Analysis of productivity growth, its components and its determinants in European countries

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Executive summary

The objective of this research is twofold. First, to estimate total factor productivity growth across 13 European countries and different economic sectors over the 1995-2014 period. The use of stochastic frontiers allows for the decomposition of productivity growth into technical efficiency change, technical progress and scale efficiency change. Then, to test the relationship between productivity growth and a set of explanatory variables.

L'objectif de cette recherche est double. Dans un premier temps, il s'agit d'estimer la croissance de la productivité dans 13 pays européens et différents secteurs d'activité économique au cours de la période 1995-2014. L'utilisation de frontières stochastiques permet de décomposer la croissance de la productivité en un changement d'efficacité technique, un progrès technologique et un changement d'efficacité d'échelle. Ensuite, il convient de tester la relation entre la croissance de la productivité et un ensemble de variables explicatives.

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1. Introduction

This research aims to tackle two important challenges in economics, namely measuring productivity growth and identifying some of the reasons that cause its variability across economic sectors.

Thanks to the new version of the STAN database, it was possible to carry out such a study on 13 European countries, over the 1995-2014 period and at three different levels of aggregation. Aggregated data enables estimations at the country level rather than at the firm level.

The use of stochastic frontiers to estimate productivity growth allows its decomposition into three components: a change in technical efficiency which refers to technical catching-up; technological progress which is regarded as an upward shift of the frontier and a change in scale efficiency which corresponds to a change in the scale of operations. In this way, it is possible to explain where the growth of productivity comes from.

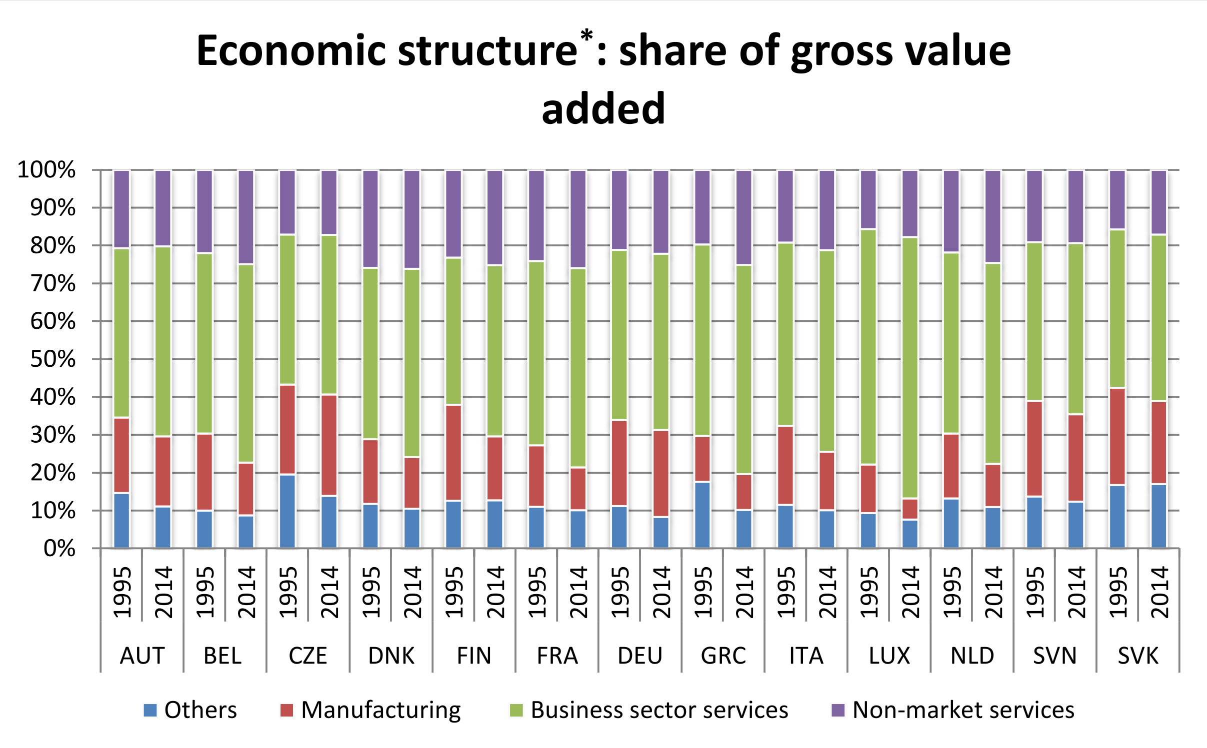
The study period is particularly interesting in the sense that it covers the Global Credit Crisis of 2008 (Arner, 2009). It was the first time since the Great Depression of the 1930s that a crisis of this dimension erupted. The crisis has indeed impacted productivity growth as well as technical efficiency.

As a first step, productivity growth will be derived for every country in no particular sector but for the aggregation of all economic activities. This will allow for a time analysis of the growth in productivity and its different components.

Then, the manufacturing sector and the business sector services will be compared. It may be interesting to focus on these two sectors since there is a reallocation of the economic structure going on in all countries. Indeed, it can be seen from figure 1.1 that the share of the manufacturing sector has decreased over the 1995-2014 period in all countries except in Czech Republic (CZE) whose share has risen by 3 percentage points and in Germany (DEU) whose share has remained constant. This reallocation has been made mainly in favour of the business sector services and to a lesser extent, in favour of the non-market services. Greece (GRC) is the only country where the growth in the share of the non-market services has been more important than the growth in the share of the business sector services.

On average, the share of the manufacturing sector has decreased from 20% to 16.2% between 1995 and 2014. The eastern countries (Slovenia (SVN), Slovak Republic (SVK) and Czech Republic) displayed the highest shares for the manufacturing sector whether it was in 1995 or in 2014. Germany also experienced large shares in 1995 (22.8%) and in 2014 (23%). On the flip side, it was in Greece that this share was the smallest in 1995 (12.1%) followed by Luxembourg (LUX) (12.9%). In 2014, Luxembourg had the smallest share (5.5%) followed by Greece (9.5%).

Figure 1.1 Changes in countries' economic structure between 1995 and 2014



Source: Eurostat, author's calculations

* Others include industries A, B, D, E and F; manufacturing refers to industry C; business sector services correspond to the aggregation of industries G to N and the non-market services to the aggregation of industries O to U (for a detailed list of the industries see Appendix A).

In 2014, the share of the business sector services represented on average half (50.7%) of the gross value added. This share has increased by 4.4 percentage points between 1995 and 2014. Luxembourg, with a share of 62.2% in 1995 and of 69.1% in 2014, displayed the highest shares of the group. It was followed by Greece in 1995 (50.6%) and in 2014 (55.3%). Finland (FIN) and the eastern countries experienced the smallest shares for the business sector services in 1995 and in 2014.

Therefore, one may wonder what happened regarding productivity. Actually, the average level of efficiency and the average productivity growth appear to be higher in the manufacturing sector.

The last step consists in estimating productivity growth in four different industries: two from the manufacturing sector (the pharmaceutical industry and the transport equipment) and two from the business sector services (the IT and other information services and the scientific research and development). Those industries were not chosen randomly: they are all technologically intensive. The pharmaceutical industry and the scientific research and development are defined as high R&D intensive activities while the other two are considered as medium-high R&D intensive activities.

Once the measures of productivity growth are derived, it is possible to test some of the main hypotheses that have been developed in the economic literature in order to explain the different growth patterns in productivity. This is referred to as a two-stage approach; the first stage corresponding to the estimation of the stochastic frontiers and the derivation of productivity growth measures and the second stage relating to the specification of a regression model (Battese and Coelli, 1995).

The remainder of this research is organized in the following manner: section 2 browses the literature related to the different methods available to estimate productivity growth and to productivity analysis in industrial activities and in OECD countries. Section 3 presents the data. Section 4 explains the methodology of stochastic frontier analysis and section 5 reports the results. Section 6 is dedicated to the explanation of the variability of productivity growth across economic sectors. Section 7 concludes.

