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PROJECTED GROWTH EFFECTS OF THE BIOTECHNOLOGY INDUSTRY – THE FOURTH PILLAR OF THE FINNISH ECONOMY?

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ABSTRACT: This study aims to assess the impact of the Finnish biotechnology industry on the economic growth in Finland. The study employs official data from Statistics Finland and new survey data covering 84 Finnish biotechnology companies. The study offers methodological insights into how a new emerging industry can be treated as a statistical branch in an input-output forecast model and how probability distributions can be utilized in the model instead of point estimates. An econometric forecast for the economy-wide growth impact of the biotechnology industry in Finland is estimated. In the estimation procedure this study employs the survey data both in forming growth anticipations within a new emerging industry and assessing inter-industrial growth effects. Applied Monte Carlo simulations predict that the contribution of the biotechnology industry to annual GDP growth in 2002-2006 will be in the range of 0.05-0.09 percentage points per annum with a probability of 90%. In comparison with the major sectors of the Finnish industry – forest industry, industry of metal products and machinery, and electronics industry – this implies that it will rather take decades instead of years for the biotechnology industry to become a fourth pillar of the Finnish economy.

KEY WORDS: biotechnology, economic forecast, growth contribution, input-output model, monte carlo simulation.

1 Introduction

1.1 Background

There have been growing expectations concerning the economic potential of biotechnology during the last two decades in Finland. Biotechnology is anticipated to become an important driving force in the economy after the era of information and communications technologies. Schienstock and Tulkki [1] have even raised a question whether the biotechnology industry will become a fourth pillar of the Finnish economy, next to forest industry, industry of metal products and machinery, and electronics industry.

In Finland, the number of dedicated biotechnology firms has grown rapidly in the 1990s and is estimated to be one tenth of such firms in Europe (Kuusi [2]). The public sector has expended considerable resources in training and R&D in this field. Private investments and venture funding have also grown decisively (Hermans and Tahvanainen [3]). The main application areas of biotechnology in Finland include pharmaceuticals, diagnostics, functional food, biomaterials, enzymes, and the food and chemistry businesses, as well as services related to these fields (see *e.g.* and Hermans and Luukkonen [4]).

Biotechnology is not easy to define as an industrial branch. The OECD Ad Hoc Meeting on Biotechnology Statistics defined 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]. Public attention is usually paid to small dedicated biotechnology firms, but they are not the only ones to make and commercialize biotechnological discoveries. Some established larger firms are also involved in biotechnology R&D and commercialization. The entire field is closely related to scientific research, where many of the discoveries are made. The commercialization of the discoveries is, however, uncertain and the process is slow compared with, for example, the information and communications technologies (Luukkonen and Palmberg [6]).

The high risk nature of the development processes of the biotechnology industry must be taken into consideration when forecasting its economic impacts. The delays in the development processes of biotechnology companies as well as the risk of technological failure have to be included as part of the forecasting model.

1.2 The Objectives and Motivation of the Study

Despite the high investments and expectations regarding the biotechnology sector, there has not been much effort expended in estimating the economic growth impacts of the sector in the near future. It is well known that biotechnology firms report high growth potentials of sales, but the spill-over effects on other industrial branches and the growth contributions to the gross domestic product (GDP) have sparsely been analyzed. Ernst &Young [7] analyze the growth contributions of the biotechnology industry in the US in 1999.

The objective of the study is to assess the impact of the Finnish biotechnology industry on the economic growth in Finland. There were two obstacles to overcome in the construction of a forecast model. First, biotechnological applications span over several statistical subgroups in the official statistical classification, and thus the conventional statistical classes are not applicable for this new emerging industry – the official statistics and classification procedure within this area are still under construction in OECD [5]. Second, the exceptional risks related to both the technological feasibility and delays in research and development processes are not reflected in the anticipated future sales disclosed by the biotechnology companies.

In order to overcome the first obstacle, it was necessary to create a new industrial class of biotechnology in the conventional input-output table of Statistics Finland. The second obstacle was overcome by the application of Monte Carlo simulation, which simultaneously allows the implementation of the stochastic features of failure vs. success, and the probability distributions for anticipated future sales of the biotechnology companies.

1.3 Research Procedure

The forecasting procedure consists of 3 phases (Figure 1).

1. Survey data that covers production and patterns of purchases and sales in the biotechnology industry are used in the formation of input-output tables estimating linkages to other industries.
2. The biotechnology sector is added to the official input-output tables of Statistics Finland as a new branch. This enables the estimation of backward linkages to other industries. The backward linkages depict how much the biotechnology sector increases purchases from other branches when its own sales grow, and vice versa. This enables estimation of the economy wide growth potential; the estimation is based on the Monte Carlo simulation using probability distributions of firms' anticipated future sales and bankruptcy risk during 10,000 iterations.
3. The results of forecast impacts are presented and discussed in the context of the Finnish economy.

The biotechnology sector is classified under many statistical branches in official statistics (e.g. chemical production, food stuff production, business services). However, the biotechnology companies differ a lot from other Finnish companies on average (Hermans and Tahvanainen [3]; Hermans [8]). For example, there are many biotechnology companies which do not have sales yet but which expect to have high sales in the future, based on relatively high expenditures on research and development (R&D). The utilization of survey data is necessary in order to be able to estimate the input-output structures of these companies and their inter-industrial linkages and economic impacts. In the survey, small and medium-sized biotechnology companies announced their input-output structure (patterns of purchases and sales) at the end of 2001. They also disclosed their sales expectations.

