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PRODUCTION AND EMPLOYMENT IMPACTS OF NEW TECHNOLOGIES – ANALYSIS FOR BIOTECHNOLOGY

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Production and employment impacts of new technologies – Analysis for biotechnology

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Abstract

Biotechnology is often regarded as a key technology with high potential for far-reaching social, environmental and economic impacts. Among others, the development and diffusion of biotechnology may have considerable economic effects on production and employment. This paper analyzes the economic impacts of different diffusion paths of biotechnology in some major application fields. Bottom-up technology information from literature, expert judgements and explicit scenario assumptions for various impact factors are combined and integrated in an input-output framework to calculate direct and indirect production and employment effects. The impact on net production and employment differs greatly between the different application sectors and depends on the respective importance of the various impact mechanisms. The indirect economic effects are rather high and exceed direct economic effects. These findings show the importance of a bottom-up approach as well as the consideration of indirect economic effects for appropriate analyses of the impact of biotechnology.

Keywords: economic impacts of technologies; employment effects; input-output model; biotechnology;

JEL-classification: C67, O14; O33; J23

[1] This paper draws on the doctoral thesis of the author at the University of Hohenheim, Department of Economic Theory 520H. The results were presented and discussed at the FZID PhD Workshop 2009, CC Innovation & Knowledge.

1. Introduction

Biotechnology is often regarded as a key technology with high potential for far-reaching social, environmental and economic impacts. Applications are spread across a wide range of industries like pharmaceuticals, health care diagnostics, chemicals, agriculture, food, materials technology, energy, environmental monitoring etc. Consequently, biotechnology is considered to have strategic importance for knowledge-based economies. Many nations try to develop biotechnology capabilities to realize economic impacts (Arundel 2003). However, insights about potential economic impacts on a meso- or even macroeconomic level are still limited, since there are major methodological challenges to quantifying possible paths of diffusion and economic impacts of biotechnology. Most of the economic effects from technologies with wide applications like biotechnology can be expected due to its diffusion and adoption by user firms in application industries (OECD 2005). Modelling seems to be a reasonable approach towards considering impacts in application sectors and complex interactions within an economy’s set of markets. But several difficulties arise, since adequate data sources for this process technology with related applications in very diverse sectors are scarce. Moreover, the impact of biotechnology may differ widely between the various sectors, as the techniques and applications used can vary quite substantially, and different impact mechanisms may gain importance (Rose/McNiven 2007). In order to analyze the net effects of biotechnology, negative economic impacts have also to be taken into account, e.g. due to the (relative) "shrinkage" of conventional value chains or negative budget effects, caused by extra costs for the provision and application of biotechnology processes (e. g. subsidies and tax exemptions for biofuels).

Only few modelling approaches which take biotechnological diffusion in several application sectors into account currently exist. Menrad et al. (2003) and Nusser/Wydra (2007) analyze direct and indirect gross production and gross employment related to biotechnology diffusion. An important starting point for analyzing net impacts is the work of Dewick et al. (2006). They estimate the impact of biotechnology on economic structure with expert judgements for potential changes of input-output coefficients for the EU, USA and China in 2020 and 2050. While this analysis provides specific insights on the impact in various application sectors and considers differences between regions, it focuses solely on input changes in production chains.

The objective of the present study is to provide additional insights into the economic impact of biotechnology and to assess the net production and employment impacts of biotechnology diffusion in Germany. Economic impacts in several applications fields of biotechnology are modelled for different scenarios with a time horizon to 2020. Bottom-up technology information from literature, expert judgements and explicit scenario assumptions for various impact factors (e.g. diffusion rate, oil and feedstock prices, political measures) are combined and integrated in an input-output framework. The input-output model allows a disaggregated analysis and captures some of the indirect economic effects in other sectors. In order to capture the cross-sectional character of biotechnology, heterogeneous application sectors (biopolymers, bioethanol, biopharmaceuticals and biotechnological fine/specialty chemicals) in respect to type of dominant innovation, regulatory and political framework conditions, diffusion barriers as well as linkages to biomass production are selected for the analyses.

This approach enables us to study the differences in impact between application sectors and the importance of different impact factors, like diffusion rate or oil and feedstock prices. From a methodological point of view, the direct combination of different data sources, techno-economic studies as well as expert judgements builds on a broader information basis than previous studies for biotechnology. The basic input-output model is extended in several ways to take changes in demand and constraints on agricultural markets into account.

Section 2 begins with a short overview of the theoretical arguments regarding economic impacts of emerging technologies and discusses these arguments for the case of biotechnology. In section 3 the methodology applied in this study to measure diffusion and economic impacts of biotechnology is introduced. Section 4 presents the results of current and potential diffusion paths, and related production and employment figures are given in section 5. Finally, section 6 summarises the main findings and discusses the research results.

2. Economic impact mechanisms of biotechnology

The overall impact of technologies on production and employment results from the interaction of different impact mechanisms (e.g. Vivarelli 1995; Pianta 2005; Walz 2006; Zeddies 2006). In the case of employment, on the one hand it is claimed 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

2005). It is possible to discern various compensation routes that alleviate the labour-saving effects (Hagemann 1995):

- New markets for product innovations extend the total demand.
- Cost reductions resulting from more efficient production processes are passed on to the consumers via price reductions or increases in wages. In effect, this raises overall demand.
- The machines and aggregates required for these modern production processes have to be newly engineered. This leads to more jobs in the capital goods sector.
- The use of new technologies improves the international competitiveness of innovative domestic companies, thus positively influencing domestic value added and employment.
- In addition, structural effects may occur (Walz 2006). The labour intensities and the import intensities of the value chains of new products and process can differ and lead to higher or lower value added and employment.

