Science and Public Policy, volume 28, number 5, October 2001, pages 371–380, Beech Tree Publishing, 10 Watford Close, Guildford, Surrey GU1 2EP, England

Innovation and employment

The direct and indirect impacts of new technologies on employment: the example of the German biotechnology sector

Stefan Wörner and Thomas Reiss

This paper explores employment effects of new technologies using the example of modern biotechnology and empirical data for the German biotech industry. We differentiate between direct employment effects in small and medium-sized biotechnology firms and indirect effects in established industries. Our findings support theoretical considerations arguing that high technologies per se *do not generate substantial new employment. Rather their impact on employment is more of an indirect nature leading to employment stabilisation and growth. We recommend putting more public and political attention to the indirect employment effects of biotechnology since they are quantitatively and qualitatively much more important than their direct counterparts.*

Dr Stefan Wörner and Dr Thomas Reiss are at Fraunhofer Institute for Systems and Innovation Research, Breslauer Strasse 48, 76139 Karlsruhe, Germany; E-mail: Thomas.Reiss@isi.fhg.de; Stefan.Woerner@isi.fhg.de; Webpage: www.isi.fhg.de.

The empirical part of this paper is based on data for the German biotechnology industry which have been gathered during a project on 'European biotechnology innovation systems' which was carried out by a team of eight European research groups and funded by the European Commission within the TSER programme (contract number SOE1-CT98-1117). It is also based on the Fraunhofer-ISI contribution to the expert committee 'Employment effects of biotechnology' within the '*Bündnis für Arbeit*' of chancellor Schröder, which was supported by a grant of the BMBF. The authors are grateful to the anonymous reviewer.

BIOTECHNOLOGY MAKES USE OF the principles and rules guiding the structure, function and reproduction of living creatures for serving technical needs. This rather old strategy that had been used centuries ago for producing beverages or food, for example, gained new momentum with the availability of a radical new toolbox, which allowed the targeted engineering of DNA — the software of life. This toolbox emerged during the 1970s and was termed 'genetic engineering'. It transformed biotechnology from a trial-and-error based time-consuming selecting and breeding technology to one of today's key (high) technologies.

The ability to manipulate DNA created huge expectations with respect to new products and new jobs. However, the first wave of modern biotechnology, which focused on using the information of DNA for producing biopharmaceuticals, had rather limited overall economic impact. Still there are some examples that could be considered as success stories. In 1982, recombinant insulin was the first biopharmaceutical approved in the USA; it was followed by recombinant human growth hormone in 1985, and alpha-interferon and hepatitis B vaccine in 1986.

By August 2000, there were 84 biopharmaceuticals approved in the USA and Europe combined (Walsh, 2000). Some of these drugs can be considered as blockbusters with world-wide annual sales of more than US$1 billion (Epogen sales in 1999: US$1,760 million, produced by Amgen; Humulin, US$1,088 million, Eli Lilly; Neupogen, US$1,260

 0302-3427/01/050371-10 US$08.00

The Fraunhofer Institute for Systems and Innovation Research (ISI) is a member of the Fraunhofer Society (FhG) which is the leading research organisation for applied research in Europe. ISI has a permanent staff of 70 scientists with different academic backgrounds. Dr Thomas Reiss and Stefan Wörner belong to the department Innovations in Biotechnology at ISI. The group systematically analyses the innovation dynamics of modern biotechnology and its economic, social, ethical, legal, and environmental framework conditions and impacts.

Dr Thomas Reiss is head of the department, has a background in molecular biology and has been working for more than ten years on foresight, technology assessment and innovation policies in biotechnology. Since 1999 he has been a member of an expert group for biotechnology of the *Bündnis für Arbeit*, convened by Chancellor Gerhard Schröder.

Dr Stefan Wörner recently completed postgraduate studies at Fraunhofer-ISI and the University of Karlsruhe on real options valuation in the bio-pharmaceutical industry.

million, Amgen; Procrit, US$1,505 million, Ortho Biotech (ISB, 2000)).

On the German market, biopharmaceuticals have reached a share of about 6% of the total market for pharmaceuticals, which corresponds to about US$4 billion (VFA, 2000). Assuming that the German market represents the situation in other European countries and the United States in this respect, the world market for biopharmaceuticals could be estimated at about US$20 billion (6% of the US$343 billion world market for pharmaceuticals (VFA, 2000)).

A second wave of modern biotechnology is based on a different principle and started with the initiation of the human genome project in 1988. The goal of the new approach is no more to manipulate DNA and use it for producing goods in optimised organisms; it now aims to analyse DNA and understand its function. From this information new targets for developing drugs and the new concept of molecular medicine could be developed. This analytical approach led to completely new ways of developing drugs (Reiss and Hinze, 2000).

The sequence of the human genome, which became available as a 'working draft' in June 2000 (Macilwain, 2000), combined with new functional models for diseases, provides an increasing number of drug targets. The number of these targets is estimated to be between 3,000 and 10,000, which is at least an order of magnitude higher than the present situation with about 420 drug targets (not including infectious agents such as bacteria and viruses) (Drews, 1996). Using novel high-throughput screening systems, chemical or natural compounds can be tested against these drug targets. New synthetic approaches such as combinatorial chemistry provide the required variety of different molecules.

Taken together, the elucidation of the information stored in DNA and the new platform technologies has led to a new paradigm of drug discovery and development, which is about to pervade the whole pharmaceutical industry. Thus the promises of modern biotechnology are becoming an economic reality. Today there is probably no large pharmaceutical firm which is not following this approach.

This changing technological paradigm has important implications for the assessment of employment effects of biotechnology, because different types of actor are involved to different extents during the various stages of the process. There is a cohort of highly specialised genomics firms, which, together with public-sector research organisations, are exploring the sequence of the human genome. A second set of small and medium-sized enterprises (SMEs) has specialised in the development of the required platform technologies such as high-throughput screening and combinatorial chemistry. Finally, established pharmaceutical firms adopt the (pre)products and technologies provided by small and medium-sized high-tech firms and transform them into the development of new drugs. Obviously biotechnology exerts different employment effects at theses different stages, which need to be considered.