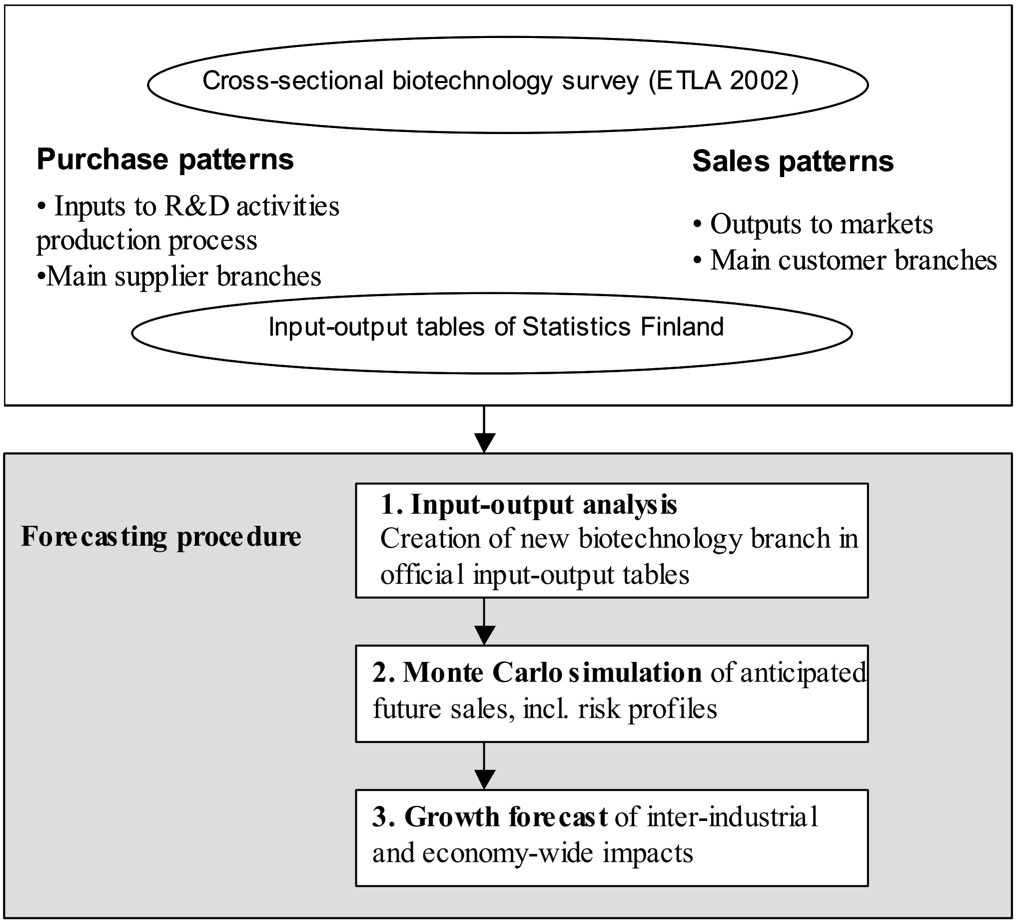

Figure 1. **The framework of the forecast model.**

Most large biotechnology related companies did not reveal their patterns of purchases and sales. Consequently, they could not be included in the new statistical branch of the biotechnology industry described above. The majority of the large companies represent more mature entities compared to the biotechnology SMEs; thus, their input-output structures are closer to the average industrial classes than the biotechnology SMEs. Therefore, the large companies are treated as part of the existing statistical classes.

Input-output modeling reveals supply and demand linkages between different branches. An industry uses the outputs of other industries as intermediate inputs in its own production processes. The industry sells its own output to another industrial branch, which uses that, in turn, as an intermediate input in its production. Input-output tables conclude these inter-industry linkages, and they have been used in many contexts, such as industrial forecast models (e.g. Burridge [9]), regional forecast models (Rickman [10]), and forecasting the dynamics of production within a pharmaceutical company (Marangoni and Fezzi [11]).

The word simulation refers to any analytical method which attempts to imitate a real-life system; usually other types of analyses are mathematically too complex or too tedious to produce (Drakos [12]). One type of simulation is the Monte Carlo simulation, which randomly generates values for uncertain variables to simulate a forecast model using numerous iterations. The Monte Carlo simulation is used in a multitude of applications;

examples thereof are nuclear reactor design, radiation cancer therapy, traffic flow, oil well exploration and econometric Dow-Jones forecasting (ibid.). Monte Carlo simulation has also been used in the estimation of the input-output multipliers (see e.g. Bullard and Sebald [13]; Roland-Holst [14]).

This study constructs input-output multipliers from the cross-sectional data, and the simulation is utilized in the forecasting procedure. Without the use of simulation, an input-output model would result only in a single outcome: a scenario in which all the positive expectations of the biotechnology companies are realized. However, such a scenario does not reflect the most probable outcome.

The presented forecast procedure uses both the input-output model and Monte Carlo simulation to numerically analyze the effect of varying uncertainty factors. The first factor is the threat of bankruptcy. It is defined as a stochastic outcome: bankruptcy or continuing business at the end of 2006. Exogenous foreign demand constitutes the second uncertainty factor. It is included as a probability distribution of anticipated exports by the Finnish biotechnology companies. These uncertainties are included in the simulation. Instead of a single outcome, the model produces a distribution of all the potential outcomes given the assumptions behind the initial probability distributions. The assumptions are discussed in detail below.

This study is divided into four sections. The present section introduces the background, objectives and rationale of the forecasting procedures. Data employed in this study and assumptions behind the model are examined in Section 2. The input-output relations between biotechnology sector and other branches, those that use biotechnology in their processes and products and those that are suppliers to the biotechnology firms are also depicted. Section 3 employs a numeric Monte Carlo simulation based input-output analysis to construct a growth contribution scenario for the Finnish economy as a whole. Section 4 concludes the results of the forecast and relates the projected growth of the biotechnology industry to the three main pillars of the Finnish economy.

2 The biotechnology industry in Finland

2.1 Data

This study employs a survey conducted by ETLA. The survey contains financial and business activity information on 84 Finnish biotechnology firms. A problem of the representativeness of the survey data arises because there were 131 biotechnology firms active at the end of 2001, and thus survey data represent only 64% of the sector. Furthermore, the sample seems to be slightly biased toward the older age groups: the sample contains three-fourths of the companies founded 1991-1996 as well as companies founded earlier than 1991, but only 49% of the companies founded 1997-2001 (Table). In order to form a plausible estimation to depict the entire biotechnology sector in Finland, weights were constructed reflecting the age groups of the firms; the weights are inverses of the percentage shares of the sample in different age groups.

Table 1. The number of biotechnology firms in the sample of the ETLA survey respective to total population sorted by age groups.

	before 1991	1991-1996	1997-2001
The ETLA sample	25	34	25
The total number	34	46	51
Percentage share of sample	74 %	74 %	49 %
Weight	1.36	1.35	2.04

The survey contains information on purchase and sales patterns of 72 small and medium-sized enterprises (SMEs): from which main branches did they purchase their inputs, and to which main branches did they sell their outputs. This information was integrated as a new branch in the official input-output tables of Statistics Finland. The SMEs disclosed only the three most significant branches that they trade with, and thus there was not enough detailed information on all of the subclasses. This problem was eliminated by aggregation of branches, in which the entire input-output table was condensed to a 7x7 table.

Detailed purchase and sales data were not disclosed by the large companies, and therefore they were placed in the conventional industrial and service branches best fitting their activities. The existing structures of the branches of large companies were assumed to adequately illustrate their input-output patterns. The large companies are often multi-functional in the sense that they also have more conventional products. These estimates contain only the share of biotechnology related sales disclosed by the companies, not their entire conventional production.

A stochastic feature was included in the forecasting model. A discrete dichotomous setting for the probability of going bankrupt was added to the model. The bankruptcy risk was set at 5.7% for small and medium-sized firms according to US experience in the biotechnology industry, and 1% for large-sized firms [15]. In Finland, the relative share of bankruptcies has been slightly above 5% according to the ETLA biotechnology database.

