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TECHNOLOGY FLOWS IN THE AUSTRIAN ECONOMY

The OECD has been measuring the "total R&D content" of output flows for several years. This measure not only includes direct expenditure on research and development but also the R&D content of intermediate and investment goods, both domestic and imported. In many cases, this presents a more meaningful approach to measuring levels of technology. For the first time, computations of the total R&D content were carried out for the Austrian economy. The results are presented in this study. For a small open economy, technology flows embodied in imports are particularly relevant. The fundamental change in the pattern of technology flows demonstrates Austria's evolution towards a knowledge-based economy.

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Industries not only differ in their direct R&D intensity (i.e., direct expenditure on research and development per unit of output) but also with respect to their use of external sources of technology. While innovative activities of some industries (such as the pharmaceutical industry) are primarily based on their own research and development, other industries receive their technology primarily from sources outside the industry. The same can be said for nations as a whole: while large advanced economies tend to rely largely on domestic research and development (although this element of autarky is eroded in the process of globalisation), small or less advanced countries are much more dependent on technology developed abroad.

MOTIVATION AND GOALS OF THE STUDY

Direct business enterprise expenditure on R&D is an important measure, which is widely used both as a descriptive indicator and as a variable in a large array of economic models. However, measures of direct R&D by definition do not contain any information about the diffusion of technology among industries or countries, and, a fortiori, do not contribute to answering the question as to who finally benefits from the R&D efforts performed at a particular "location". Consequently, in many analytical applications, measures of direct R&D are inadequate. One area where this deficiency becomes evident is empirical research on the relationship between R&D and productivity growth (*Hutschenreiter*, 1995, 1998).

Although statistics on direct business enterprise expenditure on R&D are provided on a fairly regular basis, measures of *total R&D content* (synonymously we will use the term *technology content*) of an industry's or country's output are not readily available. At the OECD (*Papaconstantinou – Sakurai – Wyckoff,* 1996), efforts were made to quantify the total technology content of output flows by complementing direct R&D expenditure with R&D embodied in domestic and imported intermediate and investment goods ("indirect R&D")[1]. However, the OECD study was confined to 10 OECD countries well-covered by the OECD data sets. At present, owing to deficits in its input-output and R&D statistics, Austria is not among those countries and consequently was not included in the OECD study.

This study is designed to bridge this gap. For the first time it was attempted to quantify the total R&D content of flows of goods and services in the Austrian economy. The method of computation corresponds to that applied in the OECD study mentioned above.

There are several a priori reasons why this study should be of interest in the Austrian context. On the one hand, the international dimension of knowledge and technology diffusion is of particular importance for small countries. Analogous to foreign trade, the relative importance of transborder "knowledge" or "technology" transactions can be expected to be a decreasing function of country size. On the other hand – as emphasised in the literature on catching up and convergence[2] – this is specially true for countries lagging behind the world technological frontier. So far, no empirical research has been done to address these issues in the Austrian context.

Moreover – as a special aspect – there is an "Austrian performance paradox": rather unfavourable evidence regarding R&D inputs and various structural aspects of the Austrian economy is in contrast with a favourable macroeconomic performance. In spite of low levels of investment in R&D (*Marin*, 1995), Austria's long-run economic performance in terms of growth of per-capita income and productivity has been remarkable – both when compared to its own development between the two world wars, and to that of other European countries (*Butschek*, 1999). This favourable long-term development was attributed, among others, to the successful adoption of imported technology (*Steindl*, 1977). One explanation refers – in the terminology of this study – to a supposedly higher total R&D intensity, in particular due to imports of investment goods (Austria's long-term share of capital formation in GDP is relatively high).

The measurement of research and development "embodied" in intermediate and investment goods ("indirect" R&D) is interesting in its own right. Today, descriptive measures of "embodied technology flows" are frequently used to complement the traditional science and technology indicators (see, e.g., *European Commission,* 1997, *OECD*, 1998). Moreover, they also serve as an input in a number of analytical applications. Among the well-known applications of measures of embodied research and development are econometric analyses of the relationship between R&D and productivity growth. *Sakurai – Ioannides – Papaconstantinou* (1996), for example, use the database provided by *Papaconstantinou – Sakurai – Wyckoff* (1996) for econometric estimates of the impact of direct R&D expenditure and R&D embodied in intermediate and investment goods on total factor productivity growth. These data are also used by *Ioannides – Schreyer* (1997).

RECENT DEVELOPMENTS IN ECONOMIC THEORY

Modern economies are increasingly linked through international trade, foreign direct investment, migration and knowledge flows. The adoption of knowledge or innovations generated abroad is essential for the growth performance, in particular of small countries. Based on some recent developments, during the last decade economic theory has shown new interest in examining the role of knowledge dissemination in the long-term growth of nations. Since the early 1990s, endogenous growth models – based on a marriage of the theories of growth and international trade – have been applied to examine the factors of long-term growth in the context of open economies.

International knowledge and technology flows are an important additional "productivity transmission channel", in particular for small open economies. This has been taken into account by new approaches in economic theory.

[1] Total R&D content and innovation expenditure (see the contribution of Hannes Leo in this issue) are both designed to complement (direct) R&D expenditure with additional components. While total R&D content is constructed on the basis of R&D data, innovation expenditure also includes non-R&D cost elements.

[2] For a survey see *Fagerberg* (1994).

Method of computation

The *total R&D content* of industry j's output is defined by the sum

$$TTTL_j = R_j + TINT_j^d + TINV_j^d + TINT_j^m + TINV_j^m,$$

R_j . . . *direct R&D expenditure* of the industry, $TINT_j^d$ . . . R&D embodied in domestic intermediate inputs purchased by the industry, $TINV_j^d$ . . . R&D embodied in domestic investment goods, $TINT_j^m$ . . . R&D embodied in imported intermediate inputs, $TINV_j^m$ . . . R&D embodied in imported investment goods. The last four components – to be defined rigorously below – together make up "indirect" research and development.

The *direct R&D intensity* of an industry is defined as its direct R&D expenditure per unit of gross output, i.e.,

$$r_i = \frac{R_i}{X_i} \qquad (i = 1, \ldots, n).$$

As usual, the Leontief inverse is defined by

$$B = (I - A^d)^{-1},$$

I . . . identity matrix, A^d . . . matrix of domestic input coefficients. A characteristic element b_{ij} of matrix B represents the direct and indirect requirements of output i necessary to turn out one unit of final demand of good j[1].

R&D embodied in domestic intermediate inputs of industry j is given by

$$TINT_j^d = \sum_{i = 1,\, i \neq j}^{n} r_i\, b_{ij}^*\, X_j.$$

Instead of the traditional "final-demand-to-output" multipliers (i.e., the elements of the standard Leontief inverse introduced above) "output-to-output" multipliers are used (for a detailed exposition of this type of multipliers see *Miller – Blair,* 1985). A characteristic element b_{ij}^* of the "output-to-output" multiplier matrix B^* is algebraically derived by dividing the columns of the Leontief inverse by its respective diagonal element. The application of output-to-output multipliers instead of the traditional Leontief multipliers avoids double-counting that part of the R&D content of industry j which is already included in R_j, the direct expenditure on R&D by industry j.