The sketched (bio)technology scenario will most probably not be confined to the pharmaceutical sector. Rather the underlying principles could be transferred to other industries such as the chemical or the agro-food industries. Plant genomics is already utilised in many international seed companies, microbial genomics is becoming increasingly important in the food industry (Mlot, 1998; Menrad *et al*, 2000).

This paper explores employment effects of modern biotechnology taking into consideration the different stages of the new biotechnology paradigm and the various organisations, which are involved at different levels. We differentiate between direct employment effects in small and medium-sized biotechnology firms and indirect effects in the established industries such as pharmaceuticals, which are increasingly affected by modern biotechnology.

There is empirical evidence in the literature about a certain relationship, albeit unknown, between innovative high-technology firms and employment generation initiated by these companies. We argue that this has a quantitatively low direct impact compared to the size of a whole economy (and the unemployment rate it may face). Indirect quantitative and qualitative effects are probably more important, but are hard to estimate. Some attempts have been made in the past: their accuracy and the assumptions made will be discussed.

The role of high-tech SMEs in biotechnology will be described in order to delineate why it should be advantageous for a country to have a prospering biotechnology industry. However, we do not argue that biotechnology could solve the problem of unemployment, which some European countries face at the moment.

Direct employment effects

Theoretical background

Employment effects of modern technologies are controversially discussed in the economic literature. Two theories stand in the centre of the discussion: the first claims that technological change mainly increases the potential for rationalisation (Penzkofer *et al*, 1989) leading to displacement of labour. Growth rates in productivity would then be higher than in production. Thus more of the work-force would be dismissed than is hired elsewhere. This hypothesis neglects the finding that skilled jobs and new technology are complementary, while unskilled jobs and new technology may be substitutes (Griliches, 1969; Bound and Johnson, 1992).

Secondly, the theory of compensation of labour claims mainly positive employment effects (Stoneman, 1983; Klauder, 1986). The following are usually mentioned to underpin this theory:

- New markets for products and processes for various areas of application extend the total demand. Higher demand increases employment (Stoneman, 1983).
- Cost reductions by more efficient production processes are passed on to the consumers via price reductions. In effect, this increases overall demand (Hagemann, 1985).
- The machines and aggregates required for these modern production processes have to be newly engineered. This leads to higher employment at the supply companies (Stolz and Camenzind, 1992).
- Innovative domestic companies improve the international competitiveness, thus positively influencing employment (Klauder, 1986).

Model simulations indicate that product as well as process innovations should show positive effects on employment in the long run. Short-term, only product innovations should provide a beneficial influence on employment (Katsoulacos, 1986). However, empirical investigations do not allow clear conclusions regarding direct employment effects of innovations. There is evidence for both positive and negative impact (König, 1987; Grupp, 1997) depending on the type of innovation (product or process) and the diffusion rate (van Reenen, 1997).

One theory about employment effects of modern technologies claims that technological change increases the potential for rationalisation, thus displacing labour; the compensation of labour theory claims mainly positive employment effects

Pianta *et al* (1996) find a close and significant link between investment and employment for six of the large OECD (Organisation for Economic Co-operation and Development) countries, however they do not state the same relation between patents (as an indicator for innovation) and employment.

High-tech start-ups are more likely to create employment than other young firms but their overall contribution to job creation is rather modest (Westhead and Cowling, 1995; Storey and Tether, 1998). This has been found in several European countries (Tether and Massini, 1998; Mustar, 1997; Olofsson and Wahlbin, 1993; Lumme, 1994).

A number of recent studies revealed that growth of employment seems to be concentrated in a few science-based firms (Garnsey and Cannon-Brookes, 1993; Westhead and Cowling, 1995; Tether and Massini, 1998). However, even in the case of the very successful companies, growth rates in employment are rather modest (compared to sales growth, for instance). These findings suggest that support for small start-ups may hardly be justified by more efficient employment creation than in large firms (Tether and Massini, 1998; Tether, 2000).

In cases of science-based sectors such as biotechnology, indirect effects on employment become more important since additional agents are evolving that bridge the gap between knowledge-generating organisations and established industries that are utilising this knowledge. In general, the service sector works as the link between the science base (the scientific–technological excellence of a society) and industry. Therefore, jobs are increasingly created in the service and supplies sectors (ZEW *et al*, 1999).

The quantitative employment effects triggered by modern biotechnology can be summarised in five dimensions (ZEW *et al*, 1999):

- Direct job creation through sustainable start-ups and establishments of multinational corporations (MNCs).
- Substituting effects by replacing traditional companies.
- Income effect by consumption expenses of newly hired staff. Empirical studies have found that the introduction of new machines does not cause wages to rise very much, but workers who use modern techniques are more capable than non-users, that is, they implicitly have unobservable characteristics that are more highly rewarded (Hall and Kramarz, 1998; Entorf *et al*, 1996).
- Competitiveness effect, particularly in industries in late phases of the production chain.
- Job creation in supplying and service companies.

Hence, there is evidence that high-tech SMEs contribute less to quantitative job creation than expected. Their qualitative contribution is hard to measure but nevertheless exists. Several authors have tried to describe the functions or characteristics of SMEs in the innovative process:

- Small firms contribute specialised equipment that is utilised in large companies to develop more valuable innovations (Pavitt, 1984), for instance, equipment and supplies firms offering screening and detection facilities for drug development to the biotechnology industry.
- Small firms offer (special) services, improving efficiency of R&D and production processes of larger firms (Soete and Miozzo, 1989), for instance, contract research organisations (CROs) revolutionise conventional pharmaceutical R&D of traditional pharmaceutical firms.
- Rothwell (1983) understands small firms as complementary to large firms for innovative developments within a systems approach of innovation.
- Autio (1997) attributes a catalysing effect to small firms within an industrial network.

It is crucial to know that, although small (science-based) firms develop more innovations than large companies (Acs and Audretsch, 1990; Pavitt *et al*, 1987; Kleinknecht *et al*, 1993), the latter produce innovations with higher value (Tether, 2000). This seems to imply that quality (that is, excellence and commercial success of a firm) is more important than quantity (that is, number of SMEs) where employment creation in a country is concerned.