The growth forecast was based on the future sales figures according to the firms' announcements. All biotechnology firms expect successful growth potential in the next 5 years, in 2002-2006. The estimation of exogenous foreign demand set into the input-output model was based on the anticipated future exports disclosed by the companies (Table 1).

Instead of relying only on the estimates announced by the firms, probability distributions were utilized to create a weighted anticipated future export for every single firm. It was assumed that all the firms have the same risk of either delays in entering the marketplace with new products, or a market penetration that will not evolve as optimistically as expected. Thus, the probable anticipated future sales were formed by applying a uniform distribution. The lower limit of the distribution was set by current exports (in the end of 2001). The upper limit was set by the anticipated future exports in 2006 as announced by the company. Finally, a Monte Carlo simulation with 10,000 iterations was run using the parameters above.

2.2 Input-output structure

The Finnish biotechnology industry is based on intensive international relations and foreign trade; two thirds of the sales are exported and almost one third of the purchases are imported (Figure 2). The biotechnology industry purchases most of its domestic intermediate inputs from the service sector. Other domestic inputs contain the wages of labor and the profits or losses of the companies. The great losses, almost 100 million euros in 2001, reduce the net domestic inputs. The inputs add up to 209 million euros.

Biotechnology SMEs 2001

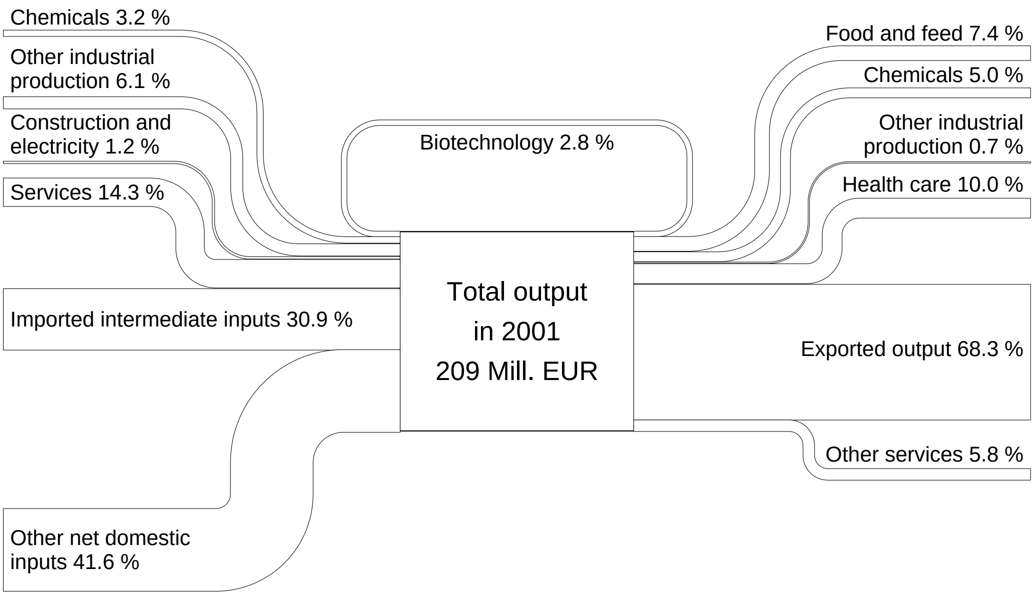

Figure 2. The input-output structure of the Finnish small and medium-sized biotechnology companies.

In input-output models inputs always equal outputs, and thus total output is 209 million euros. The largest domestic customer branches to which the output is sold, are health care services, food and feed industry, and chemical industry (incl. pharmaceuticals). Over 60% of the total output of services and products are exported. Thus, the foreign trade intensity is relatively high within the Finnish biotechnology SMEs.

2.3 Growth prospects

Biotechnology firms are active in many industrial sub-branches. Most of the companies are related to pharmaceuticals or diagnostics, or both. There is also a significant number of firms involved in service activities, biomaterials, and the food industry. A few of the companies are focused on enzyme production or agriculture.

The biotechnology companies seem to anticipate high growth in demand for their products. The global market potential appears to be particularly attractive. Table 2 presents the anticipated growth rates of sales of the Finnish biotechnology industry by sub-branches.

Table 2. The anticipated annual growth rates of biotechnology sales of products and services for the 5 consecutive years, as anticipated by the Finnish biotechnology companies in 2002.

Growth rate in %	Domestic sales	Exports	Entire sales
Pharmaceuticals	4 %	36 %	22 %
Diagnostics	4 %	17 %	14 %
Biomaterials	17 %	94 %	49 %
Food and feed	3 %	11 %	7 %
Industrial enzymes	7 %	5 %	5 %
Agriculture	21 %	24 %	23 %
Services	12 %	101 %	38 %
Other	6 %	19 %	18 %
Total	7 %	27 %	21 %

The table shows how the growth prospects vary among each sub-branch of the bio-technology sector. The companies believe their sales will grow annually 21% on average over the next five years. The growth is expected to be realized mainly on the international markets. It seems that most of the firms expect that they can exploit a market potential throughout the world (Figure 3).

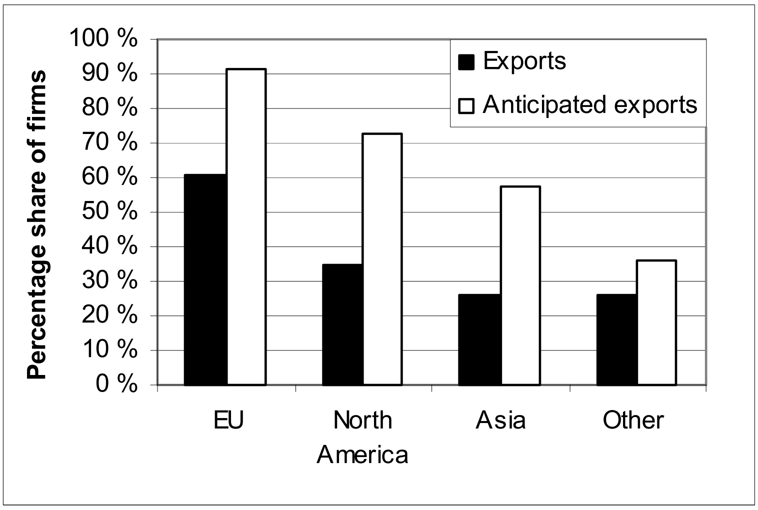

Figure 3. Export areas of the Finnish biotechnology firms in 2001 and in 2006 (anticipations).