2. Literature

There exist different methods to estimate productive efficiency. Two main groups of techniques can be identified: the parametric frontier models and the non-parametric methods, for instance Data Envelopment Analysis. The parametric frontier models can be further separated into deterministic and stochastic models. The main difference between the deterministic approach and the stochastic approach lies in the fact that the former fits a frontier function over the data and assumes that all deviations are due to inefficiency (Prasada Rao, 2005), while the stochastic method allows to distinguish between technical inefficiency and statistical noise. Murillo-Zamorano and Vega-Cervera (2000) argued that none of these methods is more desirable than the other and that a parametric and a non-parametric approach should be used jointly to improve the accuracy of the productive efficiency measurement. On the other hand, Bosman and Fecher (1992) (as cited in Ambapour, 2001) thought that the choice of the methodology depends on whether or not the underlying technology is known in the economic sector surveyed.

The founders of Stochastic Frontier Analysis (SFA) are Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). They estimated productive efficiency by means of frontier production functions. They introduced in their model a composed error term comprised of a disturbance due to inefficiency and a statistical disturbance due to random effects and measurement errors. The former authors used an additive disturbance term while the latter used a composed multiplicative disturbance one.

In 1982, the first empirical application of deterministic production frontier to measure productivity growth was carried out by Nishimizu and Page. They were able to decompose total factor productivity change into technical efficiency change and technical change. They specified a Translog production function which imposed few restrictions on the structure of production. Their research covered different regions and different industrial sectors in the former Yugoslavia between 1965 and 1978. Their main findings were that the technical efficiency change was more important than technological progress until 1970 and that after this year, the country suffered from serious losses in efficiency. This allowed them to explain the decline in output growth that Yugoslavia encountered in the 1970s.

A lot of other studies on productivity growth have been carried out so far but some of them are particularly relevant for this research. Gouyette and Perelman (1997) used two different approaches (frontier analysis and Divisia index method) to measure productivity growth in the service and manufacturing sectors across 13 OECD countries (including Australia, Canada, Japan, the United States and European countries) over the 1970-1987 period. They also checked for the presence of convergence. Some of their results are interesting. First they found that, in the service sector, the average level of technical efficiency was rather high in Belgium and the Netherlands and that the Scandinavian countries did not perform well at all. It is also what is found in this study: the Netherlands, Belgium and France are the leaders while Finland does not show really good performances in terms of technical efficiency. Then, they noted that the manufacturing sector was more sensitive to global economic evolutions. In this research the productivity growth and technical efficiency have been more affected by the global crisis in the manufacturing sector than in the business sector services. Their study also confirmed the phenomenon of convergence in service activities meaning that the countries which did not perform well in terms of efficiency benefited from faster growth in productivity. In this work, some evidence of convergence is found in the manufacturing sector. Finally, in their paper, the average level of technical efficiency appeared to be lower in the manufacturing sector than in the service sector while the opposite held true for the productivity growth. It is only half true here. Indeed both the average efficiency level and the growth in productivity are higher in the manufacturing sector.

Perelman (1995) also studied the productivity growth for 11 OECD countries (including Canada, Japan, the United States and European countries) in 8 industrial sectors over the 1970-1987 period. He applied two different methodologies: a parametric approach (Stochastic Frontier Analysis) and a non-parametric approach (Data Envelopment Analysis). It appeared that the “chemicals” and the “textiles” industries benefited the most from technical progress and that the “basic metal products” sector suffered from great losses in technical efficiency. Among the four sectors analysed here, the pharmaceutical industry displays the most important technological progress.

Fecher and Perelman (1992) used a parametric production frontier allowing for the decomposition of productivity growth into technical change and technical efficiency change. They reviewed 13 OECD countries in 8 industries from the manufacturing sector and 3 industries from the services sector over the 1971-1986 period. They learnt that on average the growth in productivity was mainly due to technological progress.

In the latter two papers, the last part consisted in testing the relationship between potential explanatory variables and productivity growth as well as its components. They found that innovation positively affected productivity growth while in this work it is not what is highlighted.

3. Data

3.1 Data description

The data used in this study comes from the new SNA08, ISIC REV.4 version of the STructural ANalysis (STAN) database managed by the Organisation for Economic Co-operation and Development (OECD). It allows for industrial analyses at a relatively detailed level of activity across countries, thereby making it possible to estimate production frontiers for the pharmaceutical products (C21), the transport equipment (C29-C30), the IT and other information services (J62-J63) and the scientific research and development (M72) (see Appendix A for the detailed list of industries available in STAN). This database is widely based on the annual national accounts (SNA08)[1] of individual OECD member countries and uses other sources such as results from national surveys to estimate any missing data.

The main interest of STAN lies in the fact that it provides information on output, labour and capital. This allows for the estimation of production frontiers. For the purpose of this work, production (gross output) is taken as a proxy for output; labour is represented by the hours worked and capital by the gross capital stock.

The period of observation covers the years 1995 to 2014 for most countries. This choice was dictated by the availability of data (see table 3.1.1 for data coverage).

The three variables used in this work can be defined as follows:

- The production (gross output) is expressed in millions and in terms of the current price value in the reference year (2010). According to the OECD (2005, p. 11), the production "represents the value of goods and/or services produced in a year, whether sold or stocked". It includes the intermediate consumption which is sometimes used as an input as is the case in Fecher and Perelman (1989). The intermediate consumption can be seen as the value of inputs that are consumed during the production process; for instance energy, rentals for equipment and so on.

- The hours worked, displayed in millions, account for total employment, that is to say the hours worked by the self-employed workers and the employees. This measure of labour is more precise than the number of working persons or jobs or the number of full-time equivalent workers which are also available in STAN.

- The gross capital stock is also expressed in millions and in terms of the current price value in the reference year (2010). The OECD (2009, p.38) defines the gross capital stock as: "The stock of assets surviving from past investment and re-valued at the purchasers prices of new capital goods of a reference period". Thus, the measure of gross capital stock neglects the depreciation of assets and only takes into account retirement. The capital stock is evaluated using the method of *perpetual inventory* meaning that past capital formation accumulates and that the value of assets is deducted only when they reached the end of their service lives.

This research covers three different levels of aggregation. The first one corresponds to the aggregation of all the industries listed in Appendix A (from 1 to 99). The second one refers to the manufacturing sector and the business sector services. The manufacturing sector corresponds to the aggregation of industries 10 to 33 and the sector of business activities to the aggregation of industries 45 to 82. The last one is the most disaggregated level. Indeed, four different industries are reviewed; two from the manufacturing sector, namely the pharmaceutical products (C21) and the

[1] The national accounts are published according to the System of National Account 2008 (SNA08).

transport equipment (C29-C30) and two other ones, which are the IT and other information services (J62-J63) and the scientific research and development (M72) from the business sector services.

Table 3.1.1 presents the data coverage for the different levels of aggregation across the 13 countries.

Table 3.1.1 Data coverage

	All industries	Manufacturing, Services	C21, C29-C30, J62-J63, M72
AUT: Austria	1995-2014	1995-2014	1995-2014
BEL: Belgium	1999-2014	1999-2014	1999-2014
CZE: Czech Republic	1995-2014	1995-2014	1995-2014
DNK: Denmark	1995-2014	1995-2014	1995-2014
FIN: Finland	1995-2014	1995-2014	1995-2014
FRA: France	1995-2014	1995-2014	1995-2014
DEU: Germany	1995-2014	1995-2014	1995-2014
GRC: Greece	1995-2014	1995-2014	1995-2014
ITA: Italy	1995-2014	1995-2014	1995-2014
LUX: Luxembourg	1995-2014	1995-2014	/
NLD: Netherlands	1995-2014	2000-2014	2000-2014
SVK: Slovak Republic	2004-2014	2004-2014	2004-2014
SVN: Slovenia	2000-2014	2000-2014	/

The next part of this section goes over the average annual growth rates of the different variables at the three levels of aggregation.

