

TOWARDS REALISTIC EXPECTATIONS

THE SCIENCE SYSTEM AS A CONTRIBUTOR TO INDUSTRIAL INNOVATION

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1 Introduction

The relationship between basic research and technology is an important one, given the considerable sums governments spend on basic research and the public expectation of academic research as a contributor to national competitiveness. Although the current debate of the linkages of science and technology is by no means a new one it can be said that major long-term policy changes often depend, among others, on a better understanding of the innovation process, and especially the links between those who produce knowledge and those who use it.

It is a well known fact today that science and technology are key resources for economic development although the division of labour between academic research and industrial innovation is seen in a new light. Over the last decade, the debate over the role of universities in fostering technical advance has intensified.

Many innovation studies (e.g. SAPPHO, 1971) describe the general characteristics of successful innovations, yet every innovation has its own unique story. However, one fact remains common to most of the innovation surveys, and especially those related to major innovations: Even in non-linear innovation processes there are linkages to fundamental and basic research. Such dynamics partly explain the rise in academic-industry relations due to new models of innovations that break down institutional barriers and open up new ways of creating and transferring science and technology. As a result of these studies some argue that universities can and should play a larger and more direct role in assisting industry. The growing links between public and private sector science, especially between universities and industry, are important aims of public policy initiatives. One of the European policy concerns with respect to public research is the belief that European firms lag behind their American competitors in their ability to turn basic and applied research, partly conducted by universities and government research institutes, into competitive new products and processes.¹ The solution taken in some European countries is either to directly steer public research funds into areas with potential commercial applications or to provide incentives for public research institutions to shift towards commercially valuable research.

Another view of the changing nature of universities and public research organisations is that the increasing co-operation between the two sectors reflects rather fundamental institutional changes. Universities, for example, are becoming more autonomous and prepared to redefine their strategic aims in the context of declining real resources. One indicator is that the percentage of academic research funded by industry has grown in Europe on average from 3% in 1983 to about 6% in 1993. Thus, universities are induced to spawn a wide range of local and regional linkages with the private sector, as well as generating spin-off companies to service larger companies. Following this belief, some argue that countries would be better off if they left the funding of science to private companies (see e.g. Kealey, 1996). Government money for science only displaces private funding, and private funding works better.

A third view of course regards this as no more than a receipt for disaster as the public science base is sacrificed to the (short-term) needs of private industry. As Brooks (1993, p. 225) notes: "The function of universities in the national research system should remain mainly the creation of "public knowledge". The relatively modest level of

¹ See e.g.: Green paper on innovation (European Commission, 1995): "Compared with the scientific performance of its principal competitors, that of the EU is excellent, but over the last fifteen years its technological and commercial performance ... has deteriorated. [This] indicates the strategic importance of transforming the scientific and technological potential into viable innovations" (p. 5).

'privatisation' of university research that has already taken place in the last decade should not be encouraged to grow." Hence, many academics and others see these developments as a threat to the integrity of academic research. They fear that greater involvement with industry and commerce will corrupt academic research and teaching, divert attention away from fundamental research, and potentially destroy the openness of communication among university scientists which is an essential component of academic research.

During the last decades a well established paradigm regarding the distinct approaches to knowledge production and use has been developed. It is a striking fact that in the 1970s the myth and reality of *sunrise technologies* determined the technology policy in Europe with a more or less clear distinction between basic and applied research. Today, the situation is completely different with policies trying to tie basic and applied research on the one side and the users on the other side more closely together. For example, the EU-framework programmes have changed during the past decade more and more towards innovation and technical change driven initiatives. Structured procedures are being developed to mate industry with experimental basic research.

There is clearly a need to understand the factors giving rise to these developments and to evaluate the significance they have in the wider innovation context. The following report therefore starts by giving an overview of how the change of economic effects around fundamental research has affected the role of universities as a knowledge supplier. It should be analysed how these developments indicate a shift in the role of academia in innovation and how new models for innovation emerged that break down institutional barriers and open up new ways of creating and transferring science and technology.

The structure of the study is the following. Chapter 2 is a review of the literature and provides a brief summary of the different approaches concerning the interplay of scientific research and the economy. Whereas these first approaches are more or less based on a macroeconomic level, the main critiques and methodological problems in connection with econometric approaches are summarised. At a less macro level, many of the benefits are difficult to capture in economic statistics.

Due to this finding, chapter 3 summarises recent case studies and surveys and provides some view on comprehensible economic benefits which result from basic research. These new approaches are focused more on the indirect effects and thus main tasks of the science system and provide an intellectual framework for understanding the links between science and industry on a more microeconomic level. What emerges is a more detailed picture of the relationship between basic science and industrial innovation.

Chapter 4 focuses on the empirical evidence of the impact of academic research. The first section analyses patents granted at the American patent office. The so-called "Science Linkage Indicator" sheds light on the linkage between science and technological development in looking into patents and tracing back the scientific inputs into patents. The second section summarises the results of an existing study² concerning the co-operative behaviour of innovative firms in Austria. The survey contains questions of relevance due to the role of universities as co-operation partners in the process of product development.

² Schibany, A. (1998): Co-operative behaviour of innovative firms in Austria: *tip*-survey, Vienna.

Chapter 5 summarises the results of an empirical survey which was designed in order to get a broader view of the modes of interactions between the academic and the industrial sector. Within this survey, the emphasis is directed towards motivations and barriers of co-operation as well as a broad estimation of how the industry values academic knowledge.

The main results are shown in chapter 5. Finally some tentative policy conclusions are drawn in chapter 6.

2 The role of basic science

Basic science is one of building-blocks of innovation systems and of a good innovation infrastructure. However, the nature of the relationship between basic science and the economy is changing, as applied scientific activity becomes increasingly interdisciplinary, and as the boundaries between university and other parts of the knowledge-producing system become increasingly blurred. This had impact on several theoretical approaches: for years it was quite attractive to measure the direct economic returns to basic research on the basis of an econometric evidence. In the meanwhile the focus lies less on the macro level because many of the benefits that flow from basic research are difficult to capture in economic statistics. Hence, recent findings try to explore some micro-level mechanism which aim to explain the sources and mechanism behind macroeconomic benefits identified by the econometricians. The following chapter will therefore try to give an overview of the different approaches and will explore the major categories of linkages operating between science and the economy (technology).

2.1 The 'old' paradigm

The idea that science plays an originating role in industrial innovation and transmits utilitarian knowledge to society built the basis of the "old economics of science" (Dasgupta and David, 1994, p. 490). On political level this so-called linear model was also legitimated by an influential report, prepared by Vannevar Bush³, for how the U.S. government support for science should be structured after the war. Although the specific institutional recommendations from the report were not adopted, it set the terms for the subsequent intellectual debate about science policy. But nevertheless he selected the university as the centerpiece of post-war science policy specifically because of its independence and autonomy (see Brooks, 1996). The claimed responsibility of the government for maintaining the independence of the scientific establishment involved substantial and growing national government funding of basic research in government laboratories and universities.

However, the "old economics of science" has two main characteristics: first, a quite distinct idea of scientific knowledge as a public good, and secondly, about the innovation process itself.

Science as a public good

From a theoretical point of view the seminal contribution to the analysis of the production and distribution of basic scientific knowledge, notably the analytical work of Nelson (1959) and Arrow (1962), recognised and incorporated the worldview developed by V. Bush. They analysed the implications of the difficulties of privately appropriating the economic value of basic research findings. According to this paradigm, new research findings are thought of as a *public good* which is freely available with the main characteristics defined in terms of indivisibility and non-excludability from the use. These characteristics were necessary to the objective of the economic analysis,

³ Vannevar Bush: Science –The Endless Frontier; United States Office of Scientific Research and Development (1945).

namely to understand why perfect competition fails to achieve an optimal allocation of resources, i.e. why companies systemically under-invest in basic research and why should the state fund such an investment?

Indeed, the production of new knowledge is dominated by the classical "free-rider" problem and the consequence is that, in a competitive system, firms choose a lower amount of investment in research activities than is required by social optimality. The aim of such an approach is to provide adequate incentives for achieving an optimality in resource allocation. Once articulated in this form, scientific knowledge was thought of as a "kind of intellectual bank account" (Brooks, 1994, p. 477) on which society as a whole would be able to draw automatically. Thus, describing scientific knowledge as a *public good* would lead to a private under-investment which is socially inadequate. But this approach has also been relevant for public policy insofar, as it defined the necessary compensating role of public-policy makers in basic research activities.

Although the characterisation of scientific knowledge as a public good describes one fundamental aspect of the production of knowledge (most of the results of academic research is published in journals or is accessible by the public), two main points could be emphasised against the conventional "public good" argument of science:

- The status of basic research is reduced to a source of information and the process by which this information is produced is ignored. However, associating the output of research activities with information alone allows a convenient economic framework for explaining policy intervention. But the problem of the production of information is not dealt with such an analysis. It was even stressed by mainstream theory that the "Arrowian" view of R&D "... does not consider alternative environments in which R&D is undertaken" (Dasgupta and Stiglitz, 1980, p.271).
- The innovation process is reduced to a mechanistic process of adoption of a new stock of information. Behind this lies the assumption that a new technique can be instantaneously and efficiently adopted. Hence, a more realistic assumption of the existence of marginal progress of technical innovation or that new techniques derive from old ones is not taken into consideration.

Looking back at the intellectual framework which justified public intervention in research, it is striking that over time, progressively fewer references have been made to the empirical evidence, and more to the standard theorems of welfare economics. In stressing the public-good character of science, the distinction and interaction between science and technology has been more or less ignored.

The linear process of innovation and its missing links

Much of the public debate about science and technology policy has for decades been implicitly dominated by this specific model ("linear" model) of the innovation process. In that model, basic research produces a flow of theories and findings that are refined through applied research, tested in the development process, and finally commercialised as industrial innovations. Hence, this model builds the framework for categorising the processes of knowledge creation according to their commercial aims. But this linearity includes a theory of knowledge production as well. Each level in the linear model produces outputs that are transferred to the next level as inputs. In keeping with the sequential nature of the model, the flow is unidirectional: later stages do not provide inputs for earlier stages (Steinmueller, 1994).

In recent years policy experts and policy advisors have been travelling round the world to spread the message: "the linear model of innovation is dead" (Rosenberg, 1994, p. 145). New theories and approaches about innovation and its social and economic embeddedness are challenging the well known arguments for policy intervention. They show that the linear model depicts only one of academia's potential contribution to the creation of technological know-how. As many empirical studies have shown, only a few industries, like chemicals and pharmaceuticals have always benefited directly from basic research in organic chemistry, clinical medicine and molecular biology (Pavitt, 1991). Thus, the linear model applies only in rather special circumstances and in a limited range of industries.

But in general, the traditional pattern of connecting basic research to industrial innovation is waning. Its assumption about the self-governance of science and the unidirectional transfer of knowledge from science to technology are inconsistent with empirical studies of the conduct and institutions of science. Evolutionary theory, systems of innovation approaches and new knowledge about the social shaping of technology show that there are many contributions from academia to industry and most of them are indirect and difficult to measure (Kline and Rosenberg, 1986; Rosenberg, 1982; Dasgupta and David, 1994). The significance of these studies is that, on the one hand, they cast suspicion on the separability of the activities performed by scientists from external social and technological influences. On the other hand, related studies of industrial innovations have revealed a much more complex pattern of knowledge creation, transfer and utilisation than suggested by the linear model. Thus, there are reverse flows of causation that shape the development of R&D on firm level as well as the development of science. This means that the 'linear' model of knowledge transfer is not the proper one. Science does not 'cause' innovation in such a direct way that increasing the amount of science will automatically increase the amount of innovation: funding more science will result mostly in more science (with some long-run impact on the private funding of RTD). Although science may still be the pursuit of knowledge "without practical ends", the very definite means and constraints that shape scientific activity has to be considered (Rosenberg, 1982). Thus, according to the 'innovation-system approach', the amount of economically productive technology adoption can not be increased without the availability of skills and knowledge. The results of the academic research are important on the one hand, but creating the potential and the human capital to ensure the adoption of new findings are essential for the performance of the enterprise, as well.

Despite the decline of the linear model, it has been a useful point of departure and an influencing impact of policy makers. New approaches, such as network models, offer a more complex and diversified view of examining the interaction between scientific research and industrial innovation. These theoretical considerations can also be seen as the basis for the changing expectations that the state and society have regarding basic research. However, the past years have seen a shift in the types of innovation policies that are in use in Europe and the USA. The traditional legitimization of public funded research institutes such as universities and government laboratories has changed. The encouragement (or requirement) to direct their research effort to areas that are of interest to private firms can be observed. Thus, the public and governments in most European countries expect more direct and specific benefits from their investments. Although the necessity of public funding of basic research is unchallenged, the traditional justification for public funding of basic research needs to be expanded. In addition to the public good view of science and the linear process of innovation, it is necessary to take other forms of economic benefits of basic research into considerations as well.

2.2 The macroeconomic framework

As a first approach, the econometric studies based on a more macroeconomic level emphasised one important finding: there is a link not only between R&D in general and economic growth but that basic science plays a role in this link. A number of studies have now been undertaken which investigate the economic returns to R&D and science. Almost all have found large and statistically significant economic benefits from performing science, although the quantitative, scientific base for these views is rather thin. Any attempt to find answers to questions like whether the current level of investment in science and technology is too large or too small, or whether the returns to such investments have declined over time or for what type of investment, has turned out to be a difficult task. There are difficulties in measuring economic growth and the contribution of science and technology to it "... because of the more general problem of estimating behavioural relationships and inferring causality from aggregate non-experimental economic data" (Griliches, 1995, p. 52).

Much of the literature on the economic pay-offs from public investments in basic research has adopted the framework of *cost-benefit analysis*. Due to the divergence between private and social return of basic research, economic benefits of many basic research results cannot be captured by a single firm or industry. The results of R&D can spread throughout the economy, with applications far beyond those imagined by the original researcher – the so-called *spillover effect*. Spillovers mean that an individual firm or innovator will realise only a fraction of the total returns to an innovation; that is, the innovation yields benefits to others for which the original researcher is not fully compensated.⁴

It was the pioneering work of Griliches (1958) with the measurement of the social returns from research investments which has produced a large literature which consistently finds high returns on such investments. This approach was the first attempt which tried to capture the dimension of the impact of basic research on an empirical level. As will be shown below, most of the following studies were pointing in the same direction.

In place of the conventional cost-benefit analysis, an alternative approach proposes that the science system does much more than supply information which may eventually underpin inventions. It plays a vital role in maintaining the innovation infrastructure as a whole, and therefore industrial innovation.

2.2.1 *Measuring the economic impact of research and development*

There are a number of studies⁵ which have tried to assess the impact of investment in research and development. In general, these studies have found a statistically significant and positive impact in terms of growth. Moreover, most of the studies examine the rationale for government involvement in R&D and show consistent findings of "a significant positive and relatively high rate of return to R&D investments at both the private and the social level" (Griliches, 1995, p. 82).

⁴ Examples are the laser and transistors, which are now a part of everyday life. The inventors of the laser probably had no idea that it would eventually be used in a wide range of applications. Likewise, the American physicists who invented the transistor at Bell labs in 1948 could not have imagined that their invention would be used today in radios, computers and other countless other electronic devices.

⁵ For an overview of the results of the main studies, see Griliches (1995).

However, most of these studies rely on great databases providing aggregate data for measuring the social rates of return to research. Although the results differ in the extent and exhibit a high variety, all studies have one result in common: private rates of returns to R&D are high, and the returns to society are even higher (see Table 1).