A rather surprising finding is that the enzyme related industry expects only a moderate 5% growth. Finland is regarded as a giant in pulp and paper production, which is a heavy user of enzymes, and thus it would be expected to stimulate the demand for new enzyme applications (see Laestadius [16]). At the other extreme, biomaterials production is anticipated to grow almost 50% annually.

The forecast procedure utilizes the companies' anticipations regarding their future exports growth. However, using the companies' own anticipations introduces two possible types of bias to the model

1. randomness at company level: an arbitrary assessment of anticipated future exports
2. systematic error at industry level: a tendency of the entire biotechnology sector to over-estimate systematically the level of anticipated future exports over the period of the survey.

Hermans and Kauranen [17] have analyzed the first type of bias. They related the measurable intellectual capital factors to the anticipated future sales of the biotechnology SMEs in Finland. The intellectual capital theory suggests that the interrelation of human, structural, and relational capital acts as a driver for value creation in a knowledge intensive business (see e.g. Edvinsson and Malone [18]). In the study, they were able to construct an intellectual capital model, which explained 70% of the variance of anticipated future sales. Consequently, measurable intellectual capital was tightly related to the anticipated future sales of the biotechnology SMEs: if a company holds a relatively high (low) level of intellectual capital, it also has high (low) growth prospects, respectively. Therefore, it seems well-reasoned to rely on the companies' anticipations in the ordinal sense, that is, the companies with highest anticipated future sales are those who probably will sell more than those with lower expectations.

Despite the ability to explain the variance of anticipated future sales of the biotechnology SMEs, the second bias remains. There are two main reservations. The first is related to the high risk in developing new biotechnology innovations, and particularly in converting them into commercially exploitable products. Second, there are doubts about the expected short time interval (here 2002-2006) for converting large losses into a flourishing business. The companies seemed to disclose their anticipated future sales within the most optimistic scenario, probably omitting the possibility of technical failures or severe time delays in product development. An example of this optimistic approach is visible in Figure 3, in which approximately 70% of the companies plan to have access to the highly competitive North American marketplace within five years.

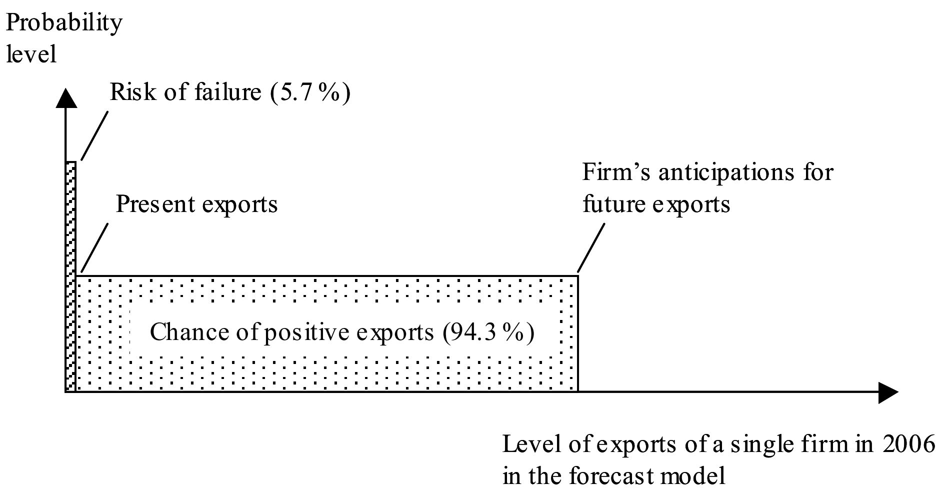

Figure 4. Probability distribution of an individual firm's exports

In order to control the second bias, probability distributions were applied while forecasting the economic impacts: discrete probability distribution covering the bankruptcy risk, and a uniform distribution covering the sales anticipations between the present and anticipated future exports (Figure 4). In other words, there is a 5.7% chance that a single firm will go bankrupt and 94.3% chance that its exports will be between the exports of 2001 and the anticipated future exports for 2006 [15].

3 Economic forecast

3.1 Input-output analysis

The econometric modeling procedure is initiated by input-output analysis. Input-output tables are utilized in order to estimate growth prospects covering inter-industrial linkages as well as contributions to the whole economy until end of 2006. A conventional Leontief-type input-output matrix was constructed (see *e.g.* Forssell [19] and Giaschini [20]). The input-output model describes the interlinkages between all branches of industry.

Horizontal rows imply how the output of a single industry is used: as intermediate inputs in production processes of other industries and as end products to satisfy the domestic and foreign demand. Vertical columns depict how much an industry uses intermediate inputs from other industries and from imported inputs, and how much value added it produces. The method used in this study assumes that these structural multipliers, depicting the shares of input and output usage out of output, are fixed over the period that is analyzed. Equation 1 states the above relation formally:

$$(1)\quad x_i = \sum_{j=1}^{n} a_{ij} x_j + y_i = X = AX + Y = \begin{bmatrix} x_1 \\ x_2 \\ \cdots \\ \\ \\ x_n \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & & \\ \cdots & & \cdots & \\ & & & \\ & & & \\ a_{n1} & & & a_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \cdots \\ \\ \\ x_n \end{bmatrix} + \begin{bmatrix} y_1 \\ y_2 \\ \cdots \\ \\ \\ y_n \end{bmatrix}$$

Multiplier *a* is counted as a dividence: $a_{ij} = \frac{x_{ij}}{x_j}$, in which x_j is the total (intermediary and final) output produced by the industry. The term x_{ij} measures how much the industry *j* uses the production of the industry *i* as an input. When *i* equals *j*, the multiplier *a* measures the intermediate inputs used within the companies of the same industry itself. The term *y* denotes a value of end products in an industry *(1,…,n)*. Capital letters without subscripts are matrix notations referring to the terms above.

Because $X = AX + Y \Leftrightarrow Y = (I - A)X \Leftrightarrow X = (I - A)^{-1} Y$. Therefore,

(2)

$$x_i = \sum_{i=1}^{n} b_{ij} y_i = X = (I - A)^{-1} Y = \begin{bmatrix} x_1 \\ x_2 \\ \ldots \\ \\ \\ x_n \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \ldots & & b_{1n} \\ b_{21} & b_{22} & & & \\ \ldots & & \ldots & & \\ & & & & \\ & & & & \\ b_{n1} & & & & b_{nn} \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \\ \ldots \\ \\ \\ y_n \end{bmatrix},$$

when $[b_{ij}] = (I - A)^{-1}$. Presented another way:

(3)

$$(I - A)^{-1} = \left[\begin{bmatrix} 1 & 0 & \ldots & & 0 \\ 0 & 1 & & & \\ \ldots & & \ldots & & \\ & & & & \\ & & & & \\ 0 & & & & 1 \end{bmatrix} - \begin{bmatrix} a_{11} & a_{12} & \ldots & & a_{1n} \\ a_{21} & a_{22} & & & \\ \ldots & & \ldots & & \\ & & & & \\ & & & & \\ a_{n1} & & & & a_{nn} \end{bmatrix} \right]^{-1}$$

$$= \begin{bmatrix} 1-a_{11} & -a_{12} & \ldots & & -a_{1n} \\ -a_{21} & 1-a_{22} & & & \\ \ldots & & \ldots & & \\ & & & & \\ & & & & \\ -a_{n1} & & & & 1-a_{nn} \end{bmatrix}^{-1} = \begin{bmatrix} b_{11} & b_{12} & \ldots & & b_{1n} \\ b_{21} & b_{22} & & & \\ \ldots & & \ldots & & \\ & & & & \\ & & & & \\ b_{n1} & & & & b_{nn} \end{bmatrix}$$

where b_{ij} expresses how much the industry *i* needs to produce so that the industry *j* could produce one unit of final product *j*.

