij} of W_n is defined as

$$w_{ij} = 1 \text{ if } z_{ij} \geq F \text{ and } w_{ij} = 0 \text{ if } z_{ij} < F.$$

Adjacency matrices have to be considered only as long as at least a single element of the highest layer exceeds the filter value F. In a next step of the procedure, the matrices $W_1, W_2, W_3, \ldots$ have to be combined in a way that corresponds to the different numbers of layers that can be combined to establish a linkage, i.e. the length of the linkage. If, e.g., a linkage is based on subsequent intermediate relationships, this implies that elements of W_1 and W_2 must combine in a suitable way. This is done through forming matrices $W^{(n)}$ in the following manner:

$$W^{(n)} = W_n W^{n-1}$$

From this, a dependency matrix D is formed by applying Boolean summation (indicated by #) to the matrices $W^{(n)}$

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

An element of the dependency matrix D greater than 1 indicates the existence of direct or indirect technological flows between the respective two sectors which exceed the filter value F.

Finally, the connectivity matrix H is calculated by adding the transposed dependency matrix D' to D. Matrix H specifies the degree of technological flows or interconnectivity:

$$H = D + D' \text{ with } h_{ij} = d_{ij} + d_{ji}$$

A typical element of the connectivity matrix h_{ij} can only adopt the values 0, 1 and 2 and can be interpreted as follows:

If $h_{ij} = 0$, sector i and j are isolated.

If $h_{ij} = 1$ (there is unidirectional link between sector i and j), sector i exports technology to sector j.

If $h_{ij} = 2$ (bilateral relations, direct and/or indirect, exist between the sectors i and j), sector i exports technology to sector j and vice versa.

Matrix H defines a graph that can be visualized in a chart or analyzed directly. In our analysis we focused on the bilateral relations, since these are assumed to form a growth bipol. Growth impulses within a bipol are reinforced because they are fed back by the receiving sectors to the delivering sectors. Sectors with bilateral relations form the core of the graph (core sectors). Sectors with only unidirectional relations are either source-sectors or sink-sectors, depending on whether they have more technology delivering or technology receiving relationships with other sectors. Except from the analytical step of binarisation, notions of source-sectors and sink-sectors correspond to the notions of technology deliverers and technology recipients, introduced in the previous subsection.

A specific methodological issue of SMFA is the selection of the filter value F. Schnabl (2000) proposes a procedure to endogenize the selection of F by optimisation of a suitable criterion, e.g. entropy. We experimented with these procedures, but decided to imply another filter selection method that guarantees that exactly m bilateral connections are found, where m can be chosen by the researcher. This decision seemed appropriate for the present analysis, which applies the SMFA simultaneously for six different countries. In this way, the differences between the selected countries do not interfere with a standardized method of interpretation of the results of SMFA. The results presented later on are based on $m = 10$.

SMFA deals with both versions of technology-flow matrices ("actual structure" and "standard structure"). The sectors that show up as core sectors for both the actual structure and the standard structure according to the SMFA are then defined as core of the national innovation system.

It is a question of particular importance to see whether the sectors that belong to the various technology fields are part of the core of the national innovation systems in many of our selected European countries.

Appendix B

Table B1. EU-15 industry growth clusters (average annual growth rates in %, 1979–2001)

Sector	Value added	Employment	Productivity
Cluster 1			
Mining and quarrying	-0.2	-5.2	5.4
Textiles	-0.8	-3.2	2.6
Clothing	-0.2	-3.5	3.4
Leather and footwear	-1.1	-3.3	2.4
Basic metals	0.7	-3.1	4.1
Building and repairing of ships	-0.1	-3.3	3.6
Cluster 2			
Food, drink and tobacco	1.1	-0.6	2.1
Wood and products of wood	1.1	-1.0	2.4
Pulp, paper and paper products	2.0	-1.0	3.3
Printing and publishing	1.6	-0.1	2.1
Mineral oil refining and nuclear fuel	-3.7	-2.0	-1.6
Chemicals	3.3	-1.3	4.9
Non-metallic mineral products	1.0	-1.3	2.7
Fabricated metal products	0.8	-0.8	1.9
Mechanical engineering	0.6	-1.1	2.0
Insulated wire	2.8	-1.0	4.1
Other electrical machinery n.e.c.	0.5	-0.7	1.5
Radio and television receivers	0.2	-2.4	2.9
Scientific instruments	-2.6	-0.2	-2.1
Other instruments	1.6	-1.9	3.8
Motor vehicles	1.6	-0.7	2.9
Aircraft and spacecraft	1.7	-0.6	2.8
Railroad and transport equip. n.e.c.	1.0	-2.1	3.4
Furniture; manufacturing n.e.c.	0.4	-0.7	1.6
Electricity, gas and water supply	2.1	-1.3	3.7
Construction	0.8	-0.2	1.2
Inland transport	2.3	0.2	2.6
Water transport	0.7	-2.5	3.6
Cluster 3			
Rubber and plastics	2.4	0.6	2.1
Telecommunication equipment	9.6	-1.3	11.0
Sale and repair of motor vehicles	1.9	0.9	1.4
Wholesale trade	2.7	1.1	2.2
Retail trade	2.1	1.0	1.6
Air transport	6.0	1.4	4.9
Supporting transport activities	3.7	1.3	2.9
Communications	6.3	0.3	6.5
Financial intermediation	3.2	1.1	2.6
Insurance and pension funding	2.2	1.1	1.7
Research and development	2.4	1.7	1.2

Sector	Value added	Employment	Productivity
Cluster 4			
Hotels and catering	1.0	2.4	-0.9
Auxiliary to financial intermediation	3.1	2.7	0.8
Real estate activities	2.5	3.4	-0.5
Renting of machinery	5.3	3.4	2.2
Computer and related activities	7.6	6.5	1.5
Legal, technical and advertising	4.3	4.2	0.6
Other business activities n.e.c.	4.0	4.7	-0.2
Cluster 5			
Office machinery	29.9	-0.6	30.5
Electronic valves and tubes	33.3	-0.1	33.7

Source: European Comission (2005c).