Table 1: Private and Social Rates of Return to R&D

Author (year)	Estimated rates of return	
	Private	Social
Nadiri (1993)	20-30	50
Mansfield (1977)	25	56
Terleckyj (1974)	29	48-78
Sveikauskas (1981)	10-25	50
Goto-Suzuki (1989)	26	80
Bernstein-Nadiri (1988)	9-27	10-160
Scherer (1982, 1984)	29-43	64-147
Bernstein-Nadiri (1991)	14-28	20-110

Source: Table adapted from Griliches (1992) and Nadiri (1993)

2.2.2 Social and private rates of returns to R&D

The consequences of the existence of important *spillovers* is that private firms will not invest enough in R&D from a societal perspective. This point was developed by many studies, theoretically as well as econometrically.⁶ Most of them have demonstrated that investments in R&D yield high returns to investors and even higher returns to society. One recent review of econometric studies concluded that the average private rate of return to an innovation seems to be between 20 and 30 per cent, while the social rate of return is closer to 50 per cent (Nadiri, 1993). An earlier case-study approach found that the median private return to the innovations studied was 25 per cent, while the median social rate of return was 56 per cent (Mansfield et al., 1977). In short, "in spite of [many] difficulties, there has been a significant number of reasonable well done studies all pointing in the same direction: R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates" (Griliches, 1992, p. 43).

Because of the divergence of social and private returns to R&D there is a common recognition of the need for government funding of basic research. Indeed, the federal government in all OECD countries fund the most part of basic research. Basic research is by definition not directed at solving an immediate problem or at inventing a particular product. While basic research – as will be shown in more detail below – can have immediate returns, economic returns from investments in basic research may be many years away, and may not have applications bearing any similarity to what the researcher originally thought. Hence, there is the problem to trace particular applied research outcomes back to basic research investments and to compute a rate of return on these basic research investments (Martin and Salter, 1996; David et al., 1994). Since such transfers are not priced or sold and are rarely adequately recorded by other means, the extent of their applications remains unknown.

⁶ Pavitt (1997) argued that business firms invest less than economically and socially desirable in basic research, because of two essential (and economically efficient) freedoms that basic researchers have: to publish and to change jobs.

Since much of the returns to basic research are not appropriated by the innovator, the gap between social and private returns is particularly large, and therefore the problem of under-investment is particularly severe. Firms are typically reluctant to invest much in basic research. Thus, universities and non-university centres comprise the largest group of performers of basic research. However, knowledge transfer from universities to private enterprises should be seen in a broad frame with certain direct and indirect effects. Some of these can certainly fall within the scope of state R&D sponsorship and is not only a chance of occurrence. As will be shown in more detail below, the study by Mansfield (1991) reveals, that on average 10% of the industrial innovations could not have been developed without direct reference to research done at universities and colleges. This study estimated the median social return to research done at academic institutions to be 28%.

Another study (David, 1994) notes that it is difficult to assign a particular rate of return to basic research, since its results may be used in many diverse ways. Instead, it suggests that basic research should be viewed as an input into applied research in many areas. Basic and applied research interact in many ways, increasing the productivity of both.

2.2.3 Limitations of measuring the impact of basic R&D

Most of the cited studies are beset by difficulties of method and in attributing causation. There are no reliable methods for estimating the value for money from publicly funded basic research, since the results of public R&D weave their way through the economy in countless directions. Once a research investment is embodied in processes or products used to produce other goods or in techniques used to generate further research findings, the link between the investment and the downstream activities that create economic value is obscured. Thus, it is rarely possible to isolate "key" contributions of basic research to commercial applications.

The main critics on such econometric studies can be summarised as follows:

- Many of these studies adopt a high level of aggregation in their analysis and rarely control for inter-industry differences in technological opportunity or appropriability. Moreover, the studies are based on production function models which do not consider the process of technical change. Thus they do not reveal how the economic returns of basic research are realised and provide no basis for comparing the productivity impact of basic research in different scientific disciplines.
- Typically the studies are conducted on annual data and examine short-term effects, whereas the payback to basic research is likely to be spread over the very long term (Martin and Salter, 1996). Indeed, attempting to capture adequately the returns to publicly funded research is much more difficult than estimating the returns to industry-funded R&D, much of which involves technical services and incremental product development.
- This leads to the problem that most econometric approaches towards the measurement of the economic benefits of research instead focus on the contribution to growth stemming from investments by private industrial firms in research (basic and applied) *and* development activities. It is an well established fact, that business firms on average spend at least three times more on development activities (i.e. designing, building, and

testing prototypes), than on research activities (i.e. developing, testing and refining scientific laws and models) (Patel and Pavitt, 1995).⁷

If research is the critical factor for national innovation performance, then improving such performance need only focus on expanding research expenditures by industry and government. For example, as was noted above, the rate of return to industrial R&D lies mainly between 0.2 and 0.5 [i.e. 20-50 per cent], with most estimates resulting in a higher social than private rate of return. Such rates of return are nevertheless very impressive. Indeed, they are considerable larger than the rates of return generally expected from money investments, which raises the question of why private businesses do not undertake more R&D and governments do not invest more in basic research, respectively?

The shortly described limitations of econometric approaches suggest, that the uncritical acceptance of the results of these cost-benefit analyses supports an unrealistic view of public science and technology policy.

First, the demonstration of a high benefit-cost ration for research investment understates the importance of the "complementary assets" (Teece, 1986), i.e. investments needed to commercialise technological advances derived from basic research.⁸ Because of the non-linear pattern of utilisation of basic research it is difficult to find a method for measuring the benefits. Considerable investment in applied research and development investments are generally necessary to translate any basic research advance into new products and processes.⁹ Inasmuch as the exploitation of basic research results depends on these complementary investments, it is difficult, and usually erroneous, to directly attribute to any single basic research output the entirety of the economic benefits associated with an application. These benefits typically are separated from the basic research "event" by a substantial period of time and additional R&D expenditure.

Second, a more fundamental problem is that the 'output' – in terms of greater productivity, profits and so on – is assumed to come from the higher level of R&D inputs provided by the country or sector in question. In practice, partly because of the spillover consequences it is usually impracticable to match outputs directly to the specified inputs. The returns reaped in a specific sector are likely to involve also "spin-off benefits" (Martin and Salter, 1996, p. 9) from other sectors. Hence, one should therefore also take into account R&D conducted in other sectors which are used as inputs in other areas. This problem is more significant in estimating the effects of basic research due to the fact that the linkages from basic research to use in production are multiple and complex. For example, chemistry is used not just in the chemical sectors but also in a large range of user industries, and other academic disciplines like physics and mathematics have still more pervasive impacts. Another example is, as most case studies show, that one of the primary benefits of basic research for industry comes through the transfer of skilled graduates from academia to industry. In most econometric studies this effect is ignored.

⁷ Even more problematic, such approaches are limited by virtue of the fact that R&D is merely one factor in the process of technical change. For example, Denson (1985) has suggested, that R&D accounts for only 20 per cent of all technical progress. Therefore, econometric approaches, which focus solely on R&D, and especially industrial R&D, fail to capture many of the activities contributing to technical progress.

⁸ For a discussion of "complementary assets", see below.

⁹ Given that the goal of basic research is increased understanding of a subject or natural phenomenon, rather than the creation of specific applications with economic value; such application-oriented research activities are normally categorised as applied research.

To summarise, virtually all econometric studies about the impact of research on productivity and growth have suggested positive and indeed impressively large rates of return. However, such attempts have been plagued by errors of measurement and errors of conception. The latter come mainly from weaknesses in theory as to how the R&D of one side and the economic and social aspects on the other are related. Investments in basic research are more often an investment in a learning capability, a capability to solve complex problems, than in the direct creation of new technologies, products or processes.

Given the difficulties to measure the economic impact of research at the macro level the received rates of return seem not to be very robust. This does not mean that, however, the effects of basic research are not real nor that they are not substantial. But it should indicate, that the traditional methods for measuring the benefits of basic research do not cover all results of the research process. It remains the assurance that regardless of the specific results all studies show positive rates of return. It can at least be said that research matters and does have positive impact on the economic performance. This leads to the necessity to analyse the effects and the utility of research done mainly at universities on a microeconomic level, hence to look at the paths and transfer mechanism on the firm level.

2.3 The new approach to basic research

One of the reasons for the lack of attention concerning the broader impact of basic research and the interface between science and technology in particular has been a "common confusion" (Pavitt, 1991, p.112). Although the results of science has some attributes of a *public good* (i.e. codified, published, easily reproduced and therefore deserving of public subsidy), it is certainly not a *free good* (i.e. costless to apply). Adopting this new approach by focusing on the user-side of the knowledge production, greatly complicates the assignment of causation, but offers several directions of research.

According to new models of innovation, the process of creating new technologies does have a more collective character which implies that the role of basic research is much more embedded in an economically and technological context than being the exogenous transmitter of knowledge. Hence, the results of basic research can not costlessly assimilated by any potential user. Only large companies have very often the complementary assets in terms of particular investments, capabilities and personnel needed to put specific scientific results to economic use.¹⁰

Regarding the public support of basic science it can be stated that public investment in basic science not only has public effects but also leads to private returns. However, this is a normal characteristic of public investment. But those making private returns also themselves make complementary investments. From the perspective of society, the interesting aspect is that the state investment leads to additional activity which would not have taken place without it; that it generates social returns which are bigger than the social investment. In these circumstances it is hardly surprising, that there is a significant correlation between public investment in R&D and business-funded R&D activities (Martin and Salter, 1996). Thus, many empirical studies demonstrate that federal spending on R&D

¹⁰ For a detailed analysis of the so called 'absorptive capacity', see below.

stimulates additional private spending on R&D (Levy et al., 1983). This complementarity holds up in basic, as well as applied research (Robson, 1993).

On a microeconomic level, a company has to be aware of the connections between research activities and other functions within the company. Specific case studies (e.g. Quéré, 1994) demonstrate the evolution from linear conception of innovation towards an iterated vision of the innovation process inside the firm. They consider the production process as a sequential process which needs time to be revealed and which is mainly characterised by the organisational design, that is the way in which the capabilities and skills are progressively acquired by its human resources.

On a macroeconomic level, countries and companies benefit academically and economically from basic research performed elsewhere, only if they belong to the international professional networks that exchange knowledge (Pavitt, 1997). Within this 'network conception' (Steinmueller, 1994) of basic research the focus lies on generation and distribution of new knowledge. Moreover, firms and governments must make increasingly complex choices about specialisation, competition and co-operation – relying exclusively on the public disclosure of scientific knowledge as a foundation for national growth and prosperity exhibit as rather difficult and not very effective.

New modes of knowledge

A highly influential contribution to the discussion of the new characteristics of knowledge was made by Gibbons et al. (1994). They argue that science is splitting into two modes of knowledge production. Mode 1 is traditional disciplinary science, especially basic science. But the important recent changes have happened in Mode 2, which includes not only the practice of applied science in universities and other research institutions but also the generation of knowledge elsewhere in society.

The boundary between the traditional, university-based applied sciences and the other parts of Mode 2 has been broken down by the massive output of qualified scientists and engineers from the universities into the economy since the post-War expansion of higher education, and by changes in research funding systems which deliberately promote research across institutional boundaries.

Mode 1 is discipline-based and carries a distinction between what is fundamental and what is applied; this implies an operational distinction between a theoretical core and other areas of knowledge (such as engineering sciences, where the theoretical findings are translated into application). By contrast, Mode 2 knowledge production is transdisciplinary. It is characterised by a constant flow-back and forth between the fundamental and the applied, between the theoretical and the practical modes. Thereby Mode 2 does not simply apply results obtained in Mode 1. Distinct types of knowledge are also created in the process of doing Mode 2 work.

For not going into detail, the specifics and characteristics of the distinction can be summarised: Gibbons et al. (1994) say that their analysis makes the traditional view of technology transfer – as a process where important ideas are passed down from the heights of academia into the industrial grounds for using – obsolete, because knowledge production is no longer the monopoly of the academics. This approach therefore focuses on how knowledge is produced, rather than why.

Summary

To summarise the main findings, concerning the performance of basic research, the new approach emphasises the social or individual embeddedness of scientific knowledge (Martin and Salter, 1996). It suggests that scientific knowledge is often person-embodied or the outcome of a set of interactions. In this context, scientific knowledge resides in individuals, independently or as a collectivity. Adherents of this new approach tend to view the benefits of publicly funded science as flowing mainly from *training and the development of networks* – that is in the interactions of individuals. Although *spillover* effects emphasised by the traditional paradigm still matter, the new approach emphasises learning effects, tacit knowledge, skills, methodologies, problem-solving ability and networks.

Hence, the economic effects of basic research has to be seen much broader, not only as generating new knowledge but together with the "absorptive capacity" of the user side. While previous academic work was more or less engaged in finding methods for the measurement of the direct impact of basic research to economic performance there is now more emphasises on the indirect effects and thus knowledge-specific outcomes.

3 Links between Science and Technology

Over the last decades there has been developed a relatively clear division of labour between academic and industrial research (see e.g. Rosenberg and Nelson, 1994).¹¹ On the one hand, R&D to improve existing products and processes became almost exclusively the province of industry, in fields where firms had strong R&D capabilities. Industrial R&D is almost totally aimed at bringing into practice and commercial use the next generation of technological development. It is thus focused directly on shorter term problem-solving, design and development. Industry is therefore more effective in dealing with problems that are located close to the market place. Moreover, it is widely accepted that the ability to innovate rapidly is a vital component of the competitiveness of firms and a major cause of economic and social well-being.

Thus, knowledge, learning and the resulting capacity to react on changing demand play a growing and crucial role for firms as well as in developed economies as a whole. Useful products and processes result from knowledge inputs from a wide variety of sources, and meet performance constraints along multiple dimensions. The current focus on knowledge has - combined with an interactive theory of innovation - led to the analysis of firm-internal factors, which determine successful innovations, or influence the absorption of outside created knowledge.

Basic research on the other hand became increasingly viewed as the task of universities. Academic institutions dominate in the publication of scientific papers with the main purpose to produce codified theories and models that explain and predict natural reality. To achieve analytical tractability, this requires simplification and reduction of the number of variables. Despite this purposeful level of abstraction of academic research, this does not mean that such research is not guided by practical concerns. As Rosenberg and Nelson (1994, p. 340) state: "... it is a gross misconception to think that if research is 'basic' this means the work is not motivated by or funded because of its promise to deal with a class of practical problems. Nor does it mean that university scientists and engineers are not building and working with prototypes and applicable industrial technology. Indeed this is a central part of academic research in many engineering fields. [...] What university research most often does today is to stimulate and enhance the power of R&D done in industry, as contrasted with providing a substitute for it."

Case studies and surveys of the last years analysed the interface between the academic and the industrial sector in more detail. They provide some interesting links between these sectors which see the benefits of basic research in a more detailed picture. However, the more detailed the links, the harder to measure. By focusing on the complex relationships between the academic and the industry sector one should not forget a common habit: both, companies' as well as scientists' actions, are driven by their needs and the incentive-systems within which they operate.

The following sections try to explore some aspects of the nature of these interactions which lead to a broader view of linkages between the industrial and the academic sector, covering direct as well as indirect effects. Within this

¹¹ Perhaps this goes back to the fundamental insight of Adam Smith, into the engine that drives economic growth, namely the division of labour. He argued that efficiency improves when production is broken down into specialised tasks and performed with specialised machinery. But in chapter one of his *Wealth of Nations* he pointed out that technical advances were made not only at the point of production, but also by suppliers of capital goods, and by "philosophers and men of speculation, who ... are often capable of combining together the powers of the most distant and dissimilar objects", which is what scientists were then called.

approach the mutual influence is neither unilateral nor does the 'responsibility' of producing spillover effects lies exclusively on one side. There are several questions which arise when the linkage of science and technology is addressed in a more detailed way:

- What role does technological development itself play in using scientific knowledge?
- What are the prerequisites on a firm level using academic knowledge?
- Are there scientific opportunities for technological development?
- Can scientific research be limited to the production of theories and publications alone?

3.1.1 *The changing nature of technology*

The emphasis on the importance of knowledge is very much influenced by the changing nature of technology. Technology cannot be adequately described as easily transferable information. It consists mainly of person –(and institution) embodied knowledge, which is transferred mainly through interdependent learning, personal contacts and mobility. This is because technology is complex.