R&D embodied in domestic investment goods purchased by industry is defined by

$$TINV_j^d = \sum_{i=1}^{n} r_i \left(\sum_{h=1}^{n} b_{ih}\, I_{hj}^d \right),$$

b_{ih} . . . an element of the usual Leontief inverse B, I_{hj}^d . . . demand of industry j for the domestic investment good h.

R&D embodied in imported intermediate inputs of industry j is given by

$$TINT_j^m = \sum_{k=1}^{l} \sum_{i=1}^{n} r_{ik}\, \alpha_{ik}\, X_{ij}^m,$$

r_{ik} . . . R&D intensity of industry i in the exporting country k ($k = 1, \ldots, l$), α_{ik} . . . import share of country k in total imports of commodity i, i.e.,

$$\alpha_{ik} = \frac{m_{ik}}{\sum_{k=1}^{l} m_{ik}}.$$

Thus, the "import proportionality" assumption is made. Finally, X_{ij}^m is intermediate demand of industry j for the imported intermediate input i.

R&D embodied in imported investment goods purchased by industry j is defined by

$$TINV_j^m = \sum_{k=1}^{l} \sum_{i=1}^{n} r_{ik}\, \alpha_{ik}\, I_{ij}^m,$$

I_{ij}^m . . . demand of industry j for the imported investment good i.

The computation of R&D embodied in imported goods – in contrast to domestic goods – captures only first-round effects. To capture total effects, a linked international input-output model would be required. Consequently, the volume of imported technology is underestimated in both the present study as well as the OECD study.

[1] The interested reader not familiar with the basic concepts of input-output analysis is referred to *Miller – Blair* (1985) or any other standard textbook of input-output economics.

Traditional international trade theory has been concerned with "gains from trade" due to specialisation. The latter is based on comparative advantages, which, in turn, arise from differences in factor endowments and technology across nations. More recently, economies of scale are recognised as an additional source of welfare gains (*Helpman – Krugman,* 1985). Finally, endogenous growth theory also deals with dynamic increasing returns and learning mechanisms (survey by *Grossman – Helpman,* 1995). This led to new insights regarding the role of international linkages (including knowledge flows) as additional "productivity transmission channels" (*Helpman*, 1997).

Endogenous growth theory[3] provides a suitable analytical framework to assess the economic impact of international knowledge flows. "R&D-based" endogenous growth models – such as *Romer* (1990) or *Grossman – Helpman* (1991) – identify innovation (in particular, the accumulation and diffusion of knowledge) as the driving force of long-term economic growth. Several hypotheses with respect to the impact of international technology diffusion on productivity growth can be derived from these models:

- Access to a larger pool of knowledge increases the productivity of R&D activities in the countries involved, thus enhancing future productivity growth. Thus, in addition to the traditionally recognised channels of technology diffusion (international trade, foreign direct investment, etc.), a country's productivity growth is positively correlated to the degree of its openness to flows of information and to its capability to absorb and utilise knowledge produced abroad. In this process, domestic R&D may be instrumental to maintain absorptive capacities (*Hutschenreiter – Kaniovski – Kryazhimskii,* 1995, *Borisov – Hutschenreiter – Kryazhimskii,* 1999).
- In an open economy, international trade provides opportunities to use input goods developed abroad that qualitatively differ from domestic input goods, and thus to increase productivity.
- Both international trade and foreign direct investment provide opportunities for cross-border learning about products, production processes, market conditions, etc.

THE STRUCTURE OF TOTAL R&D CONTENT

In Austria, direct R&D expenditure accounts for nearly half of the total R&D content of output. The most important components of "indirect research and development" are imported and domestic intermediate goods. Over time, the share of imported technology is increasing.

The method applied here to quantify the total technology content of flows of goods and services in the Austrian economy follows that of the OECD study by *Papaconstantinou – Sakurai – Wyckoff* (1996) in order to provide opportunities for international comparisons (on the procedure of computation see Box "Method of computation").

Basically, this approach rests on the following assumptions:

- Direct R&D expenditure is a proxy for technology embodied in products.
- Intersectoral input flows, as captured by the input-output tables, are the carriers of technology flows across industries and economies.
- The "import proportionality" assumption asserts that the imports of a certain input good are distributed proportionally across all receiving industries. The share of the country of origin in total imports of the respective product is applied to all receiving industries.

Due to the restrictions imposed by a lack of data for Austria, some adaptations had to be made in the implementation. In particular, this concerns the level of aggregation (see Box "Data Sources"). Due to absence of R&D data for the service sector in the present study – just as in the OECD study by *Papaconstantinou – Sakurai – Wyckoff* (1996) – direct R&D expenditure refers to the manufacturing sector only. Consequently, the total R&D content is underestimated by neglecting both the direct expenditures on R&D of the service sector and the technology content of service inputs.

Figure 1 shows the structure of the total R&D content of aggregate output. Total R&D content comprises direct R&D expenditure of the manufacturing sector and R&D embodied in intermediate and investment goods originating in the manufacturing sector and absorbed by all sectors (including the service sector). In Austria, direct expenditures on R&D of the manufacturing sector (the conventional R&D measure) amounts to nearly half of the total R&D content of the aggregate output of all sectors. In 1994, 45.2 percent of the total R&D content were accounted for by direct R&D and 54.8 percent by R&D embodied in domestic and imported intermediate and investment goods. The most important component of indirect research and development is R&D embodied in imported and domestic intermediate goods (23.2 percent and 16.4 percent, respectively). The shares of imported and domestic investment goods are significantly lower (8.3 percent and 6.8 percent, respectively). The increase in the share of imported technology is due to the growth of R&D embodied in imported intermediate goods. In contrast, the share of direct R&D does not follow a clear trend: it increased to more than 50 percent between 1976 and 1983, and dropped again to the level of the mid-1970s between 1988 and 1994 (45.6 percent)[4].

[3] See surveys by *Aghion – Howitt* (1998), *Barro – Sala-i-Martin* (1995), *Klenow – Rodriguez-Clare* (1997).

[4] The data for 1994 are not strictly comparable to those for previous years, however.

Data Sources

The OECD study by *Papaconstantinou – Sakurai – Wyckoff* (1996) is exclusively based on the OECD STAN family of databases: the Structural Analysis (STAN) Database proper, the Analytical Database for Business Enterprise R&D (ANBERD), the OECD Input-Output Database and the Bilateral Trade Database. Since Austria is not covered by either the ANBERD or the Input-Output database, this study had to draw on complementary national sources not harmonised by the OECD.

R&D expenditure

Business enterprise expenditure on R&D (BERD) was taken from the OECD Analytical Database for Business Enterprise R&D (ANBERD) database (see *OECD*, 1997A). At present, 10 OECD countries are covered by ANBERD: Australia, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, the U.K. and the USA. Austria is currently not included in ANBERD. For this reason, official BERD (OFFBERD) data as reported to the OECD by the Austrian Central Statistical Office had to be used for Austria (see *OECD*, 1997B). While ANBERD provides (estimated) time series for a number of International Standard Industrial Classification (ISIC, Rev. 2) sectors, official disaggregate business enterprise R&D data for Austria are only available for 1975, 1984, 1989 and 1993. However, due to a massive break in the time series, census R&D data for 1995 published by the Austrian Central Statistical Office were used instead of the 1993 OFFBERD data.