Against this theoretical background we will now explore direct employment effects in biotechnology firms using data for Germany.

German biotechnology industry

Since the mid-1990s, several authors have been trying to count the number of biotech firms in Germany. The available data on the development of the biotech industry in Germany are summarised in Figure 1. The authors of these surveys applied either a broad or narrow definition of biotechnology.

The narrow definition is usually described by the scientific term 'new' biotechnology, which is defined by the Office of Technology Assessment (OTA, 1991, page 29) as "the industrial use of rDNA, cell fusion, and novel bioprocessing techniques". This interpretation is normally restricted to SMEs, thus excluding MNCs. Typically, the firms in this category are founded by scientists, funded by venture capital and have very high expenditure on R&D. Commercialisation of specific know-how in biotechnology is their main business. The estimates by the diverse authors for the number of firms in this category in Germany in each year are represented by diamonds in Figure 1. The lower line in Figure 1 indicates the trend in the number of these dedicated biotechnology firms. There has been a considerable growth of such firms in Germany since about 1993 from roughly 50 to somewhere around 300 in 2000.

The upper involution line of Figure 1 represents firms which meet a wider definition of biotechnology in the sense that they use biotechnology for the development and marketing of new products, processes and services, or create more than 50% of turnover with biotechnology. This resembles the broad definition of biotechnology by the OTA (1991, page 29): "... any technique that uses living organisms (or parts of organisms) to make or modify products, to improve plants or animals, or to develop micro-organisms for specific uses". The number of these firms has grown in a similar way from about 300 in 1993 to 500–600 in 1999, as indicated by the little squares in Figure 1. The data for this set of biotech firms are much more scattered.

Other studies which did not fit into this division

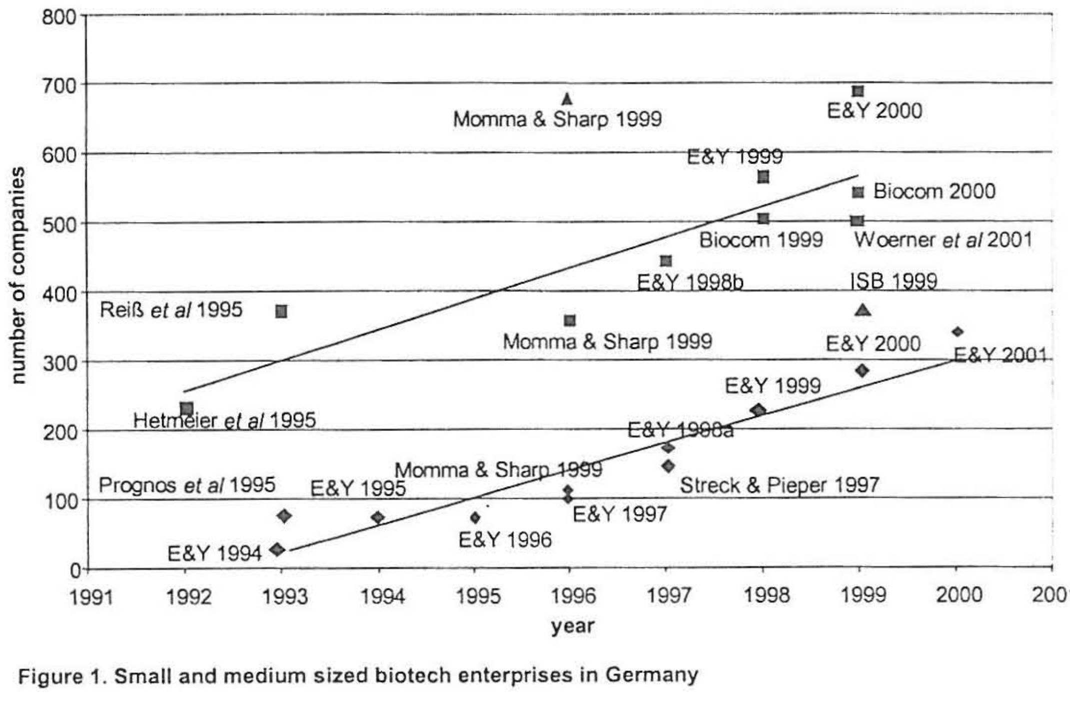

Figure 1. Small and medium sized biotech enterprises in Germany

into dedicated and extended biotechnology firms have been included separately in Figure 1. Estimates for them are represented by small triangles.

Employment potential in biotechnology firms

To assess the employment potential associated with the growing biotechnology industry in Germany we used an average of 30 employees per dedicated biotechnology firm in 1999 and extrapolated this along the time-scale (lower line in Figure 2). Taking into account that firms have grown in the past and probably will continue to grow in the future, this approach leads to an overestimation of employment before 1999, and to an underestimation beyond 1999. The calculation indicates that there were about 7,000 employees working in dedicated biotechnology firms in Germany in 1999 and that a doubling of this figure until 2005 could be expected.

Considering the wider definition of biotech firms, represented by the upper line in Figure 2, we use an average company size in 1999 of 45 employees which is based on data we collected during a recent survey on biotech firms in Germany and other European countries (Wörner *et al*, 2001). There were almost 25,000 jobs in 1999 in the total biotech industry in Germany which could increase to more than 35,000 in the year 2005 (Figure 2).

Assuming that biotech firms will grow in the future and diffusion of biotechnology will continue and affect an increasing number of firms, the future employment potential of biotechnology could be expected to be larger. Correspondingly, an exponential involution would reflect these effects better (Figure 2). We have found that an exponential curve fits the historical data more accurately.

The exponential trend cannot be persistent in the long run but may predominate in the mid-term, stagnating after some years, possibly resulting in an S-shaped curve. In that case, we could expect almost 50,000 employees in the year 2005. In summary, we expect an increase in the number of employees in the German biotechnology industry by 10,000 to 25,000 jobs until the year 2005.