Therefore, it is not possible to deduce the macro-economic impacts from an isolated view of some partial effects. Theoretical paradigms differ strongly in the view, which impact mechanisms dominate (Vivarelli 1995). Moreover the effects depend on the specific technology and prevailing conditions of competition, price and wage rigidities, investment climate etc. (Vivarelli 2007).

In the case of biotechnology, there is a great variety in the produced outputs, the related advantages of biotechnological methods vary and the framework conditions between application sectors differ greatly (e.g. highly regulated sectors like pharmaceuticals vs. textile etc.). Discussions by Dewick et al. (2004) demonstrate that advances in biotechnology are likely to be reflected in increased demand in some sectors (e.g. pharmaceuticals, specialty chemicals). Instead, Rose/McNiven (2007) point out that an important part of the impact of biotechnology is the result of substitution effects, such as changes in supply chains (e.g. substitution of raw materials or energy sources) and mainly refers to sectors with high demands for raw materials (e.g. bulk chemicals). Especially in this case, the effects triggered by the use of biotechnology are played out on a meso-economic level, where the more technology-related impact mechanisms dominate. Another important aspect is the rather low impact on labour productivity and cost reductions (Freeman 2003; Nusser et al. 2007a; Hopkins et al. 2007). In contrast, biotechnological production costs may even be higher for some applications. In these cases the diffusion of biotechnology is usually triggered by political measures. The additional costs (budget effect) incurred for the provision and use of products from biomass compared to traditional products must be compensated for by spending less elsewhere, e.g. through decreasing private consumption expenditure as a result of higher prices for fuels, in the case of bioethanol.

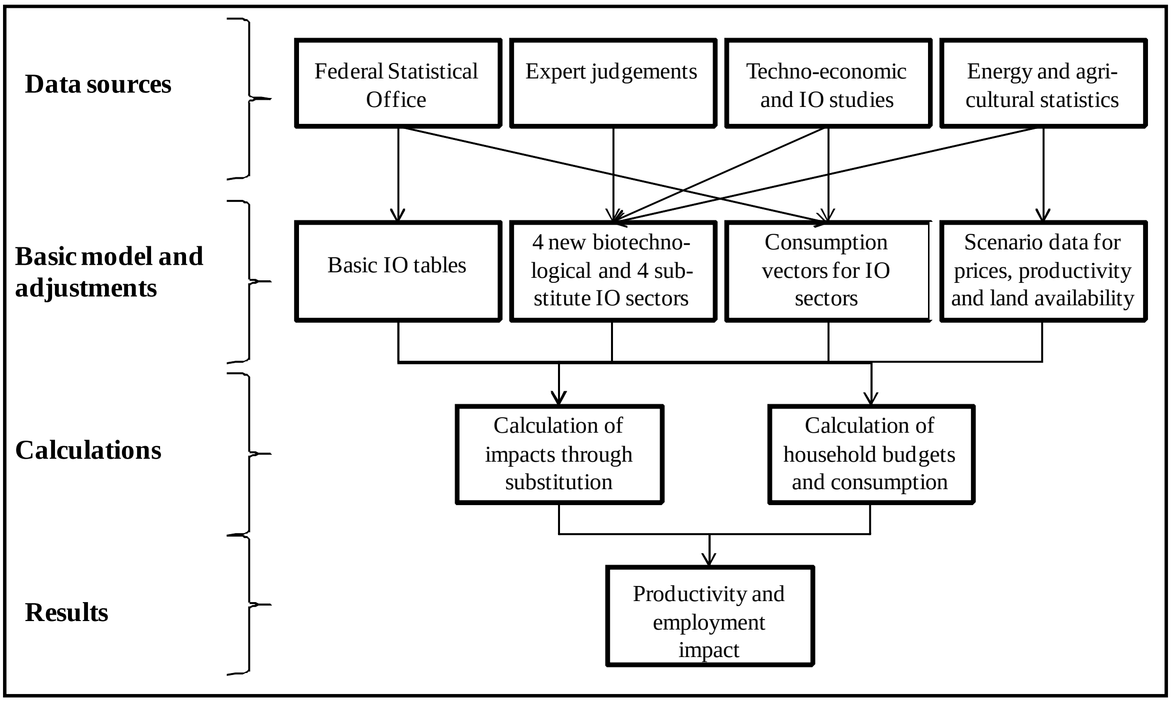
Besides the importance of different impact mechanisms, two aspects have to be taken into account in modelling biotechnology impact. Firstly, biotechnology measurement is still in its early stages and useful indicators for the impacts of biotechnology (e.g. productivity, value added, price effects) which can be linked to macro-economic models are still lacking (OECD 2005, Rose/McNiven 2007). The advantage of various models to include some mechanisms, like substitution due to price effects in the case of general equilibrium models, cannot be currently realized for biotechnology. Secondly, in some sectors biotechnological development is still in the initial stages and technological improvements are likely in the future, which greatly influence the related economic impact. Consequently, technological progress should be considered in any prospective economic analysis.

These various aspects have considerable consequences for the study design and modelling approach: instead of a highly aggregated macro-economic model, a modelling approach is required which is based on technology-specific information and analyzes the effects of changes in demand on sectoral structures, including the related indirect effects on the supply chains. As the sectors differ in work intensities and import propensities, overall employment may change. In addition, cost and budget effects should not be neglected, because covering higher costs for the users or public promotion necessitate compensation in other places. Moreover, developments in international competitiveness may change the trade balance and domestic production.

