China's exponential growth in science and the contribution of firms

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Abstract

It is shown that for all essential scientific and technological indicators China shows an exponential increase. Only for the number of R&D personnel the increase is linear. Special attention goes to the contribution of Chinese firms in the output of scientific articles. It is shown that, although this output increases exponentially in absolute numbers, its share in the total scientific output of China is lower than that of European countries. It is concluded that if China succeeds in developing a well-structured technology transfer system from research to economic development, the increasing technological and scientific outputs, illustrated in this article, will be a main source of future economic growth.

Keywords. Exponential growth, contribution of companies, R&D indicators

1. Introduction

China's economic success is phenomenal: over the latest decades its share in the world trade has been increasing seemingly without bounds. The average GDP growth rate was 9.8% during the period 1992-2003. These and all other economic data for China used in this article are taken from http://www.sts.org.cn/sjkl/ . In light of this evolution it is no surprise that also China's share in the world of science has been increasing spectacularly.

Recently King (2004) clearly showed the relationship between wealth intensity and citation intensity (his Figure 2). Leydesdorff and Zhou (2005) even claim that China and neighbouring Asian countries such as Korea are shifting the balance of the world system of science, a statement that has attracted world-wide attention (Brahic, 2005).

Just as an illustration we present in Figure 1 the growth in exports of high-tech products (in 100 million US dollar). Taking the year 1996 as year 1 this curve can be described by the exponential function y(t) = 58.68 exp(0.361*t) [R^2 = 0.984]. Its growth rate is 0.361 and its doubling time is 1.92 year. This means that every two year this type of export is doubled (a growth of 100% in less than two years). This number should be compared with a growth in the exports of goods of 12.9% of all OECD countries over the period 2001-2004 (data from *OECD Main Economics Indicators, August 2005*). In this article we will show that most input and output indicators for science and technology in China show such an exponential growth. As it is impossible that exponential growth continues for prolonged periods, the fact that nowadays growth in China is indeed following an exponential function makes our times exceptional.

For the reader's convenience we have added an appendix explaining how to calculate the doubling time of an exponential function.

