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GROWTH THROUGH RESEARCH AND DEVELOPMENT

- what does the research literature say?

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Growth through Research and Development

- what does the Research Literature say?

by

Roger Svensson

Foreword

VINNOVA´s mission is to *promote sustainable growth* by funding *needs-driven research* and developing *effective innovation systems*. Innovation systems are an analytical perspective for understanding the dynamic connection between actors, institutions and other determinants of the volumes, directions, results and impacts of innovation processes.

It is of fundamental importance for VINNOVA to understand and continuously improve the understanding of the relationships between R&D-investments and sustainable growth. Therefore, VINNOVA pursues a broad and ambitious strategy in order to generate insights into those relationships and their determinants. This strategy includes two interrelated parts. On the one hand it includes substantial research programs aiming at improving the scientific understanding of research, innovation and sustainable growth in general. On the other hand it includes continuous and ambitious monitoring, evaluation and impact studies focusing on the results and impacts of VINNOVA's activities on research, innovation and sustainable growth in Sweden. The overall strategic aim is to improve VINNOVA's and other policy makers' understanding of the issues, challenges and opportunities involved.

This study is an overview of the economic literature on the quantitative relationships between R&D-investments and economic growth. The author is Roger Svensson, associate Professor at Mälardalen University and researcher at the Research Institute of Industrial Economics (IFN) in Stockholm. The study was first published in Swedish in May 2008 by the Confederation of Swedish Enterprise. Since the scientific and policy discussion on the issues discussed in the report is highly international and since this study represents a broad overview of the current economic research on these issues, VINNOVA has funded the translation of the report into English. Thereby we hope that this study could further inform and inspire the already intense scientific and policy discussion on the nature and determinants of the relationships between research, innovation and economic growth.

VINNOVA in December 2008

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1 Introduction

In 2004, the public sector in the OECD countries spent approximately USD 190 billion on research and development (R&D), which corresponds to almost 30 per cent of all the R&D (USD 650 billion) conducted in these countries. If we examine who carries out R&D, we can see that the private sector accounts for 68 per cent, Government research institutes (laboratories) for 12 percent, universities for 17 per cent and other non-profit organisations for 3 per cent. Here there are cases where the Government funds R&D in the business/industrial sector and vice versa, but in Europe the overwhelming majority of Government funding goes to Government-controlled universities and research institutes. A widely-accepted estimated is that 25-20 per cent of publicly-funded research goes in turn to the defence industry. Here, however, there are major differences between different countries. In the USA, the percentage is 50-60 per cent and in England and France 25-30 per cent, while the figure is 10 per cent or less in most other OECD countries.

Apart from the fact that publicly-funded research is intended to satisfy public needs relating, for example, to defence and the environment, there are two main reasons that are linked to failures in the R&D market that motivate Government intervention.

- First, it has been shown that the total return on R&D investments for society as a whole (the social return) is greater than the private return (i.e. the return for the company investing in R&D). This is because the company cannot utilise all the results of its R&D and some of the new knowledge gained is transferred to other companies in the form of spillovers (see section 3).
- Secondly, R&D is associated with high risks, which creates barriers and discourages companies from conducting R&D. This applies in particular to small companies, which often have difficulties to find the funding required.

In both cases, companies on a free market will invest less in R&D than the level that is optimal for society at large (Arrow, 1962).The most logical approach for the State is to fund R&D where the difference between private and social return is considerable, i.e. where spillovers are extensive, as it is this type of R&D that would not otherwise be carried out. The research literature on publicly-funded R&D focuses a great deal on this issue of the private and social return on R&D.

The Government can perform R&D itself at its own universities or research institutes. However, the Government can also stimulate R&D that is conducted by companies, either by reducing the private cost for R&D or by increasing the return on R&D, or by helping companies to understand the opportunities offered by new technology, i.e. by reducing uncertainty. The aim of this report is to summarise what the research literature in the field of economics says about how publicly-funded R&D affects productivity and growth. Above all, however, the report addresses *how* government research policy and the Government-funding of R&D should be organised to be as effective as possible. This covers both publicly-funded R&D that is performed by companies and R&D at Government-controlled universities and research institutes.

The report is arranged as follows. Section 2 discusses the advantages and disadvantages of different types of public-funding of R&D. Section 3 analyses what differentiates R&D from other forms of input and why spillover effects occur. The empirical literature on the return on R&D and the relationship between R&D and growth is presented. This applies to both private R&D and public R&D. How publicly-funded R&D affects private R&D theoretically and empirically is presented in section 4. How R&D at universities can be transferred to business and industry and who should own the results of university research is discussed in section 5. Europe is compared to the USA here. Section 6 analyses the issue of how the Government should finance the universities – by means of a fixed allocation or on a project basis (competition). The consequences of funding on a competitive basis are discussed and advantages of scale in the university sphere are analysed. Section 7 summarises the conclusions.

2 Government instruments for funding R&D

The Government has three main instruments for funding research, each of which has advantages and disadvantages in economic-theoretical terms (David et al., 2000; Guelec and van Pottelsberghe, 2003).

2.1 Own R&D at Government research institutes and universities

The Government can itself conduct R&D that is mainly funded by the Government at its own research institutes and universities. In Europe, this type of R&D accounts for the major part of the Government research budgets. A primary objective of the research institutes is to satisfy public needs. The universities mainly produce basic research that can then be used by companies in their applied research. The universities, however, have a more independent research agenda compared to the research institutes, which makes them less sensitive to Government directives. The Government controls large parts of the universities' research budgets, however, which makes them relevant to the politicians. The universities and research institutes affect the productivity of business and industry and private R&D indirectly.

2.2 Direct funding of the companies' R&D

The Government can provide *direct funding for R&D* that is performed by companies. This form of funding aims to increase the marginal return on the companies' R&D. There are two alternatives here:

- Funding of contract R&D, where the funder rather than the performer owns the results of the research. This is common in the defence industry, for example.
- Funding in the form of *grants or subsidies* where the companies that perform the R&D own the results.

In the case of direct funding, it is often the Government that decides what type of project should be funded. Direct funding can, for example, be awarded to projects where the social return is high compared to the private return (the early phases of technology projects) or to projects that are useful to the Government's own objectives (defence, healthcare). R&D grants often comprise specific demands, e.g. that the company establishes cooperation with universities or other companies. Another demand may be that the company should appoint a certain number of new employees. An obvious disadvantage of this type of specific funding is that the Government distorts competition. Nor is it certain that the Government is capable of identifying promising projects.

2.3 Tax incentives for company R&D

The Government can help companies to conduct R&D by offering *tax incentives* that aim to reduce the costs of R&D. Most OECD countries permit R&D costs to be written-off entirely in the same year the investments are made, which means that the depreciation sum is deducted from taxable income. The Government can also provide tax credits which are deducted from the companies' taxable profits. Another method is to permit the accelerated depreciation of machinery and buildings used for R&D purposes (Hall and van Reenen, 2000).

A disadvantage of tax incentives from the Government's point of view, but an advantage from the companies' point of view, is that the companies themselves can decide what type of R&D they want to invest in – irrespective of the size of the difference between the social and private return of the R&D concerned (cf. direct funding above). As the R&D costs are offset against profits, there is a risk that the companies will choose projects that provide a high return in the short term.[1] Furthermore, it is very likely that projects will be chosen in which the difference between private and social return is small (David et al., 2000). An advantage of tax relief is that it is does not distort competition or discriminate between different *established* companies. Tax incentives do, however, have a certain discriminating effect. They are seldom available to new companies or to companies where investments are greater than sales, i.e. those companies that are perhaps the most innovative and that are in the greatest need of external funding (Hall and van Reenen, 2004).

[1] An example is a company that has hardly any income at all and that is facing the choice between two R&D projects: one that will provide a short-term profit and one that will provide a profit in the long term. If the Government now changes the regulations and introduces tax reductions for R&D investments, the company will be more prone to choose the short-term project than it would have been before the tax reductions were introduced.

3 R&D, return and growth

3.1 Theory on R&D and growth

In earlier neo-classical theory, knowledge was regarded as an exogenous variable that, together with a company's input goods, labour and capital, affects productivity. In endogenous growth theory, on the other hand, investments in R&D that provide new knowledge are seen as an important factor that explains growth and increased productivity (Romer, 1990). This theory regards new technology not only as an exogenously produced input good that the company utilises – new technology can also be created within the company. In endogenous growth theory, investments in R&D can provide long-term growth and lead to rising returns to scale. This is because previous R&D investments that were made to generate specific knowledge do not need to be made again. The replication of previous production does not therefore have to bear the burden of any R&D costs.

Common capital goods such as machines and means of transport, and even labour, are products for which there is rivalry – they cannot be used at the same time for different purposes. Knowledge, however, is a product that is non-rivalry. This means that a company's use of the product (knowledge) does not diminish any other company's use of the product (Jones, 2004). However, knowledge is often also non-excludable. A company that has invested in R&D to acquire new knowledge may find it difficult to prevent other companies from using this new knowledge – unless it is patented. Knowledge becomes "a public good". It is also highly unlikely that a company will itself have the expertise required to utilise all the knowledge generated by the R&D concerned. These factors explain how R&D can lead to spillovers to other companies and can lead to rising returns to scale – which otherwise contradicts the neo-classical theory.

The non-excludability of new knowledge and the occurrence of spillovers lead, as mentioned above, to a great risk that companies on a free market will invest too little in R&D. There are three ways of addressing this problem:

- Intellectual property rights can protect the originators of new knowledge. Patents are the most common instrument used here, but copyright and trade marks are also used. These exclude others from using the knowledge concerned.
- The State can assume responsibility for the funding and production of new knowledge, with the aim of ensuring that the knowledge is then disseminated. State universities and laboratories that conduct R&D are

the foremost examples of this system. Sometimes the State just provides the funding and allows companies to perform the R&D (see Section 2). This is particularly effective if the private return is low and the social return high.

- A contract can be draw up between a party that produces the new knowledge and another party that is interested in it. Contract research where the State funds companies that perform R&D in the defence industry is an example of this.

R&D that is performed by a company often leads to new and/or improved goods and services that the company then sells. The company may not be able to utilise some of the results of its R&D and these may then be transferred through various channels (imitation, personnel who change jobs, licensing, cooperation between companies) to other companies – so-called spillovers. Mansfield (1981) estimated that the cost of imitating a product is 65 per cent of the original innovation costs. Performing R&D also leads to further training for the company's personnel. In addition, the company becomes better at absorbing knowledge that is generated at universities and other companies (Cohen and Levinthal, 1989, Geroski, 1995).This is decisive for the ability of a company to utilise spillovers from other companies. Many observers, including Callon (1994), point out namely that knowledge generated as a result of R&D is not a public good that can be utilised by just anyone. A certain form of education and training and the right networks are required to be able to understand and utilise new knowledge – receiving knowledge generated by others is thus associated with a cost. Another characteristic of knowledge is that it cannot always be codified but is "tacit", i.e. the researchers/scientists know more than they can put into words (Rosenberg, 1990; Pavitt, 1991). In general, this requires the participation of the researchers concerned if new research results are to be converted into innovations.