Gross output

Gross output data used to calculate sectoral R&D intensities are taken from the OECD Structural Analysis (STAN) database. For 1994, gross output data were unavailable for some STAN sectors in some of the countries. These aggregates were decomposed using disaggregate information for the most recent year available. The same applies to the Austrian data.

Foreign trade

The shares of the 10 OECD countries covered by ANBERD in Austrian imports are calculated separately on the basis of the OECD Bilateral Trade Database (BTD). The remaining countries are grouped into two categories: the "Dynamic Asian Economies" (DAE: China, Hong Kong, Malaysia, Singapore, South Korea, Taiwan, Thailand) and the Rest of the World (ROW).

Input-output data

Input-output tables for Austria are available for 1976, 1983, 1988 and 1994. For each of these years the following four matrices were used in the computation of total R&D content:

- domestic intermediate goods (activity × activity),
- imported intermediate goods (activity × activity),
- domestic investment goods (activity × activity),
- imported investment goods (activity × activity).

The matrices for 1976 and 1983 are based on data published by the Austrian Central Statistical Office. The matrices for 1988 and 1994 are based on WIFO projections of these official data. From the original commodity x activity tables, activity x activity tables were derived on the basis of the industry-based technology assumption (see, e.g., *Miller – Blair*, 1985, Chapter 5).

For Austria, input-output data (1976, 1983, 1988, 1994) are not available for the same years as disaggregate business enterprise R&D statistics (1975, 1984, 1989, 1995) but for adjacent years. As an approximation it was assumed that at the industry level R&D intensities remained unchanged for adjacent years (1975/1976, 1983/1984, 1988/1989, 1994/1995).

Special Issues

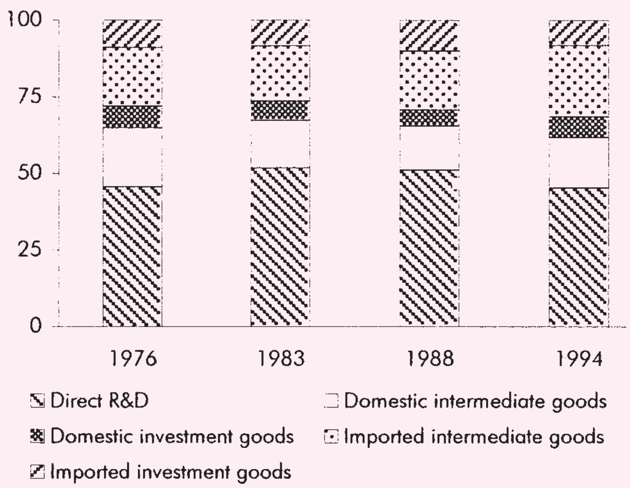
Due to constraints imposed by the availability of data for Austria, the level of aggregation is somewhat higher than that applied in the OECD study by *Papaconstantinou – Sakurai – Wyckoff* (1996), which is based exclusively on the OECD STAN family of databases. While the OECD study uses 36 ISIC (Rev. 2) sectors – of which 22 manufacturing industries coincide with ANBERD – this study deals with 20 sectors of which 13 belong to manufacturing.

In order to increase consistency with the Austrian data, the four-digit industry "office and computing machinery" (#3825 of ISIC, Rev. 2) was included in the three-digit industry "electrical machinery" (#383 of ISIC, Rev. 2) throughout. The "other manufacturing" sector was dropped due to a lack of R&D data.

Since adequate service sector R&D data are not available – like in *Papaconstantinou – Sakurai – Wyckoff* (1996) – only direct R&D expenditures of the manufacturing sector (#3 of ISIC, Rev. 2) are used. However, the remaining seven industries outside manufacturing are included as receivers (users) of technology originating in the manufacturing sector.

Figure 1: Total R&D content of output

Percentage shares



Source: WIFO.

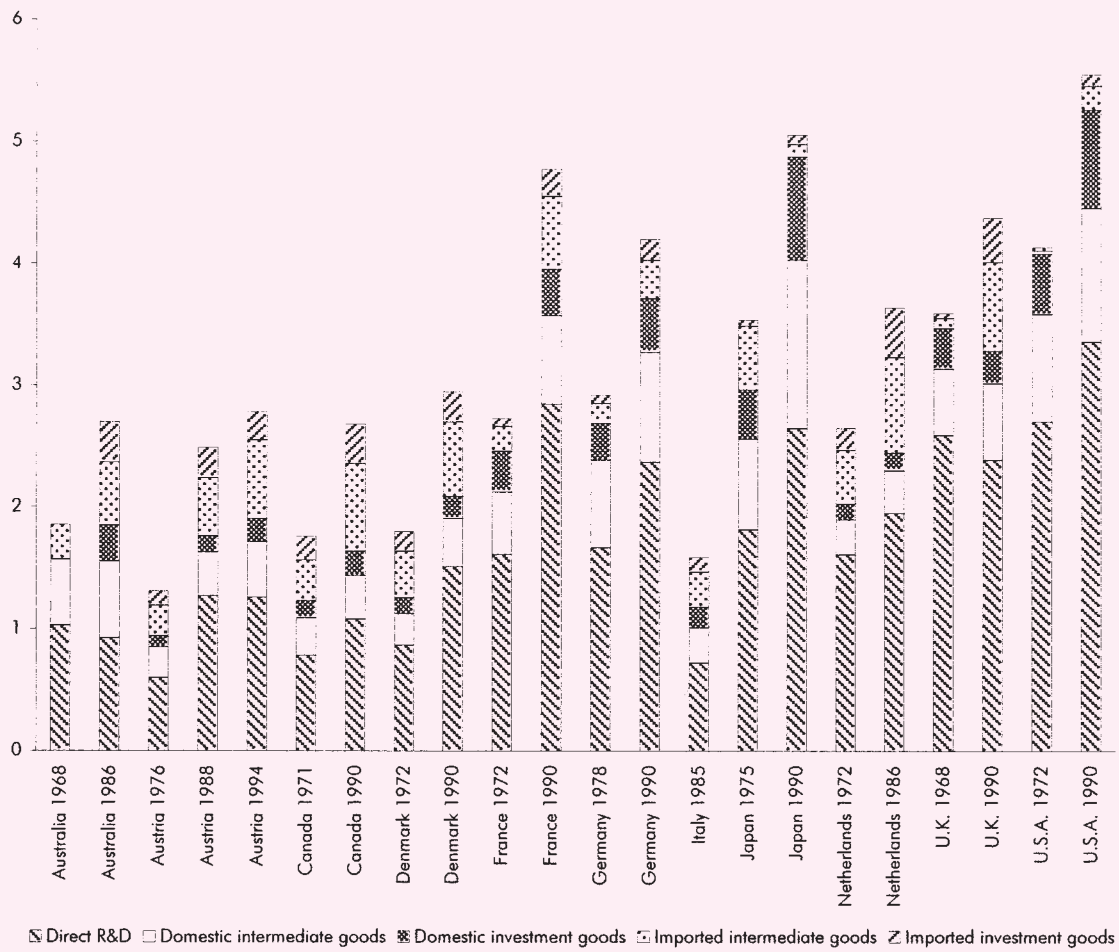
TOTAL R&D INTENSITY IN AN INTERNATIONAL COMPARISON

Total technology intensity (defined here as the ratio of total R&D content to gross output of the manufacturing sector) is, for many purposes, a more meaningful measure of the technology level of a nation's (or industry's) production than direct R&D intensity. In particular in small and lagging countries, it is likely to be considerably higher than direct R&D intensity. Consequently, international comparisons based solely on direct R&D intensities are likely to understate the technology level of such countries.

