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## **Diffusion and economic impacts of biotechnology – a case study for Germany**

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**Abstract:** While the economic impact of biotechnology is disputed, empirical data and research about diffusion and economic impacts of biotechnology in application sectors is rather limited. In this paper, actual and prospective diffusion of biotechnology in different application industries is analysed on a disaggregated level by combining production data with a written expert survey. On the basis of these results, an input-output model was used to calculate the direct and indirect employment effects of biotechnology in Germany for the years 2004 and 2020. The results suggest a further diffusion of biotechnology in all application sectors. The subsequent employment occurs in both application industries and upstream sectors.

**Keywords:** biotechnology; technology diffusion; employment; input-output model; Germany.

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## 1 Introduction

It is often claimed that biotechnology will be the next technology to deeply transform the economy and society. According to such opinions, the development and application of biotechnology has the potential for far-reaching economic, social and environmental impacts. Consequently, biotechnology would gain in strategic importance to knowledge-based economies and their governments. Nations that fail to develop biotechnology capabilities will lag behind others in realising economic impacts (Arundel, 2003). On the other hand, the potentially revolutionary impact of biotechnology is called into question. In particular, the failure as yet to achieve major breakthroughs in industry, the public's fears and opposition, as well as the currently limited applications to certain manufacturing and resource sectors raises scepticism about the future (Hopkins et al., 2007; Pisano, 2006; Arundel, 2003; Freeman, 2003).

To gain further insight into this debate empirical data accompanied by adequate foresight procedures are needed. But, to date, measurement of biotechnology is still in its early stages and there is a lack of comparable data on the impacts of biotechnology (OECD, 2005; Rose and McNiven, 2007; Senker et al., 2007).<sup>1</sup> Moreover, existing conceptualisations and surveys provide little information about the diffusion of biotechnological techniques in application sectors and their consequential economic effects.

Therefore in this paper, actual and prospective diffusion of biotechnology in different application industries is analysed and related employment impacts are assessed. Diffusion of biotechnology is assessed using a bottom-up approach. Values for production groups on a disaggregated level are combined with techno-economic data and expert judgement to determine the extent of diffusion. The combination of these various types of information is often acknowledged to give accurate results. To gain further insight, potential developments in future diffusion scenarios are considered. This approach is applied to four application sectors in Germany for the years 2004 and 2020.<sup>2</sup> Biotechnology-related employment is analysed using an integration of the results of biotechnology diffusion in an adjusted input-output model.<sup>3</sup>

This paper begins with a short overview of the theoretical arguments regarding economic impacts of emerging technologies. Following this overview, it discusses statistical and measurement issues relating to the impacts of biotechnology. The focus lies on the usage of biotechnological methods in application industries. In Section 3, the methodology applied in this study for measuring diffusion and economic impacts of biotechnology is introduced. The results of current and potential diffusion paths as well as related employment figures are given in Section 4. Finally, Section 5 summarises the main findings and discusses the limitations of the research results.

## 2 Background

### 2.1 Theoretical overview

The understanding of how a new technology impacts on the economy is a pre-requisite for developing an adequate methodology for impact measurement. But theories differ in their arguments and emphasise different channels of impact (Smith, 2001). In the

following, interesting implications for the long-term impact of generic technologies like biotechnology from concepts of general purpose technologies (GPTs) are discussed, as these account more properly for the differentiated effects of different types of technological change (Palmberg and Nikulainen, 2007).

According to Lipsey et al. (2005) a GPT “is a single generic technology, recognisable as such over its whole lifetime, that initially has much scope for improvement and eventually comes to be widely used, to have many uses, and to have many spillover effects”. The evolution of the GPT is indicated by the increasing efficiency with which it delivers its services and the increasing range of its applications. New products are created, therefore, and process improvements increase the productivity of existing products. When the GPT matures it spreads throughout the economy and generates an impact on the long-term growth of production and productivity. But such technologies take a long time to diffuse and even longer to have an economic impact. The respective facilitating structure or techno-economic paradigm has to be adjusted to fit the changes in the new technologies. These adjustments involve new forms of best-practice organisation, new skill profiles in the labour force, new location patterns, new infrastructures, new consumption patterns, new types of dominant firms, new regulations, etc. (Smith, 2001). But, because of coordination problems and uncertainty among the actors, as well as the inertia effects of fixed capital and the need for complementary innovations, this process is often costly and slow.