To compare the magnitude of the expected expansion of employment in biotechnology, the number of jobs generated in other sectors in Germany is taken as a reference. We have chosen information technology (IT), consisting of hardware and software lines; telecommunication, composed of terminals for communication, infrastructure and service companies; and the electrical and electronic industry.

In 2000, the software branch of the IT sector employed 382,000 people in Germany at a growth rate of 27% (+81,000 people), whereas employment in the hardware branch declined by 8% (–10,000 people) to 108,000, yielding an overall growth rate for the IT sector of 17% to 490,000 people (Bitkom, 2001). In 2001, the growth rate should range around 4% in this sector.

In terminals for communication and infrastructure, there were 83,000 people working in 2000 in Germany, and 247,000 in service companies in telecommunication, leading to an increase of 1% (around 3,000 people) to 330,000 in the telecommunications sector (Bitkom, 2001). For 2001, industry experts expect a decline by 1%.

In the electrical and electronic industry, 884,000 people were employed in 2000 (+3% growth) and, by the end of 2001, it is expected that the number will increase to 900,000 (ZVE, 2001). Some of these sectors thus provide a higher growth rate than biotechnology in absolute terms, but some will also be much more volatile.

There is a caveat when extrapolating the number of companies expected in the future and their size.

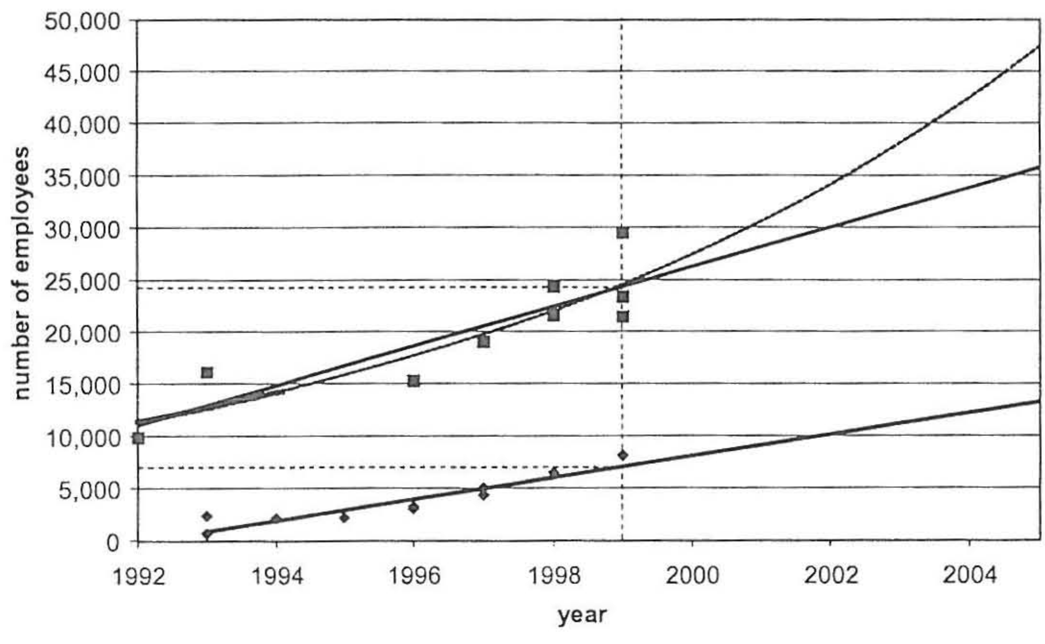

Figure 2. Employment trends in German biotech SMEs

The size distribution of new technology-based firms (NTBFs) tends to be very skewed. There are examples from the past which show that some companies grew very rapidly and accounted for most of the new employment in a particular industry, for instance, Apple Inc. The spectacular success of SAP AG has considerably influenced the overall picture in the German software industry.

In the case of the German biotech industry, however, even the most successful companies, such as Qiagen or Lion, have remained relatively small (Qiagen employs approximately 1,400 people worldwide, Lion has almost 500 employees). There are no Amgens or Genentechs on the horizon in Germany at the moment. Moreover, exceptionally successful companies in Europe seem to be more careful in hiring people than their US counterparts. Therefore, the estimates used to extrapolate the numbers for Figure 2 should be relatively resilient to exceptional cases of employment generation.

Indirect effects

There have been many attempts in economic theory to model the correlation between technical progress and (production) growth (Grupp, 1998). The neo-classic growth theory is based on the work of Solow (1956; 1957) and Denison (1962). In its basic model, income (domestic product), capital stock and workforce grow at the same rate in equilibrium. This is the exogenously determined growth rate of the population. Thus, capital intensity, productivity of labour and income *per capita* are constant. So it is not possible to explain any growth or decline in these figures, which are, however, often observed in real-life economies, such as productivity growth *per capita*.

To explain these phenomena and to incorporate technological progress, Solow uses an exogenous parameter: a public good that any entrepreneur may use free of cost and that does not induce any external effects. The rate of technological progress can be calculated theoretically by the difference between the growth in the total factor productivity and the change in the productivity explained by capital and labour (Solow residual). However, this residual also includes all measurement errors regarding the output and the inputs of capital and labour.

The basic difference between the new growth theory and the conventional neo-classical model lies in the (partially) endogenously determined growth rate and in giving up the assumption of perfect competition

Improvements to the neo-classical approach (mainly during the 1980s) can be summarised under the term 'new growth theory'. The basic difference between this and the conventional neo-classical model lies in the (partially) endogenously determined growth rate and in giving up the assumption of perfect competition. Several strands can be distinguished which basically add another factor to the (neo-classical) production function (Stern, 1991; Ramser, 1993). According to Lucas (1988), growth is either generated by human capital, (physical) capital, or R&D processes.

Romer (1986; 1989; 1990) develops a production function with four factors — labour, (physical) capital, human capital, and technical knowledge. The latter is produced by the (public and private) R&D sector in a two-sector model. The entrepreneurs in the other sector buy most of the newly generated knowledge of the first sector. External effects of the technical know-how (it is not considered as an entirely private good) mean that parts of the expertise of the R&D sector can be acquired by others at zero cost. Hence, the price that the entrepreneurs of the second sector have to pay to the R&D sector is less than the benefit it produces.