3.2 Data analysis

In table 3.2.1, the annual growth rates of production, hours worked and capital stock are presented for the aggregation of all the industries and by period. Some facts can be highlighted:

- Regarding production, it can be seen that this variable was affected by the global crisis of 2008. Indeed, a lot of countries experienced low average growth rates during period 3. In Italy during this period the annual growth rate of production was even negative (-1.2%). On the contrary, Slovak Republic displayed a positive annual growth rate of 3.5% much higher than the average (1%) during this period. Luxembourg, Czech Republic and Slovenia also experienced rather high growth rates (2.7%, 2% and 1.5% respectively). During the last period, Greece, Italy and Slovenia exhibited negative annual growth rates (-3.7%, -1.3% and -0.3% respectively). Italy and Greece encountered difficulties to overcome the crisis of 2008. They were indeed referred to as the PIIGS[2] nations because they were economically weaker than other countries after the financial crisis (Featherstone, 2011). In contrast, in Luxembourg, the growth rate was relatively high (4.3%) compared to the average rate of 0.5%. Nevertheless, this period seemed to be a period of recovery for a few countries.
- The growth in employment is less clear: the growth rate is sometimes positive, other times negative. On average it was the fastest during the first period (0.8%). Luxembourg experienced high positive growth rates during the 4 periods, well above the average ones. It may be worth noting the negative growth rate of -3.2% in Greece during period 4.

[2] PIIGS is an acronym referring to Portugal, Ireland, Italy, Greece and Spain.

Table 3.2.1. Average annual growth rates of production, hours worked and capital stock for the aggregation of all industries by period

	1: 1995-99	2: 2000-04	3: 2005-09	4: 2010-14
Austria				
Production	2.7%	2.1%	1.4%	1.0%
Hours worked	1.0%	0.2%	-0.1%	0.3%
Gross capital stock	2.4%	2.1%	1.7%	1.5%
Belgium				
Production	3.0%	1.0%	0.3%	0.5%
Hours worked	-	0.1%	0.7%	0.5%
Gross capital stock	1.8%	1.6%	1.5%	1.1%
Czech Republic				
Production	2.1%	4.3%	2.0%	0.9%
Hours worked	-0.4%	-1.0%	0.3%	-0.1%
Gross capital stock	1.9%	1.8%	2.1%	1.5%
Denmark				
Production	2.6%	1.2%	0.5%	1.0%
Hours worked	1.4%	-0.2%	0.0%	-0.1%
Gross capital stock	0.4%	0.2%	0.0%	0.3%
Finland				
Production	4.4%	1.8%	0.3%	0.1%
Hours worked	1.6%	0.2%	0.3%	-0.2%
Gross capital stock	1.5%	1.8%	1.6%	0.9%
France				
Production	2.6%	1.4%	0.2%	0.6%
Hours worked	0.7%	0.1%	0.1%	-0.1%
Gross capital stock	0.9%	0.6%	0.3%	0.4%
Germany				
Production	2.2%	0.7%	0.7%	1.1%
Hours worked	-0.1%	-0.7%	0.2%	0.5%
Gross capital stock	1.9%	1.3%	1.1%	0.9%
Greece				
Production	2.4%	3.5%	0.6%	-3.7%
Hours worked	0.6%	1.1%	0.2%	-3.2%
Gross capital stock	3.1%	3.1%	3.0%	1.0%
Italy				
Production	2.0%	1.0%	-1.2%	-1.3%
Hours worked	0.8%	0.7%	-0.1%	-1.0%
Gross capital stock	1.7%	1.9%	1.6%	0.6%
Luxembourg				
Production	7.0%	4.0%	2.7%	4.3%
Hours worked	3.0%	2.2%	2.3%	1.8%
Gross capital stock	3.3%	3.1%	3.2%	2.8%
Netherlands				
Production	4.1%	0.7%	1.1%	0.6%
Hours worked	2.0%	0.0%	1.0%	-0.1%
Gross capital stock	2.2%	1.6%	1.5%	0.8%
Slovak Republic				
Production	3.8%	2.3%	3.5%	2.2%
Hours worked	-0.8%	-0.5%	1.2%	0.0%
Gross capital stock	-	-	3.5%	2.1%
Slovenia				
Production	-	2.9%	1.5%	-0.3%
Hours worked	-0.8%	0.7%	0.9%	-0.6%
Gross capital stock	-	1.7%	2.4%	0.9%
Average (unweighted)				
Production	3.2%	2.1%	1.0%	0.5%
Hours worked	0.8%	0.2%	0.6%	-0.2%
Gross capital stock	1.8%	1.7%	1.8%	1.1%

- The growth in capital stock is on a downward trend in most countries. Indeed, the annual growth rates of capital stock are getting smaller over the periods. Luxembourg exhibited high annual growth rates during all periods (around 3%) well above the average rates of 1.8%; 1.7%, 1.8% and 1.1% during period 1; 2; 3 and 4 respectively. Before period 4, Greece also displayed annual growth rates about 3% but in the last period, its growth rate was only 1%.

The same analysis can be made for the manufacturing sector and the business sector services. The annual growth rates of production, hours worked and capital stock for the 1995-2014 period are shown in table 3.2.2. The main findings can be summarized as follows:
- The annual growth rate of production is higher in the business sector services than in the manufacturing sector in almost all countries. However, it is not the case for the eastern countries (Slovak Republic and Czech Republic) whose growth rates in the manufacturing sector are the highest (5.9% and 4.9% respectively). The average in this sector is only of 1.9%. Italy and Greece experience near-zero growth rates (0.2% and -0.1% respectively) in the manufacturing sector. It is worth noticing the annual growth rate of Luxembourg (7%) for the business sector services which is much higher than the average of 2.7%.
- In every country, for the manufacturing sector, the number of hours worked falls, especially in Denmark (-2.1%) but also in Belgium, France Greece and Slovenia. The decrease in employment is the smallest in Czech Republic (-0.3%). The average is -1.2%. Regarding the business sector services, employment is increasing in every country. Luxembourg displays the highest positive growth rate (3.5%) while in Greece it is only 0.1% and the average is 1.2%.
- The growth in capital shows the same pattern as the growth in production: the annual growth rate is higher in the business sector services than in the manufacturing sector in most countries (it is not the case for Czech Republic, Denmark and Slovak Republic). In every country and in both sectors, the capital stock is increasing. However, Germany and the Netherlands experience near-zero growth rates in the manufacturing sector (0.1% and 0.3% respectively).

The main conclusions coming out from the review of the annual growth rates of the three different variables in the four industries can be detailed in the following way (see table 3.2.3):
- In almost every country, in the pharmaceutical industry, the production is increasing except in Slovak Republic where the annual growth rate is negative (-3.4%) and in Greece where it is close to zero (0.4%). The highest annual growth rates come from Denmark (8.1%) and Belgium (6.1%). These rates are higher than the average of 3.4%.
- The pattern of hours worked is less clear. Employment is falling in Italy, the Netherlands, France and especially in Slovak Republic. Denmark experiences the highest annual growth rate (3.2%) much higher than the average of 0.1%.
- Regarding the capital stock, it is on an upward trend in every country over the 1995-2014 period except in the Netherlands where the annual growth rate is -0.4%. Greece displays the highest annual growth rate (7.3%) followed by Denmark (5.7%) and Belgium (5.2%). These rates are all higher than the average of 3.1%.