Hence the economic impact of a GPT depends on a myriad number of factors. Lipsey et al. (2005) emphasise the importance of the productivity of the GPT relative to that of the technology it is replacing; whether the new GPT is a substitute or a complement to existing technologies; the relation of the GPT to the existing facilitating structure of the economy, and the inherent properties of the GPT itself. For this reason, no clear-cut conclusions can be drawn on the economic impacts of such technologies. This is especially true in respect to employment, which has long been debated in compensation theory. On the one hand, the claim is that technological change mainly increases the potential for rationalisation, which leads to displacement of labour. On the other hand, various market compensation mechanisms can counterbalance the initial labour-saving impact of process innovation (Vivarelli, 1995; Petit, 1995; Pianta, 2004). One example of a GPT is ICT. Computers and related equipment are used in most of the industries making up the economy, and have made possible new ways of organising firms, of facilitating the emergence of new sectors (e.g., software) and of boosting productivity after a certain time-lag (Guerrieri and Padoan, 2007). But the employment impact of ICT is rather unclear, as impact differs widely between sectors and depends on different factors such as institutional settings and demand dynamics (Antonucci et al., 2003).

As noted above, the potential of biotechnology to become an important technology like a GPT is hotly debated and controversial. It is widely accepted that biotechnology appears to meet the requirement of having a wide range of applications (within human and animal health, industrial processing and almost all resource-based sectors, such as agriculture, forestry, aquaculture, and mining) while its range (e.g., shares of production in application sectors) and impact on productivity, as well as its scope for creating new products, is disputed. Accordingly, we focus our empirical approach on these aspects.

## 2.2 *Measurement of the impact of biotechnology*

The measurement of the economic impact of biotechnology is still in its early stages and faces significant challenges. Questions arise with regard to constructing an adequate and useful definition for biotechnology<sup>4</sup>, the conceptualising of various indicators and especially the collection of the data and integration with other statistics (Rose and McNiven, 2007).

Most of the economic effects from technologies with wide applications like ICT and biotechnology are expected from their diffusion and adoption by user firms in application industries (OECD, 2005). However, production or provision of technologies only generates limited impact as the rather small production shares of ICT-producing sectors illustrate. Unfortunately, the definition and separation of users and producers is not straightforward for biotechnology. The main activities carried out by biotechnology firms are research and development, the use of biotechnology techniques to produce goods or services and the use of biotechnology products as an input for manufacturing (OECD, 2005; Lim and Choi, 2006). The latter is excluded from analysis by the OECD, although it admits that the boundaries between key activities and some end uses are not always clear. A similar concept is used in this study. To be counted as a biotechnological product there must be an additional biotechnological step which builds on an intermediate step. Moreover, the provision of biotechnology know-how and techniques on the one hand (technology producers), and the use of biotechnology techniques to produce goods or services on the other hand, are separated. While the former mainly includes universities and R&D institutions, small and medium-sized dedicated biotechnology enterprises, and biotechnology suppliers, the latter includes application industries like the pharmaceutical industry, the chemical industry, the food-processing industry and so on.<sup>5</sup> But it has to be remembered that some firms can be engaged in biotechnology research and also use biotechnology as a production technique.

Most surveys of biotechnology are conducted as special biotechnology-firm surveys from private consulting or official institutes (e.g., E&Y, 2007). Although they are important in providing some basic information about research and commercialisation in biotechnology, they have, up until now, demonstrated several shortcomings. First they tend only to cover dedicated biotechnology firms, which are predominantly active in biotechnology. Some of them cover diversified 'innovative active firms', which conduct R&D in biotechnology amongst other non-biotechnological activities. But, to date, there are hardly any surveys on firms that use biotechnology but which do not perform R&D in biotechnology (IPTS, 2007)<sup>6</sup>. Second, while these surveys usually provide information about basic indicators like turnover, employment and R&D, there is for the most part no information about important indicators like trade, investments, value added or productivity. An important step in obtaining useful and comparable indicators would be the integration of biotechnology-specific data in official production statistics. This would help to connect it with other economic measures and to construct biotechnological-specific indicators like productivity, value added, trade, and so on. This could be realised on the basis of the firm or by changes in commodity classifications, but both options present difficulties: in terms of the firm, it is almost impossible to calculate separate indicators for biotechnology in diversified firms. Moreover, biotechnology-related applications are spread across a number of very diverse existing industrial sectors, e.g., food production, textile finishing, pulp and paper, agriculture, power generation, chemicals and petrochemicals, and pharmaceuticals. So the

construction of a NACE-based definition of a sector that provides or uses biotechnological methods is highly unfeasible, as it is difficult to set up clear-cut criteria to determine which sector diversified firms belong to.

In order to identify biotechnology by commodity classifications, would necessitate major changes to the classification system. Product classification does not usually distinguish between alternative production processes. So for many products a distinction between biotech and conventional (e.g., chemical) production processes as well as the introduction of some new ones would be necessary. Moreover, biotechnology is a dynamic field and certain biotechnological production methods will probably soon be expanded to other, or completely new, products (Brink et al., 2004).