It would be misleading if technology is only seen as "applied science". Moreover, all technologies are systems. One of the results of a systemic view of technology leads to a distinct understanding of technology not restricted only to artefacts. This would obscure the role of *knowledge* – accumulated through trial and error - as a key element in the innovation process. This knowledge can range from abstract scientific knowledge (codified and widely available) through to engineering know-how or operative skills. Tacit (i.e. non-codifiable) knowledge is of central importance in such learning processes, in deciding which component of the system to change, in interpreting the consequences of change, and in deciding in what to do next.¹²

Secondly, technology involves *organisation*: at the most direct level this means the management and co-ordination systems which integrate individual activities and through which production takes place.

Thirdly, technology involves *techniques*: that is, machines, tools or other equipment with their rules and procedures of operations, and their ancillary activities such as maintenance, repair, training and so on. Moreover, there is a further essential aspect: technology is produced by and exists within a *social framework*. The social system makes economic and political choices which influence the development and spread of technologies, and which develop the skills needed to operate technologies (Smith, 1994).

These characteristics lead to the insight that the capacity to solve (cope with) complex problems on firm level depends on an increasing range and combination of many critical operating variables. This leads into the creation

¹² According to one eminent engineering practitioner: "... we construct and operate ... systems based on prior experience, and we innovate in them by open loop feedback. That is, we look at the system and ask ourselves 'How can we do it better?' We then make some change, and see if our expectation of 'better' is fulfilled ... This cyclic, open loop feedback process has also been called 'learning-by-doing', 'learning-by-using', 'trial and error'. And even 'muddling through'. Development processes can be quite rational or largely intuitive, but by whatever name, and however rational or intuitive, it is an important research process ... providing means of improving systems which lie beyond our ability to operate or innovate via analysis or computation." (Kline, 1995, p. 63, cited in Pavitt, 1997, p. 8).

of knowledge that is not only specific but depends on the development of complementary and sometimes more fundamental fields of knowledge. Hence, these advances in theory, measurement and calculation have increased the number of fields of knowledge that are useful in solving complex problems.¹³ Firms are becoming increasingly "multi-technology" (Pavitt, 1997, p. 8), incorporating a growing number of fields of knowledge into their problem-solving endowment. The flows of patents, citations or product development in science based industries are thus complements to both scientific investigations and commercial activities. While attempts to measure the impact of basic research by tracing its research output to these flows have been misleading, these areas can be identified in which technological activity can be linked to scientific activities. Science dependence is thus an internal feature of technology.

As a consequence, academic and business research should be seen as overlapping and interacting systems *by their very nature* in a quite specific sense: advances in science can enhance problem-solving capabilities in applied R&D, even in an unsystematic way. Few academic results, directly and immediately, contribute to innovation on firm level but university R&D produces non-appropriable knowledge, e.g. ideas or up-to-date knowledge of new fields of science and technology. Beside the flow of often directly relevant knowledge, it is the stock of knowledge which matters in the relation between academic and applied research (see also Pavitt, 1991, 1997; Rosenberg and Nelson, 1994; Klevorick et al., 1995).

3.1.2 *The concept of absorptive capacity*

At the level of the firm, the costs of receiving information are significant, requiring complementary investments to absorb and utilise information flows. A number of empirical studies show that the level of R&D (innovation) activities of firms or the technical progress in industries depends on their possibilities to acquire and internalise usable technological knowledge from external sources (e.g. Cohen, 1995; Klevorick et al., 1995). As a consequence firms continuously have to expand their "technological capabilities" (Cohen, 1995, p. 211) and to optimise their in-house R&D potentials by applying "technological opportunities" (Klevorick et al., 1995) from outside. Thus, R&D does not only generate one product – new information – but also enhances the firm's ability to assimilate and exploit existing information. The *second face* of R&D is to augment firms' scientific and technological competencies to learn about knowledge, products and processes developed outside.

The concept of absorptive capacity (Cohen and Levinthal, 1990; 1989) is related to the idea that there is no such thing as a free lunch. Of course, some technical information is freely available to all firms, in the sense that it can be used without paying a fee for the use of the information. However, even freely available knowledge is rarely completely free because of the effort that is necessary to understand and exploit technological knowledge. For example, a firm can readily acquire a competitor's product on the market and attempt to develop a competitive

¹³ There are sometimes close links of engineering disciplines to more fundamental disciplines. In finding examples for the impact, one has only to open one page of Nathan Rosenbergs' books or papers. E.g.: "Consider computer science, which has emerged as an interdisciplinary subject lying between engineering and mathematics. In an effort to develop organising principles for computer architecture, computer science had to branch out to explore deep questions of logic, linguistics, perception, cognition and ultimately, intelligence itself. Similarly, aeronautical and chemical engineers have posed important questions for their colleagues in physics, materials science and chemistry, while focusing on the development of practical design tools. In some cases, the questions have been pursued by members of the engineering disciplines; in other cases, the questions have been passed along to other members of the academic research community." (Rosenberg and Nelson, 1994, pp. 332-333)

alternative through reverse engineering. Although the purchase price of the product could be relatively small, the cost of imitation could approach the development cost of the original invention (Patel and Pavitt, 1995, p. 18). Similarly, a firm might be unable to understand and develop the commercial significance of basic research results, although freely available in scientific journals, unless it conducts basic research itself. The ability of a firm to effectively use external knowledge, ranging from basic research and reverse engineering to the implementation of new production equipment, is called its absorptive capacity. This capacity varies with a firm's experience and the range of its innovative experience.

This absorptive capacity itself depends on the firm's own R&D. It is therefore considered that a firm's R&D satisfies two functions: R&D does not only generate new knowledge but also contributes to the firm's absorptive capacity. Because of this mediating function absorptive capacity influences and determines the exploitation of external research findings.

But one implication of this fact is, that large firms could have an advantage in both the production and the use of knowledge. This could occur because large firms are better involved in activities that make it easier to absorb external knowledge. For example, there is a positive relationship with firm size and the probability that a firm conducts R&D, or is involved in co-operative innovation processes (Schibany, 1998). In contrast to this well established fact, SMEs could be hampered in their ability to develop and adopt new technology because of a lack of scientific and technical staff or experience.

Although the concept of absorptive capacity has received a great deal of attention, there are no widely used indicators for it. One common assumption is that the amount of effort expended on innovation, for instance the amount of R&D spending or employed scientists, is an indirect measure of absorptive capacity. This could be a reasonable assumption for large firms, but, as it was mentioned above, there is no clear indicator if firms perform basic research in order to build up absorptive capacities, or if it is largely a by-product of existing innovative activities. More difficult problems emerge when looking at SMEs or firms that do not conduct R&D. There are no available indicators for measuring the ability of firms to adopt innovations that were developed outside of the firm. It just states that R&D has two faces.

3.1.3 *The concept of technological opportunities*

Mainly the study of Klevorick et al. (1995) shows that variances in R&D expenditures and innovation activities can be explained better by differences in the level of technological opportunities each firm or industry is faced with rather than by other conditions, such as firm size, market structure or market size.

Despite the importance of the concept of technological opportunities, it is not apparent how to formalise or to measure them. But technological opportunities relate to the contribution of external (knowledge) sources to firms'

innovation activities.¹⁴ These opportunities are diverse, varying in the kind of usefulness of technological knowledge from industry to industry and, to a certain extent, from one firm to another.¹⁵

According to Klevorick et al. (1995) there are three different sources of new contributions to an industry's pool of technological opportunities:

- (i) Advances in scientific understanding and technique expand the pool of technological opportunities.
- (ii) Technological advances in other industries, both inside and outside the vertical chain of production, and in other institutions in the economy, can enrich technological opportunities within a given industry.
- (iii) There are positive feedbacks from an industry's technological advances in one period that open up new technological opportunities for the next.

In this context firms can extend their technological capabilities by applying external information of industrial and non-industrial sources. Technological information stemming from suppliers, customers, and/or competitors constitute the industrial pool. Non-industrial sources relate to knowledge originated from institutions and organisations outside the business sector, here in particular from the academic sphere. Indeed, in the long run the most important source of new technological opportunity has been the advance of scientific knowledge. Close connection to scientific institutions offers firms the possibility of systematically drawing from the results and findings of academic research and utilise these kind of technological opportunities for their own purposes. Science is thus a pool of theory (data, technique, and general problem-solving capability) as well as a direct open window of technological opportunity.

However, the importance of the adaption of technological opportunities depends on an important variable - the capacities of firms to adapt knowledge stemming from academic research. Hence, the degree firms use findings of academic research correlates with the firms' ability to adapt and to implement external generated knowledge for their own purposes.

3.2 The outputs of universities

A variety of studies¹⁶ provide an interesting list of economic benefits which result from basic research mainly done at universities. The scientific research process generates economically important outputs other than published findings and theories. Examples are the training of individuals and the development of instrumentation that are complements in the conduct of future scientific and industrial research (Dasgupta and David, 1992).

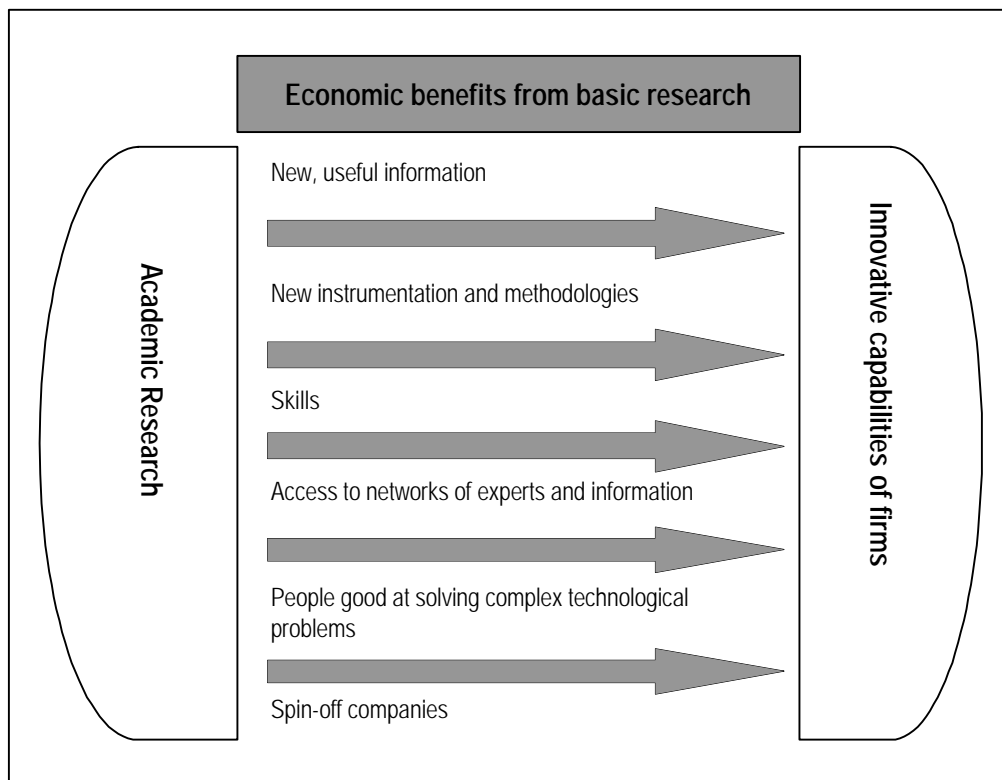
¹⁴ For example, successful basic research on gene cloning opened a wide range of opportunities to develop new pharmaceuticals, new seed varieties, new medical test devices (Klevorick et al., 1995, p. 188)

¹⁵ Perhaps the key characteristics that distinguishes industries with high technological opportunities from those in which such possibilities are limited is that those opportunities are being augmented, or renewed, at a higher rate in the former than in the latter. Thus, a high R&D intensity can be sustained in the semiconductor industry because even though firms are exploiting prevailing opportunities at a rapid rate, new ones are being created with comparable speed (Klevorick et al., 1995, p. 188).

¹⁶ See e.g.: Brooks, 1994; David et al., 1994; Gibbons and Johnston, 1974; Klevorick et al., 1995; Pavitt, 1991, 1997; Rosenberg and Nelson, 1994; Rosenberg, 1990, 1992; Martin and Salter, 1996.

These different forms of benefits are, however, interconnected and mutually supporting; for example, the training of skilled graduates not only promotes the development of professional networks but also facilitates the transfer of new information and methodologies into industry. Hence, some contributions will be *direct*, when academic research leads to applicable discoveries, engineering research techniques and instrumentation. Others will be *indirect*, when academic research training, background knowledge and professional networks contribute to business firms' own problem-solving activities. The Figure below gives an overview of the benefits (see Martin et al., 1996).

Figure 1: Economic benefits which result from basic research



The different features of external effects from science and academic research can also be explored from the outset, i.e. the actual benefits seem to vary considerably by sector. Thus, the term "science-based" industry has therefore been established among institutional concepts (Pavitt, 1984), meaning that the direction of inventive efforts at any time is strongly influenced by recent scientific or other developments coming from outside the industry, in part from university research. This bears in mind the background of scientific research which describes the rise primarily of the chemical and electronic industries.

One danger both for analysis and policy-making is devoting excessive attention to the *direct* contributions of academic research to technology and to neglect the *indirect* contributions that are often more highly valued by the practitioners themselves. As shown by the studies of Mansfield (see below), only a comparatively small proportion of the benefits flow in form of new useful knowledge that is directly incorporated in new products or processes. The Austrian survey (see chapter 5) will therefore strongly support Pavitt's claim that '... contrary to common

belief, the main economic benefits of basic research are not knowledge directly applicable in a narrow [sense], but background knowledge, research skills, instruments and methods that yield economic benefits over a much broader range of sectors' (Pavitt, 1991).

The relative importance of these different forms of benefit varies with scientific field, technology and industry. In other words, there is a great heterogeneity in the relationship between basic research and innovation with the consequence, that no simple model of the nature of the economic benefits from basic research is possible. This poses a challenge in trying to arrive at the optimum structure for government support of basic research.

New and useful information

New and useful information is the most obvious output of basic research. This leads to an expectation that any economic impacts of basic science are either very long term, if it is driven by curiosity, or short term as is shown by the analysis of Narin (.). His analysis of the citation of publicly-funded research in US patents suggests that the movement of information from science to technology can be very fast. The lag between the publication of new science and its citation in the patent literature was in many cases almost as short as the time before citation in the scientific literature itself. This, and the fact that national science was 2-3 times as likely to be cited in a patent as foreign science, suggests that many companies are well networked to the scientific community, especially to the local scientific community. With this method and analysis Narin shows that public-funded science provide the knowledge base for patenting in the USA by US companies. 85% of the science they cited was publicly funded.

New instrumentation and methodologies

New instrumentation and methodologies represent the 'capital goods' (Rosenberg, 1992) of the scientific research industry. Their transfer to the commercial sector can create the basis for production as well as for industrial research activity. However, it is not always clear when new instrumentation devised for research purposes will make the transition to industry. Rosenberg (1992) mentions in this context *the* success story of such a transfer: the computer. Computers are the scientific instrument par excellence, although the scientific research context from which they originally sprang is now largely forgotten. Nowadays, the computer has spread into uses in business, government, medical care and private households that are extremely remote from their scientific points of origin and were certainly very far from the specific purpose that dominated the thinking of the pioneers.

Skilled Graduates

Skills and skilled graduates may well form the key link between basic science and industry. Those firms needing graduates for R&D or in some other technical functions, actively seek research-trained people. 'As far as companies are concerned, formal qualifications are ... evidence of researchers' tacit ability to acquire and use knowledge in a meaningful way. This attitude of mind ... is a most important contribution to new product development' (Senker, 1995). Graduates and post-graduates do not simply transfer from universities to companies the 'state of art' of science when they passed the last exams. Studies examining the roots of knowledge used in innovations show that industrial R&D workers use their education to keep up with the state of knowledge (Gibbons and

Johnston, 1974). Hence, an important aspect of basic science education is to implant a capability for continuous learning in graduates and, therefore, among their employers.