In the 1970s and 1980s, Austria experienced a dynamic process of catching up in terms of total technology intensity (Figure 2). The latter has more than doubled between 1976 and 1988, increasing at a higher rate than that of any other country in the sample, thus approaching that of Canada. This process was mainly driven by a surge

Figure 2: Total technology intensities

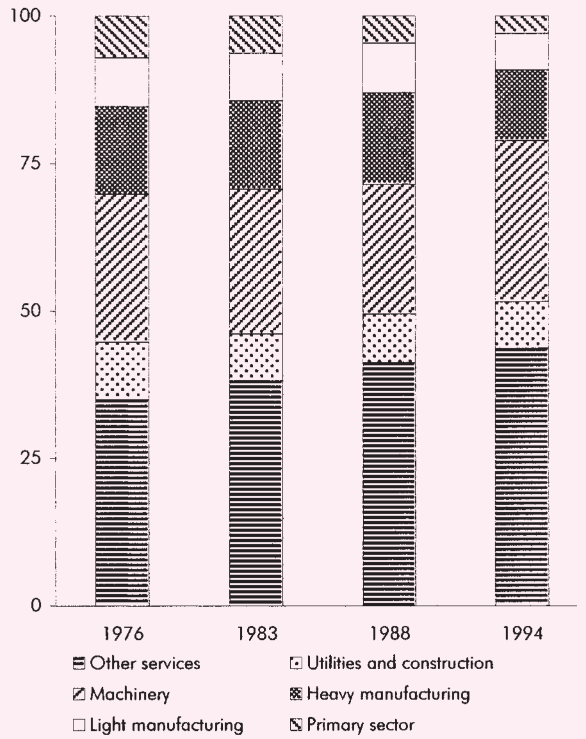
Total R&D content as a percentage of gross output of the manufacturing sector



Source: OECD, WIFO.

Figure 3: Acquired R&D by user sector

Percentage shares



Source: WIFO.

in direct R&D investment and, to a lesser extent, by embodied technology imports.

However, this process of catching up started from a relatively low initial level. In spite of an above-average increase, Austria's total technology intensity is, therefore, comparatively low by international standards. Between 1988 and 1994, this process lost much of its momentum. While the ratio of R&D embodied in intermediate goods to gross manufacturing output continued to expand, direct R&D intensity was stagnating.

Between 1976 and 1988, Austria caught up significantly in terms of total technology intensity. Later on, growth lost its momentum. Compared to other OECD countries, Austria is still lagging behind.

The ratio of technology acquired through the purchase of intermediate and investment goods to direct R&D expenditure varies considerably across countries (*Papaconstantinou – Sakurai – Wyckoff*, 1996). "Acquired technology" ("indirect research and development") is defined as the R&D content of intermediate and investment goods, irrespective of whether they are produced domestically or abroad.

Table 1: Sector classification

Sectors	Industries
Primary Sector	Agriculture and forestry, mining
Light manufacturing	Food and tobacco, textiles and leather, wood and furniture
Heavy manufacturing	Paper and printing, chemicals, stone, clay and glass, basic metal
Machinery	Fabricated metal, non-electrical machinery, electrical machinery, transport, instruments
Utilities and construction	Electricity, gas and water, construction
Other services	Transport and storage, communication and other services

Direct expenditure on R&D tends to be relatively high in the large, research-intensive countries such as the USA and France, where the ratio of "indirect research and development" to direct R&D expenditure is approximately 2 : 3. For Canada, a country with a relatively low ratio of expenditure on R&D to GDP, and strong informational and trade links to its large neighbour, the USA, the inverse relation (3 : 2) holds. In Australia, a largely resource-based economy, the ratio of acquired R&D to direct expenditure on R&D is as high as 2 : 1. In this spectre, Austria holds a middle ground with a ratio in the close to 1 : 1. To a considerable extent, the differences observed across countries are due to the varying shares of R&D embodied in imports, i.e., on the weight of international technology diffusion through intermediate and investment goods.

As expected for a small open economy, the ratio of R&D embodied in *imported* intermediate and investment goods to direct expenditure on R&D is higher in Austria (0.7 in 1994) than in large countries. This fact is a reflection of the relatively important role of imports. The ratio computed for Austria is in the same range as that of the two countries in the sample which are most comparable to Austria: It is also 0.7 (1993) for the Netherlands, and 0.6 for Denmark. For both Canada and Australia, the ratio is 0.8.

Austria's ratio of R&D content of imported intermediate and investment goods to direct expenditure on R&D exceeds that of large countries. However, it is in a range typical for small open economies. There is no evidence for Austria realising gains from imported technology in excess to those of comparable countries.

The figures presented show that Austria participates more in international technology diffusion than large countries.

However, they do not provide evidence for a particularly strong "leverage effect" exerted by imported technology putting Austria to a special advantage vis-à-vis comparable small open economies.

In 1976, the service sector was still lagging far behind the manufacturing sector as a receiver of indirect R&D. By 1994 it was at a par already.

Between 1976 and 1994, the importance of the service sector as a destination of embodied technology flows, i.e., as a user of technology generated elsewhere, increased significantly (Figure 3). In 1976, the service sector (other services, excluding utilities and construction) received 35 percent of total indirect research and development[5], while manufacturing still was by far the most important destination of embodied technology flows: light manufacturing, heavy manufacturing and machinery together accounted for 48 percent of total acquired technology. This pattern has undergone significant change: by 1994, the service sector share went up to 44 percent and thus was almost at a par with the manufacturing sector. As expected, the share of the primary sector diminished continuously, while the share of utilities and construction was stable for a decade.

THE ROLE OF TECHNOLOGY IMPORTS

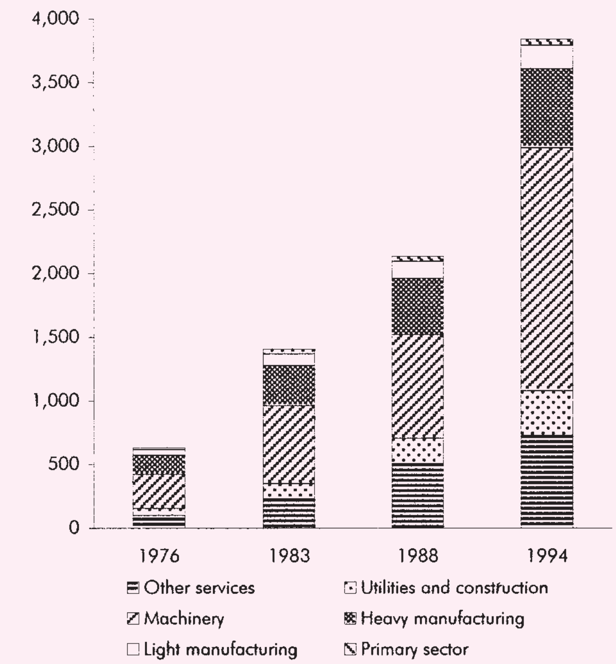
For a small country like Austria, international technology diffusion potentially plays an important role in the long-term growth process. As shown above, technology acquired from abroad has a relatively greater weight in small open economies than in the larger economies. Let us therefore take a closer look at technology imports.