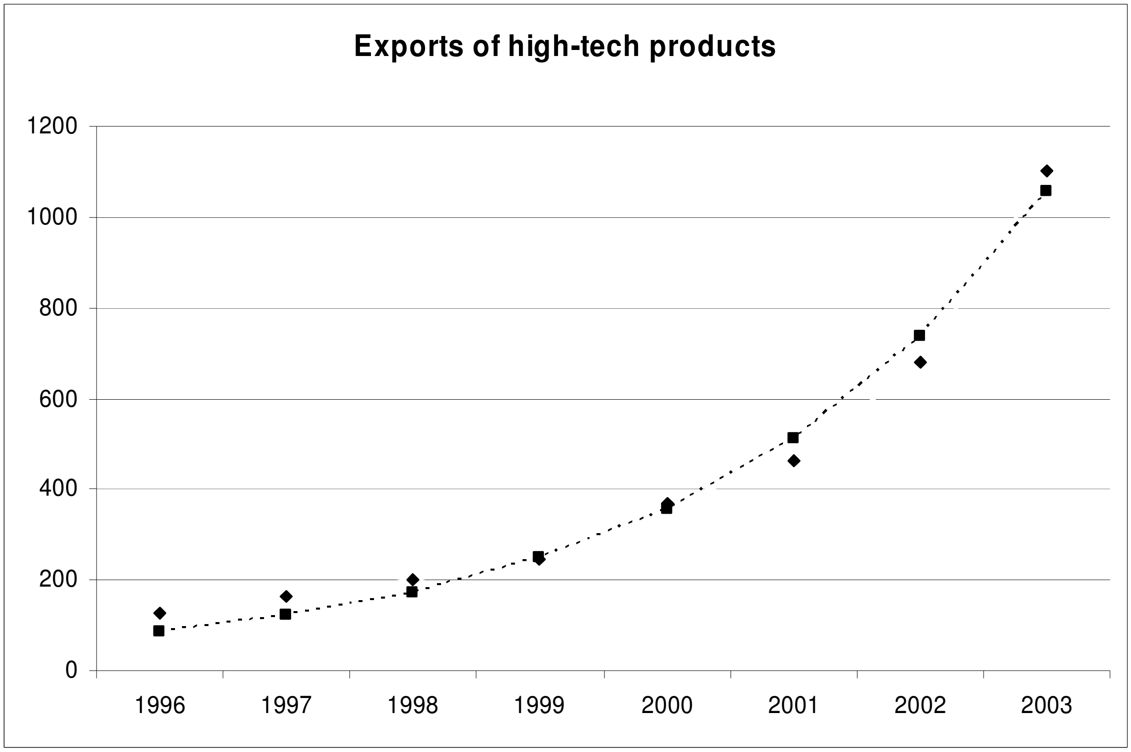

Figure 1. Export of high-tech products from China. Data are shown as diamonds while the dotted line shows the best-fitting exponential curve

2. Input indicators

Pushed by its economic growth the government of China spends more and more money on scientific and technological research and development. This is illustrated by Figure 2. Taking the year 1992 as year 1, this function can be described as y(t) = 159.9 exp(0.189*t) [R^2 = 0.997]. Its growth rate is 0.189, hence its doubling time is 3.67 year. Figure 3 shows that the number of people employed in the R&D sector increases too. This increase, however, is only linear, meaning that on average each person employed in the R&D sector receives more means to attain his or her goal. Taking the year 1996 as year 1, this function can be described as y(t) = 44.76 t + 701.2 (in 1000 FTEs) [R = 0.91].