These matrix operations enable the use of the multipliers of the inverse matrix when estimating the effects of the growth in the biotechnology industry in Finland. The input and output structure of small and medium-sized biotechnology firms were added to the model as a new branch. Large-sized enterprises were treated as a part of their conventional branch because they did not disclose any information on their purchase and sales patterns.

Table 3 depicts the inverse matrix derived from the general form of Equation 3. The coefficients are interpreted as follows. The exogenous increase of 1 unit in demand of biotechnology products and services will add 1.0518 units to the total output of biotechnology industry due to the usage of intermediate products from the companies in its own industry. One unit increase in the output of the biotechnology industry is reflected by a 0.226 unit increase in the demand of other services (vertical column "Biotechnology" in Table 3). However, only 0.0002 units of biotechnology outputs are produced for the other services (horizontal row "Biotechnology" in Table 3).

Table 3. Inverse matrix derived from input-output table.

Inverse matrix	Agriculture and other primary production	Bio-techno-logy	Food industry	Chemical industry	Other industrial production	Construction and electricity	Health care services	Other services
Agriculture and other primary production	1.2410	**0.0084**	0.4465	0.0310	0.0637	0.0422	0.0064	0.0151
Biotechnology	**0.0002**	**1.0518**	**0.0020**	**0.0018**	**0.0001**	**0.0001**	**0.0013**	**0.0002**
Food industry	0.0641	**0.0082**	1.2768	0.0294	0.0193	0.0159	0.0085	0.0223
Chemical industry	0.0247	**0.0363**	0.0178	1.0772	0.0263	0.0131	0.0092	0.0051
Other industrial production	0.0966	**0.1028**	0.2030	0.1995	1.3697	0.3564	0.0617	0.1202
Construction and electricity	0.0494	**0.0263**	0.0460	0.0484	0.0362	1.0779	0.0245	0.0652
Health care services	0.0111	**0.0034**	0.0052	0.0014	0.0016	0.0017	1.0239	0.0054
Other services	0.2439	**0.2260**	0.3688	0.2765	0.2640	0.3295	0.1898	1.3531

Table 3 shows that an exogenous change in demand for the output of other sectors results only in a negligible increase of demand for the biotechnology products and services. This reflects the fact that the biotechnological applications are not yet tightly linked with other sectors' production processes. For example, one unit increase in production of health care services induces only a 0.0013 unit increase in purchases of inputs from the biotechnology industry.

The input-output linkages can and probably will alter with time. For example, biotechnology products can replace some conventional chemical products in consumer and intermediate input markets, leading to an increase in the coefficients of the biotechnological inputs in the inverse matrix. However, this replacement, or crowding-out effect is not taken into account in the fixed coefficient input-output model based on cross-sectional data.

The multipliers are estimated from the cross-sectional data obtained through the ETLA biotechnology survey. The survey is the first of its kind in Finland. Thus, time series data are not available for the Finnish biotechnology sector, which at the moment excludes the construction of a time series model.

3.2 The Monte Carlo simulation

This section presents the results of two simulation procedures. The first simulation contains only the predicted growth impacts of biotechnology SMEs on other industries. In addition to SMEs, the second simulation contains also the large biotechnology related multifunctional companies. The twofold approach was necessary in order to avoid blurring between the inter-industrial linkages and growth contribution to Gross Domestic Product (GDP).

The input-output model estimates spill-over effects, and thus it reveals the impact of a potential growth in the biotechnology industry on other sectors in the table. However, these spill-over effects could not be assessed with a single simulation because the large companies are part of the official branches, and SMEs are part of the newly formed branch of the biotechnology industry. The first simulation, containing only SMEs, indicates how large the spill-over effect is on other branches.

The second simulation, which contains also the large biotechnology related companies, enables the estimation of the growth contribution of the entire biotechnology industry to GDP. However, it does not offer an insight into the spill-over effects on the specific branches since the output growth effects of the large companies and spill-over effects cannot be distinguished from each other.

Results of simulation 1

The value added of small and medium-sized biotechnology companies was approximately 90 million euros in 2001. According to the results of our forecast model, the predicted nominal growth contribution of the biotechnology SMEs to the GDP in 2006 will be in the range of 181-446 million euros with a 90% probability (Figure 5). This corresponds to the growth contribution of .03-.07 percentage units on annual average between 2002-2006. This prediction contains the multiplier effects from input-output tables to other than biotechnology branches. The value added of the biotechnology SMEs is predicted to be 125-309 million euros in 2006 with a 90% probability.

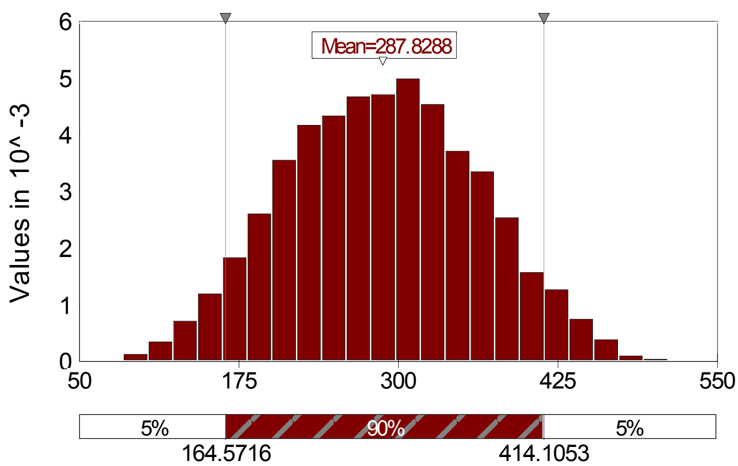

Figure 5. Distribution of the forecast nominal contribution of the small biotechnology industry to the GDP in 2006.