The importance of well educated employees and specific skills has further implications to the links between academics and industry – in a geographically as well as infrastructural way. Companies which want to exploit the personal nature of links with the academic community need to be geographically close to the university. If an institute is really good in a subject, companies will locate a laboratory nearby in order to join in the research and get early access to the results. More generally, a good local science infrastructure is attractive because it provides the scientific, technical and personal support networks needed to provide manpower for R&D (and to keep the manpower up-to-date). There are different theoretical approaches concerning this question: for instance, the study of Mansfield (1996), suggests that 'distance matters' in the academic-industry links. Thus, the geographical location of the university are, beside others, an important criteria to choose it as a co-operation partner.

Access to networks

The access to networks of experts and information is important for company R&D departments. As was already mentioned before R&D done by companies do not only produce knowledge but also represent some kind of 'search' function to identify and absorb external knowledge. Formal and informal participation in scientific networks is therefore important.

Companies employ a number of means to be involved in such networks, where this is important. Hicks (1995) has shown that corporate R&D departments increasingly publish relatively basic research results in order to create an 'entry ticket' to international scientific networks. This allows them to access technical opportunities in the science base, including the recruitment of skilled graduates who also carry with them bodies of tacit knowledge. The PACE Study (1995) emphasised the importance to firms of monitoring developments in public research, and the widespread use of informal, networking mechanisms to access these developments (see also Rosenberg, 1990). The evidence is therefore that many R&D-performing companies consider links to basic science as important and are prepared to back up this perception of importance with resources devoted to monitoring.

Solving complex technological problems

This type of contribution of basic research to the economy is the main part of the indirect effects. It means that basic science represents an enabling mechanism for the application of the stock of (basic) knowledge to industrial needs. However, the relative importance of the academic capacity differs between industrial sectors which means that the 'public good' character of the basic research must be augmented with the appropriately qualified and experienced people who are able to translate and develop the tacit knowledge needed to exploit the codified flows of knowledge developed at universities. As the relevant research shows, the mechanism through which basic research contributes to technological problem-solving are not always direct.

Spin-offs

Spin-off companies are often thought of as major benefit of research in academia and research institutes, yet the empirical evidence is at best mixed. A great part of the science park movement has been founded on the idea that there is a substantial pool of untapped ideas in the research sector which can be nurtured into commercial reality through new firm creation. However, reality does not always live up these expectations. Although the survey evidence for a link from science to company creation may be weak, there are prominent examples of companies which were in practice founded as spin-offs from science departments at universities, especially in biotechnology and instrumentation.

To conclude, the chapter has shown that there are multiple interrelationships between the university and the industry sector. Moreover, the forces that motivates the using of the knowledge and capabilities of the academic sector is different and multidimensional. Hence, the 'linear' model of science technology and innovation is generally spoken not the appropriate one.

3.3 Academic research as a contributor to technological innovation

Despite the problems concerned with the measurement of the rates of return to basic research, some recent efforts have nevertheless been made, the most important being those by Mansfield (1991, 1995, 1996a, 1996b) who has attempted "... to estimate the extent to which technological innovations in various industries have been based on recent academic research and the time lags between investment in recent academic research projects and the industrial utilisation of their findings" (Mansfield, 1991, p. 1).

His primary focus is on recent academic research - "... that is, research occurring within fifteen years of the commercialisation of whatever innovation is being considered" (*ibid.*, p. 1). Using a sample of 75 major American firms in seven manufacturing industries, Mansfield obtained information from company R&D executives concerning the "... proportion of the firm's new products and processes commercialised in 1975-85 that, according to these executives (and their staffs), could not have been developed (without substantial delay) in the absence of academic research carried out within 15 years of the first introduction of the innovation" (*ibid.*, p. 2). The results are summarised in Table 2.

Table 2: Percentage of new products and processes based on academic research, seven industries, United States, 1975-85.

Industry	Percentage that could not have been developed (without substantial delay) in the absence of recent academic research		Percentage that were developed with very substantial aid from recent academic research	
	Products	Processes	Products	Processes
Information processing	11	11	17	16
Electrical	6	3	3	4
Chemical	4	2	4	4
Instruments	16	2	5	1
Drugs	27	29	17	8
Metals	13	12	9	9
Oil	1	1	1	1
Industry mean	11	9	8	6

Source: Mansfield (1991)

The survey revealed that about 11% of these firms' new products and about 9% of their new processes could not have been developed "without a substantial delay" in the absence of academic research. The proportion of new products and processes based in this way was highest in the drug industry and lowest in the petroleum industry. One-quarter of the new drugs commercialised by the companies could not have been developed, or only with substantial delay, absent academic research.

Many innovations based on recent academic research were not invented at universities. Academic research often yields new theoretical and empirical findings and new types of instrumentation that are needed for the development of a new product or process, but it seldom results in the specific invention itself. For the new products and processes that could not have been developed (without substantial delay) in the absence of academic research, information was obtained concerning the mean time interval between the relevant academic research result and the first commercial introduction of the product or process. The mean time lag in these industries was about seven years.

Determinants of useful basic research

Although the foregoing results indicate that recent academic research has made a significant contribution to innovation, the results tell nothing about the kinds of academic research that the innovating firms believe to have been most important in this regard. In a follow-up study, Mansfield (1995, 1996b) drew a random sample of 70 major firms from these industries. Each firm was asked to cite about five academic researchers whose work in the 1970s and 1980s contributed most importantly to the firm's new products and processes introduced in the 1980s. Taken as a whole, these firms cited 321 academic researchers. Clearly, these citations are distributed over a considerable number of universities; the top four universities generally receive about 30% of the citations. The main results of this study can be summarised as follows:

- There generally is a direct relationship between the *quality of a university's faculty* in the relevant department and the percent of citations received by the university.

- Another factor is the *geographical proximity* of a university to the firms in the sample. Because there are obvious advantages with, and keeping abreast of developments at, local colleges and universities, one might expect that colleges and universities located near many of the firms would tend to be cited relatively often.
- Another factor is the scale of a university's *R&D activities in the relevant area*: a critical mass of researchers and equipment is often regarded as necessary to achieve high productivity in particular aspects of academic research.

His findings also shows that the assumption that new knowledge is a public good that quickly and cheaply becomes available to all, is far from true. That's why the localisation effect matters. The R&D process is characterised by a great deal of interaction between individuals in firms and research institutes such as universities. In order to develop new forms of knowledge or to transfer existing forms of knowledge, research performers and users often need close, personal interaction. Thus, lines of personal interaction, often informal in character, are important elements of the geographical constraint on innovation.

3.4 The funding of academic research

As evoked above, the relationships linking science and technological innovation are complex and in no way direct. Although technical innovation is clearly distinct from science, it draws increasingly on the knowledge advances made by the science base. The "scientific enterprise" (OECD, 1998, p. 140) has considerably modified the pre-condition for innovation.

From the early 1980s onwards, the policies and priorities of academic research have been increasingly influenced both by the quest for nationally relevant university research and by the pressure for accountability and cost reduction. Although these changes vary from country to country, they are driven by the same forces and have similar overall aims.

The science base in all OECD countries remains largely dependent on government resources. And for most countries, the universities are the largest single component of the national science system. However, in most countries financing trends have to be discussed against an overall background of declining government effort to support R&D as well as a slowdown of the total R&D effort in absolute or relative terms *vis-à-vis* GDP.

The distribution of R&D performing sectors varies considerably from country to country. In all countries the business sectors takes up the largest part in R&D performance, which performs more than half of the gross domestic R&D. The research effort in the higher education sector (HERD) represents between 15 and 30 per cent of total expenditure. Table 3 reveals that Austria shows with 35% the highest percentage of R&D performed in the Higher Education sector (beside Greece with over 40%) and with 56% one of the lowest share of the business sector (beside Netherlands with 52.5%).

Table 3: R&D – an international comparison, 1995

Country	R&D as % of GDP	Funding of R&D (in %)		R&D Performance by sector (in % of total R&D expenditure)			
		Public	Industry	Industry	Higher Education	Public	private non-profit
OECD (1)	2.15	34.5	59.1	67.3	17.7	12.2	2.7
Switzerland (2)	2.66	28.4	67.4	70.1	25.0	3.7	1.2
Japan	2.77	20.9	72.3	70.3	14.5	10.4	4.8
USA	2.55	36.1	59.9	71.8	15.2	9.5	3.4
EU	1.85	39.1	52.7	62.0	21.0	16.1	0.9
Belgium	1.61	26.4	64.2	67.4	27.3	3.8	1.5
Denmark	1.92	39.2	46.7	57.4	24.5	17.0	1.1
Germany (3)	2.30	37.4	60.5	65.7	18.9	15.4	-
Finland	2.37	35.1	59.5	63.2	19.5	16.6	0.6
France	2.33	42.3	48.3	61.0	16.7	21.0	1.3
Greece (4)	0.48	46.9	20.2	26.8	40.7	32.0	0.6
Ireland (3)	1.40	22.6	67.4	70.5	19.2	9.7	0.7
Italy	1.14	47.4	48.7	57.1	22.9	20.1	-
Netherlands	2.09	42.1	46.0	52.2	28.8	18.1	1.0
Austria	1.54 (3)	48.4 (3)	47.8 (3)	55.9 (3)	35.0 (4)	8.9(4)	0.3 (4)
Portugal	0.61	65.2	18.9	19.8	33.7	26.7	19.7
Sweden	3.60 (3)	33.0 (4)	61.2 (4)	74.3 (3)	22.0 (3)	3.5 (3)	0.2 (3)
Spain	0.85	43.6	44.5	48.2	32.0	18.6	1.1
UK	2.05	33.3	48.0	65.5	18.8	14.5	1.2

(1) excluding USA

(2) 1992

(3) national estimation

(4) 1993

Source: OECD (1997): Main Science and Technology Indicators, Paris; ÖSTAT

Structural change in the government funding of Higher Education R&D

Government support to university research has been maintained in absolute and as a share of government R&D expenditures in most countries. The OECD classifies the funding sources for HERD into five main classes:

- *Government*, subdivided into *Direct Government Funds*, e.g. contracts and earmarked funds, and *General University Funds (GUF)*;
- *Higher Education*, internal funds, e.g. income from endowments;
- *Business Enterprise*, e.g. R&D contracts;
- *Private Non-profit Organisations (NPO)*;
- *Abroad*.

There exists a high level of diversity in the mix of the different funding systems in the EU. But, as the following table will show, an important trend noted in a significant number of countries is the relative reduction of the core funding resources (GUF) for university research compared to contract-based resources. Table 4 presents the evolution of the relative share of the HERD funding sources for an aggregate of eight EU countries between 1983 and 1992. These eight countries are responsible for about 82% of the total HERD performed in the EU countries at the starting of the 1990s.

Table 4: HERD Source of Funds for and Aggregate of 8 EU countries [%]

	Gov. Tot.	GUF	Gov. Dir.	Abroad	Business	HE	NPO
1983	94.2	68.8	25.4	0.5	2.8	1.0	1.4
1985	92.9	65.5	27.4	0.6	3.6	1.2	1.7
1989	89.9	60.3	29.6	1.3	5.6	1.2	2.0
1991	88.7	60.5	28.2	2.1	5.8	1.2	2.2
1992	88.2	n.a.	n.a.	2.5	5.7	1.3	2.4

Source: Elaboration OECD data. The eight countries are: Denmark, France, Germany, Italy, Ireland, Spain, The Netherlands, and the UK.

Government support to university research has been maintained in absolute terms and as a share of government R&D expenditure in the aggregate. Meanwhile, the financial contribution of the business sector remains relatively flat and modest in the majority of countries. However, within the structure of the Government support the share of GUF has substantially declined, while the share of Direct Government Funds has increased, although not sufficiently to offset the decrease in the other component of government funding. The declining importance of government funding has been compensated by a raise in the share of the other sources of funds. Where the figures are available, Abroad, Business, Private Non-profit Organisations (NPO) and Higher Education Sources of funds show positive trends. Particularly relevant are the changes in the two sources Abroad and Business.

Table 5: HERD Funding Sources by Countries

		AUT	BEL	DNK	FRA	DEU	GRC	ITA	IRL	NLD	SWE	GBR
Direct Govern. %	1981	n.a.	39.4	10.9	45.1	18.7	10.5	0	14.9	5.7	13.0	15.1
	1985	n.a.	43.4	12.2	47.0	19.8	n.a.	0	11.5	7.1	24.1	25.0
	1989	11.0	25.5	20.6	48.1	22.4	12.0	0	19.0	7.8	27.7	27.6
	1993	14.4	26.7	20.9	46.4	21.4	15.7	0	27.1	5.7	20.3	27.1
GUF %	1981	n.a.	46.8	85.6	52.6	75.6	89.5	96.2	67.6	91.1	87.0	66.1
	1985	n.a.	43.4	80.7	51.2	74.3	n.a.	98.0	66.0	88.1	74.7	57.2
	1989	86.4	52.2	70.5	49.4	70.6	71.6	96.4	46.7	87.6	62.0	47.3
	1993	82.7	49.5	66.5	46.3	70.6	43.4	93.4	39.7	89.5	68.6	41.6
HE %	1981	0	2.9	0	0.9	0	0	0	0.4	0.3	0	3.8
	1985	0	2.7	0	1.0	0	n.a.	0	2.3	0.2	0	4.2
	1989	0	5.6	0	1.0	0	0.3	0	4.2	0.1	0	4.8
	1993	0	3.6	0	2.1	0	5.9	0	4.4	0.1	0	4.4
Business %	1981	n.a.	9.3	0.7	1.3	5.7	0	2.7	7.1	0.3	0	2.8
	1985	n.a.	8.7	1.0	1.3	5.9	n.a.	1.5	6.9	1.0	1.1	5.2
	1989	1.8	12.6	1.5	4.6	7.0	6.2	2.6	9.2	1.1	9.2	7.7
	1993	1.9	15.4	1.8	3.6	6.9	3.8	4.7	7.3	1.5	7.3	7.8
NPO %	1981	n.a.	0	1.6	0.1	0	0	0	2.6	2.3	0	4.9
	1985	n.a.	0	4.3	0.1	0	0	0	1.9	3.1	0	6.4
	1989	0.3	0	4.4	0.1	0	0	0	1.8	2.9	0.5	8.4
	1993	0.4	0	5.0	0.1	0	0	0	1.5	2.7	0.5	12.5
Abroad %	1981	n.a.	1.6	1.3	0	0	0	1.1	7.3	0.3	0	1.8
	1985	n.a.	1.8	1.8	0.1	0	n.a.	0.6	11.4	0.4	0.1	2.1
	1989	0.5	4.1	3.0	0.7	0	10	1.0	19.1	0.5	0.7	4.1
	1993	0.4	4.8	5.8	1.5	1.1	31.1	1.9	20.0	0.4	3.3	6.1

Sources: OECD (1997). Due to the different ways of classifying the various funds, a zero value either refers to zero funds or the inclusion of the funding type in a different class.

For most of the countries, government funds are responsible for more than three-quarters of total expenditures. Only Greece, Ireland and the UK have lower shares of about 60% in 1993. All countries, without exception, witnessed a decrease in the importance of government funds. For example, in France government funds decreased from 98% to 93% while in the UK they fell from 82% to 69%. Greece, the UK and Ireland show the largest reduc-

tion and have the lowest share of government funds at the end of the period. On the other hand, Austria, Germany, The Netherlands and Italy suffered only a small reduction in government funding and have the highest shares at the end of the period. Within this group Austria has with 97.1% the highest share of government funding with little structural change during the last decade.