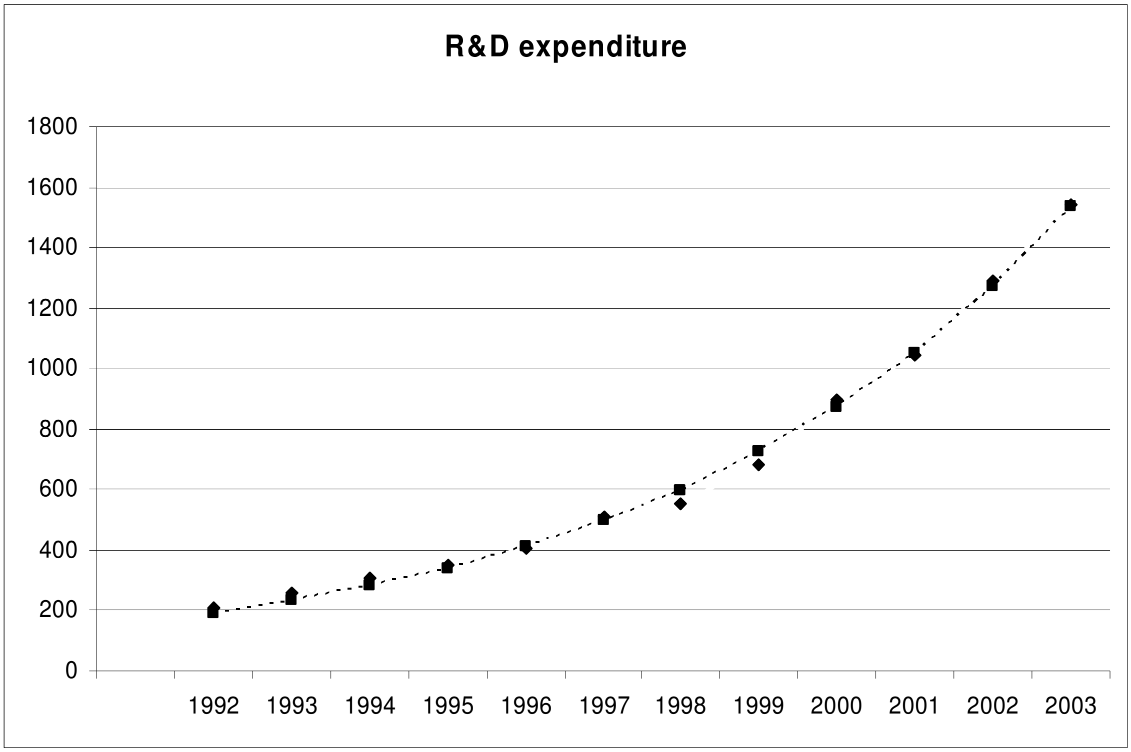

Figure 2. R&D expenditure in China (in 100 million yuan). Diamonds represent data, while the dotted line is the best fitting exponential function

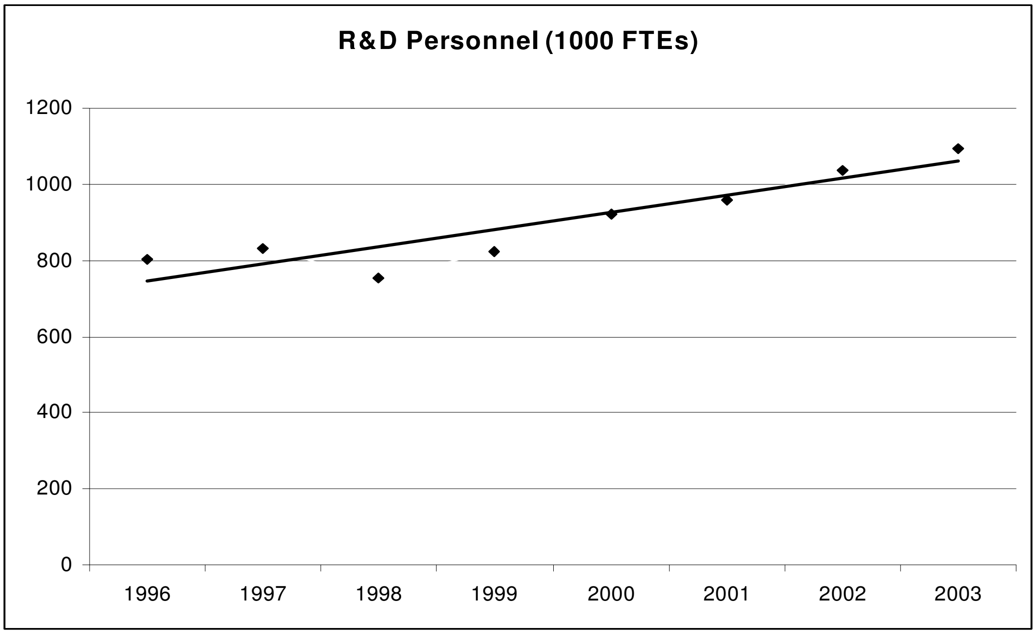

Figure 3. Linear increase in the number of R&D personnel. Diamonds represent data, while a best-fitting straight line is also shown

3. Traditional publication and citation indicators

China is nowadays in a ‘quantitative expansion phase’ (Jin & Rousseau, 2005). This expression refers to the fact that although China’s publication share in the world has been increasing exponentially, its impact defined as the number of citations per publication lags far behind. In this article we will, however, not discuss this state of affairs - for this the reader is referred to (Jin & Rousseau, 2005) - but we will instead focus on exponential growth. Indeed, we have shown (Jin & Rousseau, 2005) that, over the period 1991-2003, the absolute growth curve as well as the relative growth curve (relative with respect to the SCI database) of Chinese publications are exponential functions. Further, the number of internationally co-authored Chinese articles as well as the number of citations to Chinese articles are exponential curves. For the absolute growth in publications covered by the SCI the doubling time for Chinese articles is 4.7 years; for the proportion of Chinese articles in the database it is 5.98 years. The doubling time for internationally co-authored articles is 4.2 years, while for the number of Chinese articles that belong to the group of 10% most-cited it is 2.35 years.