3. Methodological approach

In order to take due consideration of the aspects discussed above, this study assesses the impact of biotechnology in a bottom-up approach from a techno-economic perspective. The results are integrated in an input-output framework to assess indirect economic effects in other sectors. The study design consists of several steps: firstly, a set of scenarios is developed for biotechnological development and price paths for oil and biomass. Secondly, a detailed analysis of biotechnology in different application sectors is conducted and the different impact mechanisms are assessed. Thirdly, the results of the first two steps are integrated in an input-output-model to analyze (net) economic effects. The overall methodological approach and data sources are summarised in figure 1 and discussed in more detail below, after the description of the selected application sectors.

Figure 1: Schematic block diagram of the overall modelling setup



Due to the utilization of biotechnology in many sectors and restraints in data availability, the study focuses on four different application fields. In their entirety, but also in each single case, selected applications should represent a significant proportion of the economy. Four heterogeneous application sectors are selected to study the cross-sectional impact of biotechnology: biopolymers, bioethanol, biopharmaceuticals and biotechnological fine/specialty chemicals. These applications differ widely in many aspects, e.g. the specific advantage of biotechnology, the type of innovation (product vs. process), the effect on production costs, input demand of biomass sector, state of technical development and sectoral context. Table 1 summarizes main attributes of biotechnology in the different sectors. Although the overall economic impact of biotechnology cannot be covered by this selection, the various application fields at least represent the cross-sectional character of biotechnology.

Table 1: Characterization of the selected biotechnology application fields

	Biopolymers	Bioethanol	Fine and specialty chemicals	Biopharmaceuticals
Type of innovation (process/ product)	Process	Process	Process/Product	Product
Changes in production costs	Slight decrease	Increase	Decrease	Increase
Input of biomass	High	High	Low	Very low
State of technical development	Early diffusion/ demonstration plants	Early diffusion	Diffusion	Diffusion

Scenarios

Scenarios provide a structured description of possible future development paths, depending on current and future framework conditions. For the analysis of the production and employment effects of biotechnology diffusion in Germany with a time horizon to 2020, the following set of scenarios is used:

- a reference scenario for biotechnology diffusion, based on literature and expert judgements
- a "high-diffusion" (HD) scenario with favourable conditions for higher diffusion paths of biotechnology
- a hypothetical basis scenario with no further diffusion of biotechnology in the various application fields.

In the reference scenario, assumptions for prices of oil and biomass are mainly based on OECD projections. The oil price is set at 70 US$/bbl (2005 real prices), the price for wheat is 120 €/t, for sugar 32 €/t and for lignocelluloses 55 €/t.[2] The HD scenario reflects a higher price ratio of fossil to renewable resources, the real oil price is set at 100 US$/bbl based on IEA estimates. Prices for biomass increase due to higher production costs, which depend partly on energy costs (e.g. fuel for tractors). But overall the price increases remain beneath the higher oil prices (wheat 126 €/t; sugar 33 €/t; lignocelluloses 55 €/t). In addition to these price assumptions, more favourable policy strategies for diffusing biotechnological processes are assumed. The sector-specific assumptions for the quantitative mapping of the scenarios in the four application fields are summarized in chapter 4.

As the aim of this study is to explore the effects of further biotechnological diffusion, all values are subsequently compared to those calculated under the basis scenario, in order to single out the impacts of each of the scenarios with biotechnology diffusion.

Input-Output modelling of biotechnological change

For each scenario an input-output framework is set up to account for direct and indirect production and employment effects associated with the diffusion of biotechnology. The plain input-output model (IO model) used in this study is based on the input-output tables produced by the Federal Statistical Office for the year 2005. 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). Employment impacts are calculated by multiplying the biotechnology-related production volume and employment coefficients (gainfully employed persons per unit of gross production value). Since the scenarios analyzed refer to the year 2020, in principle one should endeavour to project the input–output table to this year. However, since the official macro aggregates necessary for the estimation are not available, the dynamic dimension is not regarded. Instead, the results should not be interpreted as directly representative of a hypothetical year 2020, but as “what if” scenarios. In order to avoid overestimations of employment impacts, labour productivity improvements were estimated on developments between 1995 and 2005 for all scenarios. Moreover constraints on domestic availability of surplus land are considered,

2 All estimates are based on 2005 real prices.

as land availability and food needs will limit the growth of agriculture (OECD/FAO 2008). Supply and demand developments for biomass were estimated on the basis of various studies (e.g. SRU 2007, Nusser et al. 2007b). The domestic availability of biomass from food crops is set at 70% in the reference scenario and 80% in the HD scenario. For lignocellulose production on non-crop land (e.g. unused portions of food plants such as corn stover or industrial waste products) is presupposed.

IO models are sometimes considered inappropriate for long-term studies as the IO production function does not allow for substitutions among inputs and technological change.[3] But as has been demonstrated in several studies (e.g. Faber et al. 2007), adjustments can be made. In this study, such adjustments were made for the sectors with biotechnological diffusion. A new "biotechnology" sector is introduced into the IO model for each application field, to study the biotechnological effects in detail. If the original structure is expanded, a considerable amount of structural information can be consistently derived about the flow of goods and services, intermediary effects and induced and indirect employment. A new sector in an IO model is defined by the amounts obtained from all other sectors, the amounts delivered to all other sectors, imports to and added value from the new sector. Inputs to the new sector are inserted into a new additional column to the table, outputs from the new sector into a new row. In general, IO sectors should have a rather high degree of homogeneity. As a variety of technologies, resources and products are involved in each sector, a more disaggregated analysis for biotechnology applications (e.g. for different types of biopolymers) is useful. In order to build an average IO vector, shares of different products or resources (e.g. share of bioethanol from wheat) are assumed. For each scenario, detailed estimates are made for the biotechnology development from the survey.