3.2 Empirics: private R&D at the aggregated level

The studies that, on an empirical basis, have estimated the link between R&D on the one hand and productivity or economic growth on the other have usually used some form of production function. Here, R&D investments – often divided into internal and external R&D – together with the production factors physical capital and labour – are the factors that determine productivity, which is measured as value added or sales. It can be difficult here to demonstrate that there really are spillover effects even if a link is found between productivity and external R&D, as these effects are always indirect. The studies differ greatly in terms of the aggregated level (company, industry or nation), model specification (the other explanatory factors that are included in the model), sources of data (countries, periods of time) and how they measure key variables (stocks, flows or changes). It may therefore be difficult to compare the studies with each other. It is important to note here that the indirect spillover effects take longer to act than the direct effects of the company’s own R&D (private return).

One problem associated with estimating how much R&D affects productivity is that R&D can hardly be regarded as an exogenous variable. The amount that is invested in R&D often depends on the expected sales level. This makes it difficult to know in which direction the causal link is working. Griliches and Mairesse (1995) believe that the problem of endogenity leads to biased estimates. Crepon et al. (1998) was the first to attempt to get around this problem by first estimating whether and how much companies invest in R&D and then test the effect of the estimated R&D on productivity.

Ejermo et al. (2006) have done useful work by reviewing a number of studies that investigate the effects of private R&D at the aggregated level. The research literature draws the conclusion that there is no link between R&D and growth in poor countries. This is despite the fact that the poorest countries invest more in R&D in relation to GDP than middle-income countries (Birdsall and Ree, 1993; Gittleman and Wolff, 2001). In the case of the developed countries, there is a strong statistical link between R&D and productivity, but the elasticity is between 0.13 and 0.20, which means that if R&D increases by 1 per cent then productivity will increase by 0.13 to 0.20 per cent. This ratio applies even when spillover effects are taken into account (Verspagen, 1995; 1997; Verspagen and Meister, 2004). This does not necessarily mean that SEK 1 invested in R&D will provide less than SEK 1 in sales as R&D and productivity are different quantities (sales are in general many times greater than investments in R&D).

When estimating how R&D affects growth or productivity at the aggregated level it is important to take into account the spillover effects from other countries. This is done by dividing R&D into that conducted within the country and that conducted abroad. Several studies at the aggregated national level have shown that the R&D conducted in other countries is as important or more important than the R&D conducted within the country for the growth of productivity in the country concerned (Lichtenberg, 1993; Coe and Helpman, 1995; Eaton and Kortum, 1999; Guellec and van Pottelsberghe, 2004). The latter study found, for example, that the elasticity of domestic R&D in relation to growth is 0.13 (cf. above) - an effect that comprises both private return and domestic spillovers - while elasticity for foreign R&D (international spillovers) is as high as 0.49. Coe and Helpman (1995), however, estimate that elasticity for foreign R&D in relation to domestic productivity is 0.29. Both Lichtenberg (1993) and Guellec and van Pottelsberghe (2004) also find that productivity in small countries is affected to a greater extent by the R&D conducted in other countries than productivity in large countries.

3.3 Empirics: private R&D at the company level

Wieser (2005) has reviewed the studies carried out in recent years that estimate how R&D affects productivity at the company level. His summary of these studies is that R&D has a positive and statistically significant effect on growth in terms of sales and productivity. The private return is between 7 and 69 per cent. The median is 27 per cent and the mean value is 28 per cent. Elasticity is between 0.03 and 0.38, where the mean value is 0.10 and the median 0.13. Many studies also show that the spillover effects are considerable. The return to other companies is often twice as high as the private return, which means that the social return (private return + spillovers) is on average 90 to 100 per cent. The social return is thus two to three times higher than the private return. Some studies also indicate that spillover effects *between* sectors are greater than the effects *within* sectors. The conclusion that the social return on R&D is much higher than the private return is extremely important in an economic-political perspective, as it is precisely this that motivates the State to fund R&D.

An interesting question from the policy point of view is what sectors or types of company generate more or less return on R&D. Several studies find that some sectors have a higher or lower return than the average, but it is not possible to draw any general conclusions because the results of the studies vary so much. For example, it appears that certain sectors (e.g. the auto industry and the engineering industry) have a lower level of return than the manufacturing industry as a whole, but this difference is not statistically significant. Wieser (2005) also notes that it is not possible to prove that companies that focus solely on research achieve a higher return on their R&D than manufacturing companies. This indicates that competition within and between sectors is a factor that evens out the return on R&D in different sectors and different types of company.

3.4 Publicly-funded R&D, productivity and growth

Publicly-funded R&D that is conducted by companies should have a similar impact on productivity, growth and the ability of companies to absorb new knowledge as the R&D funded by companies. It is not certain, however, that the Government is as good at finding promising R&D projects as the market, which could lead to a weaker impact. There is also another important difference in the case of contract research (which is common in the defence industry) as here it is the funder (the Government) that owns the results of the research. This means that companies cannot freely exploit the results of their research on the market, and that they therefore have less incentive to conduct the R&D effectively and efficiently.

A few studies have directly compared the return on privately-funded and publicly-funded R&D. Mansfield (1980), Griliches (1986) and Lichtenberg and Siegel (1991) all find that publicly-funded R&D has a lower return than privately-funded R&D. However, Griliches (1992), in a summary of several studies, draws the conclusion that there is no major difference in return between privately-funded and publicly-funded R&D at the company level. The total social return on publicly-funded R&D is between 20 and 65 percent and on privately-funded R&D between 28 and 80 per cent (private return of 15 to 40 per cent).

Lichtenberg (1993) has investigated, at the aggregated level, how R&D conducted by companies affects productivity depending on how the R&D is funded. He concludes that R&D that is funded by the Government has a much weaker impact on productivity than the companies' own R&D. Sometimes, publicly-funded R&D has no impact at all.

Guellec and van Pottelsberghe (2004) have also investigated, at the aggregated level, the link between different types of R&D and productivity for 16 OECD countries in the period 1980-1998. They found that privately-conducted R&D that is funded by the Government has a negative effect on productivity. This result, however, is explained almost entirely in terms of defence expenditure. If public-funding has civil aims the impact on productivity is positive. Another conclusion is that the positive impact of private, domestic R&D on productivity has increased over time (1980-1998).The effect of foreign R&D on domestic productivity has been stable, while the effect of publicly-funded R&D that is performed by companies has weakened over time.

Poole and Bernard (1992) have shown empirically that the stock of defence-related innovations had a negative and significant effect on productivity in several sectors in Canada in the period 1961-1985. Nadiri and Mamuneas (1994) have investigated how the stock of public R&D capital and the infrastructure stock affect the cost structure in the manufacturing industry in the USA. They have shown that the stock of public R&D capital has positive and significant productivity effects and is associated with quite considerable spillover effects. However, Park (1995) finds that public R&D loses its positive impact on productivity if private R&D estimates are taken into account.

Medda et al. (2006) have analysed Italian companies and found that publicly-funded R&D is sought and used to a greater degree for high-risk projects that may have effects in the long term. R&D funded by the companies themselves relates to projects where a safe return is envisaged. Strategic R&D projects are often performed in alliances with other companies to avoid the results being internalised by other companies in the form of spillovers. Basic research that provides a relatively low private return compared to the social return is often conducted by the companies in collaboration with laboratories and universities.

Irwin and Klenow (1996) have shown that those companies that participated in a publicly-funded R&D consortium in the semi-conductor industry in the USA experienced a higher growth in sales than companies that did not take part. The companies in the consortium avoided the duplication of R&D work. There was, however, no difference in labour productivity between those companies that participated and those that did not.

Branstetter and Sakakibara (1998) have investigated a Government-subsidised research consortium in Japan whose aim was to bring together companies that had complementary R&D projects in order to increase productivity. They found that private R&D investments were stimulated rather than being squeezed out by this publicly-funded R&D initiative.

On the whole, it appears that publicly-funded R&D performed by companies has a positive effect on productivity and growth, but that this effect is somewhat weaker than when the companies fund their R&D themselves. Defence-related R&D that is funded by the Government has a negative rather than a positive effect on productivity and growth.

3.5 Effects of basic research and university-funded R&D

The R&D performed by the universities focuses much more on basic research than the R&D conducted by the companies. According to the OECD, basic research accounts for 65 per cent of the universities' research and 28 per cent of the research conducted by Government research institutes, but for only 5 per cent of the R&D conducted by the private sector. A theoretical argument common to all the literature is that the difference between the private and social return on R&D is probably very considerable in the field of basic research, which would provide incentives for greater intervention by the Government. Salter and Martin (1999) and Bager-Sjögren (2006) have reviewed the literature on how publicly-funded basic research at universities (and laboratories) theoretically affects economic growth:

- If publicly-funded R&D is conducted at universities or laboratories the stock of knowledge available to companies and society at large increases. To enable the dissemination of this new knowledge, it is important that it is codified, e.g. published in journals.

- Basic research also leads to the development of new methods and instruments that will be useful in future R&D work in both the universities and the companies.
- Knowledge produced in the universities can also be patented and then sold or licensed to companies that in turn increase their productivity, which is a direct effect of university research. An alternative is for the university researchers to start new companies themselves to exploit the new knowledge.
- As in the case of R&D at companies, conducting research at universities means that the personnel get further training and that their ability to absorb new knowledge increases. The ability to absorb new knowledge is extremely important to the ability to benefits from the research conducted by others.
- Probably the most important effect is that the Government universities train and provide a pool of researchers and students that the private sector can benefit from. These researchers can subsequently take their knowledge with them – whether it is codified or tacit – when they take jobs in sectors outside the academic world.

Zellner (2003) has conducted a survey to examine what type of knowledge is transferred from the universities to the companies when researchers change their place of work. He notes that it is not only the concrete research results that are important to the innovativeness of the companies. Zellner divides knowledge into the ability to analyse, methodology and propositional knowledge (truths that the research has arrived at), and in terms of to what extent these three types of knowledge are general or specific. His empirical results show that the companies value general knowledge higher than specific knowledge with regard to analytical skills, research discipline and methodology. Scientific analytical skills are also valued more highly than propositional knowledge.

As mentioned above, basic research is seen as being associated with high spillover effects. In the literature, however, it is difficult to find any studies at all that have actually empirically tested whether the difference between private and social return is greater in the case of basic research than in the case of applied R&D. Griliches (1992) argues that it may be difficult to demonstrate spillover effects from basic research as these can be spread over such a wide area. Some studies have, however, looked at university research - which predominantly consists of basic research - more closely, and at how this affects growth and productivity.

Salter and Martin (1999) have conducted a literature review and note that R&D at universities has a positive social return in the range of 25 to 50 per cent, but this is lower than the social return for private R&D. This is, however, a question of a comparison between a number of studies that have used different methods and data.

Guellec and van Pottelsberghe (2004) show in their aggregated analysis that R&D performed at Government universities and research institutes has a considerable positive effect on the growth of productivity (elasticity is 0.17 per cent), but that R&D at universities has a stronger effect than R&D at Government research institutes. The authors believe that this points to the necessity of the Government encouraging research institutes to collaborate with the private sector. R&D in the public sector has a lower impact on productivity if it is defence related. A final conclusion drawn by the authors is that R&D at Government universities has a greater effect on productivity the lower the percentage that is funded privately. The authors explain this by saying that in the event of close cooperation with companies the universities focus more on applied research than on basic research. It is presumed that basic research has greater long-term effect on growth.

Audretsch and Lehmann (2005) analyse spillovers from German universities and expected technical universities to have a greater spillover effect than general universities on a range of technologically-intensive companies. However, they found no difference in the impact of the different types of university.