Table 4 presents the main results of the forecast procedure. The overall contribution of the biotechnology business is slightly positive for the economic growth in Finland. As mentioned above, the gross domestic product (GDP) is expected to grow an additional 0.02-0.06 percentage units on annual average by the impact of the growth of biotechnology industry. The biotechnology industry is forecast to grow 18-34% on annual average between 2002-2006. The spill-over effects produced by the biotechnology industry are distributed unevenly among other branches (Table 4).

The spill-over effects are highest on the chemical industry, corresponding to an increase in production of 0.04-0.09 percentage points in annual terms. The production of Other Industry (including production of instruments and food industry) is predicted to be stimulated by 0.01-0.02 percentage points on annual average.

The service sector forms the largest sector in the Finnish economy; it produces 63% of the GDP. Despite a relatively low growth contribution of 0.01 percentage points, the contribution corresponds to 34-86 million euros during 2002-2006; this is the largest contribution to any other branch in monetary terms. The impacts on construction, and agriculture and forestry remain low both as percentage points and in monetary terms.

Table 4. The Monte Carlo simulation-based anticipated nominal growth contributions of small and medium-sized biotechnology companies in annual terms.

Branch	1. Annual growth contribution to a single branch (2002-2006), percent, range of 90 % probability	2. Annual growth contribution to GDP (2002-2006), per-centage units, range of 90 % probability	3. Nominal contribution to the growth of the value added in 2006, million euros, range of 90 % probability
Agriculture, forestry, and other primary production	0.01 – 0.02 %	0.00 – 0.00 %	1 - 3
Biotechnology SMEs	18.1 – 33.7 %	0.02 – 0.04 %	114 – 286
Chemicals	0.04 – 0.09 %	0.00 – 0.00 %	3 - 7
Other industry	0.01 – 0.02 %	0.00 – 0.00 %	10 – 25
Construction	0.01 – 0.02 %	0.00 – 0.00 %	3 – 7
Services	0.01 – 0.02 %	0.01 – 0.01 %	34 – 86
GDP	**0.02 – 0.06 %**	**0.02 – 0.06 %**	**165 – 414**

As a whole, the high relative economic growth of value added of small and medium-sized biotechnology firms have only a low spill-over effect on the entire economy over the next five years according to the forecast model. There are two potential reasons for the low spill-over effects. First, there is a lack of the input-output data of large companies in the survey. This has been discussed above. Second, the volume of purchases and sales was still very low in 2001.

It must be born in mind that even a single company showing significant success and consequently purchasing higher volumes, would have a significant impact on the entire input-output structure over time. In the second simulation, the classification of the large biotechnology related companies as a part of the conventional branches counteracts the effects of a single company affecting the input-output structure of the entire biotechnology industry.

Results of simulation 2

After predicting only the economic impacts of small and medium-sized biotechnology companies, a second forecast model was constructed combining SMEs and large multi-functional biotechnology companies. The multi-functional companies are those that also have essential production activities in branches other than biotechnology. All the large companies are placed in their conventional branches (not the biotechnology industry) in the input-output model.

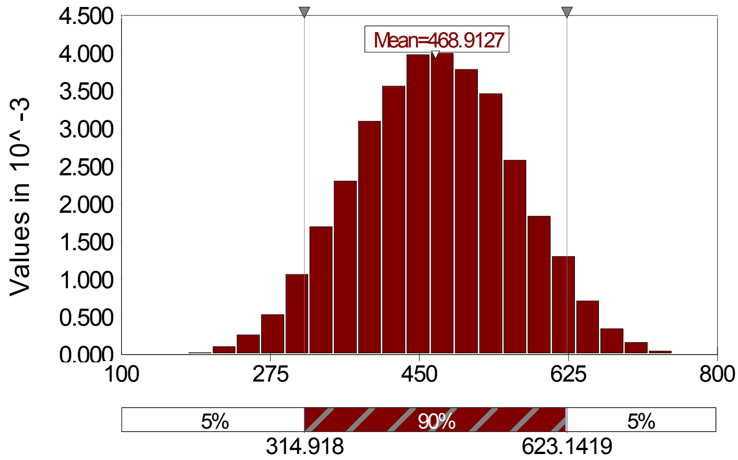

Figure 6. Distribution of forecast nominal contribution of the entire biotechnology industry to the GDP in 2006.

The value added of the entire biotechnology industry with a production that utilizes biotechnology based products or processes, was about 500 million euros in 2001. The forecast model estimates that the growth of the entire biotechnology industry will contribute 315-623 million euros to the growth of the GDP in 2006 (Figure 6) with a 90% probability. This corresponds to a growth contribution of 0.05 – 0.09 percentage points to the GDP growth rates per annum (Table 5).

Table 5. The Monte Carlo simulation-based anticipated nominal growth contributions of entire biotechnology industry (incl. large companies) in annual terms.

Branch	1. Annual growth contribution to a single branch (2002-2006), percent, range of 90 % probability	2. Annual growth contribution to GDP (2002-2006), percentage units, range of 90 % probability	3. Nominal contribution to the growth of the value added in 2006, million euros, range of 90 % probability
Agriculture, forestry and other primary production	0.03 – 0.06 %	0.00 – 0.00 %	6 – 14
Biotechnology SMEs	18.3 – 33.7 %	0.02 – 0.04 %	115 – 285
Chemicals	0.18 – 0.99 %	0.00 – 0.01 %	15 – 81
Other industry	0.03 – 0.10 %	0.01 – 0.02 %	51 – 134
Construction	0.01 – 0.03 %	0.00 – 0.00 %	6 – 13
Services	0.02 – 0.04 %	0.01 – 0.02 %	79 – 155
GDP	**0.05 – 0.09 %**	**0.05 – 0.09 %**	**315 – 623**

Table 5 presents the growth contributions of the entire biotechnology sector to other branches and the total GDP growth. The impact on the production of chemicals and chemical products is greatest: the annual growth contribution of biotechnology-related value added is forecast to reach the range of 0.18 – 0.99 percentage points. The entire biotechnology industry contributes to the growth of the production of Other Industry by 0.03 – 0.10 percentage points on annual average. Growth contributions to other sectors are not as significant.

The growth rates of production of a single branch can be very different from the growth contribution rates presented in Table 5. For example, the growth rate of value added in agriculture and other primary production can even be negative covering the years of the forecast and thus its contribution to the GDP would also be negative.

This study considers anticipated exports to be an exogenous variable. In other words, the increase in domestic demand resulted from an increase in the use of inputs in domestic production. If part of the domestic production had also been considered exogenous, the growth rates would have been slightly higher.