Besides positive production and employment effects from increasing utilization of biotechnology, negative impacts may occur, among others due to the (relative) "shrinkage" of conventional production and research methods (e.g. fossil-based petrol). For an investigation of the net effects, the different investments in the substituted fossil products, their operation and management as well as their different import quotas and costs are additionally determined by literature and expert information.

3 For a detailed discussion, see Faber et al. (2007).

Different types of change compared to conventional methods are distinguished to analyze the various economic impact mechanisms (section 2). Biotechnology may require changes in production processes which result in

- lower/higher input coefficients for specific inputs (e.g. for energy in the case of biopolymers) or different related investment volumes;
- a more efficient use of all inputs due to process innovation;
- substitutions between inputs (e.g. biomass instead of oil.).

In the first two cases production costs may differ and lead to reactions on the demand side via changes in product prices or increases in wages. In this study it is assumed that lower production costs directly result in price reductions and eventually to a higher disposable income. In contrast, higher production costs are recollected from private consumers through an increase in general taxation of the equal amount, reflected by a reduction in the disposable income of consumers and therefore in aggregate demand. In order to capture the consumers' substitution behaviour, price and income elasticities are adapted from Neuwahl et al. (2007).

Apart from changes in the input structure, product innovations enabled by biotechnology increase the quality and variety of goods and may open up new markets. But integrating product innovations into modelling frameworks is difficult (Pianta 2005), since the additional diffusion in complementary to existing products is unclear. Moreover, in the present case of biopharmaceuticals, the demand side is largely driven by regulations. These influence the financing of new products and the degree to which markets may grow. Even if innovations lead to rising pharmaceutical markets, it is open whether higher health costs induce lower consumption for other goods and services or can be interpreted as an additional demand. Therefore, the modelling approach distinguishes between two cases. In the first case, the additional expenditures are compensated by falling consumption due to lower disposable income. In the second case, an additional demand for the pharmaceutical product innovations arises with no reductions for other consumption goods. In consequence, saving rates are lower. While both cases represent a maximum development, no plausible estimate for a mixture of these cases can be given yet.

The bottom-up technology information and projections are derived from techno-economic studies and expert judgements in combination with scenario assumptions. Cost degressions caused by learning-effects are also taken into account. A critical step in this methodology is the selection of the experts. On the one hand, employees from biotech-active firms have possibly the highest expertise, but on the other hand, overoptimistic views of experts are thinkable, as most of the business models of these stakeholders rely totally on successful developments in biotechnology (Hopkins et al. 2007). In this study, experts were selected on the expertise dimension and on the dimension of the perspective on the biotechnology chain. Around half of the 40 interviewed experts were from firms which use biotechnology and conventional technology methods. These users of biotechnology have a high expertise concerning the advantages, disadvantages and changes through biotechnology and probably a more objective view, as they do not depend heavily on biotechnological success. The other half of experts was selected along the value chain and included plant manufacturers, researchers and core biotech firms.[4]

The necessary investment ratios are derived from literature, technology databases and expert information. The investment volumes were divided into annual investment streams and then assigned to the relevant supply (sub-) sectors (e.g. plant construction, mechanical engineering) and integrated in the input-output model. In order to ascertain employment in the cultivation of renewable raw resources in German agriculture, specific employment factors were constructed based on the German agricultural statistics.

Despite these various model adjustments, the reader should bear in mind some limitations of the adopted modelling approach: firstly, the two important impact mechanisms of product innovations and changes in international competitiveness are taken explicitly into account, but they could only be considered by rough estimates at a highly aggregated level. More detailed analysis, e.g. for potential first-mover advantages, would be desirable. Secondly, changes in the international demand and supply side of biomass could only be partially considered in the analysis as it was outside the scope of the underlying study to investigate worldwide developments. Thirdly, innovation and diffusion dynamics and their economic outcomes could not be regarded explicitly and the diffusion is estimated exogenously. Besides, price effects are included only partially, but this impact mechanism seems of minor importance in the chosen application fields of biotechnology. In spite of these limitations, the methodology used is able to provide some interesting and well-founded insights regarding the economic effects of biotechnology.

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4 A list of participating organisations is available from the author.

4. Technological developments and sectoral input variations

In the subsequent analysis, potential diffusion rates of biotechnology and variations in sectoral inputs are assessed for all application sectors. The production costs are calculated as important intermediate results to estimate the input coefficients and demand variations. Detailed figures are presented in the annex tables 4 to 7.