On the basis of survey interviews, Mansfield (1991) investigates how important university research is for innovations at 75 American companies. His findings are that the development of approximately 10 per cent of new industrial products and processes would not have been possible without considerable delays if the relevant basic research had not been conducted in the academic sector. His estimate is that the return on academic R&D is 28 per cent. In a follow-up study in 1998, Mansfield shows that the significance of academic research is even greater - 15 per cent of the new products and 11 per cent of the new processes would not have been developed without academic basic research. These innovations accounted for 5 per cent of the companies' sales. Beise and Stahl (1999) have conducted a similar study but with a much greater sample of companies – 2 300 in all. They find that approximately 5 per cent of all sales for new products could not have taken place without academic R&D. The also find that academic R&D has a greater impact on new products than on new processes. One weakness of these studies is, however, that they are based on estimates made by the managers at the companies.

A new large database on EPO patents has been compiled in recent years (Giuri et al. 2007). An examination of this database reveals that university researchers are recorded as the inventors for almost 5 per cent of the patents. In the case of another approximately 12 per cent of the EPO patents, which are owned by industry, knowledge produced at the universities (probably in the course of basic research) was decisive for the granting of the patents.

Adams (1990) finds that the creation of an increased knowledge base at the universities (in the form of published research articles) has a positive impact on the growth of productivity in the manufacturing industry in the USA, but that the time lags here may be several decades long (15 to 30 years). An entirely different method is used by Narinin et al. (1997). They test to what extent academic articles are cited in 400 000 USA patents and find that more than 40 per cent of all the references that are *not* to other patents are references to academic journals. They also find that references to academic journals have increased considerably over time. A weakness of this method is, however, that it is often the administrators at the patent office, rather than the inventors, who manage the references. The increase in academic references may be due to a new policy from the patent office to make more such references, or to the fact that academic research results have become more available to the administrators.

Marsili (1999) compares the proportion of American research data that is made up of basic research in different industrial sectors with to what degree these sectors employ scientists. He finds that sectors that conduct a lot of basic research also have a high percentage of scientists among the personnel. He also investigates to what extent the knowledge is codified in different sectors by examining how often patents quote academic journals. The results show that different sectors utilise academic basic research in different ways. In some sectors (e.g. the pharmaceutical, chemical and petroleum industries) the link is direct, with many academic references and a great deal of interest in academic R&D. In other sectors (such as the automobile, telecommunications and computer industries) benefit is drawn from basic research more indirectly by employing researchers who solve technological problems.

Several studies conclude that it is more probable that academic R&D will have an impact on companies that are located in the proximity of universities. Katz (1994) shows that collaboration between universities and companies within a country is more likely if they are located close to each other, which indicates that research collaboration requires cooperation in the same place. Hicks and Olivastro (1998) show that 27 per cent of the references in USA patents are to academic articles produced in the same federal state as that where the patents were applied for. At the national level too there is empirical evidence that patents refer to academic articles from the same country to a disproportionately high degree (Narin et al., 1997). A theoretical argument that explains this proximity and interaction between researchers and companies is that a part of the knowledge is tacit, i.e. the knowledge cannot be codified and is therefore tied to the researchers

(Rosenberg, 1990; Pavitt, 1991). Direct communication between university researchers and companies and cooperation on site may be decisive to the rapid and effective sharing and transfer of knowledge (Wolfe, 1996). Every region or country must therefore have its own capacity for basic research in order to be able to receive and utilise research results created by others. It is thus difficult for a country to get "a free ride" and to simply attempt to exploit the fruits of the research conducted in another country.

Based on the aspects presented above, it can be concluded that basic research at universities has significant positive effects on society at large – even if it is difficult to quantify these effects. However, the research literature says nothing about how much a country should invest in basic research.

3.6 R&D versus human capital

Investments in R&D entail the production of new knowledge and innovations. They also increase the ability of companies to absorb new knowledge from others. Investments in human capital mean that the personnel acquire new knowledge and increase their ability to absorb the research of others. It may therefore be difficult to distinguish between the effects of innovations and learning. As these variables are strongly correlated, it is usual to use only one of them when explaining economic growth. Mankiw et al. (1992) find that three variables – population growth, investments in physical capital and investments in human capital – explain 80 per cent of the variations in GDP per capita between countries. Differences in technological productivity are less significant. Klenow and Rodriguez-Clare (1997) believe, however, that Mankiw et al. exaggerate differences in human capital by only taking into account upper-secondary school education and not primary and secondary education. Temple (1999) uses a more complete variable for human capital and finds then that it only explains 50 per cent of the differences in GDP per capita between countries.

4 The effect of publicly-funded R&D on private R&D

4.1 Theoretical aspects

A central issue is to what extent publicly-funded R&D complements or substitutes private R&D. If public funding is only awarded to projects that the companies would have conducted in any case, then there is no justification for public funding at all.

David et al (2000) list a great number of conceivable positive and negative effects of State-funded R&D. The thinking behind the concept that publicly-funded R&D should complement private R&D is partly that an increased marginal return (direct funding) or reduced marginal cost (tax incentives) for R&D will encourage the companies themselves to conduct more R&D. There are two positive long-term and dynamic effects of publicly-funded R&D. First, it can increase the internal stock of scientific knowledge at companies or at other companies by means of spillovers. The companies can then build on this stock of knowledge in their own R&D. Secondly, the company's R&D personnel receive further education and training.

There are additional positive effects. Public-funding can be used to meet fixed R&D costs for items (e.g. test facilities or permanent R&D equipment) that can then be used in the companies' own R&D activities, thus reducing the average costs for R&D. Even in the case of contract R&D (e.g. in the defence industry), private R&D can be stimulated for several reasons. Fixed start-up costs for R&D within a particular field can be covered, the ability to assimilate new technology increases within the company and public R&D contracts signal a future demand for products from the Government.

There are, however, a number of central problems associated with public-funding:

- Publicly-funded R&D may crowd out private R&D by increasing the costs for R&D. Goolsbee (1998) and David and Hall (1999) claim that the most important effect of public-funding is that it increases the salaries of R&D personnel – at least in the short run. The companies then move their resources to other investments. Although the total sum invested in R&D may increase due to public funding, the real quantity of R&D (adjusted for higher costs) may actually be lower.
- Another argument is that publicly-funded R&D simply replaces privately-funded R&D. The companies replace their own funding with public funding and continue to conduct R&D at the same level as

previously. In such cases, the Government funds R&D that would have been carried out in any case. If the Government supports an R&D project at a company, this may also discourage other competing companies from investing in R&D. Private R&D is thus crowded out again.

- The Government often allocates resources less effectively than the market, which can create market distortions. Government intervention may also distort competition between companies – some companies are favoured at the expense of others.

Theoretically it is impossible to determine to what extent publicly-funded R&D and private R&D complement or substitute each other. Many empirical studies have investigated the degree to which public funding stimulates the companies' own R&D. These empirical studies are seldom comparable as they use different sources of data, timeframes, statistical models and aggregation levels. The studies have mainly been carried out at the company, sector and aggregated national level.

4.2 Empirical studies

Tests at the aggregated level make it possible to take indirect effects into account – both positive and negative spillovers. A company that receives direct R&D funding can increase its own R&D, but competing companies are at a disadvantage and may reduce their R&D. Nadiri and Mamuneas (1996) have shown, for example, that negative effects may also be found between different industrial sectors. On the other hand, companies that receive State funding can generate spillovers that benefit competitors or other companies. Another advantage of the aggregated level is that the Government measures can be seen as exogenously given. This cannot be done at the company level as in the case of direct public funding because the companies that receive such funding are not randomly selected (Lichtenberg, 1984). Wallsten's (2000) empirical study at the company level supports the view that a positive link between a company's R&D and public funding is not necessarily evidence that the public funding is effective. A problem with studies at the aggregated macro level is, however, that both private R&D and the public funding of R&D can be determined by the same factors, for example the economic cycle. This can give rise to erroneous links between publicly-funded R&D and private R&D.

Most of the empirical studies have been conducted at the company or sector levels. The studies at the company level have found a mixed link between private R&D and R&D that is conducted by the companies but funded directly by the Government. Higgins and Link (1981), Lichtenberg (1984 and 1988), Toivanen and Niininen (1998) and Wallsten (1999) find that they are substitutes, while Lichtenberg (1987) finds no link at all. Howe and

McFetridge (1976), Link (1982), Holemans and Sleuwagen (1988), Antonelli (1989) and Busom (1999) find that R&D that is directly funded by the Government and private R&D are complementary.

At the company level, it has also been estimated how tax credits affect the willingness of companies to invest in R&D. Generally, it has been found that the marginal effect between tax credits and R&D expenditure is close to 1, i.e. if tax credits increase by SEK 1 then the companies' R&D expenditure increases by at least SEK 1 (Berger, 1993; Hall, 1993; Hines, 1993; Nadiri and Mamuneas, 1997; Dagenais et al., 1997). The interpretation then is that tax incentives are at least as good as direct public funding at stimulating the companies own R&D. Indirect effects (e.g. spillover effects) have, however, not been taken into account (Hall and van Reenen, 2000). There is a study of Sweden in which the tax effects on company R&D have been simulated (Mansfield, 1986). In the short term, however, the effect was only SEK 0.3-0.4 more R&D per SEK 1 of reduced tax, although the effect increases if measurements are made over a longer period of time.

A few studies have been done at the sector level. These often relate, however, to publicly-funded R&D in general rather than to the direct funding of R&D in companies and how this affects private R&D. Buxton (1975), Goldberg (1979) and Levin and Reiss (1984) find a complementary link, while Lichtenberg (1984) finds no link. A problem here is that some sectors are more technology-intensive than others and have more scope for both public and private R&D, which indicates a positive link. Some of the studies attempt to take this into account.

The link is also stable at the aggregated national level. According to David et al. (2000), seven of eight empirical studies show a positive link between the direct public funding of R&D conducted at companies (mainly contract R&D) and private R&D. Elasticity or the marginal effect is in the range of 0.1-0.4, i.e. if publicly-funded R&D conducted by companies increases by one per cent, then the companies' own R&D increases by 0.1-0.4 per cent. Levy and Terleckyj (1983) and Terleckyj (1985) find that State-funded contract R&D has a positive link with private R&D and productivity. Robson (1993) and Diamond (1998) investigate how State-funded basic research is related to private basic research. Both find a positive link.

Guellec and Pottelsberghe (2003) investigate the link between the public funding of R&D and the companies' own R&D in 17 OECD countries. This study is particularly interesting because it is the only study that investigates and compares how all three forms of public R&D funding are related to private R&D.

The direct public funding of R&D in the private sector has a positive effect on private R&D. This applies whether the funding is in the form of tax incentives or direct allocations. Both of these types of public funding are more effective if they are stable over time. This is because companies do not invest in R&D if uncertainty prevails about how long-term the Government's support will be. Direct allocations and tax incentives are, however, substitutes – if one of them increases and stimulates private R&D, then the effect of the other on private R&D will decline. If the instruments are used separately without coordination they are less effective. This result indicates that the R&D funding measures taken by ministries and authorities need to be coordinated.

Guellec and van Pottelsberghe (2003) estimate that the effect of public funding is strongest up to a level of approximately 10 per cent of the companies' own R&D investments – after which the effect declines. The effect on private R&D of publicly-funded R&D that is performed by the companies can be delineated as an upside-down U curve. Countries that invest too little or too much in the public funding of private R&D stimulate private R&D less than countries that provide funding at an optimum level (approximately 10 per cent). If public funding reaches over 20 per cent it tends to crowd out or substitute private funding. The positive link between publicly-funded R&D and private R&D does not apply, however, in the defence industry.