Up-to-date official statistics and existing firm surveys can therefore provide only limited information about the diffusion of biotechnological techniques in application, and the economic impact of this (OECD, 2005; Rose and McNiven, 2007). To fill this information gap and to provide some foresight and scenarios for the future, various techno-economic studies have been carried out using a mix of methods and sources, often based mainly on expert judgement, case-studies, and various statistical data. For example, Dewick et al. (2006) investigate the effects of biotechnology on economic structure by examining expert judgements on potential change of input-output coefficients. Menrad et al. (2003) analyse the employment impact of biotechnology in Germany with a hypothetical diffusion rate of 100% in 25 years within relevant product groups.

An alternative for measuring the diffusion of biotechnology in application for major application sectors is the biotechnology-related-sales (BRS) concept (see Section 3.2, OECD, 1998; McKinsey & Company, 2003; Deke, 2005; Reiss et al., 2008). This raises a lot of methodological questions, such as the correctness and comparability of the data used, the usefulness of expert judgement and the underlying assumptions. Existing studies have used quite different approaches for measurement (definition of biotechnology, aggregation level, examined sectors, scenario assumptions, etc.), some of them with very optimistic results, which has led to criticism (Herrera, 2004; Arundel, 2002). In the following, a proposition for an alternative measurement for the BRS concept is applied to the case of Germany in the years 2004 and 2020. Methodological challenges and potential means of improvement are discussed. Moreover, in order to assess the impact of biotechnology diffusion the indicator is linked with an input-output model to study employment effects.

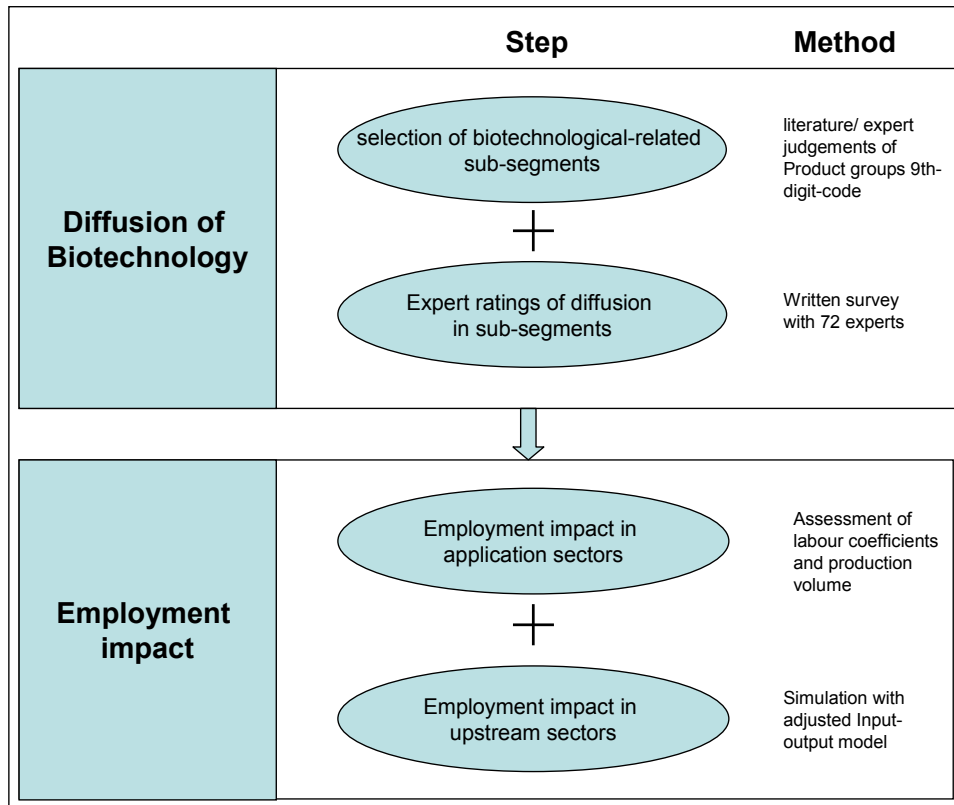
### **3 Methodology**

#### *3.1 Overview*

The methodological approach used in this study consists of two phases: on the one hand the analysis of diffusion and on the other hand the analysis of the employment impact. First the present and potential future diffusion of biotechnology in application sectors was ascertained. As a wide diffusion of technology is the main condition for economy-wide impacts, but this is still unclear in the case of biotechnology, the main emphasis of our research focuses on this aspect. The four sectors with the highest assumed diffusion of biotechnology were analysed: chemicals, pharmaceuticals, food-processing and agriculture. On the basis of these results, the related employment effects of biotechnology were assessed. In order to study the impact on the whole economy, the indirect

employment effects of those economic activities that make biotechnological production possible also have to be considered. So, besides direct employment in application sectors related to the use of biotechnology, employment impacts via backward linkages using an input-output model were also calculated.<sup>7</sup> The overall methodological approach is summarised in Figure 1 and discussed in more detail in the following.