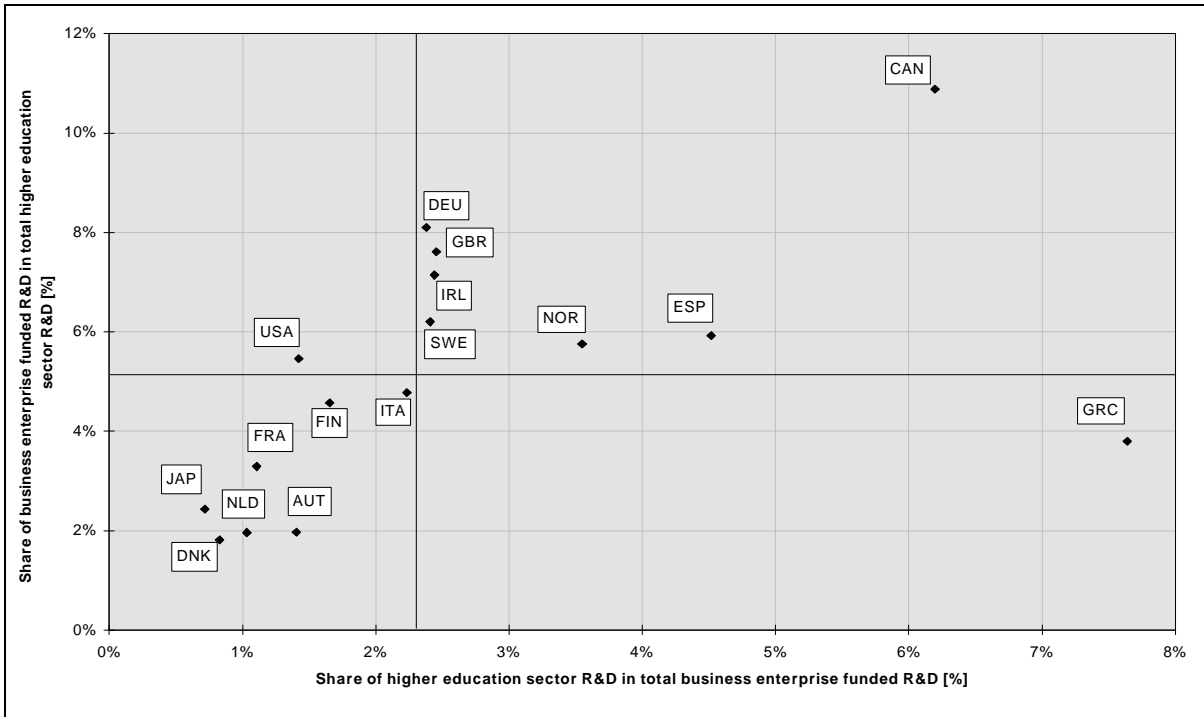
3.4.1 Non-governmental sources of funding

Due to the declining in support for public funding to university research, universities are searching for new sources, such as the private sector, and new basis for support. An increasing funding by the private sector leads towards a greater commercial application of university research. This private source of funds became important for the higher education systems of the small less-advantaged countries such as Greece, and Ireland. Particularly for these countries, but also for other EU countries, is that an important part of the funds received from abroad can be ascribed to the European Commission. For Austria, the current data are from 1993, well before Austria became a member of the EU. But the data from 1996 indicate, that the part of GERD financed from abroad is 2.5% (see Table 4). Generally, the growth of foreign funding for R&D performed in the higher education sector is an indication of an increased internationalisation (or Europeanisation) of university research.

The share of HERD financed by business showed some stabilisation during the early 1990s. Moreover, in some cases the data show a decrease of the share of HERD financed by business enterprises. On average, the share of business financed HERD was nearly 6% at the beginning of the 1990s. Most of these funds are funnelled to universities via contract research or co-operative R&D projects with industry. Although these links are of various types, they are all characterised by an exchange of knowledge among participants, with the university usually in the role of the most important supplier of knowledge (see among others Rosenberg and Nelson, 1994).

For a more detailed analysis the following Figure 2 shows the share of higher education sector R&D in total business enterprise funded R&D.

Figure 2: Enterprise-funded R&D in the higher education sector, 1993



Source: OECD-MSTI, ÖSTAT, Austrian Report on Technology, 1997

The figure indicates that to the extent of 1.4% of their research expenditure, Austrian business enterprises have R&D carried out in Austrian universities. They are therefore clearly below average, but equal to the business enterprise sector of the USA. Compared with France, the Netherlands, Denmark and Japan, Austria exhibits a higher share of university research in total business enterprise funded R&D. In general, i.e. across all countries, there is a notably low share of private R&D resources, averaging 2.3% allocated to universities.

Concerning the shares of enterprise-funded R&D in the research budgets of the universities the median of the figure reveals a little more than 5% - an even minor value than the mean value. The figure reveals (with leaving Belgium out of account, n.b.) that the shares are not higher than 8% and not lower than 1.9%. And just at that lower threshold lies Austria.

To summarise, the figures indicate, nationally as well as internationally, that contract research in the sense of enterprise funded R&D in universities is of minor relevance and that indirect knowledge transfer between the academia and the industrial sector is to be carried out through other mechanism.

4 Empirical evidence of the impact of academic research

Three existing data sources are of relevance to the aim of the present study. Hence, they contain information of knowledge transfer between academia and industry. It is therefore appropriate to analyse the results relevant to our topic in more detail and try to find hints of possible benefits of academic research directed towards industry.

The first section analyses patents granted at the American patent office. These data are regularly compiled by CHI Research Ltd., who also compute several indicators. These data and indicators are the basis of the analysis which is presented below.

The second section summarises the results of a study concerning the co-operative behaviour of innovative firms. The survey contains questions of relevance due to the role of universities as co-operation partners in the process of product development.

4.1 Measuring direct effects of academic research on technological development by patent analysis

One way to analyse the linkage between science and technological development is to look into patents and try to trace back the scientific inputs into patents¹⁷. Such data and indicators are on a regular basis provided by CHI Research Ltd., which compiles information based on US patent office data. The indicator used for the analysis given below is the so-called "Science Linkage" (SL), which measures the average number of citations of scientific publications in an industrial patent. Data series covers the years 1985 to 1996 (see Table 6).

¹⁷ Of course both the usual caveats apply: patents are just one among a number of indicators which can be used to measure technological development - and, as the others, only a partial one. Second, inputs from science to technological developments can take very different forms (advice and consultancy on a personal basis, development of instrumentation etc) which are not reflected in this indicator.

Table 6: Science Linkage by sector [1985 – 1996]

SIC	Sector	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
3	Total Manufacturing Industry	0,31	0,33	0,40	0,44	0,51	0,53	0,58	0,67	0,85	0,89	1,21	1,46
31	Food, Drink & Tobacco	0,35	0,41	0,61	0,60	0,61	0,65	1,21	0,90	1,08	1,30	1,94	1,54
32	Textiles, Footwear & Leather	0,09	0,11	0,22	0,21	0,18	0,19	0,31	0,29	0,26	0,27	0,52	0,69
35	Chemicals	0,73	0,82	1,00	1,09	1,25	1,35	1,52	1,79	2,42	2,57	3,42	4,60
351+352-3522	Industrial Chemicals	0,74	0,85	0,97	1,04	1,17	1,30	1,42	1,65	2,21	2,40	3,18	4,00
3522	Pharmaceuticals	2,17	2,31	2,98	3,22	3,59	3,78	4,53	5,13	6,79	7,55	8,66	11,25
353+354	Petroleum Refining	0,29	0,19	0,25	0,32	0,38	0,36	0,35	0,33	0,37	0,62	1,52	1,33
355+356	Rubber & Plastics Products	0,18	0,17	0,22	0,24	0,26	0,25	0,23	0,32	0,37	0,41	0,59	0,58
36	Stone, Clay & Glass	0,17	0,20	0,27	0,32	0,41	0,37	0,37	0,37	0,47	0,49	0,80	0,85
37	Basic Metal Industries	0,34	0,29	0,47	0,52	0,60	0,54	0,43	0,61	0,70	0,82	1,04	1,02
371	Ferrous Metals	0,25	0,19	0,18	0,63	0,64	0,37	0,41	0,53	0,45	0,52	0,75	0,91
372	Non-Ferrous Metals	0,42	0,38	0,67	0,43	0,57	0,69	0,45	0,67	0,87	1,04	1,27	1,12
38	Fabricated Metal Products And Machinery	0,21	0,23	0,27	0,30	0,34	0,34	0,35	0,38	0,45	0,49	0,68	0,74
381	Fabricated Metal Products	0,06	0,08	0,07	0,08	0,09	0,09	0,08	0,09	0,10	0,17	0,21	0,19
382-3825	Non-Electrical Machinery	0,07	0,08	0,11	0,12	0,15	0,14	0,15	0,17	0,21	0,24	0,43	0,49
3825	Office Machinery & Computers	0,24	0,25	0,31	0,32	0,41	0,45	0,35	0,52	0,58	0,65	1,09	1,21
3830-3832	Electrical Machinery	0,24	0,28	0,32	0,37	0,39	0,39	0,39	0,42	0,52	0,61	0,76	0,79
3832	Electronic Equipment & Components	0,44	0,47	0,52	0,58	0,63	0,70	0,69	0,67	0,72	0,78	0,96	0,95
3841	Shipbuilding	0,03	0,01	0,04	0,03	0,03	0,03	0,00	0,03	0,04	0,05	0,10	0,10
3843	Motor Vehicles	0,01	0,02	0,03	0,03	0,02	0,01	0,02	0,02	0,02	0,02	0,07	0,08
3845	Aerospace	0,02	0,06	0,07	0,07	0,07	0,08	0,06	0,07	0,07	0,12	0,26	0,24
3842+3844+3849	Other Transport Equipment	0,01	0,01	0,03	0,02	0,01	0,06	0,02	0,02	0,01	0,03	0,07	0,06
385	Instruments	0,41	0,42	0,50	0,58	0,62	0,58	0,67	0,72	0,92	0,93	1,27	1,48
39	Other Manufacturing	0,05	0,05	0,09	0,09	0,07	0,09	0,10	0,15	0,11	0,19	0,27	0,52

Source: CHI Research

General trends

Only a small number of **industrial sectors** do have very strong Science Linkage, among which some usual suspects can be found: e.g. Pharmaceuticals and Instruments. A more surprising finding is the high ranking of sectors like Industrial Chemicals and Food, Drink and Tobacco, the latter most likely being caused by references to advances in the Bio-sciences. These four branches consistently occupy the top four notches in the SL ranking.

On the bottom end of the league, again a mixture of usual suspects and surprises can be found: while Shipbuilding and Other transport equipment are normally not seen as high-tech branches, the consistently weak SL of Aerospace and Motor Vehicles deserves further thoughts on knowledge flows in these sectors. A possible explanation would e.g. be the stronger reliance of these branches on technological rather than scientific progress and would be reflected in a larger number of patents (rather than scientific publications) cited as input into a respective patent.

The ranking of branches according to their SL remains remarkably stable over the period in question, Electronic Equipment and Components being the exception with a relative decline vis-à-vis the other branches from fourth place at the beginning of the period to eleventh place at the end.

The analysis of the SL of total manufacturing on the *country* level (see Table 7) shows that:

- The SL fluctuates considerably between the years - which should warn against a light-handed interpretation of rankings in individual years.
- Nevertheless a general tendency towards an increased reliance on scientific publication can be depicted in practically all countries. In the relatively short period of 12 years, this increase is manifold.
- The SL as such is not an indicator for the technological level of a countries' industry - countries like Hungary, Greece, Iceland, Poland and Mexico being among those with the highest SL. This is probably a reflection of the fact that the number of patents from these countries is low so that small deviations in SL in individual patents would bias the picture considerably. Another explanation could be that only patents from very high-tech companies from these countries are registered at the US patent office. Thus the entry barrier would "skim off the cream".
- at a first glance at the aggregate level of total manufacturing, the share of overall and of industrial R&D in GDP do not seem to be correlated very strongly with SL. Countries like Japan, Germany, Sweden and Finland do have high levels of industrial R&D, but only weak SL. This picture might change, once one looks into a more disaggregate *branch* level. CHI research also claims for example that SL has been found to be predictive of a *company's* stock market performance.

Table 7: Science Linkage – an international comparison

Total Manufacturing Industry												
Country	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
AUS	0,27	0,24	0,28	0,42	0,32	0,26	0,58	0,82	1,00	1,56	1,58	1,70
AUT	0,08	0,08	0,22	0,20	0,27	0,32	0,16	0,20	0,37	0,92	0,56	1,56
BEL	0,17	0,21	0,40	0,36	0,46	0,41	0,50	0,42	0,63	0,83	0,96	1,22
CAN	0,27	0,27	0,39	0,35	0,48	0,44	0,54	0,59	0,73	1,07	1,36	1,96
CZE	0,11	0,22	0,11	0,25	0,56	0,18	0,26	0,88	0,36	0,76	2,03	1,38
DEN	0,50	0,59	0,26	0,34	0,68	1,28	1,33	0,94	0,98	1,48	1,73	1,98
FIN	0,21	0,28	0,30	0,18	0,26	0,23	0,35	0,32	0,38	0,53	0,79	1,11
FRA	0,25	0,27	0,33	0,35	0,33	0,34	0,39	0,47	0,45	0,67	0,69	1,02
GER	0,19	0,18	0,25	0,28	0,28	0,29	0,32	0,35	0,44	0,47	0,63	0,70
GRE	0,32	0,64	0,08	0,24	0,40	0,83	0,07	0,28	2,62	2,06	6,70	3,85
HUN	0,29	0,31	0,49	0,73	0,47	0,49	0,62	0,77	1,18	1,25	1,93	1,21
ICE	0,00	0,15	0,00	0,29	0,80	0,13	0,50	0,05	0,00	7,85	8,14	2,11
IRE	0,27	1,50	1,38	0,58	0,35	0,44	0,33	1,00	0,74	1,28	0,78	2,23
ITA	0,17	0,19	0,17	0,26	0,26	0,24	0,22	0,35	0,42	0,48	0,80	0,75
JAP	0,17	0,19	0,21	0,24	0,28	0,27	0,30	0,33	0,39	0,44	0,56	0,58
LUX	0,00	0,05	0,00	0,00	0,13	0,11	0,00	0,07	0,10	0,06	0,07	0,08
MEX	0,07	0,39	0,57	0,24	0,50	0,81	0,14	0,25	0,47	0,92	2,26	1,38
NET	0,19	0,21	0,32	0,40	0,46	0,51	0,37	0,58	0,60	0,78	0,87	1,03
NOR	0,05	0,13	0,07	0,20	0,22	0,22	0,47	0,30	0,25	0,55	0,94	1,39
NZE	0,33	0,31	0,25	0,17	0,28	0,39	0,47	1,39	0,06	1,14	1,13	0,55
POL	0,29	0,81	1,35	2,49	1,37	1,06	0,73	1,21	1,78	3,95	0,68	2,80
POR	0,00	0,00	0,00	0,00	0,18	0,00	0,05	0,71	0,00	0,00	3,58	0,45
SKR	0,05	0,04	0,14	0,15	0,12	0,26	0,14	0,23	0,23	0,24	0,35	0,35
SPA	0,16	0,18	0,10	0,22	0,09	0,40	0,78	0,36	0,80	0,67	1,58	1,49
SWE	0,15	0,15	0,17	0,22	0,32	0,20	0,15	0,49	0,65	1,06	1,12	1,26
SWI	0,29	0,24	0,34	0,41	0,46	0,56	0,58	0,67	1,00	0,79	1,11	1,07
TUR	0,00	0,89	0,86	1,00	0,00	0,00	0,83	5,15	3,75	5,09	0,38	1,29
UKM	0,29	0,36	0,37	0,46	0,49	0,62	0,64	0,74	0,83	0,87	1,27	1,53
USA	0,39	0,43	0,52	0,58	0,68	0,72	0,79	0,90	1,15	1,17	1,61	1,97
WORLD	0,31	0,33	0,40	0,44	0,51	0,53	0,58	0,67	0,85	0,89	1,21	1,46

Source: CHI Research

Science Linkage of Austria's industry

On the aggregate level, the SL for Austria's industry has been *ranking* among the weakest of the countries under consideration. The exception being the last year of the series, 1996, in which Austria advances to ninth place. It remains to be seen in future developments whether this could be seen as an indication for the start of a catch-up process or a statistical outlier. As has been said earlier, the SL sometimes fluctuates widely and should not be interpreted on a year-to-year basis.