Table 3.2.2 Average annual growth rates of production, hours worked and capital stock in the manufacturing sector and the business sector services for the 1995-2014 period

	Manufacturing	Business sector services	
Austria			
Production	2.7%	2.8%	
Hours worked	-0.5%	1.1%	
Gross capital stock	2.0%	2.8%	
Belgium			
Production	0.5%	2.0%	
Hours worked	-1.7%*	1.0%*	*(1999-2014)
Gross capital stock	1.2%	2.0%	
Czech Republic			
Production	4.9%	3.1%	
Hours worked	-0.3%	0.4%	
Gross capital stock	4.1%	2.6%	
Denmark			
Production	0.7%	2.9%	
Hours worked	-2.1%	1.2%	
Gross capital stock	1.0%	0.6%	
Finland			
Production	2.1%	2.7%	
Hours worked	-1.0%	1.2%	
Gross capital stock	0.8%	2.2%	
France			
Production	0.8%	2.4%	
Hours worked	-1.8%	0.9%	
Gross capital stock	0.7%	0.7%	
Germany			
Production	1.9%	2.2%	
Hours worked	-0.6%	0.6%	
Gross capital stock	0.1%	2.0%	
Greece			
Production	-0.1%	1.4%	
Hours worked	-1.8%	0.1%	
Gross capital stock	2.8%	3.1%	
Italy			
Production	0.2%	1.1%	
Hours worked	-1.3%	0.8%	
Gross capital stock	0.8%	1.9%	
Luxembourg			
Production	1.7%	7.0%	
Hours worked	-0.7%	3.5%	
Gross capital stock	1.3%	3.9%	
Netherlands			
Production	1.7%	2.6%	
Hours worked	-1.1%	1.0%	
Gross capital stock	0.3%*	1.7%*	*(2000-2014)
Slovak Republic			
Production	5.9%	2.7%	
Hours worked	-0.8%	1.9%	
Gross capital stock	3.4%*	3.1%*	*(2004-2014)
Slovenia			
Production	2.0%*	2.4%*	*(2000-2014)
Hours worked	-1.8%	1.5%	
Gross capital stock	1.0%*	2.0%*	*(2000-2014)
Average (unweighted)			
Production	1.9%	2.7%	
Hours worked	-1.2%	1.2%	
Gross capital stock	1.4%	2.2%	

- In some countries, the production of transport equipment is increasing. However, Greece and Denmark experience negative annual growth rates (-5.5% and -3.2% respectively) while in Finland and in Belgium the growth rate is close to zero (-0.4% and -0.3% respectively). The highest growth rates come from Slovak Republic (14.9%) and Czech Republic (11.3%) which are higher than the average of 2.9%.
- In almost every country, employment is decreasing, especially in Denmark (-6.5%). Only three countries experience positive annual growth rates: Slovak Republic, Czech Republic and Austria (4.9%, 3.0% and 1.2% respectively). The growth rate in Germany is close to zero. The average is negative (-1.0%).
- The capital stock is growing over the 1995-2014 period except in Finland and in the Netherlands where the annual growth rates are negative (-1% and -0.7%) and in Denmark where it is close to zero (-0.1%). The average is positive (2.1%). Slovak Republic and Czech Republic also display the highest annual growth rates (6.1% and 5.9% respectively).

- In the "IT and other information services" industry, production is increasing in all countries. It is in Germany that the annual growth rate is the highest (9.2%), followed by Denmark (8.1%), Finland (8%) and Austria (8%). In Italy, it is the smallest (3.2%) and the average is 6.7%.
- Employment is also increasing in all countries; especially in Greece (8.4%). France and Italy display the smallest annual growth rates (2.4% and 3% respectively). These rates are below the average of 5%.
- The capital stock follows the same pattern: it is growing. The highest annual growth rate comes from Greece (10.6%), followed by Czech Republic (9.4%). The average growth rate is rather high: 6.7%. It is in Italy that the growth rate is the smallest (2.7%).

- In "the scientific research and development" industry, the production is growing apart from Slovak Republic which experiences a negative growth rate of production of -4.3%. The growth rates in Czech Republic, the Netherlands and France (1.1%; 1.3% and 1.4% respectively) are not quite high compared to the average of 2.7%. Austria and Belgium display the highest positive growth rates (7.4% and 7.1% respectively).
- The hours worked follow the same trend as production: employment is increasing in all countries except in Slovak Republic (-5.3%). Czech Republic exhibits a growth rate close to zero (0.2%). It is still in Austria that the growth rate is the highest (4.9%), then in Greece (4.3%) while the average is 1.9%.
- The annual growth rate of capital stock is positive in all countries without exception, meaning that the gross capital stock is growing over the 1995-2014 period. The smallest rates are found in Czech Republic (0.6%) and Finland (0.7%). The three highest growth rates come from Austria (5.6%), Greece (5.6%) and Belgium (5.1%) which are all higher than the average of 2.9%.

The next section is devoted to the explanation of the stochastic frontier analysis.

Table 3.2.3 Average annual growth rates of production, hours worked and capital stock in the pharmaceutical products, the transport equipment, the IT and other information services and the scientific research and development for the 1995-2014 period

	Pharmaceutical products (C21) 1995-2014	Transport equipment (C29-C30) 1995-2014	IT and other information services (J62-J63) 1995-2014	Scientific research and development (M72) 1995-2014	
Austria					
Production	4.4%	4.9%	8.0%	7.4%	
Hours worked	1.1%	1.2%	6.3%	4.9%	
Gross capital stock	2.4%	3.7%	8.6%	5.6%	
Belgium					
Production	6.1%	-0.3%	7.2%	7.1%	
Hours worked	1.7%*	-3.0%*	4.4%*	3.7%*	*(1999-2014)
Gross capital stock	5.2%	1.7%	7.0%	5.1%	
Czech Republic					
Production	3.1%	11.3%	6.7%	1.1%	
Hours worked	2.1%	3.0%	4.8%	0.2%	
Gross capital stock	4.6%	5.9%	9.4%	0.6%	
Denmark					
Production	8.1%	-3.2%	8.1%	5.9%	
Hours worked	3.2%	-6.5%	5.2%	3.7%	
Gross capital stock	5.7%	-0.1%	5.8%	1.1%	
Finland					
Production	5.4%	-0.4%	8.0%	1.8%	
Hours worked	0.3%	-1.9%	5.2%	2.3%	
Gross capital stock	2.4%	-1.0%	6.5%	0.7%	
France					
Production	3.7%	2.3%	4.2%	1.4%	
Hours worked	-1.0%	-2.0%	2.4%	0.8%	
Gross capital stock	2.5%	1.9%	4.9%	1.5%	
Germany					
Production	3.3%	4.1%	9.2%	3.5%	
Hours worked	-0.2%	0.3%	4.5%	2.8%	
Gross capital stock	1.8%	2.3%	8.6%	2.7%	
Greece					
Production	0.4%	-5.5%	4.1%	2.5%	
Hours worked	0.6%	-4.2%	8.4%	4.3%	
Gross capital stock	7.3%	2.5%	10.6%	5.6%	
Italy					
Production	3.7%	0.8%	3.2%	2.2%	
Hours worked	-1.2%	-1.9%	3.0%	2.3%	
Gross capital stock	2.0%	1.0%	2.7%	3.2%	
Netherlands					
Production	2.4%	2.8%	7.7%	1.3%	
Hours worked	-1.1%	-1.3%	5.6%	1.5%	
Gross capital stock	-0.4%*	-0.7%*	3.7%*	1.1%*	*(2000-2014)
Slovak Republic					
Production	-3.4%	14.9%	7.8%	-4.3%	
Hours worked	-4.6%	4.9%	5.3%	-5.3%	
Gross capital stock	1.2%*	6.1%*	6.1%*	4.4%*	*(2004-2014)
Average (unweighted)					
Production	3.4%	2.9%	6.7%	2.7%	
Hours worked	0.1%	-1.0%	5.0%	1.9%	
Gross capital stock	3.1%	2.1%	6.7%	2.9%	

4. Methodology

Before getting into the methodology itself, it may be useful to understand properly the different concepts of productivity.

Following Pompei (2016), the productivity can be seen as efficiency in production: the quantity of output which is produced from a given set of inputs. Single factor productivity and total factor productivity can be measured. A common measure of single factor productivity is labor productivity. This study addresses only total factor productivity. Coelli, Estache, Perelman and Trujillo (2003) defined the Total Factor Productivity (TFP) as the ratio of output over input. When there is more than one output or input, weights must be applied. Usually, price information is used to compute these weights. The growth of TFP can be due to technical efficiency change, technical change and, when there are variable returns to scale, scale efficiency change.