**Figure 1** Methodological approach for the analysis of diffusion and economic impact of biotechnology (see online version for colours)



### 3.2 Diffusion of biotechnology

In order to analyse the diffusion of biotechnology across various sectors in a comparable way it must be measured in monetary terms. Therefore, the BRS concept is used for major application sectors. This concept evaluates the extent of adoption of biotechnology in monetary terms within the different application sectors. It captures different categories of market contributions from biotechnology products, the sales of new products directly attributable to the use of modern biotechnology, and sales of products manufactured by improved processes that make direct use of modern biotechnology. Where modern biotechnology or derived products are used at certain stages of a production process, the output is calculated as being entirely due to the impact of modern biotechnology, although the modern biotechnology-based process may be just one amongst several non-biotechnological steps in the production process. An important assumption behind

this interpretation is that biotechnological methods have been taken up by the user in order to be, and to remain, competitive in the respective product market.

To assess the BRS for the applications sectors, production data were combined with information taken from the literature and expert judgements. One major concern here is the aggregation level. Information derived from the literature, or expert judgements on a highly disaggregated level are far from being widely available. But a high aggregation level may be a possible source of overestimation when using such an approach. Experts are often unaware of aggregate values, e.g., the share of turnover of different product groups in the chemical sector. So their estimations for the share of biotechnology in a sector may be biased, even if they are able to give plausible estimations for the share of biotechnology in the production of specific products. Therefore, in order to investigate the impact of aggregation level on the results, the use of a combination of experts' bottom-up (disaggregated production groups in an application sector) and top-down (whole application sectors, e.g., the pharmaceutical industry) ratings is proposed in this paper in order to check for consistency. In the 'bottom-up' approach the biotechnology turnover share for product groups is analysed. For each product group the turnover share of biotechnology was multiplied by the total sector share of sales of these products and added up to provide a total share of biotechnology turnover in the respective sector.<sup>8</sup> In the 'top-down' approach the turnover share for the whole application sector is assessed.

The main problem in conducting a bottom-up approach is getting a sufficient number of experts for specific products, such as the 800-odd chemical products on the 9-digit code of product classifications set out in the European Community Production survey (PRODCOM). Because of that, products that are already produced by biotechnological methods or where the technological feasibility of biotechnological production is assumed, were selected on the basis of expert opinions and literature. These products were aggregated to 10–15 product groups mainly using the 6-digit code of the PRODCOM classification were aggregated (see Annex, Table 1). On this basis experts from universities, research institutes and industry were asked about the share of biotechnology turnover in 2004 and 2020 from a 'bottom-up' and 'top-down' perspective. In addition, the effects of biotechnology innovation (e.g., new products) in each sector and aggregated product groups were assessed by the experts. Most of these experts were from firms using bio techniques for the production of goods and services. It is assumed that they have the best knowledge when it comes to comparing competing technologies and that they are probably less biased in terms of providing over-optimistic estimations, as their own reliance on the prosperity of biotechnology is relatively low. In total, 72 experts answered the questionnaire. A modification of this approach is carried out for the agriculture sector, in which the measurement of biotechnology is very challenging. While genetic-modifying techniques (GM) are often considered to have the highest potential in increasing yields and competitiveness, future diffusion is especially uncertain. It relies heavily on consumer acceptance and regulation. Because of this, expert ratings for GM techniques and other biotechnological processes were asked for separately. As expected, the latter showed an enormous divergence in opinion even for 2020, and was not considered further, with only non-GM-related sales being included in the indicator.

In order to check the consistency of this approach the results were discussed in expert interviews, and triad patent analysis for the share of biotechnology in the application field in 2004 was carried out. The share of biotechnology patents amongst all patents in an

application field was found to be within the range of the biotechnology turnover share. The patent analysis thus confirms the results for market diffusion of biotechnology, but it must be kept in mind that comparability of these indicators is limited.

### 3.3 *Employment impact*

On the basis of these diffusion indicators the employment effects of biotechnology for Germany are considered. For the respective upper and lower limits in 2004 and 2020 scenario values for employment are calculated. The numbers can be interpreted as a plausible corridor of employment that is affected by the use of biotechnology methods in the main application sectors.

In a first step, the biotechnology-related production volume was calculated by multiplying the biotechnology turnover share by the sectoral production volume. Problems could arise as the former is based on sales, while the latter is measured by production values. As there were no major differences in value for the sectors in 2004, they could be assumed to be roughly equal. For 2020, the sectoral production volume was estimated based on past trends from 1995 and 2004, and the results were fairly consistent with other prospective outlook studies (e.g., Prognos, 2002).