Bioethanol

The scenarios introduce different replacement shares of conventional fuels for bioethanol. The major part is produced by first generation bioethanol from wheat and sugar beet. Although second generation technologies are still at demonstration plant stage today, a partial diffusion of bioethanol from fermentation of lignocellulose feedstock is assumed. The reference scenario is based on interim plans of the EU's new Renewable Energy Directive of 2008, which obliges Member States to ensure that 10% of their transport fuel comes from renewable sources, only 3/5 of which are allowed to come from first generation biofuels. Hence, bioethanol from wheat and sugar take a share of 6% of total fuels and another 1.25% are expected from lignocellulose feedstock. The high-diffusion scenario reflects the ambitions of the German government in 2008 of a 14% share. The offsetting of oil-derived fuels with bioethanol was made on an energy equivalence basis. The inputs to the bioethanol sector were constructed based on process chain data derived from the "Wheels to Wheels" study (Concawe 2006) combined with scenario assumptions for prices for oil and renewables. The main bioethanol conversion process costs are decreased slightly in the reference scenario compared to data from Concawe (2006), and to a higher degree in the HD scenario, by introducing learning effect cost reductions on capital costs, labour costs and other fixed operating costs for the year 2020. The substituted petrol sector was constructed by a disaggregation of the mineral oil sector using estimates for the input share of oil in each scenario (MWV 2006). In the reference and HD scenario bioethanol production costs are higher than for petrol and lead to increasing fuel prices and consequently to lower final demand.

As production costs for bioethanol in Germany are also higher than in some other countries, e.g. Brazil, international competitiveness is limited. Moreover, a total domestic production of the demand for bioethanol seems unrealistic, due to land availability constraints. Estimations from literature for import quotas in Germany vary between 20 to 50% (WI/RWI 2008; Nusser et al. 2007b). For both scenarios the import quota is set at

30% and the export quota at zero. For the substituted conventional fuels, Germany is instead a net exporter. But important differences between oil-based fuels and bioethanol lie in the different import quotas of the value chain. While oil is totally imported, biomass for bioethanol is at least partly produced domestically.

Biopolymers

Currently the diffusion of biotechnologically produced polymers is low. But increasing oil prices, growing interest in renewable resources, concerns regarding greenhouse gas emissions and improved properties (e.g. in surface finish) have created a renewed interest in biomass-based polymers[5]. Hence, techno-economic studies (e.g. Crank et al. 2004) and the interviewed experts in this study estimate an increasing market penetration of biopolymers. A share of 4% of total polymers is expected in the reference scenario. A main driver for diffusion of biopolymers is the ratio of oil prices to biomass, as the price difference of the respective main input strongly affects the economic advantage of biopolymers. In the high diffusion scenario biopolymers have a share of 8% of all polymers produced.

The international competitiveness of domestic enterprises with regard to biopolymers is rather unclear. Although Germany may have disadvantages due to the domestic availability of cheap biomass, patent analysis from Beucker/Marscheider-Weidemann (2007) and expert judgments state a high technological competitiveness. As it cannot be determined which of these contradictory arguments will dominate, no differences between the trade balances of oil-based polymers and biopolymers occur in either scenario. The inputs to the biopolymer sector were constructed from process chain data derived from Patel et al. (2006) combined with expert judgments and the scenario assumptions for prices. In the reference scenario biopolymers have slightly lower production costs of about 3%, in the high-diffusion scenario the cost advantage is about 20%, due to higher oil prices. For the input structure (e.g. demand for labour, auxiliaries) only minor differences apart from the substitution of oil are expected, so the main drivers for economic impact are the slight cost decline and the substitution of fossil resources.

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5 Only the biotechnologically produced polymers are considered, other polymers from biomass (e.g. starch) are not included.

Biotechnologically produced fine and specialty chemicals

In fine and specialty chemicals biotechnology processes can have several advantages over traditional chemical synthesis, including more specific reactions, less demanding production conditions (such as lower temperature and pressure, and milder pH conditions) and lower energy inputs, waste, and environmental impacts. According to expert judgements the share of biotechnologically produced products is expected to increase from about 5% in 2005 (Nusser et al. 2007b; von Armansperg/Patel 2006) to 10% in the reference scenario and to 15% in the HD scenario. The economic impact may differ between these heterogeneous products. In some cases, improved functionalities of fine/specialty chemicals lead to a higher product quality. While significant quality improvements of a product may have similar effects like product innovations on creating new markets (Tether 2003), this seems not to be the case for fine/specialty chemicals. According to expert judgements, the creation of new markets or a significant expansion of existing markets are rather unlikely. Therefore in the scenarios no additive impulses of product innovations are considered and the impact of biotechnology is modelled as a pure process innovation. A significant impact lies in a more efficient production, as the process steps may be reduced (e.g. riboflavin). Moreover, advanced biotechnology-facilitated production processes are likely to reduce value inputs of energy and inputs of refined oil products, e.g. biotechnology catalysts using plant-derived feedstock instead of petroleum-based feedstock in the production of chemicals and synthetic fibres. In the reference scenario the production cost reduction averages 10% and splits up in decreases for various inputs. In the HD scenario the production costs for biotechnological products are 15% lower than for traditional chemicals, due to learning effects.