It is also apparent that in the defence industry the public funding of private R&D and public R&D that is conducted at Government-controlled laboratories or universities both crowd out private R&D. Although it is certainly the case that the public funding of R&D in the defence industry seldom aims to stimulate private R&D, these crowding-out effects should nevertheless be taken into account. This may be due to the fact that public funding in the defence industry mostly takes the form of procurement processes in which the invention often belongs to the Government. Civil publicly-funded R&D at universities is neutral in relation to private R&D.

The results indicate that the public-funding of R&D in the form of direct allocations or tax incentives is more effective than publicly-funded R&D at universities or laboratories when it comes to stimulating private R&D. R&D that the Government performs itself can of course provide knowledge that is used in the private sector, but it does not stimulate private R&D investments. These are, however, the conclusions of one study.

On the whole, therefore, most studies – particularly those at the aggregated level – find a positive link between publicly-funded R&D (direct allocations and tax incentives) and private R&D. Golsbee (2000) claims, however, as mentioned above, that publicly-funded R&D in the first instance increases the salaries of R&D personnel and thus the costs of R&D. He believes that the studies at the aggregated level find more positive links between publicly-funded R&D and private R&D than the studies at the company level because the former include the positive salary effects. On the other hand, the company studies do not take into account indirect spillover effects between companies, which may explain the weaker links.

5 The transfer of knowledge from universities to industry

The research performed by university researchers contributes to economic growth in several ways, as mentioned in section 3.5. This research increases the knowledge base and the methods available to society, as well as the ability to absorb new knowledge. The universities educate a pool of researchers that can then seek employment in industry. New discoveries at the universities can be made available for commercialisation in the private sector through patenting or licensing (section 5.3). Alternatively, the researchers can set up their own companies to commercialise the patents (section 5.5). Academic patents, defined here as patents in which university researchers are registered as the inventors (but not necessarily as the owners), may be a key instrument in transferring technology from the universities to industry. There are also alternatives, however, in the form of R&D collaboration with companies in which the latter provide the funding and often also own the results (section 5.4).

5.1 Incentives in the university world

The universities often pursue basic research and laboratory work on a small scale in projects that are a long way from commercialisation. The companies, on the other hand, are more interested in applied research that leads to new or improved goods and services that can subsequently be produced on a large scale. The question is *how* the new knowledge produced at the universities should be made available to industry and, not least, *who* has an incentive to repackage the knowledge so that it becomes attractive to industry. Scaling-up work from the universities' small-scale laboratory experiments to large-scale production often requires pilot and prototype activities that are both expensive and associated with high risks. Finding someone who is prepared to take on this role is often difficult.

Irrespective of who is responsible for the commercialisation of university inventions, the active participation of the researchers/inventors is usually required for commercialisation to be successful (Zucker et al., 1998; Audretsch and Stephan, 1996; Siegel et al., 2002). Jensen and Thursby (2001) show that 71 per cent of the commercialisable university inventions studied require the participation of the researchers. This is because the researchers often have specific technical (tacit) knowledge about the inventions that cannot be codified and that is needed when adapting the innovations to the needs of the market. It therefore becomes important that the individual researchers have incentives to participate in the commercialisation process. A rule of thumb is that the further the project is away from commercialisation and the less codifiable the knowledge is, the greater is the involvement required on the part of the researchers.

The incentive structure that is usually found in the university sphere is that the researchers receive prestige (appointments as professors etc.) and payment in accordance with how useful their research is to other university researchers, i.e. the extent to which they publish their work in research journals (Dasqupta and David, 1994; Stern, 1999). This does not provide any incentive to commercialise the inventions. Working with commercialisation entails an alternative cost in terms of time and money for the university researchers to the detriment of their traditional research work (e.g. publication) and teaching.

It is not only the use of time that creates a conflict between publishing the research results and commercialising them. University research with publication in journals is based on openness. It is believed that it is precisely this openness that generates new knowledge, as researchers can freely build on each others' results. However, there is a conflict between, on the one hand, publishing new research results in journals in the traditional way, which entails openness and making the results available to all, and, on the other hand, commercialising the results with or without a patent. In a commercialisation process, the aim is to keep the discovery secret for as long as possible. This means that it is not possible to publish an article before the patent application has been submitted and approved. If the results have already been published elsewhere, the patent will not be approved. If a patent is not applied for and it is decided instead to exploit lead times in a newly-established company it becomes even more important to refrain from publishing the new discovery (Geuna and Nesta, 2006).

Henrekson (2002) presents four ways in which researchers can receive payment and thus be given an incentive to participate in a commercialisation process: 1) Research grants from companies, which usually means that the external company owns the results; 2) Consulting assignments with external companies with remuneration in the form of a salary; 3) Payment in the form of royalties in connection with licensing or part-ownership where the external company runs the commercialisation process; and 4) Direct part-ownership if the researchers themselves are involved in starting a new company. Variable payments in the form of royalties or part-ownership as in examples 3 and 4 mean that the researchers are paid in accordance with how successful the commercialisation process is. This gives them a better incentive to work hard than if they only received a salary or a fixed payment (Jensen and Thursby, 2001). This has to a certain extent been verified empirically. Patents with license agreements that have both fixed and variable payments survive longer than those that have either fixed or variable elements (Svensson, 2007b). If the knowledge cannot be codified and it is thus difficult to get a patent for the research results, it has been shown that part-ownership is much more effective than licensing (Shan, 2002).

5.2 Who should own the research results?

The question of what incentives university researchers have to become involved and of who should commercialise the knowledge produced at universities should be closely linked to the question of who should own the research results. It is, after all, the owners who are able to control the research results and earn money from them. In this respect, different countries have different systems and as a result the different players – universities, university departments and researchers – have different incentives.

In 1981, the Bayh-Dole Act was introduced in the USA. This gave the universities proprietary rights to publicly-funded research results produced by university researchers. In practice, however, it is often a case of shared ownership between the university, the researcher and the researcher’s department. Since the Bayh-Dole Act was introduced, the American universities have set up internal units that work exclusively with the commercialisation, patenting and licensing of research results, so-called Technology Transfer Offices (TTOs). These offices are manned by technical experts, lawyers, accountants and marketing experts. As a result, patents and licensing contracts at the universities have increased many times over the last deacades. Several studies have concluded that it is the fact of ownership that has given the universities the incentive to build up this expertise at their TTOs and to pursue commercialisation (usually by means of licensing agreements with external companies) (Mowery et al., 2004).

The universities in the USA are decentralised, independent and exposed to competition. They compete for research funds, students and the best researchers. They have a free pay-setting system for their researchers and this means that there are major pay differentials. One way for the universities to compete is to offer the researchers advantageous conditions in connection with the commercialisation of research results. Universities that offer high-quality education can charge higher student fees. In return, the students expect the education offered to be relevant to their chosen professional careers. This means that professors must adapt the syllabus and their research to fields that have a potentially high economic value. According to Rosenberg (2000), the competition between the American universities means that they are quick to adapt their research and their syllabuses to new fields that are in demand in society at large. In such an environment, where the universities are endogenous and flexible institutions, it is no great step for the researchers and their departments to collaborate with companies in the commercialisation process. In the USA, the government has in the first instance tried to give the individual researchers and the universities good regulatory frameworks and incentives to create their own reward systems in connection with the commercialisation of research results (Goldfarb and Henrekson, 2003).

In Sweden, it is the university researchers themselves that own the results of their research through the so-called Teacher's Exemption. Almost all of the universities are run by the Government and centralised in one way or another. It is the Government that decides on the size of the universities and their budgets and appoints professors. The scope for wage setting is limited and the universities cannot therefore be seen as direct competitors. This has several consequences for the dissemination of technology. The universities receive no income from commercialised university inventions and thus have no incentive to help the researchers with patenting, licensing contracts, legal matters, networks or commercialisation. The researchers have to establish networks with companies themselves. However, as the universities find it difficult to retain personnel that have established contacts with companies, due to the inflexible pay-setting system, they generally do not want the researchers to work with commercialisation at all. The result is that the researcher limit their external activities to consulting assignments and those who become more deeply involved often keep this secret (Etzkowitz et al., 2002). In Sweden, the government has attempted to facilitate the transfer of knowledge from the universities to industry by setting up a number of agencies (see section 5.7).

According to Henrekson (2002), abolishing the Teacher's Exemption in Sweden and replacing it by making the universities or departments the owners of the research results would not necessarily lead to more inventions from the universities being commercialised. The reason for this is that the Swedish Government-run universities – unlike the privately-run American universities – are neither run with a view to making a profit nor subject to competition. The result of abolishing the Teacher's Exemption could be that the universities simply sit on the research results without any incentive to pursue them commercially. In order to increase entrepreneurship among university researchers, Henrekson (2002) proposes instead that the link between research successes and the allocation of resources by the Government should be strengthened, i.e. that the universities should compete more for public funding (see section 6), and that more general measures should be taken to improve the corporate climate.[2] The former proposal would represent a first step towards increasing the readiness of the universities to compete, which is probably a prerequisite for getting them to assist in the commercialisation of university inventions at all.

In recent years, several European countries have introduced new regulations and strategies with the aim of promoting patenting at the universities. Germany, Austria and Denmark, for example, have rescinded privileges for researchers, who previously had proprietary rights to the results of research funded by Government-run universities.[3] Lissoni et al. (2007) are critical of these measures and believe that they have been based on statistics that indicate that universities in the USA have a much higher propensity to apply for patents than the European universities, which appears to be the case if one focuses on the academic patents *owned* by the researchers or universities. This is not correct, however, because most of the patents produced at universities in Europe are owned by external companies (see section 5.5). Lissoni et al. (2007) also believe that the universities in Europe have much less control of the researchers than the universities in the USA. French and Italian universities have so little autonomy in relation to the central government that they have hardly any experience of acquiring funding for commercial projects and do not know how to handle intellectual property rights such as patents.

5.3 Patenting and licensing of university research results

The main reason why university inventions are patented is that this probably facilitates the transfer of knowledge from the universities to companies. If the universities generate knowledge or inventions that can be applied in commercial products then companies should be interested in this knowledge. However, if the companies are to make the additional investments (prototypes etc.) required for commercialisation, then the competitors must be prevented from making imitations. In other words, companies want to be given exclusive rights to products, for example by means of licensing agreements, which means that the inventions must be patented. If the universities, rather than the researchers, own the patents this is seen as a guarantee that the applied development of the invention will be controlled and that applied research of an inferior quality will be excluded (Verspagen, 2006).

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[2] These include reducing the taxation of entrepreneur incomes, loosening the regulation of the labour market and removing restrictions on competition.
[3] Italy has moved in the opposite direction. Here the inventions were previously owned by the universities but now they are owned by the researchers.

Phan and Siegel (2006) have reviewed a number of studies of how technology transfer can be conducted as effectively as possible in connection with patenting. These studies have used data from the USA, but also to some extent from England. In both of these countries the universities/departments have proprietary rights to the research results and, particularly in the USA, there is competition between the universities. Many of the studies address how the TTOs should be organised and are therefore not applicable to the situation in Sweden.