These astonishing doubling times are illustrated in Fig.4.

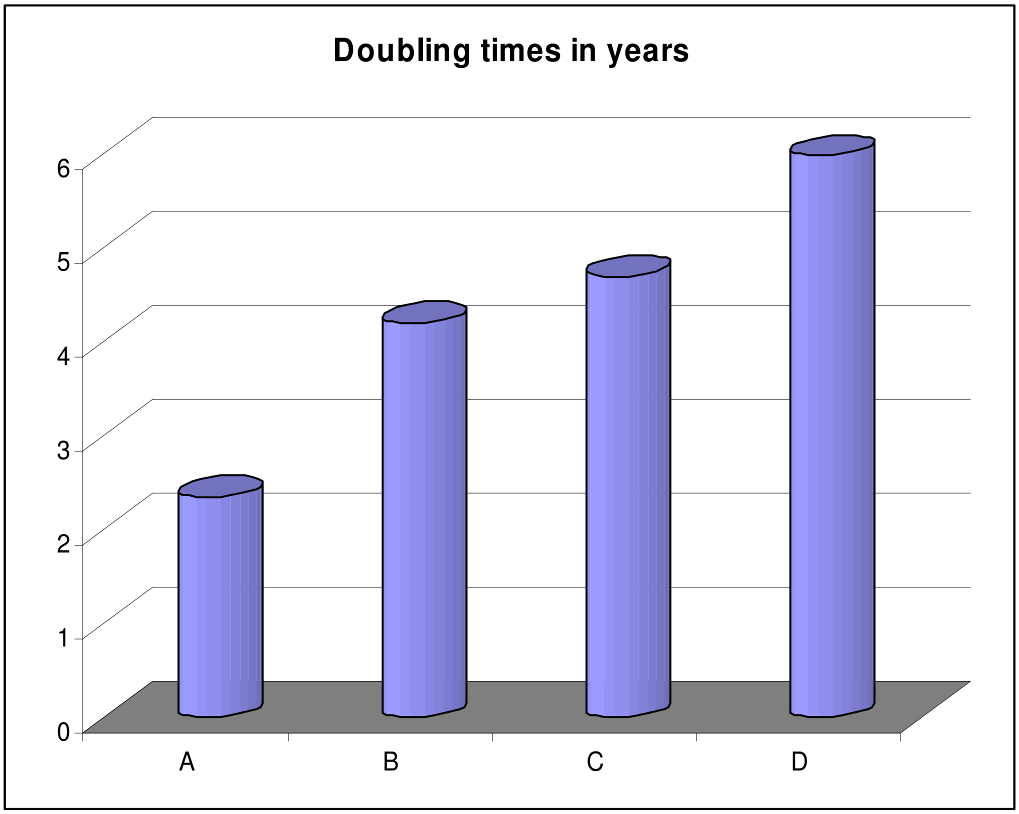

Figure 4. Doubling times
A: number of Chinese articles that belong to the group of 10% most-cited
B: Internationally co-authored articles
C: Chinese publications in the SCI
D: Relative number of Chinese articles in the SCI

All these numbers illustrate Price's exponential model (Price, 1963; Fernandez-Cano et al., 2004). Of course, one does not expect that such an exponential growth would be sustainable over prolonged periods.