These positive external effects (spillovers) are favourable to the whole economy and induce growth. In such an economy, R&D is the main driver of growth. Other factors, such as capital, mainly transform technical knowledge in commercial outputs.

It is arguable who will benefit most from the spillover effects and whether the share of know-how that is not being paid for may induce declining expenditure in R&D.

This link between technological progress and growth may be underpinned empirically by the development of the contribution to net output in the German economy. It shows that in the mid-1990s the research-intensive industries took the lead in the growth process. This also demonstrates that high technologies, with a contribution of 11.5% to industrial output, enjoyed the strongest growth. In 1996, high-tech exports rose by 13% and advanced technology exports by 7.5% (Grupp *et al*, 1997).

Thus, technological progress has been identified by numerous authors as a major driver of growth in an economy and has been incorporated in economic literature on the new growth theory. The new growth theory shows that technological progress induces growth via positive external effects and (private) investments in new knowledge. However, the models are sometimes rather specific based on unrealistic assumptions, that try to capture more or less unknown economic processes by sophisticated methods (Solow, 1991).

Economic effects of biotechnology

We will now explore the impact of biotechnology-driven technological progress on the employment of certain industries. At present, biotechnology exerts its strongest changing forces in the pharmaceutical industry (Jungmittag *et al*, 2000). In consequence, the future competitiveness of the pharmaceutical industry will depend, among other things, on its ability to adopt this new (bio)technology and adapt it to its specific needs. We expect similar effects, with some time lag, in other areas, such as the chemical, agro-food and environmental industries.

For analysing such economic effects of biotechnology, we apply a production-oriented approach (Grupp *et al*, 1997). First, we investigate the extent to which all product categories of the considered industries, as covered by the official production statistics, would be affected by biotechnology. We differentiate between those categories which already today use biotechnology in the production process and those where related R&D is carried out internationally, which will lead to industrial applications in the future. The first group is defined as current substitution potential, the latter as future substitution potential which is expected to be realised in five to ten years.

We argue that the substitution potential can be considered as a measure that indicates the extent to which the competitiveness of the industry is dependent on biotechnology. In other words, production volumes as identified by this analysis would be endangered if the industry were not able to use biotechnology or have access to the required biotechnological know-how. These assessments are mainly based on interviews with experts from research organisations and industry, complemented by literature analyses.

Second, combining the identified biotechnology production volumes with average figures for labour productivity, we calculate the number of jobs affected by biotechnology. This reveals data on jobs in established industries which are dependent on biotechnology know-how and can be considered as a measure for indirect employment effects of biotechnology in these industries. The following labour productivity values were used for these calculations: pharmaceuticals 161,000 €/employee; chemicals 164,000 €/employee; environmental technologies 97,000 €/employee; agro-industry 44,000 €/employee; food-industry 170,000 €/employee; bioprocessing industry 103,000 €/employee.

Using this approach we estimate that currently there are 220,000 jobs in German industry depending at least indirectly on biotechnology (Figure 3). Within the next five to ten years, this number could increase to about 500,000 to 600,000 jobs. The potential indirect effects will be strongest in the agro-food sector, followed by the pharmaceutical and chemical industries. The realisation of this potential depends on the regulatory and demand conditions that may considerably affect the actual outcome in future.

The uncertainty regarding the general legal and social framework impedes predictions. Uncertainty is likely to be highest in the agro-food sector, where bans on genetic manipulation or poor social acceptance of genetically modified food ingredients may destroy biotechnology's potential in this industry.

Future prospects of biological technologies for environmental protection face high uncertainty as well, but different from those of the agro-food sector. Business potential in this area is based on both end-of-pipe technologies and technologies for production-integrated environment protection. The

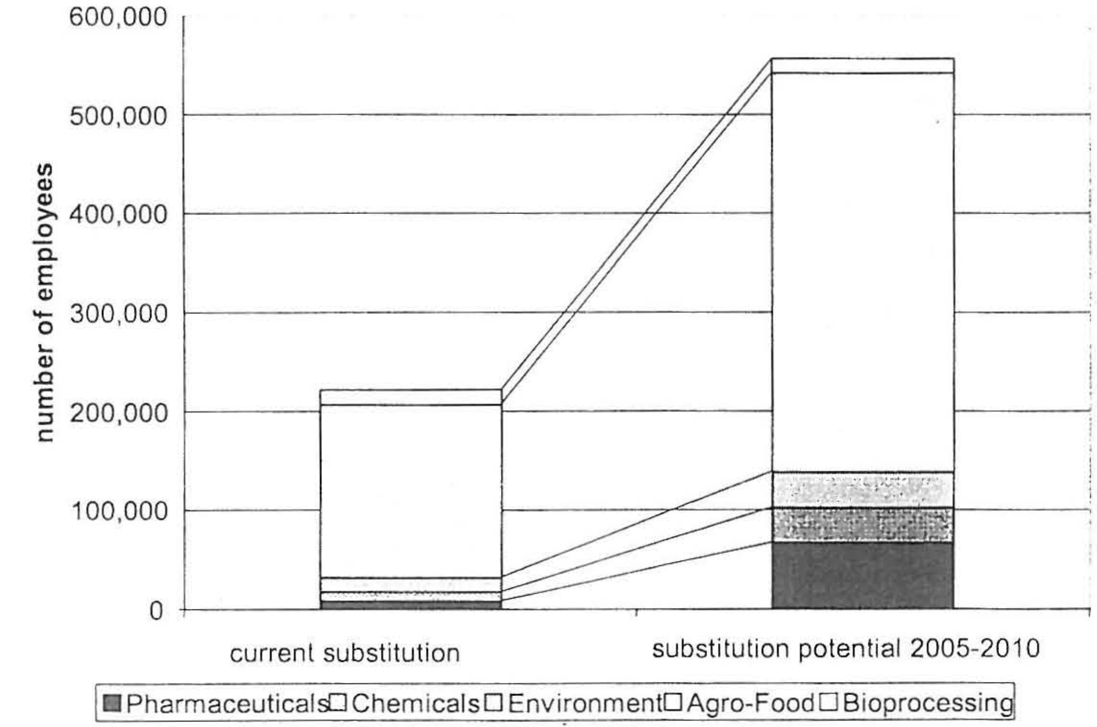

Figure 3. Biotech employment effects in established industries

environmental industry is thus very much dependent on public demand and strongly influenced by policy. Direction and speed of development is thus unclear.