There are, however, several interesting conclusions. In the USA, the TTOs deal with the contacts and agreements with the companies. Normally, the revenues from licensing are divided between the researcher, the researcher's department and the university. If the individual researchers receive only a limited share of these revenues, their incentive to reveal new commercialisable research results to the TTOs will be reduced. In such cases, it may be more profitable for the researchers to reveal the results in a journal and to attain high academic prestige instead of allowing the TTOs to patent the new inventions. Phan and Siegel (2006) propose, on the basis of a number of studies, that the researcher's share of the royalty revenues should be increased from the usual 33 per cent to 75 per cent, as this increases the effectiveness of knowledge transfer. Another problem is that the flow of information between the researchers and the TTOs does not always run smoothly. Here, the personnel at the TTOs need to improve their communication. It is also important that the personnel at the TTOs have some form of variable remuneration and thus an incentive to successfully negotiate license agreements with external companies.

Statistics from the USA show that the distribution of licensing revenues from university patents is extremely skewed. Mowery et al. (2001) present data for a couple of leading American universities that show that the majority of the patents provide almost no revenue at all. The five best patents accounted for at least 75 per cent of the revenues at the respective universities. There is also a skewed distribution between the universities. More than half of the universities in the USA have annual licensing revenues below USD 1 million and only 10 per cent have licensing revenues above USD 10 million. Only a few universities can expect to grow rich from patents and licences. In many cases, the licensing revenues do not cover the costs of the TTOs (Verspagen, 2006).

Recently, criticism has been levelled at the American system with university patents and TTOs. It is said that the TTOs act as monopolies to which all activities are centralised. As the personnel at these offices are often remunerated in accordance with the license revenues, they tend to maximise the revenues rather than maximising the number of inventions that are commercialised or knowledge transfer (Litan et al., 2007). Nelson (2007) believes that patenting and license agreements are not good measures of how successful the universities are at knowledge transfer as these channels represent closed dissemination mechanisms rather than open mechanisms (conferences, seminars, publication in journals). There is therefore a risk that closed dissemination mechanisms dampen rather than encourage knowledge transfer.

The patenting of university research has the disadvantage that it may block the further development of the invention. In some areas, research successes are cumulative, i.e. new discoveries build further on the foundations laid by previous discoveries. When something is patented, accessibility to it is restricted. Patenting can thus block further development. One example is genetic tools in the field of life sciences.[4] This argument is of course also applicable to research results produced by companies. It may, however, be particularly fateful in the case of university research as this often relates to basic research that has an effect on a great number of different applied research projects (Geuna and Nesta 2006; Verspagen, 2006).

If the patenting of research results becomes an increasingly important task, universities may change their behaviour. They may begin to invest in research areas where it is easiest to get a patent, e.g. applied research. This would entail the universities moving from basic research, which is believed to have long-term effects, to applied research with its more short-term effects. The universities would then begin to behave more like companies (Geuna and Nesta 2006; Verspagen 2006).

Trajtenberg et al. (1997) have investigated citation patterns and show that university patents are cited more often than company patents. This is interpreted as a measure of the fact that universities work more with basic research than companies do. Henderson et al. (1998) have studied whether there is a change in citation patterns over time. They find that university patents have become relatively less cited and less general over time at the same time as the number of university patents has increased. The authors draw the conclusion that there has been a shift in university research – possibly towards more applied research – so that it is having less impact on the research of others. Mowery and Ziedonis (2002) show, however, that leading universities such as Stanford and the University of California have not reduced their basic research. The decline in citations is explained instead by the fact that less well-known universities have begun to patent their research results following the introduction of the Bayh-Dole Act in 1980.

[4] Several patent systems permit the use of patented knowledge for research purposes as opposed to commercial purposes. This means that a patent cannot block further research. However, this is an exception that is weak in many cases as the patent owner can litigate against it (Geuna and Nesta, 2006).

The authors believe that it is to be expected that these universities will have patents of a lower quality. Sampat et al. (2003) also find that there has not been a reduction in the citation of university patents, nor a shift away from basic research over time. The empirical evidence that there has been a shift in university research towards more applied research is thus mixed.

The question of which is the most effective method for transferring knowledge from the universities to industry has been investigated in a number of interview studies and case studies. Verspagen (2006) has reviewed this literature and summarises it by saying that researchers at the universities and managers at the companies believe that the patenting of university research results is a relatively unimportant channel for the transfer of knowledge. Informal channels such as consulting activities, the recruitment of researchers and students by companies, conferences and collaboration between universities and companies are more important.

5.4 Joint ventures between universities and companies

An alternative to the knowledge produced at a university being patented by either the researcher or the university is a joint venture between the university/department and an external company. Joint ventures often relate to contract research in which an external company provides the funding and becomes the owner of the research results while the university department or individual researcher performs the R&D project. Sometimes it is the case that the university or the researcher becomes a part-owner together with the company. This system is common in European countries (Lissoni et al., 2006).

Aghion and Tirole (1994) believe that a system in which the company is the sole owner of the research results is ineffective compared to a system in which the researcher or the university owns a patent that is licensed exclusively to an external company. The problem with joint ventures is that those involved must *in advance* (before the results of the research are known) agree on who will own the research results (i.e. the company) and how much the company should pay to the university for conducting the R&D. Such a contract is incomplete. When the payment is decided in advance the university has no incentive to do its best. The company will also find it difficult to check that the university researchers are really making an effort. The researchers’ incomes are not linked to the results they achieve. If the university or researchers patent the research results and then license these results exclusively to the company (with fixed and variable payments) then all the parties involved will have an incentive to do their best.

A better alternative would then be for the external company to offer some form of reward system to the researchers involved, such as options or part-ownership. In Sweden, collaboration has primarily taken place with large companies like Ericsson, ABB and Tetra Laval (Lissoni, et al., 2006). In the course of such collaboration, these major companies have been unwilling to offer the researchers payments that are linked to the research results. As a result, the academic researchers have become consultants to the companies (Granstrand and Alänge, 1995; Linholm-Dahlstrand, 1997; Henrekson, 2000).

However, in an as yet unpublished empirical study Crespi et al. (2006) note that university-owned patents from collaborations with companies in Europe are not more valuable than company-owned patents from similar collaborations. They conclude that there is no empirical evidence for the argument concerning the market failure of company-owned patents from R&D collaborations as presented by Aghion and Tirole (1994).

5.5 University spin-offs and technology parks

An alternative to R&D collaboration and licensing agreements with companies is that the university researchers themselves start a company to commercialise the invention concerned. In those countries where the universities play an active role in the transfer of knowledge, licensing agreements have, historically speaking, been the most common way of commercialising university-based inventions, but the number of new university-based companies in the USA increased tenfold in the period 1980-2003 (Phan and Siegel, 2006). An obvious problem for the university researchers is that they perhaps do not have the skills or know-how required to run a company or conduct research of a more applied nature. Another problem that often arises when new companies are started is to find adequate funding, as pilot and prototype projects are expensive. In Europe, university researchers can seldom count on receiving any financial assistance from the university. This requires that the university has risk capital and investment expertise. In the USA, on the other hand, assistance may be provided by the TTOs. Universities becoming part-owners of companies started by researchers is more risky than licensing to external companies, but in general provides higher profits if the company is successful.

Both DiGregorio and Shane (2003) and Markman et al. (2005), who have studied American universities, find that when royalty payments in connection with licensing agreements are generous to the researchers then the likelihood that the researchers will start their own companies decreases. This is logical as the alternative cost of starting a company in such cases increases. The number of new start-ups also depends, according to DiGregorio and Shane (2003) on the quality of the university (as measured in various ranking systems) and on to what extent the TTOs can contribute share capital. They find no link, however, between the availability of external private venture capital in the region and the readiness to start companies at universities.

Lockett et al. (2003) have conducted a survey to investigate what strategies different universities have chosen to spin-off companies that base their operations on products resulting from university research. They compared the 10 universities in England that have set up most companies with the 10 least successful companies in this respect. The successful universities have better expertise and networks for assisting start-ups. Above all, the commercial offices of the universities (comparable to TTOs) are better at identifying promising projects and forging links between researchers and their inventions and external entrepreneurs. One of the most important success factors is that part-ownership comprises all of the parties involved (especially the inventor and the external entrepreneur) so that everyone has an incentive to do their best. It does not seem to be particularly significant, however, whether the inventor leads the company or is simply an adviser – the important thing is that he or she is active.

O'Shea et al. (2005) have tested empirically why universities in the USA are better at spinning-off companies than others. Universities that have top-ranked researchers and engineers and a high degree of industrially-related funding are better at spinning-off companies. The former indicates the importance of recruiting high-quality researchers, while the latter points to the fact that an increased proportion of applied research probably increases the chances of knowledge being transferred to companies. In addition, investments in TTOs increase the probability of spin-offs.

Nerkar and Shane (2003) have conducted an empirical analysis of the factors that determine whether spin-offs at MIT that are based on university patents survive or fail. The hypothesis is that radical patents (quotations between technology classes) that replace existing products on the market and broad patents that cover many technology classes and provide more protection are more likely to lead to successful new companies. They find that companies based on radical and broad patents are more likely to survive – but only if the market is fragmented. In concentrated sectors the obstacles to establishing a new company are higher than the advantages of having a new product.

Landry et al. (2006) report that 17 per cent of all Canadian researchers in the field of science and technology have attempted to start new companies, and that 32 per cent of these researchers own intellectual property rights of some type. The authors have examined the situation and the characteristics of the individual researchers and how these affect entrepreneurship. The likelihood that the researchers will have companies increases if the researchers have external funding either from the Government or from the industrial collaboration programmes that fund their regular research. Direct financial support from companies has, however, a negative effect on the desire to start a new company, probably because the researchers then choose to transfer the knowledge directly to the company in some way. Researchers who own patents and have long experience of research and consulting work are also more likely to start a company. On the other hand, neither the number of articles published in research journals nor the number of teaching hours per week had any link with the readiness to start companies. This result indicates that the traditional tasks (research and teaching) can probably co-exist with entrepreneurship without causing harm to either.

Many universities have set up technology parks nearby with the aim of stimulating regional growth and the transfer of knowledge from the universities to industry. The point of having a technology park at a university is to bring companies and university research closer together and to facilitate collaboration between companies and the university. These parks should also make it easier for university researchers to start up new companies or become involved in the commercialisation of university inventions in some other way. The advantages of being located in a technology park are that the costs for searching for new technology are low and that there is often a pool of labour available. The disadvantage for the companies is that they are exposed to strong competition, i.e. traditional agglomeration effects. There may also be advantages for the university, for example if it wants to license inventions to companies or attract researchers (Link and Scott, 2007). Internationally, technology parks began to emerge in the late 1970s and early 1980s. In 2003, according to Link and Scott (2007), there were only 81 technology parks in the USA, 100 in England, 23 in Sweden and more than 200 in Asia. Spin-off university companies, small technological companies and the R&D divisions of multinational companies can all be found located in technology parks.

According to Westhead and Batstone (1998), English companies choose to locate their operations in technology parks in order to be able to utilise research resources and recruit university researchers. Leyden et al. (2008) conclude that companies that conduct high-quality research are more ready, or are invited, to locate their operations in technology parks.

Given the advantages of technology parks mentioned above, it might be expected that companies in such environments are better situated to grow and survive than companies outside such parks.

However, Westhead and Storey (1994) find no difference in the degree of survival between companies in technology parks and companies outside them. Furthermore, Westhead and Cowling (1995) find no difference in growth in terms of the number of employees between the groups. On the other hand, Siegel et al. (2003) show, with the help of a statistical model, that companies in technology parks are more effective in their research with regard to creating new products and being awarded patents. This is interpreted such that technology parks may function as important spillover mechanisms. All of these studies use data from England.