At a general level, an examination of the data leads to the following three observations:

- The R&D content of imported intermediates increased dramatically between 1976 and 1994. The R&D content of imported investment goods has also grown rapidly, though at a slower pace.
- In the Austrian economy, Germany plays an outstanding role as a source of R&D embodied in intermediate goods, and a still more important role as a supplier of research and development embodied in investment goods.
- The machinery sector is by far the most important recipient of technology embodied in imported intermediate goods. In contrast, the service sector (other services) is by far the most important destination of technology embodied in investment goods.

Figure 4: R&D content of intermediate goods imported from Germany by user sector

Million ATS



Source: WIFO.

The R&D content of intermediate goods from Germany has increased from ATS 632 million in 1976 to ATS 3,840 million in 1994[6] (Figure 4). This is due to the combined effect of a deepening international division of labour and rising R&D intensities in German manufacturing.

After Germany (and the "other OECD" group of countries), the USA (8.3 percent) is the second most important supplier of technology to Austria, followed by Japan (6.7 percent) and France (6.2 percent). The "other OECD" group of countries includes several European trade partners, most notably – given its volume of trade with Austria – Switzerland. The importance of the USA as a source country may be surprising at first. However, it reflects both the structure of exports from the USA to Austria and the high R&D intensity of manufacturing in the USA. The indirect R&D imports through intermediate goods from Italy, the Netherlands and the U.K. are modest, being in the range between ATS 250 and 280 million (1994), respectively. This corresponds to shares of these

[5] For the sector classification see Table 1.

[6] For a comparison: the GDP at 1976 prices (1976 = 100, 1994 = 198) has just approximately doubled between 1976 and 1994.

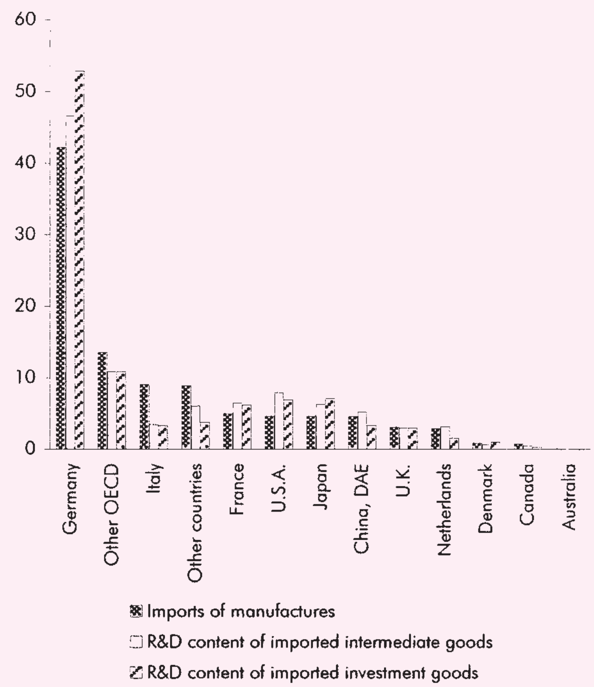
Figure 5: R&D content of investment goods imported from Germany by user sector

Million ATS

Source: WIFO.

Figure 6: Imports of manufactures and imported technology 1994

Percentage shares



Source: WIFO.

countries in the R&D content of imported intermediate goods between 3.0 and 3.3 percent. The shares of the remaining countries are negligible.

Germany dominates Austria's embodied technology imports – in particular through investment goods – to an even greater extent than its manufacturing imports. The USA is the second most important partner country in this respect (apart from the "other OECD" group of countries).

In nominal terms, the R&D content of investment goods imported from Germany increased nearly fivefold from ATS 321 million in 1976 to ATS 1,531 million in 1994 (Figure 5). Thus, it is not only much lower in absolute terms than that of intermediate goods but its growth has been less pronounced. Germany (and the aggregate "other OECD") is again followed by the USA (8.1 percent) as the second most important supplier, Japan (7.5 percent) and France (6.6 percent). Thus, the rank order of the Top-5 source countries is the same as that for imports of intermediate goods. The indirect R&D imports through investment goods from Italy, the U.K. and the Netherlands are small, in the range of ATS 106 to 51 million (1994). This corresponds to shares between 1.7 and 3.6 percent.

The shares of the remaining countries (Denmark, Canada, Australia) are negligible.

Embodied technology imports from overseas, in particular from China and the Dynamic Asian Economies (DAE), Japan and the USA have shown particularly rapid growth in the two decades under examination. This is true for both intermediate and investment goods.

As shown, Germany plays a dominant role as a source of embodied technology for the Austrian economy. As such, this is not surprising since Germany is by far Austria's most important trading partner. However, Germany's importance as a source of acquired technology even exceeds its weight in Austria's foreign trade. While Germany's share in Austrian imports of manufacturing goods is 42.2 percent, its share in research and development embodied in imported intermediate goods amounts to 45.8 percent (1994). For investment goods, this difference is even more pronounced: Germany supplies 51.1 percent of research and development embodied in imported investment goods (1994).

A comparison of source country shares in Austria's total imports of manufacturing goods with their shares in research and development embodied in imported intermediate and investment goods is provided in Figure 6. Just as

Table 2: Largest gain in technology intensity from acquired technology (Top 5)

	Intensity				
	Total	Domestic	Imported	Largest source	Percentage share of largest source
1976					
Transport	1.010	0.217	0.793	Germany	48.7
Instruments	0.965	0.202	0.763	Germany	53.6
Electrical machinery	0.711	0.124	0.587	Germany	44.9
Non-electrical machinery	0.441	0.221	0.221	Germany	49.6
Fabricated metal	0.383	0.252	0.131	Germany	50.2
1983					
Transport	1.143	0.209	0.933	Germany	56.2
Instruments	0.654	0.235	0.419	Germany	48.7
Electrical machinery	0.650	0.080	0.570	Germany	41.4
Fabricated metal	0.492	0.251	0.241	Germany	58.8
Non-electrical machinery	0.364	0.151	0.212	Germany	53.4
1988					
Transport	1.226	0.198	1.028	Germany	57.2
Instruments	0.711	0.276	0.435	Germany	47.4
Electrical machinery	0.623	0.095	0.528	Germany	45.5
Chemicals	0.493	0.092	0.400	Germany	51.0
Non-electrical machinery	0.423	0.140	0.283	Germany	52.4
1994					
Transport	2.213	0.314	1.899	Germany	53.9
Instruments	1.221	0.525	0.696	Germany	37.4
Electrical machinery	1.020	0.112	0.908	Germany	40.2
Non-electrical machinery	0.836	0.304	0.531	Germany	45.5
Chemicals	0.611	0.132	0.479	Germany	48.9

Source: WIFO.

in the case of Germany, the shares of the USA, Japan and, to a lesser extent, France in the R&D content of imported intermediate and investment goods significantly exceed their respective weight in Austria's imports of manufacturing goods. In contrast, Italy and, to a lesser degree the "other OECD" group of countries have lower shares in the R&D content of import flows to Austria than in imports of manufacturing goods.