4. Patent applications as a technological output indicator

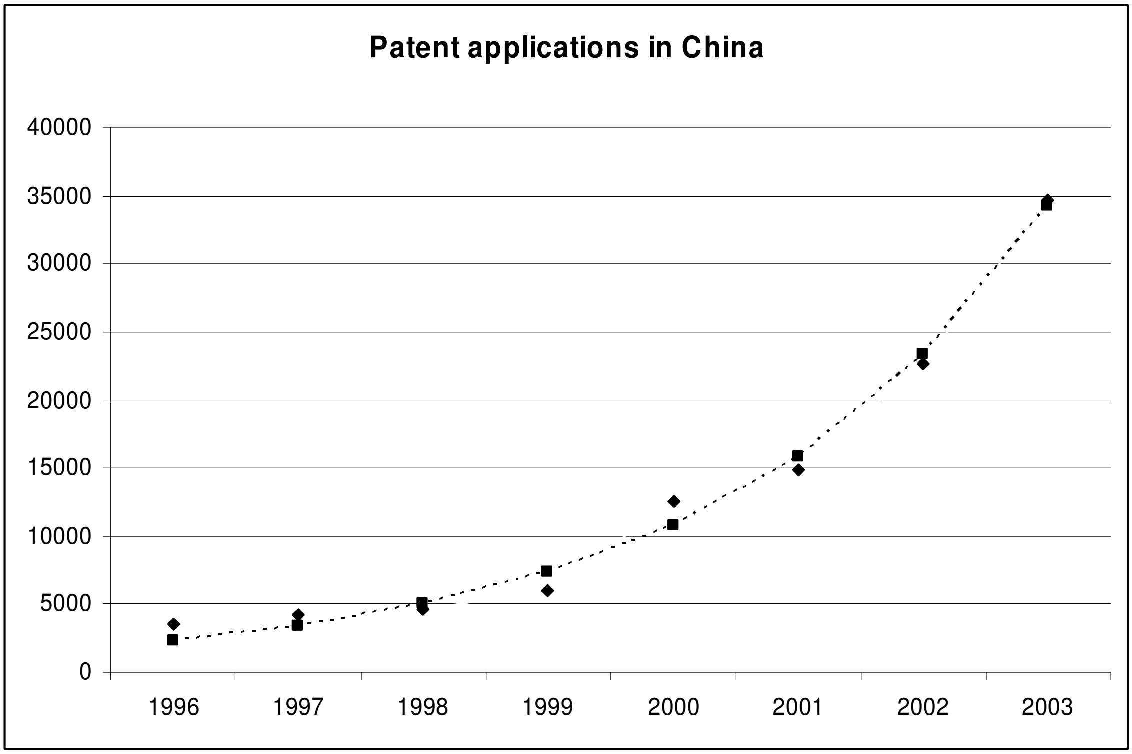

Figure 5. Number of patent applications in China. Diamonds represent data, while the dotted line is the best fitting exponential function

Also a technological indicator such as patent applications (applications in China) shows an exponential increase as illustrated in Figure 5. Here the best fitting curve is: $y(t) = 1571.5 \exp(0.385*t)$, with $t = 1$ in 1996 [$R^2 = 0.989$], with a doubling time of 1.80 year. For patents granted the corresponding best fitting curve is $y(t) = 344.4 \exp(0.362*t)$ [$R^2 = 0.902$], with a doubling time of 1.91 year. For firms only the corresponding doubling times 1.76 (applications) and 1.31 (granted) show that companies play a leading role in technological innovation (other patent applications originate from scientific institutions and universities).

5. Share of Chinese firms in the total publication output (SCI data)

Given the economic expansion of China one might assume that R&D divisions of large Chinese companies take an increasing share in the publication output of the country. It is indeed true that also the number of publications with at least one company address increases exponentially (see Fig.6). The best fitting exponential curve is $y = 78.41 * \exp(0.156 *t)$, where $t = 1,\ldots,13$ and 1991 is year 1 [$R^2 = 0.954$]. The growth rate of this exponential function is 0.156, corresponding to a doubling time of 4.44 year.