To explain these different notions, suppose a production function of the form: $y = f(x)$, illustrated in Figure 4.1 at two different points in time, t and t+1. This production function presents decreasing returns to scale and x is the only input.

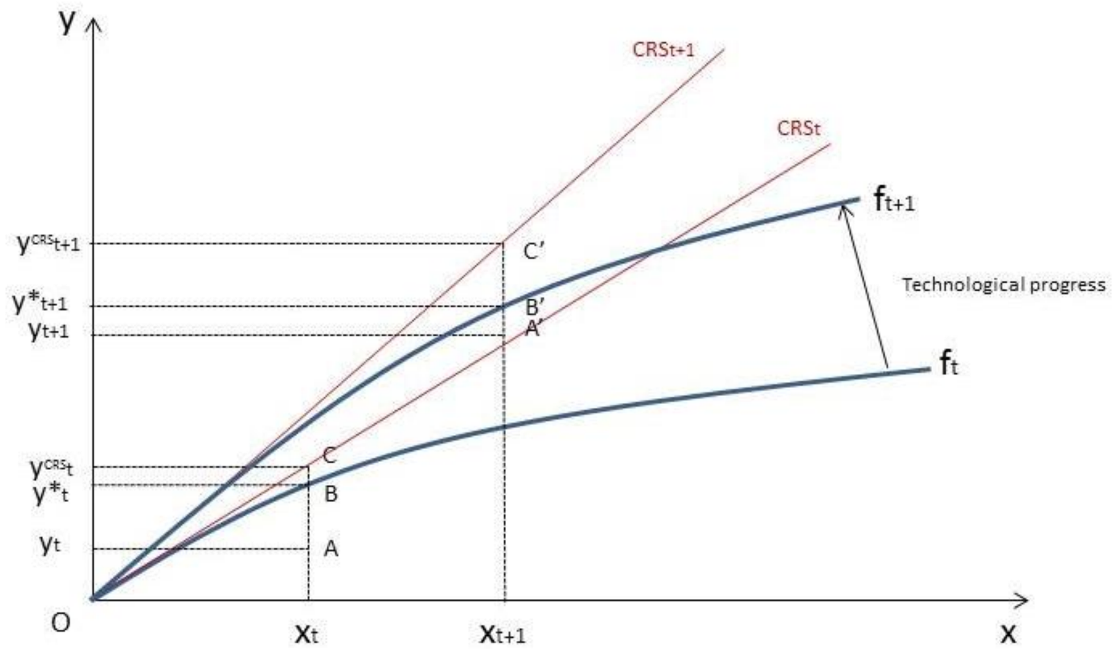


Figure 4.1 Frontier productivity measurement

At time t, if the Decision Making Unit (DMU) is located at point A, it is technically inefficient as it is below the production frontier (B). The point B represents the maximum level of output the DMU could produce using the current technology $f(\,)$ and the level of input x_t. Thus, the measure of technical efficiency (TE) of the DMU is $\frac{|x_t A|}{|x_t B|}$.

The DMU also suffers from scale inefficiency. Scale inefficiencies occur because there is usually an optimal firm size but all the firms do not operate at this optimal size. In case of constant returns to scale (CRS), the DMU should lie at point C. This implies that scale efficiency (SE) of the DMU is equal to: $\frac{|x_t B|}{|x_t C|}$. Coelli et al. (2003) called the technical efficiency that results from both measures (TE and SE) TE_{CRS} and computed it as follows: $TE_{CRS} = TE \cdot SE = \frac{|x_t A|}{|x_t B|} \cdot \frac{|x_t B|}{|x_t C|} = \frac{|x_t A|}{|x_t C|}$.

Kumbhakar, Wang and Horncastle (2015) defined technical change as a change in the production technology. It can be due to more efficient production methods using the existing inputs (disembodied technical change) or to improved quality of the inputs (embodied technical change). In figure 4.1, technical change is represented by the shift of the frontier from f_t to f_{t+1}.

Assume that in period t+1 the DMU is located at point A'. Then, from period t to t+1, the DMU has improved its productivity. Indeed, the measure of TFP in t+1 is larger than that in t: $\frac{|x_{t+1}A'|}{|Ox_{t+1}|} > \frac{|x_t A|}{|Ox_t|}$. As stated by Balk (2001), this productivity growth is the result of three different changes:

- Technological progress since the frontier has moved up;
- Improvement in technical efficiency ($\frac{|x_{t+1}A'|}{|x_{t+1}B'|} > \frac{|x_t A|}{|x_t B|}$) also called *catching-up*. This means that the DMU has changed its position relative to the frontier;
- Diminution in scale efficiency ($\frac{|x_{t+1}B'|}{|x_{t+1}C'|} < \frac{|x_t B|}{|x_t C|}$) meaning that the DMU has moved to a position where its scale of operations is further from the optimal one.

This analysis is based on an output-oriented approach. This means that technical inefficiency is measured in terms of output losses. An alternative approach is to use the input-oriented technical inefficiency which is computed in terms of overuse of inputs.

There exist several methods to evaluate TFP growth. Two of them are commonly used: Data Envelopment Analysis (DEA) which consists of linear programming methods and Stochastic Frontier Analysis (SFA) that refers to econometric approaches. This research will focus solely on SFA.

The SFA aims to estimate a common production possibility frontier that represents the *best practice* function or in other words the maximum level of output that can be attained. This function is of the type: $y = f(x) + v - u$ where v is an error term capturing noise in the data and u accounts for technical inefficiency. Kumbhakar et al. (2015) derived the measure of output-oriented technical efficiency as follows:

$$ln\, y_i = ln\, y_i^* - u_i \; ; \qquad (1)$$
$$\ln y_i^* = f(\boldsymbol{x}_i; \boldsymbol{\beta}) + v_i \; ; \qquad (2)$$

where the subscript i denotes the different observations, y_i is the observed level of output, $\boldsymbol{x}_i$ is a vector of inputs, $\boldsymbol{\beta}$ is the associated vector of coefficients, v_i is a zero-mean random error, y_i^* denotes the frontier output level and $u_i > 0$ is technical inefficiency. Equations (1) and (2) yield: $ln\, y_i = f(\boldsymbol{x}_i; \boldsymbol{\beta}) + \epsilon_i$ where $\epsilon_i = v_i - u_i$ and is called composed error term.

The term $-u_i = ln\, y_i - ln\, y_i^*$ can be rewritten as: $exp(-u_i) = \frac{y_i}{y_i^*}$ namely the ratio of the observed level of output of an observation to the maximum level of output this observation could produce. As mentioned above, this ratio is called technical efficiency.

The major issue at stake when measuring technical efficiency is to decide on which parametric distributions to impose on the error components. This is not anything dreadful for the random error v_i. A zero-mean normal distribution is widely used in the literature. The problem stems from the choice of distributional assumption for the random variable u_i. The distribution must meet two conditions: it must be in the non-negative domain and its joint distribution with v_i should have a closed form (Kumbhakar et al., 2015). A number of such distributions were proposed in the literature. The one adopted in this report is the truncated-normal distribution.

Kumbhakar et al. (2015) defined a production frontier model with a truncated-normal distribution of u_i like this:

$$ln\, y_i = ln\, y_i^* - u_i\, ; \qquad (1)$$

$$\ln y_i^* = f(\boldsymbol{x}_i; \boldsymbol{\beta}) + v_i\, ; \qquad (2)$$

$$u_i \sim N^+(\mu\, ; \sigma_u^2) \qquad (3)$$

$$v_i \sim N(0\, ; \sigma_v^2) \qquad (4)$$

The notation $N^+(\mu\, ; \sigma_u^2)$ refers to a truncation of the normal distribution at 0 from above; u_i is a one-sided error term. Note that by replacing µ by 0, the truncated-normal model becomes the half-normal model. The half-normal model was first proposed by Aigner et al. (1977) and the truncated model by Stevenson (1980) (as cited in Kumbhakar et al., 2015).