The role of biotechnology in the pharmaceutical industry is easier to estimate. It is almost certain to continue to grow. There may be some caveats, for instance, if the social debate on some issues such as gene therapy, stem cells and cloning spreads to other applications and hinders the development of ethically less controversial technologies.

The future advances of biotechnology in sectors such as chemicals and bio-processing should be hardly influenced by the general regulatory and social framework but depend much more on economical measures, that is, on how far biotechnology may reduce production cost or improve the quality of products (Hüsing *et al*, 2000).

We are aware that these figures are based on a rather simple methodological approach and not on sophisticated model calculations, which to our knowledge so far do not exist for biotechnology. Nevertheless, such estimates give at least an impression of the order of magnitude of the indirect employment effects of biotechnology. Compared to the direct employment effects in biotech SMEs (Figure 2), the indirect employment potential of biotechnology in established industries is about ten times bigger.

These results support the view of Brown *et al* (1990) who criticise the widely held wisdom that small firms create most new jobs. They contend that the direct, quantitative employment of small enterprises is not crucial for labour policy in a country. They empirically find that:

- although new and small firms create jobs when they grow, this is not necessarily a more important source of employment than large companies;
- small subsidiaries of large firms are an important factor in generating jobs: this phenomenon has also become apparent in a study among German SMEs of the production industry (Almus *et al*, 1998);
- growth rates in other indicators (such as sales) are much higher than in number of staff: this suggests a rapid rise in productivity or greater outsourcing;
- there is a larger number of small, contracting companies: this is more or less offset by many newly established or growing enterprises.
- the average share of people employed by small firms has remained relatively stable (35% in the USA since 1958);
- job losses in small firms (for instance, due to closings) occur more frequently than the industry average.

Together with our findings, these data support the view that small firms may not be the main driving factor for employment creation in biotechnology. Rather, established industries may have a higher impact. However, biotechnology firms play an important role in enabling established firms to cope with biotechnology-driven change.

Technological change leads to rationalisation potential, which may often be overcompensated by positive employment effects such as additional demand for new products, cost reductions and improved economic competitiveness

Conclusions

Direct employment in the German biotech industry amounted to about 24,000 people in 1999. Of this figure, about 7,000 employees are working in core biotechnology firms. We expect an increase of employment in this industry by 10,000 to 25,000 jobs within the next five years. This growth is driven by two factors: continued start-up formation; and growth of existing firms. The lower limit of this estimate assumes that almost no growth of firms will take place, whereas the upper limit is based on a continuous growth assumption.

Compared to these direct employment effects indirect employment effects of biotechnology in established industries are estimated to reach a number which is about ten times bigger (500,000 to 600,000 people). These indirect effects are a consequence of technological disruptions in established industries which are driven by biotechnology.

These findings are backed in economic theory. Technological change leads to rationalisation potential, which may often be overcompensated by positive employment effects such as additional demand for new products, cost reductions and improved economic competitiveness. Empirical studies underpin the hypothesis that the direct quantitative contribution of SMEs to employment creation is more or less negligible on a broader level.

Our analysis also supports theoretical considerations arguing that high technologies *per se* do not generate substantial employment. Rather the impact of high technologies on employment generation mainly is of an indirect character, leading to employment stabilisation and growth. We do not ignore that there are examples of biotechnology firms (such as Amgen and Genentech in the USA, Qiagen in Germany) which have grown from small start-ups to large firms with several thousands of employees. However these firms are not typical for the biotechnology industry in general.

Rather, firms such as Amgen and Genentech have evolved into pharmaceutical companies and therefore could be considered as representatives of the pharmaceutical sector. Thereby they have internalised the indirect effects which are exerted by small and medium-sized biotechnology firms on pharmaceutical enterprises. Qiagen, on the other hand, is a representative of the biotechnology equipment and supplies sector, where only very scarce data on industrial structure and dynamics are available. The development of Qiagen indicates that it is important to shed more light on this sector and explore its role in the whole biotechnology innovation system.

The 'new growth theory' may provide a fruitful framework to model employment effects in biotechnology. Such a model is far beyond the scope of this paper. Investigations of the employment effects should be embedded in a more comprehensive model simulating the entire sector. The data required may become available through an ongoing research project funded by the European Commission on the outcome of policy measures in European countries. This paper may thus provide a starting point for future research.

If we compare the public and political attention which is given to the different phenomena responsible for job creation via biotechnology with the significance of these phenomena, there is an obvious mismatch. By far the most attention is given to biotech SMEs. However, biotechnology-driven job creation is quantitatively much more important in established industries and the knowledge about these effects is very poor.

Therefore we conclude that future discussions on employment potential of biotechnology certainly need a stronger focus on these indirect effects in established industries. This redirection of attention would also allow conclusions to be made as to which policies would support most efficiently future employment growth through biotechnology.

References

Acs, Zoltan J and David B Audretsch (1990), *Innovation and Small Firms* (MIT Press, Cambridge MA).

Almus, Matthias, Eric A Nerlinger and Fabian Steil (1998), *Growth Determinants of Start-ups in Eastern Germany: a comparison between innovative and non-innovative firms* (Zentrum für Europäische Wirtschaftsforschung, Mannheim).

Autio, Erkko (1997), "New technology-based firms in innovation networks: symplectic and generative impacts", *Research Policy*, 26, October, pages 263–281.

Biocom (1999), *Biotechnologie — Das Jahr- und Adressbuch 1999* (Biocom AG, Berlin).

Biocom (2000), *Biotechnologie — Das Jahr- und Adressbuch 2000* (Biocom AG, Berlin).