4 Conclusions

4.1 Summary

This forecast study is intended to offer insights on the impacts of the Finnish biotechnology industry on the economic growth in Finland. The study focuses on converting expected growth potential into impacts on economy-wide growth. The use of Monte Carlo simulation enabled the use of probability distributions instead of point estimates in order to model risks related to the failure of a single company as well as time delays in its product development and market launches.

The present purchase-sales patterns of the small and medium-sized biotechnology companies were added as a new industrial sector to official statistics. This procedure employed an input-output analysis, which enabled the estimation of economy-wide growth impacts. An inverse matrix with fixed multipliers was constructed, and the impact of exogenous foreign demand between 2002-2006 was assessed using a Monte Carlo simulation with 10,000 iterations.

The high percentage growth prospects of the Finnish biotechnology industry remained relatively moderate as aggregated for the entire economy. The growth contribution for the Finnish nominal GDP growth was 0.05-0.09 percentage points annually. This equals the growth impacts of 315-623 million euros in nominal terms during 2006.

A noticeable impact on the chemical industry was seen. According to the simulations, the biotechnology companies add 0.2-1.0 percentage points to the annual nominal growth of chemical production in Finland. Many of the biotechnology firms act in chemicals-related sub-industries.

4.2 Further studies

This study opens views for further research:

1. The sub-branches of the biotechnology industry differ from each other concerning their risk profiles. For example, the predicted time span from innovation to product launch is exceptionally long in drug development as compared to development of biomaterials and industrial enzymes. The drug development is strictly regulated requiring extensive pre-clinical and clinical testing before approval to initiate marketing. The Monte Carlo simulation can be refined by using sub-branch specific risk profiles which would add to the accuracy of the model.
2. This study employed fixed input-output multipliers because only cross-sectional survey data was available. As time series become available, the changes of multipliers can be estimated over time using historical data. This would enable the incorporation of the evolvement of industrial structures into the model.
3. Rantala [21] estimates a change of input coefficients over time with the help of R&D intensities of industrial branches. In the R&D intensive biotechnology industry, the inclusion of these dynamic procedures to the input-output models could offer another way of estimating the changes of input-output multipliers behind the forecast.
4. This study does not analyze labor effects. However, the identification of labor effects induced by the growth of the biotechnology industry would be valuable in the macro-economic context (see e.g. Menrad et al. employing German data [22]).

The forecast model presented in this study can be refined to support these four research set-ups.

4.3 Biotechnology – the fourth pillar?

Industrial history shows us that if a region or a country has no previous industrial tradition in a certain sector, successful businesses and new growth emerge slowly or only seldom. Finland has pinned high hopes on biotechnology as a source of new research-intensive growth. Almost all industrialized countries have the same goal, and many of them have already long traditions in this sector, whereas Finland has a short history in biotechnology. In Finland, the biotechnology sector's volume of production measured by value added is slightly over 500 million euros. In order to get a perspective on the growth possibilities, the biotechnology sector can be compared to the development of the currently strong sectors in Finland – the forest, machinery and electronics industries.

In the early 1950s, the value of pulp and paper industry production was 500 million euros in 2000 prices (Figure 7). The electronics industry reached that level in the mid-1970s. If the biotechnology sector achieved the same growth as that of the electronics industry, it would reach the position of the "fourth pillar" of Finnish industry in about 30 years. If the life cycle of the biotechnology industry as an independent sector is comparable to forest industry, the time span would be 50 years. Finally, if the growth rate of production of the biotechnology sector was sustained at the same level as in the forecast period 2001-2006, it would take 15-30 years to reach the same production level as the electronics, machinery and metal products, or pulp and paper industries have today.

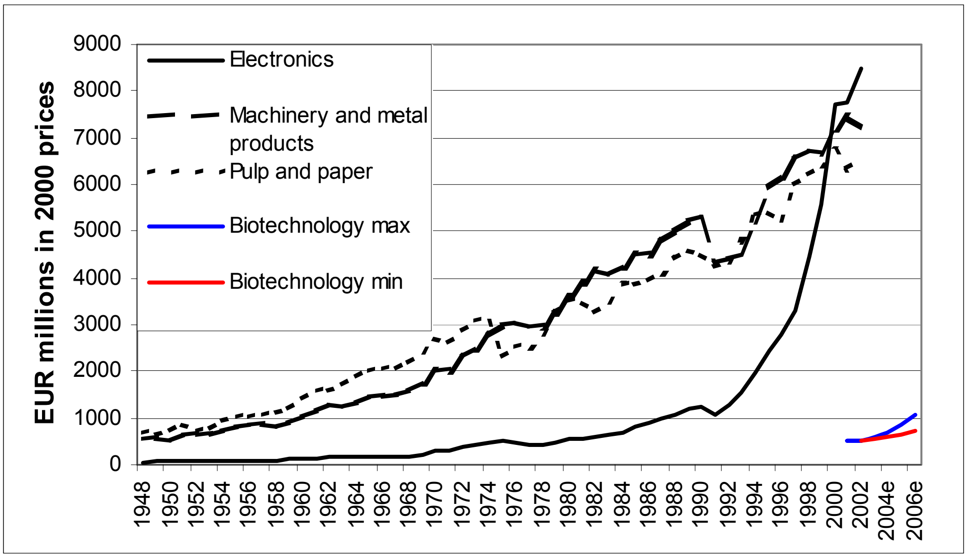

Figure 7. Industrial production by sector 1948 – 2002, in year 2000 prices (Hermans – Ylä-Anttila [23]**).**

Even with a swift growth, it will take more than a decade for the biotechnology industry to become one of the main pillars of the Finnish economy. It is likely that the Finnish economy's new engine of growth will emerge from a combination of new and old sectors. In such a scenario, biotechnology would play a significant role.

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Appendix

Simulation report of the model of small and medium-sized biotechnology enterprises.

Summary Information	
Workbook Name	SME_4.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	144
Number of Outputs	27
Sampling Type	Monte Carlo
Simulation Start Time	9.3.2004 11:04
Simulation Stop Time	9.3.2004 11:05
Simulation Duration	00:00:28
Random Seed	1692226105