Based on equations (1) to (4) the log-likelihood function for each observation can be computed. The log-likelihood is then obtained by summing this log-likelihood function across all the observations. Once the log-likelihood is maximized, the maximum-likelihood estimators (MLE) of the parameters can be derived.

Recall that technical inefficiency is captured by u_i and that $u_i \sim N^+(\mu\, ; \sigma_u^2)$. The maximum-likelihood estimate of σ_u^2 gives information about the shape of the distribution on u_i. This is enough to compute the average technical inefficiency of the sample, which is called the *unconditional* mean of u_i. Nevertheless if the interest lies in estimating the technical inefficiency, u_i, of each observation, the estimate of σ_u^2 is not sufficient. Jondrow, Lovell, Materov and Schmidt (1982) proposed a solution which considers the *conditional* distribution of u_i given ϵ_i. Since the composed error term, ϵ_i, carries individual-specific information, the conditional expectation, $E(u_i|\epsilon_i)$, yields the observation-specific value of the inefficiency. It works similarly to obtain the observation-specific estimates of the technical efficiency but then $E(u_i|\epsilon_i)$ becomes $E(\exp(-u_i)|\epsilon_i)$.

Another concern to address is the choice of a functional form. Two production functions are quite popular in the literature: the Cobb-Douglas and the Translog production function. In this work the Translog production function was chosen rather than a Cobb-Douglas. Indeed the Cobb-Douglas production function assumes that all the observations have the same scale elasticities, the same output elasticities and that the substitution elasticities are equal to one (Coelli et al., 2003). This may be too restrictive especially when the aim of the study is to compare the observations. This drawback can be overcome by using a more flexible form: a Translog production function.

As part of that work, there are two inputs, the hours worked and the capital stock, and one output, the production, thus the Translog production function is:

$y_i = \alpha_0 + \alpha_H x_{Hi} + \alpha_K x_{Ki} + \alpha_{HK} x_{Hi} x_{Ki} + \frac{1}{2}\alpha_{HH} x_{Hi} x_{Hi} + \frac{1}{2}\alpha_{KK} x_{Ki} x_{Ki} + \delta_H x_{Hi} t + \delta_K x_{Ki} t + \gamma_1 t + \frac{1}{2}\gamma_2 t^2 + v_i - u_i$; (5)

where i refers to the countries, H to the hours worked, K to the capital stock, and t to the time trend (going from 1 to 20 since the study period lasts 20 years). The variables y_i, x_{Hi} and x_{Ki} are expressed in logarithmic form. In order to allow direct interpretation of the α_H and α_K coefficients as the output elasticities at the sample means, every series has been divided by its geometric average. The time trend is also expressed in deviations from the mean. Even though there are twenty periods, all the period numbers have been set to 1 so that the Program[3] treats each observation individually. This approach follows the methodology described in Coelli et al. (2003).

Five equations will be estimated: one for the aggregation of all the economic sectors, one for the manufacturing sector, one for the business sector services, one for the pharmaceutical products (C21) and the transport equipment (C29-C30) and one for the IT and other information services (J62-J63) and the scientific research and development (M72). The last two equations represent an overall frontier corresponding to all countries and two sectors. Nonetheless, Fecher and Perelman (1992) obtained proper estimated coefficients for each sector by including sectoral dummies in the equations. Thus, these equations can be written as:

- For the pharmaceutical products (C21) and the transport equipment (C29-C30)

$y_i = \alpha_{21} + \alpha_{H21} x_{Hi} + \alpha_{K21} x_{Ki} + \alpha_{HK21} x_{Hi} x_{Ki} + \frac{1}{2}\alpha_{HH21} x_{Hi} x_{Hi} + \frac{1}{2}\alpha_{KK21} x_{Ki} x_{Ki} + \delta_{H21} x_{Hi} t + \delta_{K21} x_{Ki} t + \gamma_{1,21} t + \frac{1}{2}\gamma_{2,21} t^2 + \alpha_{29-30} D_{29-30} + \alpha_{H29-30} x_{Hi} D_{29-30} + \alpha_{K29-30} x_{Ki} D_{29-30} + \alpha_{HK29-30} x_{Hi} x_{Ki} D_{29-30} + \frac{1}{2}\alpha_{HH29-30} x_{Hi} x_{Hi} D_{29-30} + \frac{1}{2}\alpha_{KK29-30} x_{Ki} x_{Ki} D_{29-30} + \delta_{H29-30} x_{Hi} t D_{29-30} + \delta_{K29-30} x_{Ki} t D_{29-30} + \gamma_{1,29-30} t D_{29-30} + \frac{1}{2}\gamma_{2,29-30} t^2 D_{29-30} + v_i - u_i$; (6)

where D_{29-30} is a sectoral dummy equal to one if the sector corresponds to the transport equipment and to zero otherwise.

- For the IT and other information services (J62-J63) and the scientific research and development (M72)

$y_i = \alpha_{72} + \alpha_{H72} x_{Hi} + \alpha_{K72} x_{Ki} + \alpha_{HK72} x_{Hi} x_{Ki} + \frac{1}{2}\alpha_{HH72} x_{Hi} x_{Hi} + \frac{1}{2}\alpha_{KK72} x_{Ki} x_{Ki} + \delta_{H72} x_{Hi} t + \delta_{K72} x_{Ki} t + \gamma_{1,72} t + \frac{1}{2}\gamma_{2,72} t^2 + \alpha_{62-63} D_{62-63} + \alpha_{H62-63} x_{Hi} D_{62-63} + \alpha_{K62-63} x_{Ki} D_{62-63} + \alpha_{HK62-63} x_{Hi} x_{Ki} D_{62-63} + \frac{1}{2}\alpha_{HH62-63} x_{Hi} x_{Hi} D_{62-63} + \frac{1}{2}\alpha_{KK62-63} x_{Ki} x_{Ki} D_{62-63} + \delta_{H62-63} x_{Hi} t D_{62-63} + \delta_{K62-63} x_{Ki} t D_{62-63} + \gamma_{1,62-63} t D_{62-63} + \frac{1}{2}\gamma_{2,62-63} t^2 D_{62-63} + v_i - u_i$; (7)

where D_{62-63} is a sectoral dummy equal to one if the sector corresponds to the IT and other information services and to zero otherwise.

[3] ML estimation is performed by the STATA software.

Recall that the TFP growth can be due to technical efficiency change (TEC), technical change (TC) and scale efficiency change (SEC). In the case of a production function, the TFP change ($TFPC$) can be decomposed into its different components. The measure of TFPC between two periods is obtained by summing up its three components.

While the measures of technical efficiency are computed directly by the Program, the technical change requires the calculation of the partial derivative with respect to time at each data point. This is why a time trend has been included in equation (5). In the case of a Translog production function, the technical change is said to be non-neutral. This means that the technological progress depends on the variables x_{Hi} and x_{Ki}. Indeed, from equation (5) the partial derivative with respect to time is: $\frac{\partial y_i}{\partial t} = \delta_H x_{Hi} + \delta_K x_{Ki} + \gamma_1 + \gamma_2 t$. On the contrary, neutral technical change occurs when the technological progress is independent of the xs.

The last component to calculate is the scale efficiency change. Changes in scale efficiency occur because of variable returns to scale. In the literature, the condition of constant returns to scale is sometimes imposed on the production technology although this assumption is often too restrictive. A solution to offset this problem is to assume variable returns to scale and then to account for SEC in the derivation of the $TFPC$. Scale efficiency changes require the derivation of the production elasticities, the standard returns to scale elasticities and the scale factors at each data point.

The next section reports the results obtained by estimating the different frontiers at the different levels of aggregation.

5. Results

5.1 Aggregation of all industries

In order to derive TFP evolutions, the first step is to estimate the production frontier as described by equation (5). Table 5.1.1 shows the ML estimators and other parameters resulting from the estimation of the stochastic production frontier.