Biopharmaceuticals

The pharmaceutical sector is currently the main application field for biotechnology firms. Therapeutics developed using biotechnology can be classified in different groups; one separation can be achieved by differentiating large molecule biopharmaceuticals and small molecule therapeutics. Due to lack of data, the impact of biotechnology on the development of small molecules cannot be assessed. However, the analysis of biopharmaceuticals[6] compared to chemical substances offers interesting insights. The biopharmaceutical share of all new pharmaceutical compounds (new molecular entities or NMEs) that received market approval increased from 2% to about 15% in 2005 (OECD 2009). But according to analyses by Reiss et al. (2007) and OECD (2009) based on clinical trial data, a slight increase in the share of biopharmaceuticals for new molecular entities can be expected in the next years. Nevertheless, the turnover share of biotechnology can be expected to grow stronger as most biopharmaceuticals belong to high-price segments. According to Reiss et al. (2007), the turnover for an average biopharmaceutical tripled between 1995 and 2005. The interviewed experts confirm the expectation of a slight increase in biopharmaceutical shares of NMEs and a more dynamic growth in the production value share. The median for the biopharmaceutical production value share is estimated to grow from about 11% in the year 2005 (VFA 2007) to 24% in the reference scenario for 2020. Assuming a more dynamic technological development without further restrictions on the regulatory side, the share grows to 32% in the HD scenario. These developments are likely to increase total output in pharmaceutical products as biopharmaceuticals are often developed for different types of diseases than chemical substances and consequently have a more additional character. Therefore in the scenarios production growth of biopharmaceuticals leads to a higher pharmaceutical output. To model reactions on the consumer side, additional assumptions have to be made for health care costs increases in consequence of higher sales of pharmaceuticals. In the literature some examples for savings in total therapy costs through biopharmaceuticals exist (IPTS 2007). But the contrary is also conceivable, e.g. in case of longer, but unhealthier longevity (IPTS 2007). On an aggregated level, no clear judgement can be made yet (Rosenberg-Yunger 2008). As mentioned in the scenario descriptions, higher health care costs are assumed in the amount of higher pharmaceutical output, which induce reductions for other consumption goods and services. An additional alternative analysis is conducted with the assumption of an additional market demand and respectively lower savings rates. According to expert judgements, differences in the input structure for biopharmaceuticals and chemicals mainly occur through higher production costs for biopharmaceuticals, while no major differences in the resource intensity of the development of biotechnology products are expected (Hopkins et al. 2007).

6 Biopharmaceuticals are defined as ”[…] recombinant products such as interferon, interleukin, growth factors; blood factors, hormones and other peptides and proteins; antibodies, immunotoxines, and immunoconjugates“ (Reiss et al. 2007, p. 45).

5. Net production and employment effects

The above described technological survey and derived parameters for the IO model are used to calculate the impact of biotechnological development and diffusion on production and employment. Table 2 and table 3 show the net production and employment results. For easier handling of the results, the 71 sectors of the IO table are aggregated to eight macro sectors. The production and employment impacts are mostly slightly positive but differ greatly between the various application fields.

Table 2: Net production impacts (in € m) in 2020 for the reference and high diffusion scenario and different application sectors compared to the basic scenario

	Biopolymers		Bioethanol		Fine and specialty chemicals		Biopharmaceuticals		
	Reference	HD	Reference	HD	Reference	HD	Reference	Alternative reference*	HD
Agriculture	524	1019	404	741	54	85	-24	7	-39
Chemical industry	1	3	0	2	-11	-24	3940	-135	6404
Pharmaceutical industry	-343	-1145	48	133	-479	-1148	-161	3948	-167
Capital goods industry	78	144	60	146	-21	-49	58	201	84
Energy, water	-65	-167	4	17	-17	-37	-3	-5	-9
Other industries	-50	-177	-48	-288	-43	-92	103	514	135
Building industry	66	124	18	50	-11	-25	24	72	35
Services	89	140	-24	268	-25	-32	-1627	934	-2680
Total	**299**	**-60**	**462**	**1,069**	**-554**	**-1,322**	**2,310**	**5,536**	**3,761**

* In the alternative calculation for biopharmaceuticals no increase in health care costs is assumed.

The impact is mainly positive for bioethanol and biopolymers. The respective net production results vary across application fields and scenarios by between about € -60 and € 1,070 m, the employment impact lies between around 3,000 and 9,000 jobs. The higher effects in the HD scenario result from the higher oil price. Hence, the total economic burden of bioethanol usage is reduced and in the case of biopolymers private consumption increases. For biopharmaceuticals on the contrary the production impact is slightly positive but the employment effect is negative in the reference and HD scenario, as most of the negative effects occur in the labour-intensive service sectors. The employment impact is only positive in the "alternative" scenario, where the output growth of (bio-)pharmaceuticals is modelled additively and is not compensated by less consumption due to higher health costs as in the reference scenario. For fine/specialty chemicals the production and employment effects are negative. This is not surprising, as biotechnology mostly leads to process innovations in the sector without big changes in the input structures. Such process innovations tend to lead to negative employment effects (e.g. Pianta 2005).

Table 3: Net employment effects (in number of jobs) in 2020 for the reference and high diffusion scenario and different application sectors compared to the basic scenario

	Biopolymers		Bioethanol		Fine and specialty chemicals		Biopharmaceuticals		
	Reference	HD	Reference	HD	Reference	HD	Reference	Alternative reference*	HD
Agriculture	2,865	5,267	2,906	5,236	391	614	-255	74	-425
Chemical industry	-267	-495	42	116	-296	-902	-141	-118	-146
Pharmaceutical industry	2	4	1	3	1	1	6,575	6,588	10,681
Capital goods industry	402	737	341	780	-95	-225	472	955	720
Energy, water	-136	-360	5	27	-26	-57	-15	-20	-31
Other industries	-157	-427	160	599	-217	-452	-146	1786	-343
Building industry	733	1,377	198	554	-126	-275	266	797	387
Services	572	886	-670	1,997	-192	-169	-17,604	9,139	-28,999
Total	**4,015**	**6,990**	**2,982**	**9,313**	**-560**	**-1,466**	**-1,0847**	**19,202**	**-18,156**

* In the alternative calculation for biopharmaceuticals no increase in health care costs is assumed.