In the five industries with the largest contribution of indirect research and development to total technology intensity, Germany appears as the most important source of indirect research and development in all the years examined.

For the five industries with the largest contribution of indirect research and development to total technology intensity, Germany appears as the principal source of research and development acquired from abroad in the four years under examination (Table 2), although it's share decreased (in particular between 1988 and 1994). However, the position of Germany vis-à-vis Austria is not unique. Other countries show a similar pattern of "dependence". *Papaconstantinou – Sakurai – Wyckoff* (1996, p. 60) report that the USA is the principal source of embodied technology imports for all of Canada's Top-5 industries. The Top-5 industries in the other nine countries in the OECD sample have at least one additional "most important source country" (or group of countries). "Technology sourcing" in these terms is still often dominated by a single country (multiple entry of a source country). Taking a view across countries, the USA appears most frequently as the principal source of technology imports.

Table 3: R&D performance and technology use

Performers (manufacturing)	Percentage shares in total manufacturing R&D	Users	Percentage shares in total acquired technology
1976		*1976*	
Chemicals	25.8	Other services	22.5
Electrical machinery	16.9	Construction	9.7
Non-electrical machinery	11.9	Electrical machinery	8.3
Transport	8.1	Chemicals	7.7
Basic metal	2.9	Transport	6.8
1983		*1983*	
Electrical machinery	34.7	Other services	24.5
Chemicals	19.2	Electrical machinery	8.4
Non-electrical machinery	16.3	Construction	8.0
Transport	11.0	Chemicals	7.6
Basic metal	2.9	Transport	7.2
1988		*1988*	
Electrical machinery	40.0	Other services	28.3
Chemicals	18.9	Construction	8.2
Non-electrical machinery	14.5	Chemicals	8.0
Transport	11.9	Electrical machinery	7.9
Stone, clay and glass	2.0	Transport and storage	7.1
1994		*1994*	
Electrical machinery	47.9	Other services	28.9
Chemicals	20.3	Transport and storage	10.2
Non-electrical machinery	10.6	Transport	9.8
Transport	7.9	Electrical machinery	9.2
Fabricated Metal	4.9	Construction	7.9

Source: Austrian Central Statistical Office, WIFO.

PERFORMANCE AND ACQUISITION OF RESEARCH AND DEVELOPMENT

Industries performing a high degree of research and development are, in general, not the same as those which heavily acquire research and development embodied in intermediate and investment goods. While an industry's "R&D performance" is given immediately by its direct expenditure on R&D, its acquisition of embodied technology – via the structure of inter-industry intermediate and capital flows – depends on (domestic and foreign) downstream industry R&D intensities.

Table 3 confronts the Top-5 R&D-performing industries in terms of shares in total manufacturing sector expenditure on R&D with the Top-5 technology-using industries ranked according to their share in total acquired technology.

In 1994, "electrical machinery" was by far the most important R&D performing industry in Austria. This industry accounted for almost half (47.9 percent) of total manufacturing sector expenditure on R&D, followed by "chemicals" (20.3 percent), "non-electrical machinery" (10.6 percent), "transport equipment" (7.9 percent) and "fabricated metal" (4.9 percent). Thus, the performance of R&D in Austria is highly concentrated. Moreover, concentration appears to have increased over time: the Top-5 industries together accounted for 65.6 percent of total manufacturing sector direct expenditure on R&D in 1976, as compared to 84.1 percent in 1983, 87.3 percent in 1988 and 91.6 percent in 1994. In the period of observation, the weight of the "electrical machinery" industry increased particularly rapidly and was considerably higher than its share reported by *Papaconstantinou – Sakurai – Wyckoff* (1996, p. 55) for the other OECD countries (1990) in their sample.

The "electrical machinery" industry is the biggest investor in research and development. The acquisition of indirect research and development is much less concentrated. Two service industries turn out to be the most important receivers of technology.

The distribution of acquired technology across industries is quite different from that of direct expenditure on R&D (R&D performance). Table 3 shows the respective Top-5 industries. Concentration is not only much lower in this case, but the two major users of technology in 1994 were service industries: other services (28.9 percent) and transport and storage (10.2 percent). Only then we find two manufacturing industries, transport equipment (9.8 percent) and electrical machinery (9.2 percent), followed by construction (7.2 percent). Over time, the two leading service industries substantially increased their share in total acquired technology while the other industries gained little or lost in importance.

Although also in Austria other services became the most important technology-absorbing sector, its share lags behind by international standards: in several other OECD countries, the share of other services is well above 30 percent, and up to 36 percent in France and the U.K. (1993).

TOWARDS A KNOWLEDGE-BASED ECONOMY

In analogy to the OECD study *by Papaconstantinou – Sakurai – Wyckoff* (1996) manufacturing industries were consolidated to five source clusters: information, transportation, consumer goods, materials and fabrication. For a description of these clusters see Table 4. The distribution of acquired technology (indirect research and development) by source clusters and acquiring industries or sectors (Table 5) points at the meanwhile outstanding role of the information and communication sector as a source of technology.

Table 4: Classification of clusters

Cluster	Industries
Information	Electrical machinery, instruments
Transportation	Transport
Consumer goods	Food and tobacco, textile and leather
Materials	Wood and furniture, paper and printing, chemicals stone, clay and glass, basic metal
Fabrication	Fabricated metal, non-electrical machinery

Austria's evolution towards a knowledge-based economy is illustrated by the change in the pattern of technology flows.