Directly-related employment effects in application sectors were calculated by multiplying the biotechnology-related production volume and employment coefficients (gainfully employed persons per unit of gross production value). There are no indications for major differences in labour intensity between biotechnological and conventional products (see Section 4.2), and the same coefficients used for respective sectors by the Federal Statistical Office were assumed. In order to include employment effects in upstream supplier sectors, an input-output model is used to calculate the employment impacts of biotechnology in Germany for the years 2004 and 2020. Input-output modelling reveals supply and demand linkages between different industries. For example, a particular industry will use the output of other industries as intermediate inputs in its own production processes. The basic IO model used in this study is based on the input-output tables produced by the Federal Statistical Office for the year 2002. They divide the German economy into 71 production and service sectors and six end-user sectors (including, among others, private and state consumer demand, and export).

Since the production value of each sector is made up of the sum of supplies to intermediate and final demand, it is true that:

$$X = AX + Y$$

where  $X$  is total output,  $Y$  is the final demand and  $A$  is the technology matrix. The correlation between final demand and production can be formulated within this static input-output model as follows:

$$X = (I - A)^{-1} * Y.$$

Assuming a roughly linear correlation between the level of employment in a sector and the level of production in a sector, the following employment effects result:

$$L = l * X$$

where  $l$  stands for the employment coefficient  $l_i$  in sector  $i$ .  $L$  is the total employment in the economy.



It is sometimes argued that IO models are not appropriate for long-term studies as the IO production function does not allow for substitutions among inputs and technological change.<sup>9</sup> But as demonstrated in several studies (e.g., Faber et al., 2007) adjustments can be made, and such adjustments were made here for biotechnology. To adjust and project the input-output coefficients under biotechnological progress, it is best to have the input-output data for each biotechnical process, which in fact requires the establishment of unprecedented biotechnological input-output tables (Pan, 2004). However, as such data do not exist, the most appropriate sectors within existing input-output tables were chosen and adjustments were made accordingly, based on expert and literature-based information. One example is the higher backward linkages of the chemical sector to agriculture as a result of higher production of bioethanol and biotechnologically-produced polymers on the basis of biomass. Sensitivity analysis for input-output coefficients shows that variances are rather small, as it is mainly the degree of diffusion of a technology that triggers this kind of impact. In order to analyse the employment impact in 2020, developments in production shares and productivity were estimated on the basis of past trends, available theoretical and empirical evidence and results from other relevant studies (e.g., IPTS, 2002) in order to avoid biases in estimates of employment.

## 4 Results

### 4.1 Diffusion of biotechnology

As Table 1 shows, biotechnology is already influencing major application sectors. As is usual in new technology fields, the market penetration in 2004 and 2020 contains uncertainties. The diffusion rates are therefore quoted with upper and lower limits. Especially high variances appeared for 2004 in the food-processing and agricultural sectors. One reason for this seemed to be different interpretations of the proposed definition of modern biotechnology. For all applications the bottom-up results were below the estimates of experts for the whole sector. This may be a hint that studies on a high aggregation level might overestimate the impact of biotechnology. Hence the values were based on bottom-up results that were chosen and rated slightly higher (on average about 1%), as the top-down estimates may capture certain biotechnological applications that were not considered in the bottom-up product groups.

**Table 1** Biotechnology turnover share for 2004 and 2020 (in per cent, referring to the production value of the whole industry)

<i>Application industries</i>	<i>Biotechnology turnover share 2004</i>	<i>Biotechnology turnover share 2020</i>
Scenario figures chemicals	4–6%	9–18%
Scenario figures pharmaceuticals	11–18%	18–40%
Scenario figures food-processing	9–23%	17–32%
Scenario figures agriculture	11–20%	26–42%

The numbers indicate a more or less similar diffusion rate in pharmaceuticals, food-processing and agriculture, while the overall diffusion rate in the large heterogeneous chemicals sector is the lowest. In all sectors diffusion is expected to rise significantly by 2020. This conclusion also holds on the basis of product groups where the growth rates also differ significantly. In general, those product groups with the highest penetration in 2004 are also expected to have the highest diffusion rate in 2020.