Overall, the net effects are small in most cases. This can be explained by the limited differences in the value chain and trade balances between biotechnological and conventional research and production. The sectoral results show that indirect effects are of great importance for the results. Structural change is concentrated on a few sectors, a significant part of the effects occur in agriculture and service sectors as consequence of higher input for biomass and changes in consumption, which are mainly reflected in the demand for services. So while biotechnological methods are dominantly used in industrial sectors, interestingly, the effects also emerge in the primary and tertiary sectors.

In the sensitivity analysis, several parameters are checked for their uncertainty and their effect on the results (annex figure 2). Since similar effects are expected for net production results, only the sensitivity analysis for net employment is presented here. Sensitivity runs with upper and lower values for certain parameters, derived by literature or expert information, are conducted. The sensitivity analysis indicates that the results are most sensitive to the trade balance and diffusion and less affected by cost and consumption structures. The results display a somewhat higher robustness and only in few cases the prefix of the net impact changes.

6. Conclusion

This paper has analyzed the economic impacts of different diffusion paths of biotechnology in some major application fields. Bottom-up technology information from literature, expert judgements and explicit scenario assumptions for various impact factors are combined and integrated into an input-output framework to calculate direct and indirect production and employment effects. The results indicate that biotechnology is on its way to becoming increasingly relevant for the economy and is likely to gain in importance in all analyzed application sectors in the next 10 to 15 years. But the impacts on net production and employment differ greatly between the different sectors; they vary between negative and positive results. In the case of bioethanol and biopolymers, the substitution effects are highly favourable through lower import quotas and higher labour intensities in the respective value chain. For biopharmaceuticals the impacts on employment are only positive, if there are additive impulses of product innovations, or if a high international competitiveness can be achieved in these sectors.

It is clear that the above analysis draws only a limited picture of the economic effects of the utilization of biotechnology, as not all impact mechanisms could be studied in desirable depth (e.g. first-mover advantages). It also has to be kept in mind that the net production and employment impact draw only a part of the whole picture. Moreover, the background of an increasing outsourcing of conventional industrial production jobs to eastern Europe and Asia has to be regarded; many jobs can be lost due to these relocations. Compared with such a reference development, even low net employment effects can be positively judged, if biotechnology supports the competitiveness of domestic production plants.

Nevertheless, the methodology used is able to provide some well-founded and interesting insights as the results indicate that the indirect and induced employment effects are rather high and exceed the direct employment effects. This highlights the importance of a methodology which considers such impacts. Additionally, the disaggregated analysis of the various applications shows that the impact mechanisms differ greatly between the application fields. A detailed bottom-up approach is therefore necessary for an appropriate modelling.

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Annex

Figure 2: Sensitivity analysis for the employment effects in dependence of parameter variation (Reference = 100%)