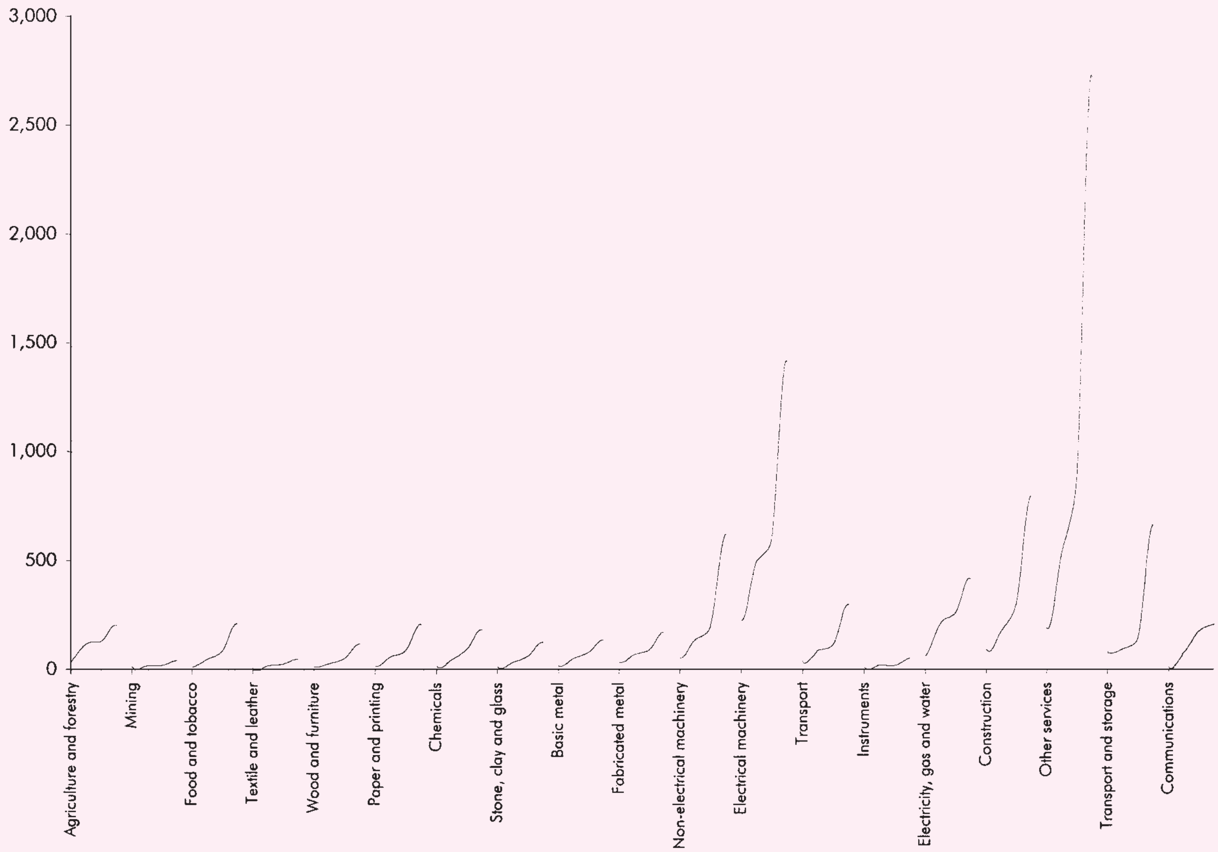
By 1994, the information technology cluster was by far the most important source of acquired technology in the Austrian economy, accounting for 43.5 percent, followed by the materials cluster (24.3 percent). Thus, there has been an almost perfect reversal of the pattern prevailing in 1976 (materials cluster 43.6 percent, information technology cluster 25.3 percent of total acquired technology). The shifts in technology flows from the remaining source clusters (transportation, consumer goods and fabrication) are minor. At the same time, the service sector became the most important user of acquired technology (51.6 percent).

In 1994, the information technology cluster was the most important source of technology, with the materials cluster lagging far behind. The reverse pattern was prevailing in 1976.

At the sector and cluster level, information technology absorbed by the service sector turns out to be the most important flow of embodied technology in quantitative terms (24.4 percent of total acquired technology) in 1994, whereas in 1976 this position was held by technology embodied in materials and absorbed by the manufacturing sector (23.1 percent). This development reflects a profound and pervasive change in the pattern of embodied technology flows. Even for the manufacturing sector, the information technology cluster is recently (1994) the most important source of embodied technology (18.0 percent of total acquired technology), thus outperforming the materials cluster (13.0 percent). In 1976, the respective shares were 12.1 percent and 23.1 percent.

Figure 7: Technology source: information technology cluster

Acquired technology by user industry 1976, 1983, 1988, 1993, million ATS



Source: WIFO.

At the same time, the largest gain in shares between 1976 and 1994 can also be observed for technology acquired by the service sector from the information technology cluster (+12.3 percentage points). This is mainly due to the gains in shares realised by other services (+8.6 percentage points).

The absorption of indirect research and development originating in the information technology cluster by the service sector is the most important technology flow in quantitative terms. Even in manufacturing, the information technology cluster was the most important source of technology, leaving behind the materials cluster. Here, too, the relations have changed fundamentally since 1976.

In 1994, 55.8 percent of the embodied technology originating in the information technology cluster was absorbed by the service sector (31.7 percent by other services), whereas 41.4 percent went to the manufacturing sector. In 1976, these two sectors were still at a par, accounting for 47 percent to 48 percent of indirect research and development acquired from the information technology cluster.

Figure 7 illustrates the enormous increase in information technology acquired by other services. In nominal terms, this flow has increased from ATS 0.2 to 2.7 billion between 1976 and 1994. In the 1990s, the electrical machinery industry, construction, non-electrical machinery as well as transport and storage also experienced rapid growth in acquired information technology.

CONCLUSIONS

In Austria, direct business sector expenditures on R&D accounts for not quite half of the total R&D content of output. The most important components of "indirect research and development" are imported and domestic intermediate goods, investment goods being less important in this respect. In the longer run, the share of imported technology in total R&D content is increasing. Although initially Austria was able to catch up, total R&D intensity was still low by international standards in 1994.

With a ratio of "indirect research and development" to direct R&D expenditure close to 1 : 1, Austria holds a middle position in the international community. In large, advanced economies, this ratio is significantly lower. As expected, the ratio of R&D embodied in imported intermediate and investment goods to direct R&D expenditure is relatively high – the same holds true for comparable small open economies, however. Thus, there is no evidence that Austria holds an extraordinary position based on above-average imports of technology. Consequently, analyses based on total R&D content cannot be expected to contribute much to the "performance paradox" mentioned in the introduction. Analyses based on innovation survey data appear more promising in this context.

Germany plays an outstanding role as a supplier of imported technology to Austria. Germany dominates technology imports – particularly through investment goods – to an even higher degree than Austria's imports of manufacturing goods. The USA is the second most important partner country in this respect (apart from the "other OECD" group of countries).

The change in the pattern of technology flows over the two decades examined provides an impressive picture of the evolution of Austria towards a "knowledge-based economy". On the one hand, the service sector has gained significantly in importance as a destination of technology flows, catching up with manufacturing by 1994. On the other hand, the weight of the information technology cluster has been increasing rapidly: already in 1994, the information technology cluster was by far the most important source of technology, outweighing the materials cluster. Thus, the relations prevailing in 1976 have been almost completely reversed.

Indirect research and development originating in the information technology cluster and absorbed by the service sector constitutes the most important flow of technology. Even in manufacturing, the information technology cluster was the most important source of technology in 1994, thus outperforming the materials cluster. Here, too, the relations have undergone a fundamental change since 1976.

Table 5: Percentage shares of acquired technology from source clusters

1994

	Source cluster					
	Information	Transportation	Consumer goods	Materials	Fabrication	Total
Primary sector	*1.21*	*0.24*	*0.06*	*0.83*	*0.65*	*3.00*
Agriculture, forestry and fishing	1.01	0.18	0.06	0.64	0.52	2.41
Mining	0.20	0.06	0.00	0.19	0.13	0.59
Manufacturing sector	*18.02*	*8.71*	*0.49*	*12.97*	*5.25*	*45.44*
Food and tobacco	1.06	0.28	0.14	0.92	0.74	3.14
Textile and leather	0.24	0.05	0.11	0.68	0.18	1.26
Wood and furniture	0.59	0.13	0.04	0.65	0.38	1.79
Paper and printing	1.04	0.11	0.02	0.72	0.38	2.28
Chemicals	0.91	0.16	0.04	4.25	0.59	5.96
Stone, clay and glass	0.62	0.12	0.01	0.59	0.31	1.65
Basic metal	0.68	0.06	0.01	1.09	0.27	2.11
Fabricated metal	0.86	0.09	0.01	0.63	0.45	2.03
Non-electrical machinery	3.13	0.74	0.02	0.91	0.86	5.66
Electrical machinery	7.13	0.14	0.04	1.49	0.42	9.22
Transport	1.50	6.82	0.02	0.86	0.64	9.85
Instruments	0.26	0.01	0.01	0.18	0.04	0.50
Service sector	*24.25*	*8.25*	*0.67*	*10.55*	*7.84*	*51.56*
Electricity, gas and water	2.10	0.15	0.01	0.28	0.28	2.83
Construction	4.01	0.54	0.03	2.23	1.12	7.93
Other services	13.76	3.08	0.56	6.64	4.93	28.97
Transport and storage	3.33	4.08	0.06	1.32	1.47	10.25
Communication	1.04	0.40	0.01	0.08	0.04	1.58
Total	*43.48*	*17.21*	*1.22*	*24.35*	*13.75*	*100.00*

Source: WIFO.