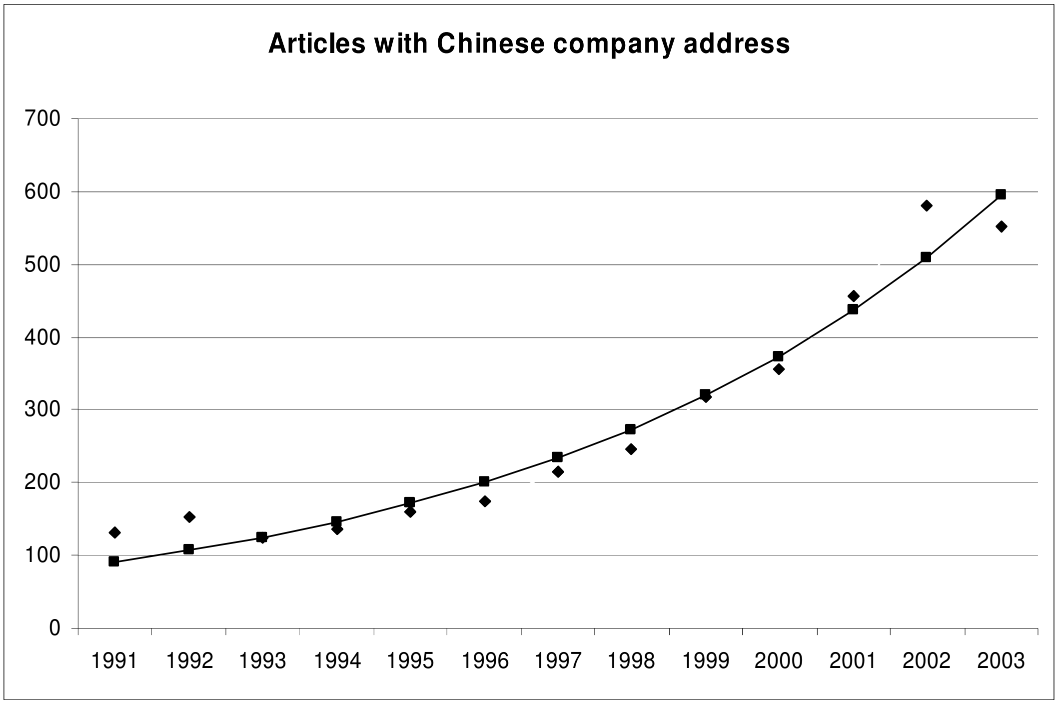

Figure 6. Number of articles in SCI with Chinese company address

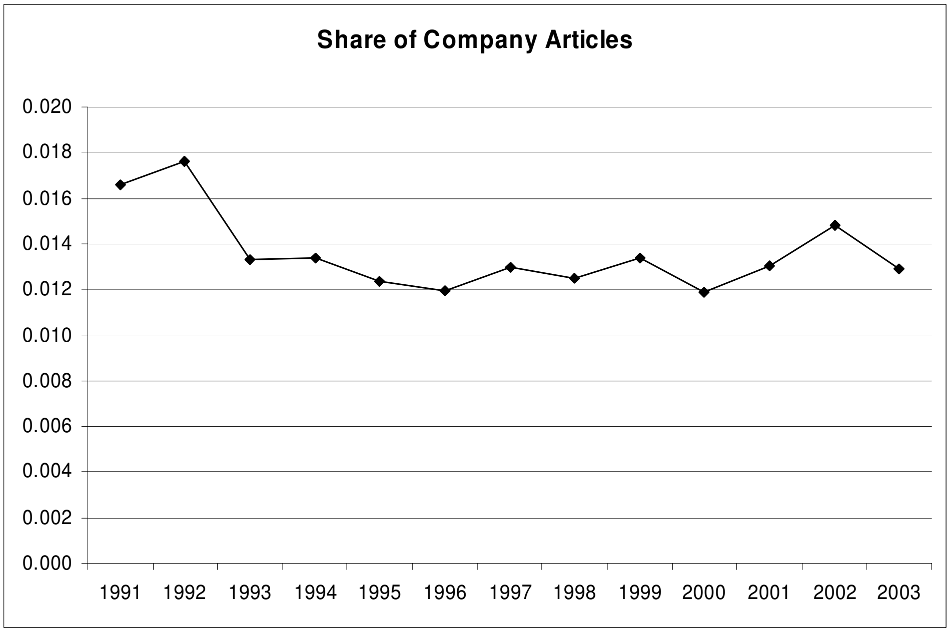

Fig. 7. Share of Chinese companies in the publication output of China

The share of articles in the SCI with a Chinese company address however fluctuates between 1.2 and 1.8% (Fig.7). Compared with Western countries this is a small percentage. Indeed, in (Schlemmer and Glänzel, 2005) we found the following table (Table 1), where we added the values for China.