A similar picture emerges when *deviations* from the world average on the branch level are analysed (see Table 8). In most years and in most branches, Austria has a consistently lower SL than the world average. The most interesting examples of branches with different developments concern Industrial Chemicals and Pharmaceuticals,

which both swung into a positive deviation from world average at the end of the period and are the main responsible for the improvements on the aggregate level of total manufacturing. Another branch with a high SL, namely Instruments, is also among the more positive developments on the Austrian side, swinging into a positive balance at the end of the period. Other Austrian "strongholds" are Other Transport Equipment and Motor Vehicles, but, as mentioned, both are to be found at the lower end of the branches' ranking regarding SL. On the downside, a widening gap of the once positive balance in Office machinery and Computing can be observed. Also, some branches figuring quite prominently in the industrial portfolio of Austria (Basic metal industries, Electrical machinery, Electronic Components and equipment) seem to loose ground vis-à-vis the other countries.

Table 8: Science Linkage – Austria's deviation from world average

	Sector	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
3	Total Manufacturing Industry	-0,23	-0,25	-0,18	-0,24	-0,24	-0,21	-0,42	-0,47	-0,48	0,03	-0,65	0,10
31	Food, Drink & Tobacco	-0,35	-0,41		-0,60	-0,61	-0,65	-0,92	-0,90	-1,08			-1,54
32	Textiles, Footwear & Leather	-0,09	-0,11	0,03	-0,21	0,05	-0,19	-0,31	-0,29	0,11	-0,27	-0,28	-0,61
35	Chemicals	-0,73		-0,06	-0,32		-0,55			-0,52	2,30	-0,93	
351+352-3522	Industrial Chemicals	-0,17	-0,40	-0,25	-0,44	-0,29	-0,76	-1,10	-0,53	0,21	3,90	-0,76	1,12
3522	Pharmaceuticals	-1,58	-1,06	1,08	-0,07	-1,26	-1,46	-2,29	-4,03	-4,20	0,29	-3,39	6,55
353+354	Petroleum Refining	-0,29		-0,25	-0,32		-0,36			-0,37	-0,62	-1,52	
355+356	Rubber & Plastics Products	-0,14	-0,17	-0,19	-0,24	-0,26	-0,25	-0,19	-0,06	-0,11	-0,14	-0,26	-0,47
36	Stone, Clay & Glass	-0,01	-0,20	-0,10	-0,32	-0,41	-0,37	-0,37	-0,06	-0,47	-0,19	-0,54	-0,80
37	Basic Metal Industries	-0,30	-0,29	-0,47	-0,52	-0,60	-0,44	-0,36	-0,61	-0,70	-0,74	-1,04	-0,93
371	Ferrous Metals	-0,21	-0,19	-0,18	-0,63	-0,64	-0,37	-0,32	-0,53	-0,45	-0,52	-0,75	-0,79
372	Non-Ferrous Metals	-0,38	-0,38	-0,67	-0,43	-0,57	-0,29	-0,39	-0,67	-0,87	-0,78	-1,27	-1,12
38	Fabricated Metal Products/Machinery	-0,17	-0,18	-0,11	-0,20	-0,16	-0,02	-0,27	-0,34	-0,35	-0,38	-0,44	-0,36
381	Fabricated Metal Products	-0,06	-0,08	0,02	-0,08	-0,09	0,01	-0,05	-0,05	-0,10	-0,16	-0,16	-0,19
382-3825	Non-Electrical Machinery	-0,04	-0,05	0,01	-0,02	-0,09	-0,10	-0,10	-0,17	-0,13	-0,23	-0,35	-0,36
3825	Office Machinery & Computers	-0,24	0,13	-0,04	-0,32	0,18	0,22	-0,15	-0,42	-0,58	-0,65	-0,43	-0,99
3830-3832	Electrical Machinery	-0,09	-0,22	-0,13	-0,09	-0,19	-0,09	-0,37	-0,42	-0,44	-0,32	-0,56	-0,68
3832	Electronic Equipment & Components	-0,26	-0,28	-0,03	-0,30	-0,22	-0,06	-0,12	-0,51	-0,45	-0,65	-0,74	-0,69
3841	Shipbuilding	-0,03	-0,01	0,46				0,00	-0,03	-0,04			
3843	Motor Vehicles	0,12	0,01	0,03	-0,01	0,08	-0,01	-0,02	-0,02	-0,02	0,12	-0,03	-0,01
3845	Aerospace	-0,02											
3842+3844+3849	Oth Transport Equipment	-0,01		-0,03	-0,02	-0,01	-0,06	-0,02	-0,02			-0,07	0,06
385	Instruments	-0,41	-0,35	-0,22	-0,46	-0,03	0,81	-0,56	-0,62	-0,74	-0,45	-0,30	0,27
39	Other Manufacturing	-0,05		-0,09	-0,09								-0,52

Source: CHI Research, own calculations

Thus, a first analysis of the CHI data points to the fact that Austria has, all in all, a weaker SL than most other countries, though there are some countertendencies namely in the chemical industries. This result can not *a priori* be taken as an indication of technological weakness of the respective industries, as technological change has many sources, among scientific inputs are but one. Nevertheless, direct scientific inputs in the form of referential publications seem to become more important across the whole range of industries and countries, Austria being no exception. It remains to be seen in further analysis, whether some stronger relations between SL and technological and economic performance can be found.

4.2 Co-operation between companies and universities in product development

As part of the Focus Group activities of the OECD NIS (Knowledge Flows in National Innovation Systems) project, Austria participated, among others, in the Focus Group on Innovative Firm Networks. It was the aim of this focus-group to study the co-operative role of different partner-categories during the process of product innovation. Austria together with Denmark has already finished his survey.¹⁸ The main reason why we mention this study here is to show that universities do play a significant role in the process of product development and that, when we compared the data from Denmark, quite distinct national variations can be found.

General description of the results

Out of a representative sample 1.006 companies from the manufacturing sector were contacted and asked whether they had developed products within the last two years.¹⁹ We further asked whether these firms have co-operated with different types of partners during the development process. The overall results are shown in Table 9:

Table 9: The result of the Austrian survey

	Number of firms
Development of one or more products within the last two years	484
No product development	443
No answer	79
Co-operation in product development	274

Source: Schibany (1998)

Hence, 44% of all contacted firms had developed one or more products; beside the 7.9% which did not answer, 48.1% had no product development. As product development and co-operation in the development process was the prerequisite, finally the interviews was pursued with 274 companies.

One interesting topic is to exhibit the relationship between firm size and propensity to innovate or co-operate, respectively. According to a traditionally and well-known analysis main firm size classes were built. Within every size class the percentage of innovative firms and firms which co-operated during the development process were estimated. The breakdown is shown in Table 10:

Table 10: Number of innovative and co-operating firms

Firm size by no. of employees	# of innovating firms	% of total by size class	# of co-operating firms	% of the total by size class
10-19	68	30.9	33	48.5
20-99	197	43.5	115	58.4
≥ 100	178	70.1	126	70.4
	443		274	

Source: Schibany (1998)

¹⁸ For Austria see: Schibany, A. (1998): Co-operative behaviour of innovative firms in Austria, Study prepared for the OECD Project on "National Innovation Systems"; tip-report, Vienna.

¹⁹ We used a guided telephone interview with supporting software or Computer Aided Telephone Interview (CATI).

The role of universities as a co-operation partner

When we first compared the results of the Austrian survey with the results of the Danish survey a certain variation both in terms of which type of collaborating partners are frequent and in terms of which type of partners are foreign is evident. A striking fact exhibit the role of universities as a co-operation partner in Austria: 89 firms (= 32.7 % of all co-operating firms) indicated that they co-operated with universities during product development. Compared with 12% of the Danish firms, Austrian firms are more often engaged in collaboration with universities. Even the percentage of firms which co-operated with foreign universities is higher compared to the percentage of Danish firms: 11% of all co-operating Austrian firms indicated a relation to an foreign university (5% of the Danish companies). In the following sections the characteristics of the firms which co-operated with universities are analysed in more detail.

Does the firm size matter?

Compared with other categories of co-operation partners a clear relationship between firm size and co-operation with universities can be shown. As Table 11 reveals, 9% of the small firms (10-19 employees), 22% of the medium-sized firms (20-99 employees) and nearly half of all big firms (≥ 100 employees) co-operated with universities. This result is by no means surprising given that larger enterprises tend to employ highly qualified personnel more likely and to have in-house R&D facilities. Concerning the role of universities during product innovation large firms might be well prepared to communicate with universities knowing their codes and their cultures, while smaller firms may have greater difficulties in this respect. In addition, small firms often do not have the personnel and financial resources to co-operate with universities.

The impact of a R&D department

Just in supporting the result of a clear dependency of the co-operation with an university on the firm size we looked at the percentage of firms which have an R&D department. As was stated before on a more theoretical level, firms conducting their own R&D are more capable to use external available information and thus are more open for co-operation. At the most fundamental level the *absorptive capacity* of a firm comprises basic skills or even the shared language but it may also include knowledge of the most recent scientific or technological developments in a given field. Thus, there is the presumption that mainly the firms with a R&D department have a higher propensity to co-operate with universities than others. Table 11 confirms the presumption in revealing the number of firms co-operating with universities according to their size class and indicating the number of firms which have a R&D department and co-operated with universities.

Table 11: Firms co-operating with universities [# , % of the total by size class]

Firm size by no. of employees	# of firms co-operating with universities	R&D department	R&D co-operation
10-19	3 (9.1)	2 (22.2)	1 (14.3)
20-99	25 (22.1)	15 (30.6)	11 (39.3)
≥ 100	61 (48.4)	46 (48.9)	34 (65.4)
Σ	89 (N=274)	63 (N=153)	46 (N=87)

Source: Schibany (1998)

The data and results can be summarised as follows:

- 32% of all co-operating firms indicated that they co-operated with universities during the process of product development. Within this sub-sample a clear connection to the firm size can be shown: larger firms show a higher propensity to co-operate with universities than smaller firms.
- 71% of the firms co-operating with universities have a R&D department. However, this result is not astonishing. It is a well know fact that the existence of a R&D department alleviates the co-operation with universities.
- 52% of the firms co-operating with universities reported that the co-operation in product development included co-operation in R&D. The result is even more interesting insofar as the percentage of R&D co-operation is more concentrated on co-operation with universities. More than half of the firms out of this sample indicated a co-operation with universities.

5 Results of the Austrian Survey

Considerations elaborated in the theoretical part of this report led us to analyse the industry-academic link on a more microeconomic base. To meet this objective, an empirical survey was designed in order to get a broader view of the modes of interaction between the academic and the industrial sector. Within this survey the emphasis is directed towards motivations and barriers of co-operation as well as a broad estimation of how the industry values academic knowledge. Additionally, the present report should depict the complementary side of the 'Wissenschaftscluster I' (Jörg et al., 1996). In that study the role of the universities within the national innovation system, including their propensity to co-operate with the industry, was analysed. The main result of 'Wissenschaftscluster I' could be seen in the evidence of a discrepancy between the 'co-operative supply' on the part of the universities and the lack of 'co-operative demand' from the industry. Thus, the academic sector signalled the readiness to co-operate with the industrial sector while the industry - from the viewpoint of the university institutes - indicate little interest. However, one question could not be solved: can this missing link between these two sectors be interpreted as a obligation for delivery on part of universities or as a obligation for collection on part of industry.

5.1.1 *Scope of the study*

For the aim of the study a questionnaire was designed covering not only co-operation with universities on a project basis but also motivations for and barriers to collaboration. As a sample for the survey the respondents from the study "Co-operative behaviour of innovative firms in Austria" (Schibany, 1998) was used. Within this study 443 innovative firms could be composed, whereby the innovation-criteria was the development of a product within the last 2 years. Thus, the firm sample for the present study is biased towards innovative firms, with a high percentage of them already having experiences with co-operation during the process of product development.

For the present study these 443 firms were contacted with the request to fill out the questionnaire. 99 firms sent the questionnaire for the analysis back, i.e. the response rate was 22.3%.

Table 12 shows the distribution of responding firms according to size classes and the sum of respondents either. Additionally the main characteristics of the responding firms in connection with the existence of a R&D department, the allocation of the R&D-expenditure and the development of the R&D expenditure within the last two years are summarised.

Table 12: Characteristics of the responding firms

	size classes (by no. of employees)			Σ
	<=50	51-200	>200	
# of firms (response rate)	43	29	27	99
# of firms which have employees with an academic degree	24	22	27	
own R&D department	12	14	21	
expenditure on R&D (mean values in % of turnover)	3.3%	3.1%	4.2%	
	never	sometimes	very often	
activities in R&D (# of all firms)	13	26	60	
Allocation of the R&D expenditure (mean values in %)				
within the firm				75.5%
purchase order from universities				2.7%
CRO				2.1%
from other private firms				6.7%
Trend of the R&D expenditures within the last two years				
	declined	constant	increased	
# (% of answering firms)				
... within the firm	5 (5.8)	34 (39.5)	42 (48.8)	
... purchase order from universities	4 (7.5)	14 (26.4)	8 (15.1)	
...CRO	5 (10.4)	8 (16.7)	3 (6.3)	
... other private firms	1 (1.8)	16 (29.1)	16 (29.1)	
... the whole R&D budget	4 (5.7)	21 (30.0)	39 (55.7)	

Source: tip-survey

The size classes were build by number of employees. Due to the small sample of firms and to get more information of the valuation of smaller firms, the smallest size class consists of firms having less than 50 employees. But nevertheless some interesting sample characteristics can be found:

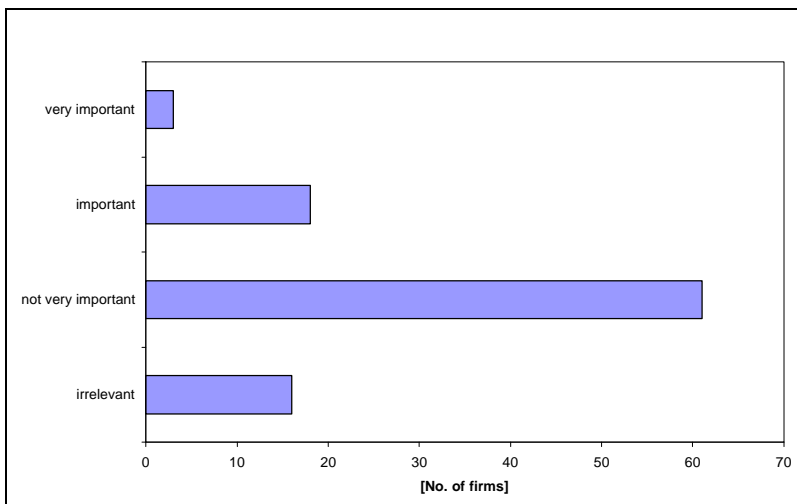
- The R&D activity of the firms is rather high. Nearly two thirds of all responding firms are continuously and 25% are sometimes engaged in R&D.
- One third of the smaller firms have an own R&D department. This share of firms increases to nearly 100% within the size class consisting of bigger firms.
- Nearly half of the answering firms (26) are in contact with universities either through declining or increasing research contracts. Compared with the academic sector the Contract research organisation (CROs) are rather underrepresented. From the 16 firms which have contact with CROs the R&D expenditure of only 3 firms have increased towards CROs. A much more intense research contact exists within the private sector. 60% of the answering firms reported that the R&D expenditure stayed constant or increased towards other private firms within the last two years.

- More than 75% of the R&D expenditure is allocated within the firm which goes along with the existence of R&D departments in most of the firms. 2.7% of the funding is used to contract universities with research agendas.

5.1.2 Results of academic R&D

Looking at the general estimations of academic R&D reveals that in general universities do not make near-market research with a direct relevance and usefulness for the industry. More than 75% of the companies indicated that the results of academic research is of minor relevance or even irrelevant for them (see Figure 3).

Figure 3: Results of R&D done by universities are for our company ...