As indicated by the wide range of upper and lower limits, there is quite a high level of uncertainty about the diffusion of biotechnology. The expectations for 2020 in particular are highly uncertain, as fast and slow diffusion can differ widely. The diffusion of biotechnology is influenced by various factors whose development is rather uncertain. The analysis of diffusion barriers shows some parallels with the development of former GPTs, although analogies should not be stretched too far. In the following literature diffusion barriers are highlighted:<sup>10</sup>

- Biotechnological knowledge is still in its early stages. Despite all the progress achieved over recent years, insights are still limited and there is uncertainty as to how much is yet to be discovered, how long progress may take and what sort of unfavourable side-effects may emerge (Pisano, 2006; Hopkins et al., 2007). Moreover, just as former GPTs' complementary technical and organisational innovations in surrounding infrastructure required adequate financing structures, so business models and integration within broader systems like the linked structures of chemicals production need to be achieved (Kern and Enzing, 2003). But these can take decades to be generated, which means that new technologies are often subject to high and increasing development costs in subsequent decades and the timescale of possible effects are unclear.
- An important barrier in the past was the lack of appropriate skills (e.g., in biochemistry) and a lack of willingness among chemists and chemical engineers within firms to invest in this competing technology (Freeman, 2003; Nusser and Wydra, 2007). Also, limits to growth in the future will probably be only partially dictated by the availability of natural resources but also by access to verified scientific knowledge and specialised skills (IPTS, 2002).
- One major factor hampering progress in the past was public acceptance (Lipsey et al., 2005; Freeman, 2003). Although in certain fields (e.g., health, industrial biotechnology) an increasing acceptance seems to be emerging, this may still be a significant barrier in other fields (e.g., GMO-modified food), (Nusser and Wydra, 2007). Demand from consumers may remain low and public policy in regard to biotechnology may be influenced in various ways.

In addition, several other diffusion factors exist (regulation, costs of natural resources etc.), (Nusser and Wydra, 2007). Hence the future development of biotechnology depends on various factors that may interact with each other and are hard to predict.

#### 4.2 *Employment impact*

The results of biotechnology-related employment impacts are listed in Table 2.

**Table 2** Employment impacts in the 2004 and 2020 scenarios in full-time equivalents (FTE)<sup>1</sup>

	<i>Direct biotechnology-related jobs gross employees (in thousand FTEs)</i>		<i>Upstream supplier jobs indirect/induced gross employees (in thousand FTEs)</i>	
	<i>2004</i>	<i>2020</i>	<i>2004</i>	<i>2020</i>
Pharmaceuticals	12,4–20,4	17,8–39,6	13,1–21,5	22,7–50,5
Chemicals	9,8–14,7	18,0–35,9	27,2–40,8	64,2–128,3
Food-processing	69,6–177,7	108,0–203,2	123,4–315,2	185,7–349,5
Agriculture	68,8–125,1	107,4–173,5	44,3–80,6	74,2–119,8
Total	160,6–337,9	251,2–452,2	208,0–458,1	346,8–648,1

Notes: <sup>1</sup>No sectoral sums for direct and indirect employment are calculated as significant double counting could occur. E.g., the pharmaceutical industry purchases biotechnology-produced inputs from the chemical firms with biotechnology or biotech-SMEs inputs of the biotech suppliers/outfitters. Owing to a lack of differentiated statistical data it is not feasible to identify the magnitude of the double counting and it was therefore considered best to avoid this calculation.

In 2004, a total of about 160,600 to 337,900 persons were employed in direct biotechnology-related jobs. The majority of these employees were working in the food-processing and agricultural industry in which the proportion of the total costs or the total value added as a result of being influenced by modern biotechnology is often low. In this sense it can be assumed that a high proportion of these jobs are currently only slightly affected by modern biotechnology methods, technologies or products. In upstream sectors the figure is around 208,000 to 458,100 employees. These impacts mainly occur in upstream service sectors (e.g., biotechnological suppliers).

Because of future diffusion the number of employees in direct biotechnology-related jobs increases in 2020 to around 251,200 to 452,200. The main impact emerges in the food-processing industry with 108,000 to 203,200 employees and in agriculture with ca. 107,400 to 173,500 employees. But the greatest change compared to 2004 is estimated to occur in the chemical industry (ca. 18,000 to 35,900 employees) and pharmaceutical industry (approx. 17,800 to 39,600 staff). In upstream sectors around 346,800 to 648,100 employees for the application sectors result. In sum, the upstream employment effects are greater than the direct biotechnology-related employment impacts of biotechnology, not only in 2004 but also in 2020.

To gain further insight into the kind of economic impact and consequences possible for employment, the experts in the written survey were asked in more detail about their estimation of the kind of economic impact biotechnology has/will have. The results are listed in Annex Table 2. The greatest importance is attributed to the creation of new products or quality improvement as well as to innovation in processes. Only negligible effects are estimated in terms of reduction of labour. Thus, in contrast with other technologies (e.g., ICT), biotechnology does not seem to have a high direct labour-saving effect. More surprisingly, relatively little importance is attributed to savings in energy and materials, which are often suggested in studies. However, some differences between the sectors are noted. As supposed, the importance of new products is believed to be especially high in the pharmaceutical industry. In the food-processing industry the main impact is the reduction in the use of inputs and less pollution to the environment, while in agriculture all possible advantages are of lesser significance. In looking ahead to 2020 the

importance of biotechnology is estimated to increase, while the kinds of advantages are estimated to remain the same.