A number of Swedish studies have also compared companies inside and outside technology parks. According to Ferguson and Olofsson (2004), there is no difference in growth in terms of sales and employees between companies inside or outside technology parks. Based on descriptive statistics, Lindelöf and Löfsten (2003, 2004) find no difference between the two groups with regard to the patenting of new products. Companies in technology parks, however, claim that they focus more on innovations, growth and profitability than companies outside. Lindelöf and Löfsten (2004) also draw the conclusion that the interaction between the universities and the companies in the technology parks is limited in terms of both contracts and the use of personnel, but that it is higher than the interaction between the universities and companies outside the parks.

Among different types of companies *within* the technology parks, Ensley and Hmieleski (2005) show that university spin-offs perform less well in terms of cash flow and sales growth than new independent start-ups. The authors explain this by pointing out that the university-based companies have a more homogenous management and are therefore less dynamic than independent companies. However, Westhead and Storey (1994) come to the opposite conclusion – university-based companies survive longer than independent companies in technology parks.

Link and Scott (2003) have studied technology parks at universities in the USA and show empirically that the geographical proximity to the university and the access to venture capital increases the growth of the companies. They also show that the parks are advantageous to the universities in terms of the number of articles published and the number of patents, and that they increase the possibility to employ highly-qualified researchers. Link and Scott (2006) conclude that the growth of the technology parks themselves correlates to how closely they are linked to the university and whether it is led by a private organisation or not. Link and Scott (2005) show that the more research-intensive the universities are the more innovative they are, and the likelihood that university-based companies will be set up in the parks is also higher. University-based companies are also more common in the technology parks the older the parks are.

Scott and Link (2006) have reviewed the literature on technology parks and claim that these increase the transfer of knowledge in both directions between the universities and the companies. They believe that there may be reasons for the Government to assist in the funding of technology parks but that these parks are probably not the instrument of first choice for improving spillovers between the universities and industry. The authors call for more studies in this field.

5.6 The Swedish R&D paradox

A common view among researchers and those who debate these issues in Sweden is that Sweden is a world leader in terms of R&D expenditure – especially public expenditure – in relation to GDP, the number of articles published in scientific journals per inhabitant and the number of patents granted per inhabitant. The paradox is that the return on these R&D investments is relatively low, which is exemplified by the fact that university researchers in Sweden have few patents compared to those in the USA and that Sweden has few rapidly-growing technology-intensive companies.

New statistics suggest, however, that this paradox may be exaggerated. Bager-Sjögren (2006) believes that Sweden's position may be overestimated. One error that is often made is that the magnitude of university research in Sweden is compared to that in other countries, despite the fact that a large part of the publicly-funded research in other European countries is conducted by Government-run laboratories/institutions. If public research at both universities and laboratories is taken into account, then the difference between the countries is much smaller (Jacobsson, 2002). In addition, the wage costs for doctoral students are included in the figures in Sweden but not, for example, in the UK. This also leads to an overestimation of Sweden's public research compared to other countries. In the case of the number of articles published, it is probable that Sweden's position is overestimated here too, as it is only the publication of articles in English-language journals that is compared. Researchers in some countries with major languages, for example France, Germany and Japan, have the possibility to publish their articles in journals written in their native tongue – a possibility that Swedish researchers do not have.

Even in the case of the second aspect – the commercialisation of university research – the estimates may be partly incorrect. On the basis of a new database for EPO patents, Lissoni et al. conclude that patenting among university researchers in Sweden, France and Italy is almost as intensive as in the USA. There are, however, major differences in the pattern, particularly with regard to ownership. In the USA, it is mainly the universities/departments that are part-owners (almost 70 per cent) and that run the patenting and commercialisation processes through their Technology Transfer Offices (TTOs). The academic patents in Europe, on the other hand, are primarily owned by external companies (at least 60 per cent) but also by the researchers themselves or the universities/laboratories. In Sweden, it is really the researchers themselves who, due to the so-called Teachers' Exemption, own the results of their research. In practice, however, many departments/researchers are funded by external Swedish multinational companies (e.g. ABB, Ericsson, Pharmacia, AstraZeneca) in the form of contract research or consulting assignments, and in these cases the researchers relinquish their proprietary rights to the external companies. In Italy and Sweden, 60 and 80 per cent respectively of the academic patents are owned by external companies, compared to 26 per cent in the USA (Balconi et al., 2004; Thursby et al., 2006). However, as we have already analysed in section 5.4, the European system of collaboration between the departments and the companies is an ineffective system in which the university researchers have no incentive to do their best compared to the American system.

According to Lissoni et al. (2007) it is primarily the academic patents that are owned by external companies that previous studies have missed when comparing the USA and Europe. Universities in the USA own 4 per cent of the USA patents, while the European universities own less than 0.5 per cent of the EPO patents. If, on the other hand, we compare *academic patents* that have been produced by the universities the figures are 6 per cent in the USA and 5 per cent in Europe, i.e. there is no great difference. Geuna and Nesta (2006) level the same criticism at the previous statistics and claim that there are actually many more academic patents in Europe even if the universities are not registered as the patent applicants. They believe that external companies are often registered as the owners of many academic patents as the result of joint ventures between the companies and the university departments.

5.7 Organisations that facilitate innovation

There has been a lack of incentive for researchers, universities and companies in Sweden to work with the transfer of knowledge from the universities to industry and to pursue the commercialisation of university inventions. The Government has therefore provided support by setting up a central bureaucracy – in the form, for example, of technology bridge foundations and agencies such as Vinnova (the Swedish Governmental Agency for Innovation Systems) and Nutek (the Swedish Agency for Economic and Regional Growth) – in order to compensate for this lack. The support provided by these organisations is funded by the Government and thus comes from above. These support measures mean that the Government is directly involved in the transfer of knowledge (Goldfarb and Henrekson, 2003). There are also industrial research institutes that are partly owned by the Government and industry. The Swedish model, which is thus characterised by the Government attempting to control the transfer of knowledge from above, should here be compared to the American model. There the Government has taken on the role of improving the rules of play for researchers, universities and companies so that they can on their own manage the transfer of knowledge from the universities to industry (Henrekson, 2002).

Ejermo et al. (2006) discuss the role that organisations that facilitate innovation such as Vinnova and Nutek can play with regard to the transfer of knowledge from the universities to industry. The authors believe that these organisations must fulfil two functions. First, they must strengthen links and form networks between public research and industry. The organisations must therefore understand the work and culture of the two parts that make up the network. Second, the organisations must fill the gap between the activities driven by scientific interests and those driven by commercial interests. The universities are interested in small-scale laboratory work for scientific purposes while the companies are interested in large-scale production for commercial purposes. There is no intermediate player that is interested in scaling-up activities in the form of pilot and prototype operations, which are often expensive and associated with high risks.

Theoretically speaking, the organisations that aim to facilitate innovation must have four characteristics in order to be successful (Ejermo et al., 2006). They should: 1) be highly skilled and knowledgeable about science and enterprise; 2) be independent and focus on the promotion of innovations; 3) have strong ties to universities, companies and the Government; 4) have reliable funding because pilot and prototype activities are costly.

On the basis of the studies reviewed by Ejermo et al. (2006) it appears, however, that there is no empirical evidence that agencies that are designed to facilitate innovation, such as Vinnova and Nutek, actually make a net contribution (the contribution made by the organisations to the promotion of innovations minus the organisations' costs) to economic growth. Evaluations of the support measures taken by the Government are rare, but in Government Bill 2001/02:2 it was stated that the centrally-controlled support measures had not had the desired effect.

A form of conditional loan was given by the Government to technology-based companies through Stiftelsen Innovationscentrum (SIC) (Innovation

Centre Foundation) during the 1990s. These loans were offered at the seed stage and were repaid as a percentage of the sales following commercialisation. However, if the project failed or was abandoned there was an almost 100 per cent likelihood that the loan would be written off. Svensson (2007a) has tested empirically to what extent inventors and small companies commercialise their patents. He finds that inventors who receive conditional loans are much less likely to commercialise their patents than those who do not receive such loans. Svensson believes that this probably relates to the way the conditions are formulated, which provides hardly any incentive to proceed with commercialisation. Instead of pursuing a risky commercialisation process and becoming liable to repay the loan, it is easier to abandon the project, write off the loan, hold on to the new knowledge gained and start a new project. Bager-Sjögren and Norman (2007) also show empirically that those companies that have received conditional loans from SIC do not perform better than those companies whose loan applications were denied. In other words, these loans have provided no benefit. Statistics from ALMI confirm these empirical studies: as much as 87 per cent of the conditional loans awarded by SIC in the 1990s have been written off.

6 Government funding of the universities

Traditionally, the tasks of the universities have included increasing the stock of knowledge by conducting research, and educating students and researchers who can then seek employment in the university sector, the public sector or the commercial and industrial sector. In pace with the increasing focus of the governments of the OECD countries on economic growth, the interest in better utilising the knowledge generated at the universities has also increased, but governments also want university research to reflect the needs of society at large. A third task has therefore been set for the university system, namely to attempt to disseminate knowledge outside the universities to industry. One example is the university statute of 1998 that stipulates that every Swedish university is obliged to draw up and apply a plan for co-operation with the society of which it forms a part. The governments of the OECD countries are therefore attempting to indirectly influence the research orientation of the universities to a greater degree. One way of doing this is to distribute the funding to the universities on a competitive, contract basis instead of making fixed allocations.

6.1 Consequences of Government funding under competition

The great majority of university funding in Europe comes from the Government (approximately 86 per cent for seven EU countries).[5] The remainder comes from business and industry (6 per cent), non-profit organisations (4 per cent) and from organisations abroad (3 per cent). The trend is that the proportion of funding from the Government is declining – from 94 per cent in 1983 to 86 per cent in 1995. The major part (57 per cent) of public funding consists of fixed allocations made in accordance with some kind of formula (e.g. the expected cost per student) or on the basis of the universities' previous costs with some form of indexation for new activities. Funding can also be allocated on a contract basis which means that the universities compete for funds, courses and research projects (28 per cent). The Government funds specify certain objectives in terms of research projects, the number of students, courses, expected research results or collaboration with other universities and/or companies. The universities

[5] England, Ireland, France, Netherlands, Germany, Denmark and Italy.

then have to apply for funding with the aim of achieving these objectives. Earlier successes for the university/department concerned in terms of articles published in research journals or course results are often decisive in determining allocations.[6] It is not always the case that direct competition is permitted, but the government can simulate market behaviour by adjusting its demand for university services on the basis of the universities' previous research results.

The trend in the OECD countries is that the percentage of fixed allocations is declining (from 68 to 75 per cent in the period 1983-1995) while the percentage of allocations under competition is increasing (from 26 to 28 per cent, 1983-1995) (Geuna, 2001). The UK is perhaps the clearest European example of funding on a contract basis as almost half of the public funding to the universities is subject to competition (Geuna, 2001), but the Netherlands, Finland, Portugal, Poland and Hungary have also begun to introduce similar funding systems (Geuna et al., 1999). Another clear example is represented by the European Commission's four framework programmes which support R&D collaboration and where allocations are subject to competition. Consequently, the participating universities have been more highly involved in R&D collaboration with companies (Geuna, 2001).