Source: tip-survey

Depending on the attitude towards universities two different conclusions could be drawn:

First, according to Figure 3 indicating that even for the majority of innovative and mostly co-operative firms the results of academic research are of little relevance. Emphasising the danger of too much industry-directed research conducted by universities the second way of reading Figure 3 would be that there is no need for universities to redirect their research activities towards more industry relevance. The results confirm basically the division of labour between firms and universities found in other surveys and studies, with universities producing outputs not directly applicable to industries needs.

In the discussion of what role universities should play within the national system of innovation, however, it should be kept in mind that the industry-university relation involves multiple flows and interactions and depends highly on involved sectors and scientific fields, the presented interpretations seem to be too simplistic.

From the perspective of academics, competing demands upon time are a major constraint on the ability to develop and maintain external linkages. Accordingly, the relationship with industry has to be based on what universities are best equipped to do, that is pursuing excellence in research and teaching, rather than attempting to dupli-

cate the functions of industry. The necessary cultural shift comes in terms of being able to understand the needs of industry and provide an interface which allows the swift and effective flow of knowledge and people to their most productive use. As far as industry is concerned one has to take into account that only a minority is actually engaged in research and therefore lacks the necessary capacity to select and identify potentially relevant research results produced by universities. Against this background the results shown in Figure 3 are not surprising. The fact that 21 % of firms consider results of academic research as important or even very important while the remaining majority of firms don't, corresponds with the concentration of research activities in the industry itself. Moreover, one has to be aware that the scientific content of innovation varies among sectors, with few depending directly on scientific progress.

5.1.3 How do companies benefit from universities?

Firms can benefit from universities in various different ways apart from directly taking up research results. To get a more differentiated picture on how universities contribute to the innovative capacities of industry we asked the firms to indicate how important different types of potential benefits from universities are. Table 13 summarises the results.

Table 13: General benefits from universities

	% of firms (Ø 90) answering relevant or very relevant	Mean values on a 1 to 4 scale (1 = not important, 4 = very important)				
		By firm size (number of employees)			Own R&D-department	
		1-50	51-200	201 and more	Yes	No
high skilled personnel	63.7	2,22	2,52	3,26	3,05	2,18
ideas for new products and processes	47.2	2,53	2,40	2,04	2,19	2,50
general and useful information	42.7	2,32	2,24	2,33	2,29	2,31
direct support in development process	41.1	2,08	2,28	2,67	2,37	2,25
new instruments and techniques	37.9	2,22	2,20	2,42	2,39	2,17
results of basic research	33.3	2,19	2,04	1,96	2,18	1,98
consulting services	32.8	1,86	1,96	2,33	2,02	2,04

Source: tip-survey, **level of significance** (p<0.01), **level of significance** (p<0.05)

As can be seen, firms benefit from universities through four main channels: from educated and highly skilled personnel, from the provision of up-to-date research (new ideas), from providing them with general and useful information and direct support in the development process. Although ideas for new product developments predominantly come from inside the company, almost on half (47,2 %) of the answering firms indicate that universities are a significant source of new ideas for new products and processes. The main message of the information presented in Table 13 is that results of basic research, which is supposed to be core output of universities, is relevant only for a minority of firms. This result corresponds with most other studies (see K. Sequeira & B. Martin 1997) and confirms the widely acknowledged importance of the availability human resources for the innovation process.

Furthermore, Table 13 reveals that large firms and those with own R&D-departments rank *high skilled personnel* significantly higher than small firms. This can be explained by the fact the demand for qualified R&D-personnel increases with firm size. Moreover, large companies are more likely to have an own R&D-department than small ones. Somewhat surprising is the fact, that neither the existence of an own R&D-department nor the firms size seem to have any impact on how important firms perceive the *results of basic research* to their work. For the vast majority (66 %) of respondents *results of basic research* are of little or no relevance. This leaves 33.3 % of firms which find results of basic research relevant or very relevant to their innovative activities. That's more than one might have expected, even so, as in our sample large science based companies (e.g. pharmaceutical) seem to be somewhat underrepresented.

Table 13 confirms another presumption: large companies find it generally easier to establish direct links with universities. Both, *direct support in development process* as well as *consulting services* appear to be more relevant for big firms than for smaller ones. Again, this has to be seen in the context of absorptive capacities. Firms can only benefit from universities when they have in-house research competence and qualified people who are able to apply academic know-how to their own needs and problems. Another reason that may explain why big companies find it easier to get direct access to universities has to do with the costs of direct interaction. It is likely that big companies have more resources for directly integrating academic research into their innovation activities than smaller firms. The importance of this finding lies most of all in the fact that direct contact to universities allows access to the pool of tacit knowledge which is cumulated in universities. In the context of academic research the aspect of tacit knowledge gets more and more attention (see Pavitt, 1997), as university researchers are increasingly seen also in their ability to solve complex problems.

In the next step we analysed the relation between different categories of benefit from universities. A factor analysis provides information about the interdependencies of the answer categories: highly interdependent are the categories *highly skilled personnel*, *direct support in the development process* and *consulting services*. These are those categories which proved to depend also on firm size. Moreover, all of them are person-embodied modes of knowledge-transfer. The second factor covers *new instruments and techniques*, *ideas for new products and processes*, *results of basic research* and *general and useful information* (see Table 14). Hence, they are more oriented towards general provision of information. There is some evidence, that basically there are two main patterns of how firms benefit from universities. While the first group depends mainly on direct personal contacts the second group also benefits from a more hands-off approach based on general information and output in "embedded form" (instruments). One could say that for the first group universities take more the role of partners and problem solvers, whereas the second group considers universities more as a distant entity which provide some useful information and ideas for new products. Overall, the second group considers universities and their output less relevant to their business than the first one.

Table 14: Factor analysis of the benefits

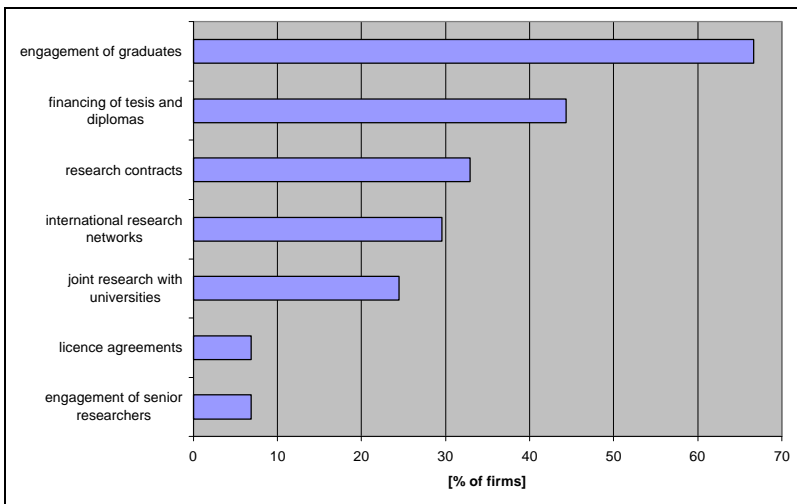
	Factor 1	Factor 2
high skilled personnel	-0.05	0.84
new instruments and techniques	0.73	0.29
ideas for new products and processes	0.84	-0.03
direct support in development process	0.38	0.66
results of basic research	0.54	0.37
general and useful information	0.72	0.22
consulting services	0.41	0.66

Source: tip-survey

5.1.4 General access to academic knowledge

As the results of the former question has shown, knowledge flows from academia to industry mainly through persons and well educated graduates. The question concerning the access to academic knowledge confirms this result. As the following Figure 4 indicates, academic knowledge flows to industry mainly through graduates and postgraduates industry recruits. One third of the companies indicated that formal research contracts was their prime channel to access academic research. The Figure has to be read as follows: 66% of the answering firms indicate that they see their access to academic knowledge through the engagement of graduates as important or very important, 44% see the financing of thesis and diplomas as their main access to academic knowledge etc.

Figure 4: Access to academic knowledge



Source: tip-survey

With respect to firm size we found significant positive correlation's in the following answer categories: *joint research with universities*, *research contracts*, *financing of thesis and diplomas* and *engagement of graduates*. Furthermore the existence of an R&D department is positively correlated with the *engagement of graduates* as a way to access academic knowledge. Overall, these results underline the importance of graduates in bridging academic research and industry. Apparently, financing of thesis and diplomas goes hand in hand with the recruit-

ing of graduates. Financing thesis and diplomas bears low risks for firms and involves usually also access to senior university staff. Moreover, this seems also to play an important role as recruitment instrument. As we shall see below, graduates play also an crucial role in establishing direct contacts with universities later on. Against this background financing of thesis and diplomas can be seen as sort of entry ticket to academic research. It bears low risks, it is easy to manage in terms of predictable costs and time and finally it can be used as recruiting instrument and thus as an instrument for establishing long term relations with university institutes.

The two least important categories are *licence agreements* and *engagement of academic researchers*. The fact that academic researchers (apart from graduates) are not perceived as a potential source for recruiting is not surprising from the perspective of firms and reflects the fundamental difference between research in universities and research in a business environment.

5.1.5 Motives and goals for research co-operation with universities

As the last chapters have shown, much of the knowledge transfer is predominantly person-embodied. It is not the direct research output of universities that matters most but the capacity to solve problems and the accomplishment of developing new ideas. Concerning universities as a co-operation partner in a research projects, the following Table 15 shows that only a small percentage of firms regard *building up new research areas*, one of the main tasks of universities as valuable for their business. The same holds for access to research networks (35.9 %). Thus, in a very comprehensible way companies are looking for academic co-operation partners with capabilities directly useful for their business and for expected learning processes. Hence, academic knowledge and capacity can have a strategically relevance for industry.

Table 15: Motives and goals for co-operation with universities

	% of firms (Ø 90) answering important or very important
problem solving capacity	72.8
expected learning processes	69.5
access to state of the art science	68.3
access to complementary know-how	66.7
cost reduction	52.4
access to additional research capacities	51.3
high quality of university research	51.3
outsourcing of R&D	42.5
access to research networks	35.9
building up new research areas	25.9

Source: **tjp**-survey

Each industry has access to all kinds of published knowledge and information, subject to time and resources. They scan published papers to find out about new developments, techniques or contacts. But as the answers to the questionnaires exhibit, the process does not stop here. Industrialists follow this up by approaching people with the relevant know-how in academia. Thus, the most often indicated answer for the motives for a co-operation with

an university is *problem-solving capacity*. This involves the transmission of tacit knowledge – the knowledge of methods, designs and techniques which work in certain ways, and with certain consequences, even when one cannot explain why. Thus, personal contacts, mainly established by alumni or conferences, provide a vital component of industry-academia collaborations and which is not communicated in research papers (see table below). Following this interpretation, one can assume that the benefits from academic research tend to be geographically and linguistically localised (this will be analysed in more detail below).

Most companies with an R&D-department wish to venture into unfamiliar technological territory. Thus, they need to access both formal and tacit knowledge from external sources: by seeking to employ researchers with the right qualifications and experiences, by using access to the state of the art science and by using complementary know-how. Hence, co-operating with universities helps firms to learn more about what is involved in a new line of research, before they commit themselves to bigger projects. The existence of a R&D department is therefore an important condition for knowledge transfer. And it is the validation of one of the main findings of the recent theories of technological change: although academic knowledge has some attributes of a *public* good, it is certainly not a *free* good. Hence, some transfer mechanism are appropriate for companies which have their own in-house R&D and which want to 'explore', 'learn' and 'absorb' knowledge about emerging areas of science and technology.

5.1.6 The establishment of the contact

One decisive category for the establishment for co-operation is the initiative of the firm. As Table 16 indicates 66% of the answering firms see their initiative as crucial for the establishment for a research co-operation with an university. Compared with this self-perception, the initiative of the universities plays a minor role from the perspective of firms.

Table 16: The establishment of the contact

	% of firms (Ø 76) answering important or very important
initiative of the firm	66.6
contact established by alumni	51.3
other personal contacts	50.0
conferences	36.3
initiative of the university	23.3
made aware by funds	23.3
publications	19.7
broker agencies	10.6

Source: tip-survey

Another important factor for a research co-operation is the establishment of a contact through alumni or other personal contacts. More than 50% of the firms rank this as (very) important. This indicates that many graduates working in firms are holding informal contacts with their former institutes or through other personal contacts. Overall, the figures underline again the importance of personal contacts and the crucial role alumni play as gatekeeper

to academic research. Mediation through broker agencies does not play any role for the establishment of the contact. Only 10% see this mediation as very important. This rating is quite similar to the awareness of the universities (see Jörg, 1996).

It is interesting to compare these answers with the answers given by university researchers summarised in Jörg, et al. (1996). While the universities signalled a readiness for co-operation, the industry see their initiative as essential for a co-operation. Hence, there is no problem with the actors. However, the problem lies in the lack of information where and on which university the relevant research is done.

5.1.7 Main factors for the selection of co-operation partners at universities

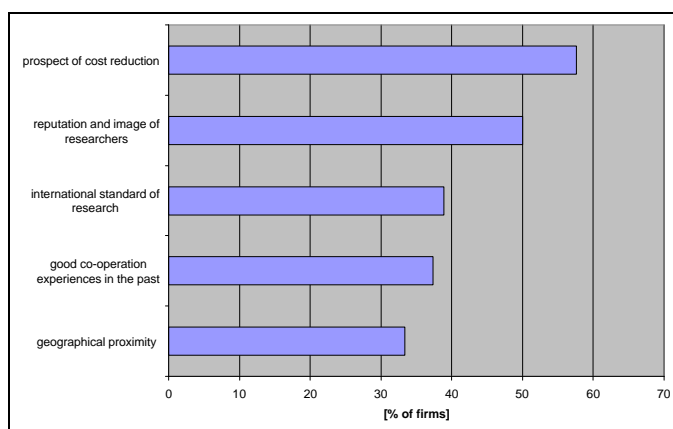
This questions tries to analyse what makes university-institutes attractive as co-operation partners for firms. There are different theoretical approaches concerning this question: for instance, the study of Mansfield (1996), suggests that 'distance matters' in the academic-industry links. This supports the former findings showing that the main motive for co-operations is to access problem-solving capacity which requires face-to-face contacts. Thus, the geographical location of the university are, beside others, an important criteria to choose it as a co-operation partner.

Another interesting insight in what drives university-industry links was provided by Mansfield (1991) and Narin (1995). The former is an empirical survey in which the characteristics of more than 200 academic researchers cited for their usefulness by industrial practitioners from 66 US firms were analysed. He showed that most of useful basic research was performed in university departments with high academic ratings according to the US Academy of Sciences. The second is by Narin, who traced the authors of scientific papers that were cited in American patents in 1993 and 1994.

Both studies found that most of the useful basic research came from universities departments that were highly rated by the US Academy of Sciences. In other words: useful science is good science (Pavitt, 1997).

In the case of Austrian our results reveal a somewhat different picture:

Figure 5: Main factors for the selection of co-operation partners at universities



Source: tip-survey

- 50% of all answering firms indicate that the reputation and image of the university researchers are (very) important as a criterion for co-operation. If reputation and image goes hand in hand with 'good science', Pavitt seems to be right in the sense that useful science is good science. This finding is a clear statement for quality. Unless universities don't provide high-quality research other measures to enhance co-operations with industry will show little effect.
- Even more interesting is the prospected cost reduction through co-operation. Thus, 58% expect a direct observable benefit from the co-operation.
- The importance of geographical proximity was indicated by one third of the answering firms.

A factor analysis exhibit a rather clear pattern of answer categories. Within this pattern the *geographical proximity* indicated by one third of the respondents shows an unpaired factor, thus these firms co-operate with universities only because of the closeness to their company. A close relation exists between *reputation and image of researchers* and *international standard of research*, thus criteria emphasising the value and the high-level performance of the institutes. The third factor consists of *good co-operation experiences in the past* and *prospect of cost reduction*.

As far as the geographical location of the universities firms are co-operating with is concerned, the results are not surprising. Austrian firms co-operate most of all with Austrian universities. Table 17 shows the distribution of firms co-operating with universities from Austria, Germany, other European universities or with universities from outside Europe. The co-operation with domestic universities indicates a highly significant dependency from the size of the firm on a $p < 0.01$ significance level.