## **5 Conclusions**

### *5.1 Discussion*

We conclude that biotechnology is on the way to becoming increasingly relevant to the economy and is likely to gain in importance in several application sectors in the next 10 to 15 years. Comparison of the employment estimations for 2004 and 2020 reveals an interesting point: the increasing share of biotechnology in application sectors and its backward linkages to suppliers exceeds the tendency of these application sectors to reduce employment via productivity effects. The economic importance of biotechnology increases through its diffusion in mature manufacturing sectors. On the other hand, the results also show limitations in the impact of biotechnology. Diffusion in these main application sectors will affect only limited parts of overall employment – around 40 million persons in Germany – in the whole economy. Only if biotechnology increases in other sectors might a major economy-wide impact emerge. But to date the diffusion in other sectors can be assumed to be rather low (Reiss et al., 2008). Moreover, there are uncertainties as to the level and timing of future diffusion. Several diffusion barriers exist, which could hamper the development and diffusion of biotechnology. How deeply biotechnology may transform the economy depends especially on its potential to enable the creation of new products and to improve the efficiency in the production of existing products (Section 2.1). In the written survey part of this study, experts expected that biotechnology would enable the creation of many products but the potential for increasing labour productivity is considered to be limited. This corresponds to other findings in the literature (e.g., Hopkins et al., 2007). So what does this mean with respect to questions about revolutionary and economy-wide impacts? One suggestion is that biotechnology may transform the economy and society in a different way from that of GPTs like ICT. Major boosts for economic growth may emerge in combination with other technologies or efficiency gains, which raise productivity and purchasing power to realise the fruits of biotechnology.

### *5.2 Measurement issues*

Due to limited data availability the methodological approach shows certain limitations, but it also opens up views worthy of further research. In this study, the BRS concept was used for four application sectors and does not therefore capture all the application fields within biotechnology. Moreover, there are two major criticisms against the BRS concept. First, the sales of a product are totally valued to biotechnology although other technologies or machines contribute to production and the application segments are to a varying degree specialised in biotech-related applications. While in some applications the assumption that the use of biotechnology fosters competitive advantage is reasonable (e.g., new biopharmaceutical products) it is more crucial in traditional fields like food processing (Arundel, 2002). Second, to study the impact of the value added by biotechnology instead of sales would be a more appropriate indicator (Rose and McNiven, 2007). Nevertheless, this concept is in our view an important starting point in

evaluating biotechnological commercialisation. To obtain a more detailed picture, the use and impact (value added, productivity) of biotechnology in application sectors should be focused on more in official government studies. Studies by the Canadian statistical office provide positive examples of this (e.g., Lonmo and McNiven, 2005). But in other countries this would require new surveys, changes to existing ones, changes in the classification system and the combination of existing databases. Moreover, to get an accurate picture, in particular about changes in the economy arising from the use of biotechnology, this should in our view be complemented by non-monetary application-specific diffusion indicators (e.g., GMO field trials, biopharmaceutical new molecular entities).

The explanatory power of the results obtained for biotechnology-related employment is limited, as substitution effects (e.g., fewer jobs in conventional chemistry) could not be taken into account. In regard to analysis of the economy-wide impact of biotechnology net-impact modelling would be desirable. Besides the calculated positive gross employment effects arising from the growth in the utilisation of biotechnology know-how, negative employment effects also emerge. Conventional processes, products and services (e.g., chemical-based pharmaceutical products, fossil energy sources) could be utilised less, avoiding expenditure and investment. In addition, negative budget effects arise, such as extra costs caused by the provision and application of biotechnology processes, products and services as opposed to conventional processes, products and services (e.g., biotechnology research funding, subsidies and tax exemptions for biofuels). Moreover, dynamic effects like knowledge spillovers or learning effects for biotechnology and competing technologies should be considered. The calculation of such negative employment effects is difficult at the present time, however, as a lot of additional data and crucial assumptions would be necessary.