Kumbhakar et al. (2015) suggested a Likelihood Ratio (LR) test that can be implemented in order to test for the presence of u_i in the model or in other words for the presence of technical inefficiency. If the test is not conclusive, then the model reduces to a simple OLS model. The LR test statistic is $-2[L(H_0) - L(H_1)]$ where $L(H_0)$ is the log-likelihood value of the OLS model (restricted) and $L(H_1)$ is the log-likelihood value of the stochastic frontier model (unrestricted). In the case of a truncated-normal distribution, the null hypothesis has two restrictions: $\sigma_u^2 = 0$ and $\mu = 0$; and thus there are two degrees of freedom. This test has a mix chi-square distribution. As the result of the test is 5.75, it indicates that the SFA model is preferred over the OLS model at the 5% level.

Table 5.1.1 Estimated parameters of stochastic production frontier

α_H output elasticity with respect to labour (*)	0.064 (1.68)
α_K output elasticity with respect to capital (*)	0.829 (21.34)
α_{HK} $(x_{Hi}x_{Ki})$	1.346 (7.87)
α_{HH} $(x_{Hi}x_{Hi})$	-1.102 (-5.88)
α_{KK} $(x_{Ki}x_{Ki})$	-1.472 (-8.94)
δ_H $(x_{Hi}t)$	-0.041 (-8.19)
δ_K $(x_{Ki}t)$	0.037 (7.74)
γ_1 (t)	0.004 (3.2)
γ_2 (t^2)	-0.004 (-6.93)
μ	0.215 (5.82)
σ_u^2	0.017 (5.72)
σ_v^2	0.001 (1.18)
Log-likelihood	168.16
Number of observations	242
LR test	5.75

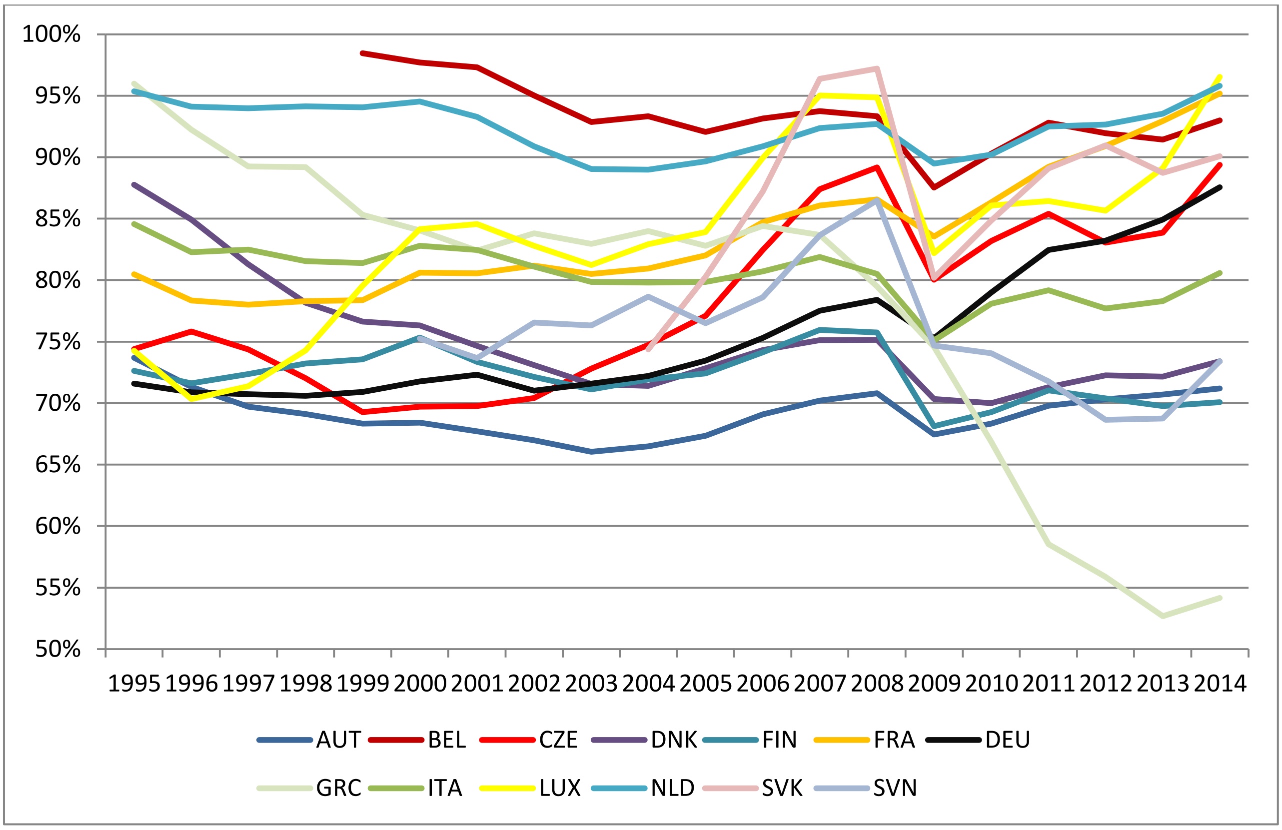
Notes: The t-ratios are in parentheses. Intercept is not shown.
(*) Elasticities evaluated at the sample means.

As can be seen from table 5.1.1, production is capital intensive rather than labour intensive. Note that the coefficient α_H is statistically significant at the 10% level. The production function presents decreasing returns to scale (0.893). γ_1 can be interpreted as the rate of technological progress evaluated at the sample means (Nishimizu and Page, 1982). It is rather law: less than half a percent. γ_2 indicates a deceleration in the rate of technological progress. δ_H and δ_K are the changes in the output elasticity of labour and capital over time (Nishimizu and Page, 1982). In this case, the bias of technical change is capital using and labour saving.

The next step in the derivation of TFPC is the estimation of technical efficiency. As stated before, these measures of TE are conditional measures. Figure 5.1.1 shows the evolution of technical efficiency levels over the 1995-2014 period across countries.

Since 1995 for the Netherlands and 1999 for Belgium, these two countries have remained leaders in terms of efficiency except between 2007 and 2008 when Luxembourg and Slovak Republic lied in front of them. On the contrary Austria and Finland did not perform well in 1995 and their situation has not changed substantially over the period. Denmark experienced a significant loss in efficiency between 1995 and 2014.

Figure 5.1.1 Evolution of technical efficiency levels across countries between 1995 and 2014



The impact of the crisis is clearly identified in figure 5.1.1. All countries experienced a significant decline in their level of efficiency between 2008 and 2009. Slovak Republic, Luxembourg and Slovenia suffered the most from the crisis in terms of efficiency. Nonetheless, in 2010, most countries started to recover from the damages of the global crisis since their level of technical efficiency was rising. This was not the case for Greece. Indeed, as stated by Featherstone (2011), in late 2009, the Greek government-debt crisis erupted. The environment in Greece was therefore not conducive to improvements in technical efficiency. This can explain why the Greek technical efficiency has fallen to that extent since 2008.

Another phenomenon can be observed in figure 5.1.1, namely convergence. This phenomenon, as explained by Färe, Grosskopf, Norris and Zhang (1994) and Gouyette and Perelman (1997), arises because some countries, the ones which are located far below the production frontier (the 'inefficient' ones) can benefit from technology spillover. This allows them to increase their level of efficiency more rapidly than the leading countries and then to reach the level of efficiency of the latter. This catching-up process is called convergence. In contrast, the leading countries can only improve their productivity through technological innovations (frontier shift) since they are already located quite close to the production frontier (they are 'efficient').

This was the case for the eastern countries, that is to say Czech Republic and Slovak Republic as well as in Luxembourg, Germany and France. These countries rank among the top 7 countries in terms of efficiency in 2014 whereas in 1995, they were at the bottom of the ranking. In 2014, Luxembourg stands in front of the two former leaders, namely Belgium and the Netherlands. France is also ahead of Belgium in 2014. Slovenia also exhibited significant improvements in terms of efficiency until 2008 but then never managed to regain the same dynamics.