Table 1. Percentage share of industry publications

	1993	2003
Finland	10.2	11.4
Slovenia	3.6	7.6
Hungary	6.0	5.9
Ireland	3.6	3.9
Portugal	3.4	3.5
Estonia	2.5	2.4
China	1.3	1.3

On the one hand this table illustrates that basic research does not play an important role for most Chinese companies, but on the other hand it clearly shows that China still has a huge potential for an increase in company publications.

6 Conclusion

The GDP is an important and often used indicator for the level of the economy of a country. China's GDP has been increasing at a rate of 9.8% per year over the latest twenty year. This economic growth has fuelled an increasing amount of R&D expenditure, even growing faster than the country's GDP. We have shown that for all essential S&T indicators China has an exponential growth. This confirms findings by Zhou & Leydesdorff (2005). Exponential growth is also true for absolute contributions of Chinese firms, publications as well as patents. Yet, the percentage contribution of scientific publications by Chinese firms is still low. This confirms results of Guan and Liu (2005) and Leydesdorff & Zeng (2001). Yet, patent data seem to show that firms are the main source of practical innovation, while universities and institutes keep their roles as producers of basic and applicable knowledge. If China succeeds in developing a well-structured feedback loop from research to economic development, the increasing technological and scientific outputs, illustrated in this article, will be the main source of future economic growth.

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Appendix

Doubling time

Assume that the number of items expressed as a function of time is given by the exponential function

$$f(t) = B.e^{at} .$$

If *a* is positive then the function is increasing and *a* is called the growth rate. If *a* is negative then the function is decreasing. We assume further that *a* is positive then the doubling time is the time necessary to double the value of f(t) .

If at time t_0, $f(t_0) = B.e^{at_0}$, then we try to find time t_1, such that $f(t_1) = 2\ f(t_0)$ (doubling). The doubling time is then equal to $t_1 - t_0$. The required calculation goes as follows:

$f(t_1) = B.e^{at_1} = 2B.e^{at_0} = 2f(t_0)$. Hence: $e^{at_1} = 2e^{at_0}$.

Now we take the natural logarithm (denoted as ln) of both sides of this equality. This leads to:

$a\ t_1 = \ln(2) + a\ t_0$ or : $a(t_1 - t_0) = \ln(2)$.

We conclude that the doubling time, namely $t_1 - t_0 = \frac{\ln(2)}{a} = \frac{0.69315}{a}$.

In words: the doubling time is equal to ln(2) divided by the growth rate.

Important remark: the term doubling time makes only sense for exponential functions. One can not calculate doubling times for other types of functions. When applying the same idea to a decreasing exponential function one obtains the half-life. Half-life too can only be calculated for decreasing exponentials. Hence, ISI's so-called half-life is not a half-life but a cited median age (Rousseau, 2006).

As an example we calculate the doubling time for exports of high-tech products. It was found that these data could be described by the function y(t) = 58.68 exp(0.361 *t). Then the doubling time is 0.69315 divided by 0.361 = 1.920075. As t is expressed in years the doubling time is 1.92 years. Note that it makes no sense to include many decimals. As a rule we will just write two decimals.

One final remark. Functions of the form $g(t) = C.b^{ct}$ are also exponential functions. Indeed, they can be rewritten as g(t) = C. exp(ln(b).c.t). Hence the growth rate (denoted as *a* before) is here equal to ln(b).c.