If the level of total public funding for the universities is maintained but a larger proportion is allocated under competition instead of in the form of fixed allocations, then theoretically a number of positive consequences can be expected (Geuna, 2001; Geuna and Martin, 2003):

- The universities should become more cost effective. It is probable that ineffective research will be identified and discontinued.
- If allocations are made on the basis of previous research results, the universities and the individual researchers will be given an incentive to perform good research.
- The Government can indirectly influence the orientation of university research by setting conditions (e.g. specific research projects or collaborations with companies and other universities) that must be met before funding is granted. In this way, the needs of society can be better met by university research.

[6] Examples of evaluation variables include 1) number of articles published; 2) quality-adjusted figures for the number of articles published where the articles are assessed in terms of which journal they were published in; 3) number of citations from published articles, which shows the impact the articles have had; and 4) the number of fully-qualified postgraduates (Geuna and Martin, 2003).

- It can be expected that the universities will become more flexible and adapt their research to a greater degree to new needs and technological changes, as the conditions for funding must be met.
- The Government will gain a better overview and a measure of what is produced at the universities with the support of public funding.
- The resources and personnel at the universities will be concentrated – at least in certain research segments (this is addressed separately in section 6.2).

As already mentioned in section 5, funding under competition is a way of getting the universities to adjust to begin competing with each other. This is probably necessary if they are to begin assisting in the commercialisation of university inventions.

Guellec and van Pottelsberghe (2004) have found, as previously mentioned in section 3, that R&D at Government universities has a greater positive effect on productivity than R&D at Government laboratories. The authors present a number of probable explanations for this, for example how the funding is allocated. In most European countries, a large part of the funding is allocated to universities on the basis of project evaluations. The laboratories, on the other hand, receive fixed institutional funding. Theoretically speaking, the former type of funding should provide more of an incentive for the rapid adaptation of R&D to technological changes. Another explanation is that R&D at Government laboratories is often aimed at satisfying needs in areas of public benefit/utility (healthcare, the environment, defence) rather than at increasing productivity, while university research often concerns basic research that is believed to provide high spillovers.

The system of allocation on a contract basis presupposes, however, that a number of conditions are met: 1) It is possible to evaluate the quality of the research; 2) It is possible to identify the most promising research programmes; 3) Cost reductions can be achieved without the quality of the research suffering; 4) Economies of scale can increase the concentration of resources and the performance/results of the research; 5) The administration costs of the State and universities for assessing and evaluating projects are low compared to the cost savings.

The allocation of funding under competition can give rise to a number of undesirable negative consequences (Geuna and Martin, 2003).[7] It is costly to evaluate research compared to granting a fixed allocation. There is a risk that evaluations based on publication over the last few years will lead to so-called salami publication or to publication inflation. This is when researchers choose to divide up the research results from a project and publish them in several different articles instead of in one article, even though the usefulness of the individual articles is not greater than if a single, overall article has been published.

If the universities respond to the more short-term wishes of industry and the Government's funding institutions take into account the universities' latest research results when allocating funding, there is a risk that the universities' research will be more short term. This is perhaps the most important negative consequence. Projects that are long term and/or associated with high risks will then never be carried out as these seldom generate results when the time comes to conduct an evaluation.

The empirical evidence that public funding on a project basis instead of on the basis of fixed allocations creates the above mentioned positive or negative consequences is weak. According to the researchers in this field that I have been in contact with, there are hardly any empirical studies that investigate these consequences.

6.2 Increased concentration and economies of scale

One of the most important consequences of funding on a project basis is that research will become concentrated and polarised (Geuna, 2001). It is probable that those universities and departments that have had the best research results over the last few years will be awarded the majority of the Government contracts (increased concentration). As a result, there is also a high probability that the most proficient researchers will try to move to the departments that have other well-qualified researchers in order to get a share

[7] Geuna and Martin (2003) also present other possible negative consequences, for example that research is separated from teaching. This is when teaching is given a lower priority because it is the research results that count in an evaluation. Geuna (2001) believes that conflicts of interest may arise if the researcher receives funding from different quarters or if the researcher intends to commercialise his or her results. In the latter case, a good strategy may be to keep the results secret as long as possible in order to withhold information from competitors, which is in stark contrast to traditional university research where one should disseminate the results and increase the stock of knowledge. A striking example of a conflict of interest is that researchers in the field of chemistry who are funded by companies often cite patents in their published articles – not because the patent application was submitted before publication but because the company does not permit the researchers to publish their findings before the patent application is approved.

of the funding (increased polarisation). Here there are empirical examples regarding the private funding of university research in Europe that is always subject to competition. One example concerns the universities in the UK where 6 per cent of the departments were awarded 33 percent of the private funding in the mid-1990s (HEFCE, 1998). This increased concentration would be positive if there were economies of scale in the research at the universities.

The research literature reveals, however, that there are mixed empirical results regarding the existence of economies of scale in the production of university services. On the basis of cost functions, Cohn et al. (1989) and Johnes (1997) conclude that there are economies of scale with regard to teaching and administration. Bowen and Rudinstein (1992) conduct another form of statistical analysis and find that large postgraduate programmes are more successful at producing qualified postgraduates than small programmes. In a recent empirical study, Bonnacorsi et al. (2007) analyse whether there are economies of scale for teaching at European universities. The authors find that there are economies of scale up to a total of 3 000 to 3 500 employees (both researchers and administrative staff) at individual universities, but that the benefits level out thereafter.

However, the research literature draws more mixed conclusions regarding economies of scale in research – it is often found that there are no links at all between size and performance. The studies that are based on cost functions have found certain economies of scale. Johnes (1997) concludes that there are economies of scale in relation to research. Cohn et al. (1989) also believe that there are limited economies of scale for research and that there are synergies (scope economies) between education and research. However, these studies perform an indirect analysis from the supply side by studying cost functions.

Perhaps more weight should be attached to those studies that directly compare size and performance. These have found that there are weak or no links between size and productivity. Martin and Skea (1992) have conducted an extensive analysis of the size of departments, the number of articles published and the number of citations at science departments in the UK. Size explained only a limited amount of the publication activity, but when postgraduates were taken into account this link disappeared altogether. Nor was there any link between the size of the departments and the number of citations of the departments published articles per employee. Finally, Martin and Skea (1992) found that the degree of teaching did not affect research productivity.

Martin et al. (1993) use statistical analysis to investigate the link between the size of university departments and the number of articles published, and citations from these articles at a number of science faculties. They find that both the number of articles published and the number of citations increase linearly with size in the fields of chemistry and physics, i.e. there are no economies of scale for the research. In the fields of biochemistry and mathematics, however, there are certain economies of scale for both citations and the number of articles published. With regard to biochemistry, the authors explain this by saying that the departments have fixed costs for equipment that can be used by many researchers. Kyvik (1995) finds, following statistical analysis, that there is no significant link between the size of departments and productivity measured as the number of articles published. Interviews also show that researchers at small departments are more satisfied with the research environment than researchers at large departments. Bonnacorsi et al. (2007) have compared a publication index with the number of employees at European universities. They find that effectiveness falls up to 3 000 employees (researchers and administrative staff) but thereafter increases up to 8 000 employees. There is thus no general evidence that there are economies of scale for research at the university level.

The question of how large a *research group* should be to function effectively has also been discussed. A research group is defined here as researchers who collaborate with one another in some way and is thus smaller than a university department. The argument for a minimum critical mass is that researchers with different backgrounds can complement each other, as research is often labour intensive. Researchers who work in groups can also stimulate each other and exchange ideas.

On the basis of interviews, Martin et al. (1993) conclude that the critical mass for a research group is 4 to 6 researchers if one wants to compete internationally. This does not include postgraduate students and assistants. The critical mass is much more important for a particular area than for the university department as a whole. It does not really matter whether the group is located at a department with 15 or 50 researchers as long as the groups are not dependent on each other when it comes to sharing fixed costs for, for example, equipment (as is the case in biochemistry). New technology has facilitated the internationalisation of research. It is now easier and more common to collaborate with similar groups abroad than with other groups at the same department. The authors believe, however, that there may be indirect economies of scale relating to teaching. At large departments, the researchers can teach many students at the same time. They can then on average devote more time to research.

Johnston (1994) who has studied universities in the UK and Australia, and also reviewed the literature, believes that there should be a minimum critical mass of 3 to 5 senior/experienced researchers in a research group for the research to be effective. In addition there should be younger qualified researchers, postgraduate students, assistants and technical personnel. The total group may then comprise 6 to 10 individuals. Below this level, research is ineffective, but above this level productivity increases linearly with size, i.e. productivity per researcher does not increase for larger groups. In another literature review, Kyvik (1998) also claims that a favourable critical mass for a research group is 3 to 5 experienced and/or younger researchers in the fields of science, medicine and technology (i.e. marginally fewer than Johnston), with the addition of postgraduate students and other personnel. He believes that larger groups may experience problems with internal communication and effective management. It is often the best researcher who becomes the leader of the group. If the group gets too big the leader will not be able to concentrate on his or her research.

Over the last 10 to 20 years, the Government has initiated the establishment of a number of small colleges/universities in Swedish towns that often have no more than 30 000 to 50 000 inhabitants (e.g. Skövde, Växjö, Karlstad). There has been a lively debate among professors at Swedish universities on how effective it is to establish such small colleges at which each department sometimes may have no more than 3 to 5 researchers. However, very little research and few evaluations have been carried out on this in Sweden.

The strategy of setting up many small universities appears to be very doubtful, however, because: 1) the lack of economies of scale for teaching and administration; 2) there seems to be a minimum effective size of 3-5 qualified researchers for each research group; and 3) the prevailing trend is that a growing percentage of public funding is allocated under competition and this favours large universities. These two trends, i.e. establishing small universities and funding on a project basis, do not fit together well. There is a risk that the new small universities will be left with very limited resources.

If the resources are concentrated to a few universities, it is probable that the regions where these large universities are located will experience a number of positive external effects. This would be counteracted, however, by the negative external effects that would affect regions that have smaller universities that are marginalised. Dresch (1995) believes that there is a risk that the knowledge of researchers at universities with limited research resources will become obsolete and outdated. This will prevent the researchers from teaching in, from society's point of view, a satisfactory way. A strategy that may then be adopted by the small universities is to focus on only a couple of subject areas, with the result that they will have fewer but larger departments.

7 Summary

The public sector in the OECD countries funds almost 30 per cent of all the R&D conducted in these countries. A problem for companies that conduct R&D is that the private return on R&D to the companies themselves is significantly lower than the overall social return. This difference is termed spillover and benefits other companies and society at large. As a result, the actual amount of R&D conducted by companies on a free market falls below the socially optimal level. This is the basic reason why the Government should fund R&D. A logical strategy on the part of the Government should be to fund the type of R&D where the difference between private and social return is considerable – otherwise this type of R&D would never be carried out.

The Government has several instruments for funding R&D. This can be done through Government-run universities and research institutes, through directly-funded R&D projects that are performed by companies or by giving the companies tax incentives. Theoretically speaking, these instruments have both advantages and disadvantages. Research at universities often focuses on basic research, while research institutes often focus on satisfying public needs (defence, the environment). The advantage of directly-funded R&D projects at companies is that the Government decides which projects should be carried out (e.g. projects with significant spillover effects and a high social return). However, it is doubtful whether the Government is good at selecting sensible projects. An obvious disadvantage is that competition is distorted. In the case of tax incentives it is the companies themselves that choose the type of R&D that will be performed using public funds. The risk then is that the companies will select projects that have a high private return and few spillover effects, or projects that the companies would have conducted in any case. An advantage of tax incentives is that competition between *established companies* is not distorted. New companies with high investments costs and limited sales, i.e. those who are in most need of funding, are at a disadvantage, however.