REFERENCES

Aghion, Ph., Howitt, P., Endogenous Growth Theory, M.I.T. Press, Cambridge, MA, 1998.

Barro, R. J., Sala-i-Martin, X., Economic Growth, McGraw Hill, New York, 1995.

Borisov, V., Hutschenreiter, G., Kryazhimskii, A., "Asymptotic Growth Rates in Knowledge-Exchanging Economies", Annals of Operations Research, 1999, (89), pp. 61-73.

Butschek, F., "Institutional Continuity and Economic Growth – The Case of Austria", WIFO Working Papers, 1999, (115).

European Commission, Second European Report on S&T Indicators 1997, Luxembourg, 1997.

Fagerberg, J., "Technology and International Differences in Growth Rates", Journal of Economic Literature, 1994, 32(September), pp. 1147-1175.

Grossman, G. M., Helpman, E., Innovation and Growth in the Global Economy, M.I.T. Press, Cambridge, MA, 1991.

Grossman, G., Helpman, E., "Technology and Trade", in Grossman, G., Rogoff, K. (Eds.), Handbook of International Economics, Vol. III, North Holland, Amsterdam-New York, 1995, pp. 1279ff.

Helpman, E., "R&D and Productivity: The International Connection", NBER Working Paper, 1997, (6101).

Helpman, E., Krugman, P., Market Structure and Foreign Trade, M.I.T. Press, Cambridge, MA, 1985.

Hutschenreiter, G., "Intersektorale und internationale 'F&E-Spillovers'. Externe Effekte von Forschung und Entwicklung", WIFO-Monatsberichte, 1995, 68(6), pp. 419-427.

Hutschenreiter, G., "Produktivität und Technologiediffusion", Wirtschaftspolitische Blätter, 1998, 45(1), pp. 28-37.

Hutschenreiter, G., Kaniovski, Y. M., Kryazhimskii, A. V., "Endogenous Growth, Absorptive Capacities and International R&D Spillovers", IIASA Working Paper, 1995, (WP-95-92).

Ioannides, E., Schreyer, P., "Technology and Non Technology Determinants of Export Share Growth", OECD Economic Studies, 1997, 28(1), pp. 169-204.

Klenow, P. J., Rodriguez-Clare, A., "Economic Growth: A Review Article", Journal of Monetary Economics, 1997, 40(3), pp. 597-617.

Marin, D., "Learning and Dynamic Comparative Advantage: Lessons From Austria's Post-War Pattern of Growth for Eastern Europe", CEPR Discussion Paper, 1995, (1116).

Miller, R. E., Blair, P. D., Input-Output Analysis. Foundations and Extensions, Prentice-Hall, Englewood Cliffs, 1985.

OECD (1997A), The OECD STAN Database for Industrial Analysis 1976-1995, Paris, 1997.

OECD (1997B), Research and Development Expenditure in Industry 1974-95, Paris, 1997.

OECD, Technology, Productivity and Job Creation – Best Policy Practices, Paris, 1998.

Papaconstantinou, G., Sakurai, N., Wyckoff, A., "Embodied Technology Diffusion: An Empirical Analysis for 10 OECD Countries", STI Working Papers, 1996, (1).

Rivera-Batiz, L. A., Romer, P. M., "Economic Integration and Endogenous Growth", Quarterly Journal of Economics, 1991, 106(2), pp. 531-555.

Romer, P. M., "Endogenous Technological Change", Journal of Political Economy, 1990, 98(5), pp. 71-102.

Sakurai, N., Ioannides, E., Papaconstantinou, G., "The Impact of R&D and Technology Diffusion on Productivity: An Empirical Analysis for 10 OECD Countries", STI Working Papers, 1996, (2).

Scherer, F. M., "Using Linked Patent and R&D Data to Measure Interindustry Technology Flows", in Griliches, Z. (Ed.), R&D, Patents, and Productivity, National Bureau of Economic Research, University of Chicago Press, Chicago, 1984, pp. 202-212.

Steindl, J., "Import and Production of Know-How in a Small Country", in Saunders, C. T. (Ed.), Industrial Policies and Technology Transfer between East and West, Springer, Wien-New York, 1977, pp. 211-218.

Technology Flows in the Austrian Economy – Summary

The OECD has been measuring the total research and development content of output flows for several years. This measure not only includes direct R&D expenditures, but also the research and development content of intermediate and investment goods, both domestic and imported. In many cases, this presents a more meaningful approach to measuring technology levels. For the first time, computations of the total research and development content of output were carried out for the Austrian economy. The results are presented in this study.

In Austria, direct expenditures on research and development in the business sector account almost half of the total research and development content of aggregate output. The most important components in the "indirect R&D" category are imported and domestic intermediate goods. In the longer run, the share of imported technology in the total R&D content of output is increasing. Although initially Austria was able to catch up (from 1976 to 1988), total research and development intensities were still low by international standards in 1994.

With a ratio of "indirect" to "direct" research and development expenditures close to 1 : 1, Austria holds a middle position in the international community. In large, advanced economies this ratio is significantly lower. For a small open economy technology flows embodied in imports are particularly relevant. As expected, the ratio of imported intermediate and capital goods to direct expenditures on research and development is relatively high by international standards. However, the same holds true for comparable small open economies. Thus, there is no evidence that Austria holds an extraordinary position based on above-average imports of technology.

Germany plays a remarkable role as a supplier of imported technology to Austria. Germany dominates technology imports – in particular through investment goods – to an even higher degree than Austria's imports of manufacturing goods. The USA is the second most important partner country in this respect (apart from the "other OECD" group of countries including Switzerland).

The change in the pattern of technology flows over the two decades examined provides an impressive picture of Austria's evolution towards a "knowledge-based economy". On the one hand, the service sector has gained significantly in importance as a destination of technology flows, catching up with manufacturing by 1994. On the other hand, the weight of the information technology cluster has been increasing rapidly: already in 1994, the information technology cluster was by far the most important source of technology, outweighing the materials cluster. Thus, the relations prevailing in 1976 have been almost completely reversed.

Indirect research and development originating in the information technology cluster and absorbed by the service sector constitutes the most important flow of technology. Even for the manufacturing sector, the information technology cluster was the most important source of technology in 1994, thus outperforming the materials cluster. Here, too, the relations have undergone a fundamental change since 1976.