Bitkom, Bundesverband Informationswirtschaft, Telekommunikation und Neue Medien (2001), "Informationswirtschaft Beschäftigungsmotor Nummer Eins", press release, 7 June 2001, Berlin.

Bound, John and George Johnson (1992), "Changes in the structure of wages in the 1980s: an evaluation of alternative explanations", *The American Economic Review*, 82(3), June, pages 371–392.

Brown, Charles, James Hamilton and James Medoff (1990), *Employers Large and small* (Harvard University Press, Cambridge MA).

Denison, Edward F (1962), "The sources of economic growth in the United States and the alternatives before us", Committee for Economic Development, New York.

Drews, James (1996), "Genomic sciences and the medicine of tomorrow", *Nature Biotechnology*, 14, pages 1516–1518.

Entorf, Horst, Michael Gollac and Francis Kramarz (1996), *New Technologies, Wages, and Worker Selection* (INSEE, Institut National de la Statistique et des Etudes).

E&Y, Ernst and Young (1994), European Biotech 94 — a new industry emerges", Brussels.

E&Y, Ernst and Young (1995), "European Biotech 95 — gathering momentum", Brussels.

E&Y, Ernst and Young (1996), "European Biotech 96 — volatility and value", Brussels.

E&Y, Ernst and Young (1997), "European Biotech 97 — a new economy", Brussels.

E&Y, Ernst and Young (1998a), "European Biotech 98 — continental shift", Brussels.

E&Y, Ernst and Young (1998b), "Erster Deutscher Biotechnologie Report — Aufbruchstimmung", Mannheim.

E&Y, Ernst and Young (1999), "European Biotech 99 — communicating value", Brussels.

E&Y, Ernst and Young (2000), "Seventh annual European life sciences report 2000", London.

E&Y, Ernst and Young (2001), "Eighth annual European life sciences report 2001", London.

Garnsey, Elizabeth, and Peter Cannon-Brookes (1993), "The 'Cambridge Phenomenon' revisited: aggregate change among Cambridge high-technology companies since 1985", *Entrepreneurship and Regional Development*, 5(2), pages 179–207.

Griliches, Zvi (1969), "Capital-skill complementarity", *Review of Economics and Statistics*, 51, November, pages 465–468.

Grupp, Hariolf (1997), "Mittel- und langfristige Fortschrittswirkungen auf den Strukturwandel in der Beschäftigung", in H Schnabl (editor), *Innovation und Arbeit — Schicksalsfrage der Nation?* (Mohr-Siebeck, Tübingen).

Grupp, Hariolf (1998), *Foundations of the Economics of Innovation. Theory, measurement and practice* (Elgar Publishing Ltd, Cheltenham, UK, Northampton, MA).

Grupp, Hariolf, Sybille Hinze, Thomas Reiss and Ulrich Schmoch (1997), "Technologische Position Deutschlands im internationalen Wettbewerb", ISI, Karlsruhe.

Hageman, Howard G (1985), "Freisetzungs- und Kompensationseffekte neuer Technologien: Zur Gefahr einer technologischen Arbeitslosigkeit", in F Buttler, J Kühl and B Rahmann (editors), *Staat und Beschäftigung: Angebots- und Nachfragepolitik in Theorie und Praxis* (Butler *et al*, Nürnberg) pages 291–336.

Hall, Bronwyn H and Francis Kramarz (1998), "Effects of technology and innovation on firm performance, employment, and wages", *Economics of Innovation and New Technology*, 5(2–4), pages 99–108.

Helmeier, Heinz W, Wilhelm Göbel and Peter Brugger (1995): "Ausgaben für biotechnologische Forschung", Metzler-Poeschel, Statistisches Bundesamt, Wiesbaden.

Hüsing, Bärbel, Gerhard Jaeckel, Stefan Wörner and Andreas Würth (2000), "The introduction of process-integrated biocatalysts in companies. Effect of dynamics in internal and external networks. Modern biotechnology and the greening of industry", final report for the Institute for Prospective Technological Studies (IPTS), Seville.

ISB, Informationssekretariat Biotechnologie (1999), personal communication.

ISB, Informationssekretariat Biotechnologie (2000), <http://www.i-s-b.org>, last accessed 26 September 2001.

Jungmittag, Andre, Guido Reger and Thomas Reiss (editors) (2000), *Changing Innovation in the Pharmaceutical Industry* (Springer, Berlin).

Katsoulacos, Yannis (1986), *The Employment Effect of Technological Change* (Wheatsheaf, Brighton).

Klauder, Wolfgang (1986), "Technischer Fortschritt und Beschäftigung. Zum Zusammenhang von Technik, Strukturwandel, Wachstum und Beschäftigung", *MitAB*, 1, pages 1–19.

Kleinknecht, Alfred, Jeroen Reijen and W Smits (1993), "Collecting literature based innovation output indicators: the experience in the Netherlands", in A Kleinknecht and D Bain (editors), *New Concepts in Innovation Output Measurement* (St Martin's Press, New York).

König, Heidi (1987), "Innovationsaktivität und Beschäftigung: Einige empirische Ergebnisse", in R Henn (editor), *Technologie, Wachstum und Beschäftigung* (Springer, Berlin, Heidelberg) pages 1008–1017.