Knowledge is a product that is non-rivalry, which means that several players can use it at the same time. Furthermore, it only needs to be produced once. This explains why R&D and the knowledge it generates can lead to long-term growth. One problem, however, is that knowledge is also non-excludable, i.e. we can seldom prevent someone else from using it (spillovers are created). As a result, companies under-invest in R&D – even though the private return may be considerable. This means that institutions such as patent systems are required or that the Government intervenes and funds R&D projects. On the other hand, knowledge is not something that can be downloaded for free. In order to be able to use the knowledge created by others we have to be able to absorb the knowledge – an ability that is acquired by conducting one's own research, i.e. it is difficult for anyone to get a free ride.

Empirical estimates at both the aggregated and detailed levels indicate that the social return on the R&D performed by companies is greater than the private return. The private return is on average 25 to 30 per cent, while the social return may be two to three times higher. There are thus considerable spillover effects. The research literature is clear on this point – although the suggested size of the effects varies widely. Estimates also show that R&D has a positive effect on the companies' sales (micro level) and economic growth (macro level). If private R&D increases by 1 per cent, then growth increases on average by approximately 0.13 to 0.20 per cent. This should not be interpreted as a sign that R&D investments are ineffective, as 0.13 to 0.20 per cent of sales is much more in ready cash than 1 per cent of R&D.

Publicly-funded R&D – particularly that conducted at universities – is much more focused on basic research (65 per cent of all university research) than the research conducted by the private sector (5 per cent of all private R&D). Publicly-funded research can thus be expected to have primarily indirect effects on economic growth. Such indirect effects include an increase in the stock of knowledge and the development of scientific methods that become available to society as a whole. The ability of personnel to absorb and assimilate external research also increases. Perhaps the most import function of R&D at the universities is that research personnel whose skills and know-how can subsequently benefit both the universities and the companies are educated and receive further training.

With regard to the return on R&D funded by the Government the literature presents, to say the least, mixed results. On average, publicly-funded R&D has a positive return, but this is lower than the return on private R&D. This applies both to publicly-funded R&D that is performed by companies and R&D at universities/research institutes. The few studies that divide State-funded R&D into civil and defence-related R&D show, however, that defence-related R&D has no or even a negative effect on economic growth. The effects of university research on growth and productivity are difficult to quantify, but are believed to be considerable. Studies have been carried out, for example, of how often private patents cite research articles and of how large a share of private sector products is entirely dependent on academic research. Geographical proximity between universities and companies has been shown to be important in connection with the transfer of knowledge. Some of the knowledge is namely specifically linked to the researcher or researchers concerned, which makes collaboration on site necessary.

The empirical studies show in general that public-funding in the form of both direct funding and tax incentives stimulates rather than replaces private R&D. The studies find a more positive link at the macro level than at the micro level, as at the macro level one can take into account the effects of spillovers between the companies. At the aggregated level it is found, for example, that if public-funding in the form of directly-supported R&D projects increases by 1 per cent, then the R&D funded by the companies themselves increases by 0.1 to 0.4 per cent. University research in general has a neutral effect on private R&D.

The few studies that have divided up Government-funding in terms of civil and defence-related R&D show once again that it is the civil R&D that has a positive effect on private R&D. Defence-related R&D – irrespective of whether it is performed by companies or by universities/research institutes – crowds out private R&D investments. Although defence-related R&D aims to provide public benefit, these crowding-out effects should not be ignored. The lack of positive effects from defence-related R&D may possibly be explained by the fact that it is the funder (the Government) that usually owns the results of the research. Companies cannot exploit the results to the full on the market and therefore have no incentive to exert themselves when conducting the R&D.

In the case of the transfer of technology from the universities to industry it is important that the universities/departments, and above all the researchers, have incentives to pursue commercialisation. The participation of the researchers is often required in the commercialisation process as they have what is termed non-codifiable knowledge about the invention concerned that is needed when the time comes to adapt the invention/innovation to the needs of the market. There are also counteracting incentives for researchers in, on the one hand, traditional research in which the aim is to publish and reveal one’s research results in journals and, on the other hand, in the process of patenting and commercialising one’s research results. In the latter case the researcher wants to keep the results secret as long as possible – particularly if the new discovery has not been patented. Prestige in the university world is measured in the number of articles published rather than in the number of commercialised products. One problem is that there is a lack of players who are prepared to take on the role of scaling-up the universities’ small-scale laboratory work to applied R&D projects that lead to large-scale production.

A key question is who owns the results of university research, as it is the owner who controls how the research results should be used. There are different systems for dealing with this – above all in the USA and Europe. In the USA, it is the universities/departments that own the results since the introduction of the Bayh-Dole Act in 1981, but in practice it is a case of profit sharing between the researchers and the universities. According to the literature, this has proved to be a successful strategy. The patenting and licensing of university inventions has increased many times over the last decades and the universities have set up their own *Technology Transfer Offices* that aim to provide support in the form of know-how, networks with companies and patenting and licensing services. It is claimed that the Bayh-Dole Act has given the parties concerned (the researchers and the universities) incentives to commercialise research results. It must be remembered, however, that American universities are privately-run and compete in several dimensions (for students, research and funding). These universities are also flexible when it comes to adapting syllabuses and research to the areas that are regarded as relevant in business and industry. In general, the government in the USA has attempted to improve rules and regulations and to provide better incentives for universities to take the initiative on the commercialisation of research results.

In Sweden and Europe, on the other hand, the universities are run by the Government and seldom compete with each other for (public) funding, researchers and students. There is limited scope for wage setting and the Government is largely in control of professorial appointments and study programmes. In Sweden, it is the researchers themselves that own the research results through the so-called Teacher's Exemption. This could mean that there is a greater incentive for Swedish researchers to commercialise their discoveries than for American researchers. However, the universities/departments in Sweden have no incentive at all to assist individual researchers. It is rather the case that the universities do not want the researchers to commercialise their results as the inflexible wage system and other factors make it difficult to retain personnel who have managed to establish contacts with business and industry. This means that researchers often stand alone and limit their external activities to consulting assignments.

In order to compensate for the lack of incentive for researchers and universities in Sweden, the government has developed a central bureaucracy that has the task of supporting the transfer of knowledge from the universities to industry. These institutions (e.g. Vinnova and Nutek) are funded by the Government and are directly involved in the transfer of knowledge. In contrast to the USA therefore, the initiative comes from above. The Government's support measures are seldom or never evaluated. There is no empirical evidence that these measures achieve their desired results. It is not certain, however, that the American system can be introduced in Sweden, i.e. by giving the universities proprietary rights to the inventions, as the Swedish universities are not subject to competition. The consequence could be that the universities simply hold on to inventions that they do nothing about. Several co-ordinated measures would be necessary, but there are no simple solutions. A first step would be to make the universities more inclined to compete, for example by allocating public funding under competition.

There are several different ways for the universities to actively stimulate the transfer of knowledge to industry. The literature has mostly focused on the patenting of university inventions and subsequent licensing to external companies. It is believed that if the license agreements are drawn up in the right way (with variable and fixed payments) they will give researchers, university departments and external companies incentives to do their best. Another alternative is that external companies fund research projects at university departments. This is very common in Sweden. The literature is, however, sceptical about such projects if the external company is the sole owner of the research results. The problem is that the agreements on funding and ownership are often written before the research results are ready. This means that the researchers have no incentive to exert themselves and the external company can seldom check this. A third way, which is more risky than licensing, is to spin-off companies that are based on university inventions. In such cases it is important that the university has internal expertise and networks with external entrepreneurs. Part ownership between university inventors and entrepreneurs is believed to be important in order to give everyone an incentive to work hard. A fourth way is to set up technology parks close to the universities. The few empirical studies that have been carried out indicate that this may be an important complement to the other instruments for the transfer of knowledge.

Many researchers claim that there is an R&D paradox in Sweden. We invest more in R&D (in particular at the universities) in relation to GDP and publish more articles in (English language) research journals per capita compared to other OECD countries. At the same time, we have fewer university patents and fewer rapidly-growing technological companies. New statistics reveal that this view may be somewhat exaggerated. Other OECD countries invest more Government funds in R&D at laboratories than is the case in Sweden. If both universities and laboratories are taken into account then the difference is smaller. Researchers from other, major-language countries can also publish their results in journals in their native tongue. Finally, the statistics show that the percentage of patents *owned* by researchers/universities in Sweden and Europe is only a fraction of that in the USA. However, 80 per cent of the Swedish patents produced at Swedish universities are owned by external (large) companies as these fund entire research projects. If this is taken into account, Sweden and Europe are not so far behind the USA.

Traditionally, the tasks of the universities have been to increase the stock of knowledge by pursuing research and to educate researchers and students. In recent years, there have been calls for the universities to also disseminate new knowledge to industry and society at large. One way for the Government to indirectly influence the orientation of university research is to allocate funding under competition on a project basis instead of in the form of traditional fixed allocations. This enables the Government to specify certain objectives regarding the focus of the research, collaboration with other universities and industry, courses and so on which the applying universities must meet. Earlier research merits often determine which universities will be allocated funds. The trend in Europe is that funding under competition is increasing at the expense of fixed allocations.

Theoretically, funding on a project basis has several advantages compared to fixed allocations. It should lead to: 1) an increase in cost effectiveness; 2) greater incentives for the universities and individual researchers to generate good research; 3) the universities becoming more flexible and adapting to technological change; 4) the Government being able to influence research indirectly. Last but not least, funding under competition represents a first step towards increasing the readiness of the Swedish universities to compete. It is believed that this is a necessity if we are to get the universities to pay any attention to stimulating the transfer of knowledge to industry. However, funding under competition also has a number of negative consequences. Above all, there is a risk that the research will become more short-term and homogenous. Long-term projects associated with high risks will be avoided. It may also be expensive to evaluate the research. Unfortunately, according to leading researchers in the field, these effects have not been tested empirically. However, there are good reasons for subjecting the universities to competition to a greater extent than today.

One effect of funding on a project basis that can definitely be expected is that allocations will be more skewed distributed than in the case of fixed allocations, and this will lead to a concentration of university resources. This is namely so in the case of private funding for universities that is always provided under competition. There is also a risk of increased polarisation with regard to personnel. The best researchers will apply to join the large university departments where other well-qualified researchers are already working and where there is a reliable supply of funding. The smaller universities will be marginalised and may even find it difficult to perform their teaching tasks. These smaller universities will then be forced to focus on just a few specific fields.

Whether this increased concentration and polarisation is positive or not depends on whether there are economies of scale for universities. Empirical studies show that such scale economies exist with regard to teaching and administration for universities with up to 3 000 to 3 500 employees (researchers and administrators). However, the results for university research are mixed or show no links at all between size and performance. This applies both to departments and entire universities – as long as the departments do not have high fixed costs in the form of equipment that can be shared by many researchers. Several studies have shown, however, that there is a minimum effective size for research groups of 3 to 5 experienced researchers who work together closely. These groups should then be supported by postgraduate students, assistants and administrators. For these reasons, the investments in Sweden in recent decades in establishing small universities and colleges would appear to be highly doubtful.

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