Table 17: Firms co-operating with ...

	Never	Sometimes	regularly
with Austrian universities	38	44	14
with German universities	66	20	4
other European universities	78	10	2
universities outside Europe	81	5	2

Source: tip-survey

Concerning the nature of the research project, the survey differentiated between projects within basic research, applied science, experimental development and measuring and testing. Moreover, the number of projects the firm carried out together with an university within the last three years was asked. The following Table 18 gives an overview of the number of firms indicating the nature of research with the sum of the projects they executed with universities.

Table 18: The nature of the co-operative projects (1995-1998)

	# of firms	# of projects
basic science	11	20
applied science	27	112
experimental development	18	38
measurement and testing	34	198

Source: tip-survey

Two of the answer categories show a statistically significant dependency ($p < 0.05$) on the existence of an own R&D department: *applied science* and *measurement and testing*.

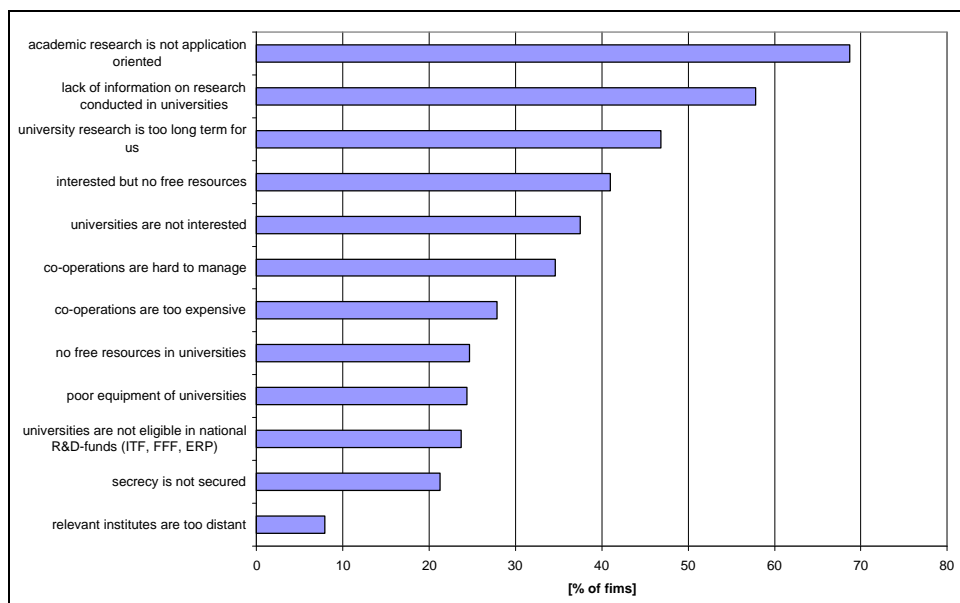
5.1.8 Barriers and difficulties for co-operations

Regarding the barriers for the emergence of co-operative R&D projects the 'Wissenschaftscluster I' (Jörg et al., 1996) exhibit a clear result from the view of the university-institutes: most of the institutes (65%) see the lack of public awareness of their R&D-potential as the main barrier for the emergence of R&D co-operations.

Asking the firms of the main barriers confirms this result (see Figure 6): 58% of the answering firms see the lack of information as a high barrier for co-operations. Hence, the missing link between the academic and the industrial sector for common research activities is a rather 'simple' one, i.e. the lack of information about the research going on at the universities and not poor equipment or missing interest (although one third of the answering firms see this as the main barrier). Policy should take a specific 'mediation function' in order to build the 'informational link' for both sectors.

Beside the missing information, most of the companies see the activities of the universities as not application oriented (69% of the firms value this kind of barrier as (very) high). This answer is to a certain extent understandable and rational from the view of the companies: companies are mostly looking at the direct and short-run effects in the co-operation with universities. Mainly indirect and long-run effects of academic research are not part of their awareness.

Figure 6: Main barriers for the emergence of co-operative projects with Austrian universities



Source: tip-survey

A second type of analysis tries to find through factor analysis interdependencies between the specific answer-categories and hence find some pattern of answers. The factor analysis exhibit four factors which explain more than 63% of the variance. The following Table 19 gives an overview of the factors consisting of different answer categories.

Table 19: Factor analysis of the different barriers

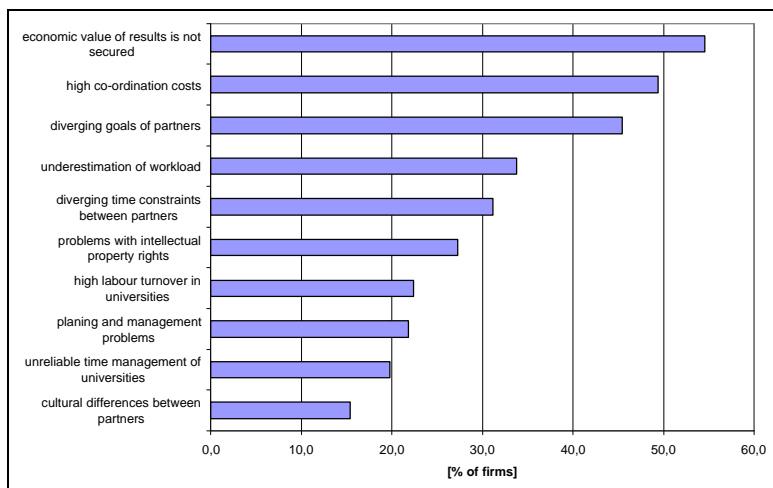
Factor 1	Factor 2	Factor 3	Factor 4
universities are not interested	co-operations are too expensive	poor equipment of universities	interested but no free resources
no free resources in universities	universities are not eligible in national R&D funds (ITF, FFF, ...)	relevant institutes are too distant	university research is too long term for us
academic research is not application oriented		secrecy is not secured	
co-operations are hard to manage			

Source: tip-survey

While factor 3 can be interpreted as the cost-factor which is a negative incentive for firms to co-operate with universities, factor 1 is the expression of a rather diffuse preconception of universities as a potential co-operation partner. Another category of answers is that research strategies of firms need not go hand in hand with research done at universities. Thus the firms see geographical distance, the poor equipment and secrecy of co-operative research in close connection. Factor 4 expresses different time-horizons between industry and academic research: universities are more long-term oriented while industry is more short-term oriented and would only engage into long-term research if resources would be free.

Regarding the difficulties and problems faced in co-operations with universities gives an similar picture (see Figure 7).

Figure 7: Difficulties faced in the co-operations with universities



Source: tip-survey

55% of the answering firms see the economic value of a co-operation with an university not secured and for about half of the firms are high co-ordination costs a negative incentive.

The third major difficulty is a confirmation of the theoretical findings of other studies hence the diverging goal of industry and academia.

6 Main findings and conclusions

If we put basic science into its context in the overall innovation system, it is clear that this system has many components and functions. There are in fact multiple interrelationships between the science and the industrial system. However, if we want to analyse the linkages in more detail one should be aware that both companies' and scientists' actions are driven by their needs and the incentive systems within which they operate. The present study discusses the linkages between basic science and the economy and tries to build a basis for considering the specific aspects of the outputs of academia.

Present characteristics of co-operative relations between the academic and the industrial sector

The results of two existing surveys regarding the role of universities as co-operation partner for private enterprises are pointing the same direction: the study 'Co-operative behaviour of innovative firms' (Schibany, 1998) and the present survey both mention universities as often cited co-operation partners. Compared with innovation-surveys at the beginning of the 90's, universities seem to play an increasingly important role for industry. The awareness of firms that they could benefit from academic research also seems to be higher. Nevertheless, the knowledge transfer remains difficult to manage. Co-operating firms must be aware of clear strategy, the definition of common aims as well as a clear definition of the competencies of the partners. Additionally, a high share of co-operating firms have a R&D department.

The direct impacts of academic research on technological and innovative activities

Direct impacts of academic research on technological and innovative activities of firms are of limited, albeit seemingly growing scope. One indication for an increasing reliance on the results from scientific research in the process of industrial innovation is the growing number of citations of scientific publications in industrial patents – a phenomenon also to be noticed in Austria. Austria seems to have improved its overall relative position vis-à-vis the world average as regards its "Science Linkage" in recent years, but it remains to be seen, whether this improvement as an indication of a sustained "catching-up".

As the analysis of patent data as well as the **tip**-survey have shown, only a few branches make strong *direct* use of the results of scientific research, while substantial benefits are derived from *indirect* flows of knowledge.

More problem-solving capacities than results of R&D done at universities

Asking for the motives of firms for co-operating with universities gives a clear picture of their expectation: not the results of academic research are relevant but the capacity to solve problems. Compared to this result the "core business" of universities - namely access to research networks and building up new research areas - is not highly rated by the enterprises. This categories might be relevant for a relatively small group of firms in the realm of transfer science. For the vast majority of firms the core tasks of academic research are not perceived as relevant to their business. Against this background, one has to be aware of the limits of how far university-industry interaction can get. Academic research differs fundamentally in terms of culture, time horizons and goals from industry R&D-activities. One can expect that co-operation takes basically place along the more peripheral activities of

universities. This is not to say, that universities should necessarily change the focus of their activities towards more industry relevant tasks. A considerable number of firms expect first of all high quality research from universities. Therefore a precondition for a good university-industry link is that universities concentrate first on doing high quality research.

Human factor matters

The main transfer mechanism of knowledge between the industrial and the academic sector is through the human factor. Asked for the general benefits from universities, 64% of the firms answered that they value *high skilled personnel* as the main output from universities and 66% of the responding firms indicate that they see their access to academic knowledge through the *engagement of graduates* as important and very important. Moreover, most of the contacts to an university was established by alumni.

The initiative comes from the industry

66% of the answering firms see their initiative as crucial for the establishment for a research co-operation with an university. Compared with this self-assessment, the initiative of the universities plays a minor role in establishing co-operations. It is interesting to compare these answers with the answers given by university researchers summarised in Jörg, et al. (1996). While the universities signalled a readiness for co-operation, the industry sees its initiative as essential for a co-operation. Hence, there are less problems with the actors. However, the problem lies in the lack of information where and on which university the relevant research is done.

Informational mismatch

Regarding the barriers for the emergence of co-operative R&D projects the 'Wissenschaftscluster I' (Jörg et al., 1996) reveals that most of the institutes (65%) see the lack of public awareness of their R&D-potential as the main barrier for the emergence of R&D co-operations.

Asking the firms of the main barriers confirms this result: 58% of the answering firms see the lack of information as a high barrier for co-operations. Hence, the real bottleneck for improving the interaction between academic research and industry is poor communication about what universities actually do and what might be relevant for industry. Compared to this, poor equipment or missing interest (although one third of the answering firms see this as the main barrier) are not the main barriers. Apparently the various initiatives aimed at providing better information on what research is conducted in different university institutes has limited impact. It is still hard for firms to identify what type of research might help them and whom to contact. The availability of information seems not to be the problem. The problem seems to be that the information on university research is not properly translated to answer industries' needs.

Missing application orientation

Beside the lack of information, most of the companies see the activities of the universities as not application oriented (69% of the firms value this kind of barrier as (very) high) and 54% see the economic value of the research

results not secured. This answer is to a certain extent understandable and rational from the view of the companies: companies are mostly looking at the direct and short-run effects in the co-operation with universities. Indirect and long-run effects of academic research are not mainly part of their awareness.

Engagement in R&D is an important factor

One characteristic of firms with co-operative relationships to universities is remarkable: the R&D activity of the firms is rather high. Nearly two thirds of all responding firms are continuously and 25% are sometimes engaged in R&D. Hence, regarding the absorptive capacity of firms, R&D engagement can be seen as an important condition for collaboration with the academic sector.

The responsibilities of universities:

Technology and knowledge transfer from the academic to the industrial sector can be either direct or indirect. The latter goes hand in hand with one of the main tasks of universities, i.e. to educate people and hence to produce skills with problem-solving capacities. The survey shows, that this type of output is one which is appreciated most by industry. Concerning the direct effect of academic research, i.e. to produce research results directly applicable to industrial needs, this must be based on a real awareness of companies' needs. This sounds rather obvious. However, the ideal starting point is not to search for possible application for new research results, but a current technical problem. Universities should respond to real needs rather than to try to create or anticipate needs. The latter is not the job universities are good at. This is basically consistent with Pavitt's underlying message suggesting that university should concentrate on doing good science: *useful science is good science*.

However, the study reveals a rather 'informational' mismatch between the academic sector and firms with specific problems expecting an solution through co-operation with an university. The critical point here is that universities should provide efficient 'entry gates' for industrial companies. The most cost-efficient kind of problem solving for companies is to find different kinds of services both rapidly and easily which correspond to their expectations. Within this context the problem of communication arises, i.e. to communicate in a manner which is understandable for firms. It is rather difficult to find a common language between the academic and the industrial sector. In the case of Austria the presumption is that the 'Außeninstitute' (or data-bases such as FODOK or the new established 'Auris') do not work as such to build a bridging platform or one-stop-shop. They have neither access to firms nor the capabilities to navigate firms through the scientific-world. Moreover, firms are in their search activities time- and money-constrained.

To conclude, a central contact point, such as in most universities the Industrial Liaison Office (ILOs), should be available for directing industrial companies towards the expertise which they need from universities. However, the configuration of ILOs are not trivial. Many questions arise: at what organisational level should they be situated (university or institute)? What are the needed qualifications and endowment? Examples of other countries (e.g. Australia) could be screened for further evidence in this aspect.

The responsibilities of firms:

When trying to directly capture benefits from collaboration with universities, most firms need directly applicable solutions for their problems. In addition, they need ideas and useful information for their innovative activities. However, companies which make use of basic science need a high degree of internal capability. In particular they need to employ a good number of people produced by the basic science education system. More generally, a good science infrastructure is attractive because it provides the scientific, technical and personal support networks needed to provide manpower for R&D and to keep this manpower both up-to-date and connected with scientific and technological change.

Towards realistic expectations

Concerning the contribution of the science system to industrial innovation the previous **tip**-study "Wissenschaftscluster I" (Jörg et al., 1996) has raised the following question: is there an obligation for delivery on part of universities or an obligation for taking-up on part of industry?

One of the main conclusions resulting from the present study is that this question has to be reformulated and that both, companies and the science sector, are driven by their needs regarding the industrial side and public task regarding the academia. Policy should therefore formulate realistic expectations with regards to university – industry co-operations.

As these two systems follow different rationales, there should be a well defined division of labour between academic research and other types of research in a national innovation system. Academic research should address mainly basic research resulting in the production of "public goods" (e.g. the publications of scientific papers) while business research should be concerned mainly with the development and testing of prototypes and hence is inherently short-term oriented. And despite examples of with close links between basic research and technology, this division reflects more or less the *purpose* of these two types of activities. Academia should do good science and the industry expects economic returns from their research activities done by well educated graduates. Thus, policy should be formulated with the view of a relatively clear division of labour between academic and industrial research.

Industry mainly is constrained by time and money. The only access for an enterprise in looking for a co-operation partner at an university is through the provision of information consisting of university related activities. But this leads to more or less "informational" problems. First, the information is based on the language and incentives of scientists and, more important, it results in high search-costs for industry. The existing information exchange in Austria seems to be inappropriate to bridge the information-supply by academia and the content-demand by industry. A lack of "entry gates" can be realised, which leads to a barrier to communicate in a form which is understandable for firms.

Technology transfer between the academic and the industrial sector needs management. The new programme *K-plus* is a good example of how well defined incentives and criteria with the necessary management requirements creates a framework, which set up a network that combines competencies available in scientific and applied re-

search institutions with those available in industrial RTD. This kind of framework is a necessary precondition to enhance the technology transfer from research institutions to industrial partners.

University institutes need a profile. The well known project descriptions done by the institutes are not very suitable for an enterprise to find an appropriate partner for a joint research project or the potential solution of an industry-specific problem. As the results from many empirical survey have shown, reputation, competence and research experience are important criteria for the selection of an co-operation partner from the academia.

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