Lucas, Robert E (1988), "On the mechanics of economic development", *Journal of Monetary Economics*, 22, pages 3–42.
Lumme, Annarette (1994), "Potential for growth: employment creation effects of the most promising technology based entrepreneurial companies in Finland", paper presented at International Conference on High Technology Small Firms at Manchester Business School, Manchester, 1994.
Macilwain, Colin (2000), "World leaders heap praise on human genome landmark", *Nature*, 405, pages 983–985.
Menrad, Martina, Bärbel Hüsing, Klaus Menrad, Thomas Reiss, Sigrid Beer-Borst and Christoph A Zenger (2000), *Technology Assessment Functional Food* (SWTR, Bern).
Mlot, Christine (1998), "Plant biology in the genome era", *Science*, 281, pages 331–332.
Momma, Stefan and Margaret Sharp (1999), "Developments in new biotechnology firms in Germany", *Technovation*, 19, pages 267–282.
Mustar, Philippe (1997), "How French academics create hi-tech companies: the conditions for success or failure", *Science and Public Policy*, 24(1), February, pages 37–43.
Olofsson, Christer and Clas Wahlbin (1993), "Firms started by university researchers in Sweden — roots, roles and growth patterns", *Frontiers of Enterpreneurship Research* (Babson College, Wellesley) pages 610–620.
OTA, Office of Technology Assessment (1991), "Biotechnology in a global economy", OTA-BA-949, Washington DC.
Pavitt, Keith (1984), "Sectoral patterns of technological change: towards a taxonomy and a theory", *Research Policy* , 13(6), pages 343–373.
Pavitt, Keith, Martin T Robson and Joe A Townsend (1987), "The size distribution of innovating firms in the UK: 1945–1983", *Journal of Industrial Economics*, 35(3), pages 287–316.
Penzkofer, Horst, Heinz Schmalholz and Lothar Scholz (1989), *Innovation, Wachstum und Beschäftigung. Einzelwirtschaftliche, sektorale und intersektorale Innovationsaktivitäten und ihre Auswirkungen auf die deutsche Wirtschaft in den achtziger Jahren* (de Gruyter, Berlin, New York).
Pianta, Mario, Rinaldo Evangelista and Giulio Perani (1996), "The dynamics of innovation and employment: an international comparison", *STI Review* (Science Technology Industry) English edition, 18, pages 67–94.
Prognos AG, Fraunhofer-ISI, Forschungsagentur GmbH (1995). *Programm "Förderung der Biotechnologie in der Wirtschaft". Wirkungsanalyse* (Prognos, Basel).
Ramser, Hans J (1993), "Grundlagen der 'neuen' Wachstumstheorie", *Wirtschaftswissenschaftliches Studium*, 22, pages 117–123.
Reiss, Thomas, Doris Holland and Klaus Menrad (1995), *Wirkungsanalyse zum Programm "Förderung der Biotechnologie in der Wirtschaft". Arbeitspapier zur Potential- und Wirkungsanalyse* (Fraunhofer Institute for Systems and Innovation Research, Karlsruhe).
Reiss, Thomas and Sybille Hinze (2000), "Innovation process and techno-scientific dynamics", in A Jungmittag, G Reger and T Reiss (editors), *Changing Innovation in the Pharmaceutical Industry* (Springer, Berlin) pages 53–69.
Romer, Paul M (1986), " Increasing returns and long-run growth", *The Journal of the Political Economy*, 94, pages 1002–1037.
Romer, Paul M (1989), "Capital accumulation in the theory of long-run growth", in R J Barro (editor), *Modern Business Cycle Theory* (Harvard University Press, Cambridge MA).
Romer, Paul M (1990), "Endogenous technological change", *Journal of Political Economy*, 98(3), pages 71–102.
Rothwell, Roy (1983), "Innovation and firm size: the case of dynamic complementarity", *Journal of General Management*, 8(6), pages 5–25.
Soete, Luc and Marcela Miozzo (1989), "Trade and development in services: a technological perspective", Working paper no 89-031, MERIT, Maastricht.
Solow, Robert M (1956), "A contribution to the theory of economic growth", *The Quarterly Journal of Economics*, 70, pages 65–94.
Solow, Robert M (1957), "Technological change and the aggregate production function", *Review of Economics and Statistics*, 39, pages 312–320.
Solow, Robert M (1991), "New directions in growth theory", in B Gahlen, H Hesse, H J Ramser and G Bombach (editors), *Wachstumstheorie und Wachstumspolitik — ein neuer Anlauf* (Mohr-Siebeck, Tübingen) pages 3–17.
Stern, Nicholas (1991), "The determinants of growth", *Economic Journal*, 101, pages 122–133.
Stolz, Peter and Paul Camenzind (1992), *Innovationen, Beschäftigung und Arbeitswelt, Chancen und Risiken aus ökomischer Sicht* (Rüegger, Chur and Zürich).
Stoneman, Paul (1983), *The Economic Analysis of Technological Change* (Oxford University Press, Oxford).
Storey, David J and Bruce S Tether(1998), "New technology based firms in the European Union: an introduction", *Research Policy*, 26(9), pages 933–946.
Streck, Wolf R and Bernhard Pieper (1997), *"Die biotechnische Industrie in Deutschland: Eine Branche im Aufbruch"* (Ifo Institut für Wirtschaftsforschung Studien zur Industriewirtschaft 55, München).
Tether, Bruce S (2000), "Small firms, innovation and employment creation in Britain and Europe. A question of expectations...", *Technovation*, 20, pages 109–113.
Tether, Bruce S and Silvia Massini (1998), "Employment creation in small technological and design innovators in the UK during the 1980s", *Small Business Economics*, 11, pages 353–370.
Van Reenen, John (1997), "Employment and technological innovation: evidence from U.K. manufacturing firms", *Journal of Labor Economics*, 15(2), pages 255–284.
VFA (2000), *Statistics 2000* (VFA, Berlin).
Walsh, Gary (2000), "Biopharmaceutical benchmarks", *Nature Biotechnology*, 18, pages 831–833.
Westhead, Paul and Marc Cowling (1995), "Employment change in independent owner managed high technology firms in Great Britain", *Small Business Economics*, 7(2), pages 111–140.
Wörner, Stefan, Thomas Reiss, Klaus Menrad and Martina Menrad (2001), "European Biotechnology Innovation Systems (EBIS) — case studies Germany", Report to the European Commission, contract number SOE1-CT98-1117.
ZEW, Zentrum für Europäische Wirtschaftsforschung, Mannheim; FhG-ISI, Fraunhofer Institut Systemtechnik und Innovationsforschung, Karlsruhe *et al* (1999), *Beteiligungskapital und technologieorientierte Unternehmensgründungen* (Gabler, Wiesbaden).
ZVE, Zentralverband Elektrotechnik- und Elektronikindustrie (2001), "Elektrotechnik weiter im Auftrieb", press release 5/01, February, Frankfurt.