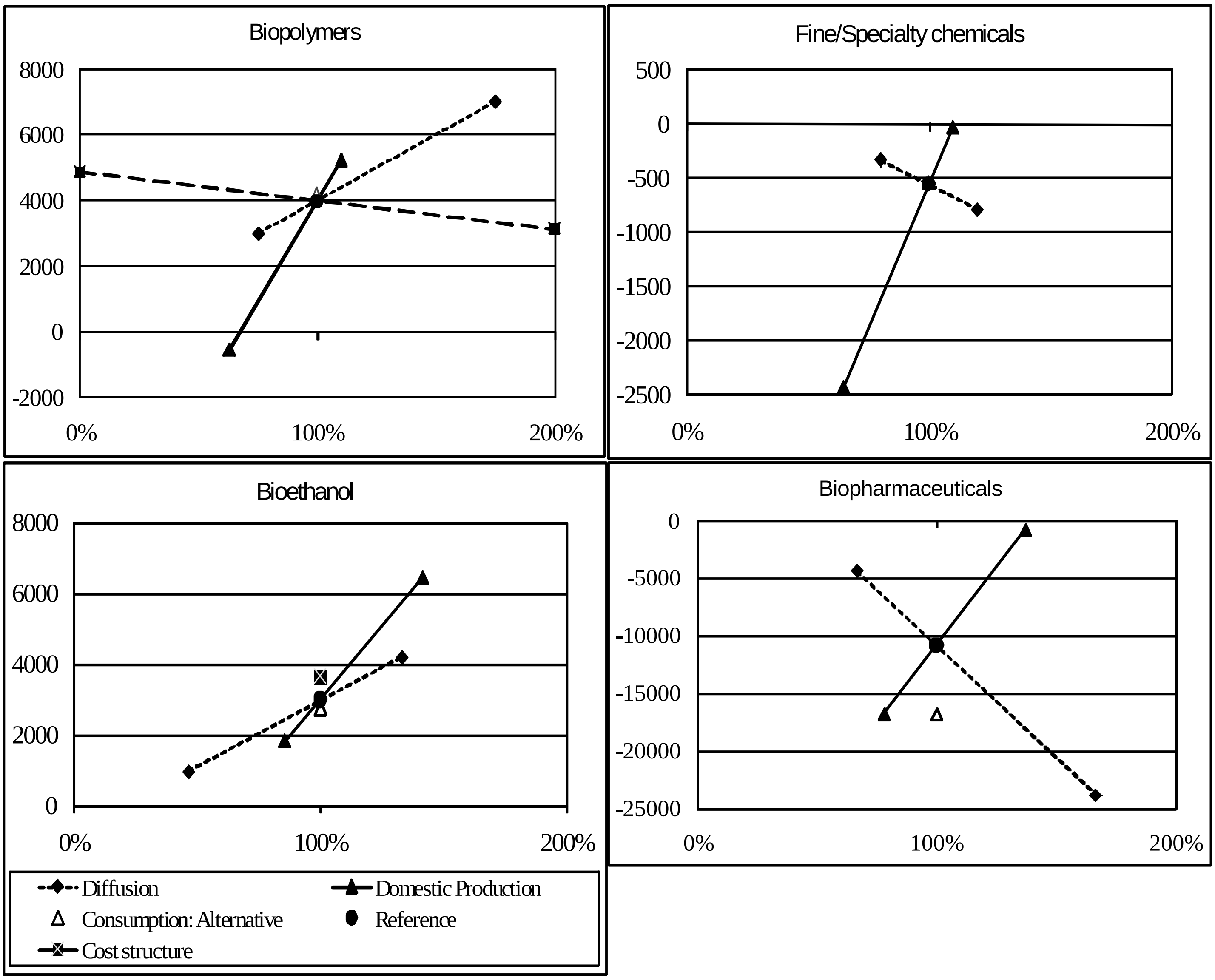

Table 4: Bioethanol production costs (in €/t)

	Reference scenario				**HD scenario**			
(Cost) parameters	**Wheat**	**Sugar beet**	**Lignoc.**	**Aver-age**	**Wheat**	**Sugar beet**	**Lignoc.**	**Aver-age**
Feedstock cost in €/t	120	32	53	-	126	33	55	-
t feedstock per t bio-ethanol	3	13	4	-	3	13	3	-
Costs per t bioethanol	**404**	**422**	**187**	**355**	**425**	**442**	**170**	**334**
..thereof transport costs	4	17	12	8	4	17	12	8
Chemical auxiliaries/lubricants	**22**	**32**	**27**	**24**	**40**	**44**	**30**	**37**
Electricity consumption	**33**	**47**	**40**	**37**	**60**	**66**	**46**	**56**
Labour costs	**20**	**16**	**29**	**22**	**22**	**18**	**28**	**23**
Overhead	**7**	**5**	**87**	**26**	**7**	**6**	**83**	**35**
Annual debt service	**42**	**32**	**93**	**53**	**44**	**33**	**89**	**59**
Capital costs	**63**	**48**	**139**	**79**	**65**	**50**	**133**	**88**
Co-product revenue	**-112**	**-71**	-	**-79**	**-117**	**-75**	-	**-70**
Total production costs	**1,414**	**1,488**	**943**	**1,282**	**545**	**587**	**578**	**562**

Highlighted values directly sum up to total costs. Average costs result from the shares of the feedstock of the additional ethanol production.

Table 5: Biopolymer production costs (in €/t)

	Reference scenario				HD scenario			
(Cost) parameters	**PLA**	**PHA**	**PDO**	**Average**	**PLA**	**PHA**	**PDO**	**Average**
Feedstock cost in €/t	120	120	120		126	126	126	
t feedstock per t biopolymer	2	5	3		2	5	3	
Costs per t biopolymer	**288**	**600**	**408**	**393**	**302**	**630**	**403**	**408**
..thereof transport costs	3	6	4	4	3	6	4	4
Chemical auxiliaries/lubricants	**539**	**480**	**214**	**411**	**585**	**535**	**213**	**444**
Electricity consumption	**178**	**147**	**71**	**132**	**242**	**205**	**89**	**179**
Labour costs	**35**	**35**	**35**	**35**	**33**	**34**	**31**	**33**
Overhead	**190**	**120**	**110**	**140**	**181**	**117**	**96**	**131**
Annual debt service	**108**	**114**	**91**	**121**	**107**	**117**	**83**	**129**
Capital costs	**162**	**172**	**137**	**179**	**161**	**175**	**124**	**193**
Co-product revenue	**-86**	**-180**	**-122**	**-130**	**-98**	**-205**	**-139**	**-136**
Total production costs	**1,414**	**1,488**	**943**	**1,282**	**1,513**	**1,608**	**899**	**1,340**

* Highlighted values directly sum up to total costs. Average costs result from the shares of the biopolymer types (one third).

Table 6: Input structure of biotechnological fine/specialty chemicals and substitutes

	Biotechnology (reference scenario)	Biotechnology (HD scenario)	Chemical substitute
Agriculture	5.5%	5.3%	0.0%
Other feedstock/auxiliaries/lubricants	46.1%	42.6%	58.2%
Capital costs	2.5%	2.3%	3.5%
Waste disposal	0.9%	0.8%	1.3%
Electricity consumption	1.2%	1.1%	1.8%
R&D inputs	0.7%	0.7%	0.5%
Services	17.4%	17.4%	17.4%
Labour costs	10.9%	10.0%	12.5%
Other value added (a. o. profits)	4.8%	4.8%	4.8%
Production costs	90.0%	85.0%	100.0%
Cost decreases (=>higher consumption)	10.0%	15.0%	
Total	100.0%	100.0%	100.0%

Table 7: Input structure of biopharmaceuticals and substitutes

	Biopharmaceuticals	Pharmaceutical substitute
Chemicals	5.0%	10.8%
Other industry inputs	38.1%	21.5%
R&D inputs	12.7%	10.2%
Other services	17.1%	16.0%
Capital costs	5.7%	3.3%
Labour costs	34.4%	26.3%
Other value added (a. o.profits)	11.9%	11.9%
Production costs	125.0%	100.0%
Cost increases (=> lower consumption)	-25.0%	0.0%
Total	100.0%	100.0%

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