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## Notes

- 1 An exception is the recently published BIO4EU study, which provides a comprehensive assessment of the adoption and impact of biotechnology (IPTS, 2007; Reiss et al., 2008).
- 2 The empirical results were conducted within a project funded by the Hans-Böckler Foundation, the German Association of Biotechnology Industries (DIB) and the German Miners', Chemical and Energy Workers' Union, (IGBCE). The full study is available at [http://www.isi.fraunhofer.de/t/projekte/wettbewerb\\_beschaef\\_t\\_pot\\_bt.pdf](http://www.isi.fraunhofer.de/t/projekte/wettbewerb_beschaef_t_pot_bt.pdf).
- 3 This paper concentrates on the economic impacts of biotechnology, although these are likely to be substantially less than its impacts on environmental conditions and on quality-of-life issues (Arundel, 2003).
- 4 In this study, the OECD definition is used (OECD, 2005). The single definition defines biotechnology as "the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services."
- 5 While in this paper only diffusion and employment effects in application branches is shown, the impact on provision sectors was also calculated in the project.
- 6 The current definitions of a 'biotechnology firm', DBF, or 'biotechnology active firm', all require the firm to perform R&D in biotechnology.
- 7 Some studies include employment effects in supply firms with the use of backward linkages in input-output models. But these results also indicate that the macro-economic importance of the biotechnology industry is rather low (Hermans and Kulvik, 2005).
- 8 For 2020, possible changes in the composition of sectoral output, e.g., higher share of fine and speciality chemicals on the basis of past trends, were considered, but led to negligible changes in the biotechnological share of production.
- 9 For a detailed discussion see Faber et al. (2007).
- 10 Unfortunately, these factors could not be explicitly considered in the calculation of scenarios values, because the exact functioning and interactions of the various influencing factors is mostly unclear and important data are missing. The factors are implicitly considered by the optimistic/pessimistic valuations of the experts.

**Annex Table 1** Aggregation of product groups for the bottom-up approach to estimate biotechnology-related turnover

<i>Sector (number of product groups on 9-digit code)</i>	<i>Selected biotechnology-related sub-segments (mostly on 6-digit code of PRODCOM product classification)</i>
Chemicals (791)	1. enzymes; 2. organic acid and derivatives; 3. amino acids; 4. sugar and derivatives; 5. vitamins; 6. monomers for polymers; detergents; 7. modified fats, fatty acids, fatty derivatives; 8. surface active substances, tensides or surfactants; 9. body-care and cosmetics; 10. finishing agents for surface treatment in textile finishing and paper production; 11. colouring and varnish; 12. adhesives based on starch/protein; 13. odorous substances, flavours; 14. diagnostic and analytic reagents; 15. lubricants; 16. fertiliser based on biomass; 17. pesticides; 18. alcohols
Pharmaceuticals (94)	1. plant-based drugs and medicines (e.g., alkaloids); 2. antibiotics; 3. hormones; 4. insulin; 5. anticoagulants, antiserum, blood fractions, blood products; 6. human vaccines; 7. veterinary vaccines; 8. vitamins; 9. peptones and protein derivatives; 10. nucleic acids; 11. other chemical agents not mentioned
Food processing (452)	1. bread and baked goods (e.g., barm, sourdough, enzymes); 2. pasta; 3. modified starch; 4. sugar and derivatives; 5. candies and chocolate; 6. alcoholic beverages; 7. fermented beverages, 8. yogurt, fermented milk beverages, milk components; 9. cheese; 10. (bio)chemical modified fats and oils, 11. meat processing; 12. fruit and vegetable processing; 13. fruit and vegetable juices; 14. yeast
Agriculture*	1. Grain; crops; 2. potatoes; 3. forage crops; 4. sugar beets; 5. oil seeds; 6. vegetables; 7. fruits; 8. must/wine; 9. flowers; ornamental plants; 10. tree nursery products; 11. cattle; 12. swine; 13. poultry; 14. other animals (e.g., sheep; goats); 15. fish; 16. agricultural services

Notes: \*For agriculture the product groups were based on the national statistics of the Federal Ministry of Food, Agriculture and Consumer Protection

**Annex Table 2** Economic impact of biotechnology

	<i>Present impact</i>			<i>Future expectations (for 2020)</i>		
	<i>Low</i>	<i>Average</i>	<i>High</i>	<i>Shrink</i>	<i>Remain</i>	<i>Increase</i>
Increased range of goods and services	7%	25%	68%	3%	18%	79%
Improved quality in goods or services	19%	31%	50%	2%	27%	71%
New methods and process steps	10%	32%	58%	6%	16%	78%
Improved methods and process steps	21%	31%	48%	9%	23%	68%
Reduced labour costs per unit output	62%	21%	17%	10%	65%	25%
Reduced materials and energy per unit output	26%	37%	37%	2%	30%	68%

Source: Written survey by Fraunhofer ISI (n = 72)



**Annex Table 2** Economic impact of biotechnology (continued)

	<i>Present impact</i>			<i>Future expectations (for 2020)</i>		
	<i>Low</i>	<i>Average</i>	<i>High</i>	<i>Shrink</i>	<i>Remain</i>	<i>Increase</i>
Accelerated processes (faster time-to-market)	31%	31%	38%	3%	30%	67%
Improved flexibility of production (e.g., small plants) or service provision	24%	47%	29%	0%	34%	66%
Reduced environmental impacts or improved health and safety	16%	38%	46%	1%	25%	74%

*Source:* Written survey by Fraunhofer ISI (n = 72)