Output		Statistics						
Name	Cell	Minimum	Mean	Maximum	x1	p1	x2	p2
Agriculture and other primary production / Value added io	D31	0.7	2.2	4.0	1.3	5 %	3.2	95 %
Agriculture and other primary production / Contribution to own branch	G31	0.003 %	0.010 %	0.018 %	0.006 %	5 %	0.015 %	95 %
Agriculture and other primary production / Contribution to GDP	I31	0.000 %	0.000 %	0.001 %	0.000 %	5 %	0.000 %	95 %
Biotechnology / Value added io	D32	58.5	198.7	353.2	113.6	5 %	285.8	95 %
Biotechnology / Contribution to own branch	G32	10.811 %	26.454 %	38.247 %	18.151 %	5 %	33.732 %	95 %
Biotechnology / Contribution to GDP	I32	0.009 %	0.029 %	0.052 %	0.017 %	5 %	0.042 %	95 %
Food industry / Value added io	D33	0.3	0.9	1.5	0.5	5 %	1.2	95 %
Food industry / Contribution to own branch	G33	0.003 %	0.009 %	0.016 %	0.005 %	5 %	0.013 %	95 %
Food industry / Contribution to GDP	I33	0.000 %	0.000 %	0.000 %	0.000 %	5 %	0.000 %	95 %
Chemical industry / Value added io	D34	1.5	5.1	9.1	2.9	5 %	7.4	95 %
Chemical industry / Contribution to own branch	G34	0.019 %	0.064 %	0.113 %	0.036 %	5 %	0.091 %	95 %
Chemical industry / Contribution to GDP	I34	0.000 %	0.001 %	0.001 %	0.000 %	5 %	0.001 %	95 %
Other industrial production / Value added io	D35	4.8	16.1	28.7	9.2	5 %	23.2	95 %
Other industrial production / Contribution to own branch	G35	0.004 %	0.012 %	0.021 %	0.007 %	5 %	0.017 %	95 %
Other industrial production / Contribution to GDP	I35	0.001 %	0.002 %	0.004 %	0.001 %	5 %	0.003 %	95 %
Construction and electricity / Value added io	D36	1.4	4.8	8.6	2.8	5 %	6.9	95 %
Construction and electricity / Contribution to own branch	G36	0.003 %	0.011 %	0.019 %	0.006 %	5 %	0.015 %	95 %
Construction and electricity / Contribution to GDP	I36	0.000 %	0.001 %	0.001 %	0.000 %	5 %	0.001 %	95 %
Health care services / Value added io	D37	0.3	1.1	2.0	0.6	5 %	1.6	95 %
Health care services / Contribution to own branch	G37	0.001 %	0.002 %	0.004 %	0.001 %	5 %	0.003 %	95 %
Health care services / Contribution to GDP	I37	0.000 %	0.000 %	0.000 %	0.000 %	5 %	0.000 %	95 %
Other services / Value added io	D38	17.3	58.9	104.7	33.7	5 %	84.7	95 %
Other services / Contribution to own branch	G38	0.004 %	0.014 %	0.026 %	0.008 %	5 %	0.021 %	95 %
Other services / Contribution to GDP	I38	0.003 %	0.009 %	0.015 %	0.005 %	5 %	0.013 %	95 %
Total / Value added io	D39	85	288	512	165	5 %	414	95 %
Total / Contribution to own branch	G39	0.013 %	0.043 %	0.076 %	0.024 %	5 %	0.061 %	95 %
Total / Contribution to GDP	I39	0.013 %	0.043 %	0.076 %	0.024 %	5 %	0.061 %	95 %

Appendix

Simulation report of the model of small, medium, and large-sized biotechnology enterprises.

Summary Information	
Workbook Name	SME_LE_03_2004.xls
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	180
Number of Outputs	27
Sampling Type	Monte Carlo
Simulation Start Time	8.3.2004 15:13
Simulation Stop Time	8.3.2004 15:14
Simulation Duration	00:00:41
Random Seed	1069949287

Output		Statistics						
Name	Cell	Minimum	Mean	Maximum	x1	p1	x2	p2
Agriculture and other primary production / Value added io	D50	2.8	9.6	16.4	5.5	5 %	13.7	95 %
Agriculture and other primary production / Contribution to own branch	G50	0.013 %	0.045 %	0.076 %	0.026 %	5 %	0.063 %	95 %
Agriculture and other primary production / Contribution to GDP	I50	0.000 %	0.001 %	0.002 %	0.001 %	5 %	0.002 %	95 %
Biotechnology / Value added io	D51	58.1	199.7	351.3	114.9	5 %	284.9	95 %
Biotechnology / Contribution to own branch	G51	10.753 %	26.556 %	38.130 %	18.304 %	5 %	33.665 %	95 %
Biotechnology / Contribution to GDP	I51	0.009 %	0.030 %	0.052 %	0.017 %	5 %	0.042 %	95 %
Food industry / Value added io	D52	0.7	2.4	4.1	1.5	5 %	3.3	95 %
Food industry / Contribution to own branch	G52	0.007 %	0.025 %	0.042 %	0.015 %	5 %	0.034 %	95 %
Food industry / Contribution to GDP	I52	0.000 %	0.000 %	0.001 %	0.000 %	5 %	0.000 %	95 %
Chemical industry / Value added io	D53	5.2	48.5	90.9	14.9	5 %	81.4	95 %
Chemical industry / Contribution to own branch	G53	0.065 %	0.593 %	1.102 %	0.184 %	5 %	0.990 %	95 %
Chemical industry / Contribution to GDP	I53	0.001 %	0.007 %	0.013 %	0.002 %	5 %	0.012 %	95 %
Other industrial production / Value added io	D54	22.5	87.7	154.8	44.1	5 %	130.9	95 %
Other industrial production / Contribution to own branch	G54	0.017 %	0.065 %	0.115 %	0.033 %	5 %	0.097 %	95 %
Other industrial production / Contribution to GDP	I54	0.003 %	0.013 %	0.023 %	0.007 %	5 %	0.019 %	95 %
Construction and electricity / Value added io	D55	2.9	9.7	16.1	6.4	5 %	13.0	95 %
Construction and electricity / Contribution to own branch	G55	0.006 %	0.021 %	0.035 %	0.014 %	5 %	0.028 %	95 %
Construction and electricity / Contribution to GDP	I55	0.000 %	0.001 %	0.002 %	0.001 %	5 %	0.002 %	95 %
Health care services / Value added io	D56	0.7	3.7	6.8	1.6	5 %	5.9	95 %
Health care services / Contribution to own branch	G56	0.001 %	0.008 %	0.014 %	0.003 %	5 %	0.013 %	95 %
Health care services / Contribution to GDP	I56	0.000 %	0.001 %	0.001 %	0.000 %	5 %	0.001 %	95 %
Other services / Value added io	D57	33.1	107.4	178.7	72.9	5 %	142.0	95 %
Other services / Contribution to own branch	G57	0.008 %	0.026 %	0.044 %	0.018 %	5 %	0.035 %	95 %
Other services / Contribution to GDP	I57	0.005 %	0.016 %	0.026 %	0.011 %	5 %	0.021 %	95 %
Total / Value added io	D58	150	469	776	315	5 %	623	95 %
Total / Contribution to own branch	G58	0.022 %	0.069 %	0.115 %	0.047 %	5 %	0.092 %	95 %
Total / Contribution to GDP	I58	0.022 %	0.069 %	0.115 %	0.047 %	5 %	0.092 %	95 %

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