The final step consists in presenting the TFPC and its different components. The mean annual growth rates are calculated over the 1995-2014 period except for Belgium (1999-2014); Slovak Republic (2004-2014) and Slovenia (2000-2014) and are displayed in table 5.1.2.

*Table 5.1.2 Average annual rates of growth in technical efficiency, technical progress, scale efficiency and total factor productivity (in %)**

	TEC	TC	SEC	**TFPC**
Austria	-0.182	0.91	-0.244	**0.484**
Belgium	-0.381	0.568	-0.218	**-0.031**
Czech Republic	0.966	-1.919	-0.004	**-0.958**
Denmark	-0.941	2.456	-0.125	**1.391**
Finland	-0.188	1.067	-0.353	**0.526**
France	0.883	0.364	0.035	**1.282**
Germany	1.06	0.11	0.057	**1.227**
Greece	-3.012	-1.713	-0.035	**-4.759**
Italy	-0.255	-0.61	0.167	**-0.698**
Luxembourg	1.38	1.932	-2.167	**1.145**
Netherlands	0.023	0.621	-0.08	**0.565**
Slovak Republic	1.916	-3.14	-0.75	**-1.974**
Slovenia	-0.69	-2.522	-1.343	**-4.555**
Average (unweighted)	0.045	-0.144	-0.389	**-0.489**

*The results presented in table 5.1.2 are computed using the coefficients significant at the 10% level.

Not surprisingly, the global crisis had a large negative impact on the TFP growth between 2008 and 2009 for all countries.

There is no general trend which stands out from table 5.1.2. Four countries have seen their TFP increase by more than 1% per year on average: Denmark, France, Germany and Luxembourg. For Denmark it is mainly due to technological progress. France benefits from both technical progress and gains in efficiency while Germany mostly takes advantage of improvements in efficiency. In Luxembourg, the positive technical efficiency change and the technological progress offset the negative scale efficiency change.

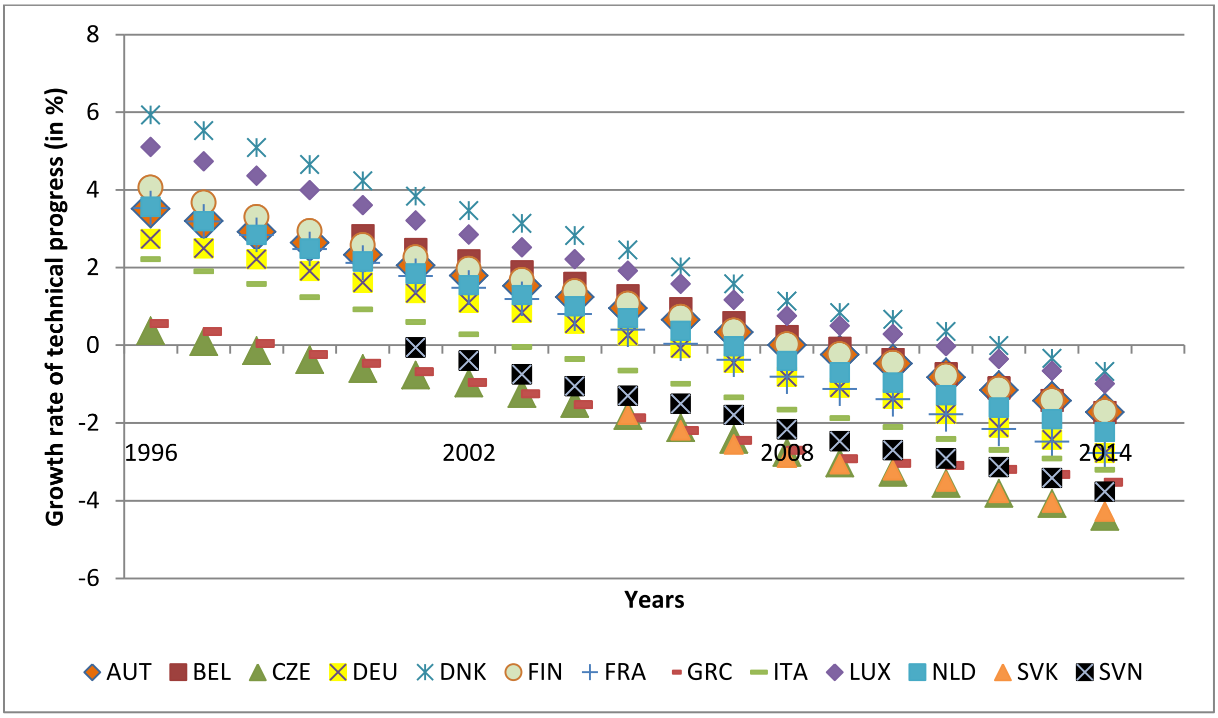
In Austria, Finland and the Netherlands, the average annual growth in TFP is around 0.5%. This results mainly from technological progress.

In contrast, TFP has decreased by more than 4% per year on average in Slovenia and in Greece and by 2% in Slovak Republic. TFPC is also negative in Czech Republic (-0.96%) and in Italy (-0.7%). In Slovenia, the negative annual growth in TFP is mainly due to negative technical change and negative scale efficiency change. Greece suffers from losses in efficiency but also from negative technical change as is the case for Italy. In Slovak Republic the gains in efficiency are offset by the negative technical change just as in Czech Republic.

In Belgium the average annual TFP growth is close to 0. The positive effect of technical change is cancelled by the negative effect of technical efficiency change and scale efficiency change.

It may be interesting to take a deeper look at the evolution of the rates of growth in technological progress over the 1995-2014 period (see figure 5.1.2).

Figure 5.1.2 Evolution of the growth rates of technical progress across countries between 1995 and 2014



Remember that, in this study, technological progress is non-neutral. That is it can vary according to the ratio of inputs. This means that differences between growth rate levels across countries are allowed but that there is a common trend for all countries (S. Perelman, personal communication, July 20, 2017). In this case, it is easy to identify the common tendency: the growth in technological progress is slowing and even becomes negative. The deceleration is explained by the γ_2 coefficient from table 5.1.1. At the beginning of the period, Denmark and Luxembourg experienced growth rates higher than 4% while in Finland, the Netherlands, France, Austria and Germany the rates were higher than 2%. The growth rates of Greece and Czech Republic were much smaller. At the end of the period, the growth rates of all the countries have become negative. It is difficult to explain negative technological change since it means that the acquired technology is, in a manner of speaking, lost. It should be recalled that the Translog production function is a very flexible functional form and hence it sometimes yields counterintuitive results. Furthermore, no restriction was imposed on the function. On another note, the crisis of 2008 is not modelled in this study although this crisis certainly affects the technology through decreases in the countries' capacity utilisation.

The next part of this section aims to compare two aggregated sectors, namely the manufacturing sector and the business sector services.

5.2 Manufacturing sector and business sector services

In order to compare the results of the two aggregated sectors, two production functions have been estimated following equation 5: one for the manufacturing sector and one for the business sector services. The different parameters obtained are displayed in table 5.2.1.

Table 5.2.1 Estimated parameters of stochastic production frontier in the manufacturing sector and the business sector services

	Manufacturing sector	Business sector services
α_H output elasticity with respect to labour (*)	0.088 (2.96)	0.104 (1.75)
α_K output elasticity with respect to capital (*)	1.012 (28.01)	0.686 (12)
α_{HK} $(x_{Hi}x_{Ki})$	-0.476 (-4.69)	1.317 (6.02)
α_{HH} $(x_{Hi}x_{Hi})$	0.363 (2.9)	-0.943 (-3.27)
α_{KK} $(x_{Ki}x_{Ki})$	0.678 (7.04)	-1.440 (-8.14)
δ_H $(x_{Hi}t)$	-0.003 (-1.94)	-0.030 (-4.94)
δ_K $(x_{Ki}t)$	-0.001 (-1.27)	0.019 (3.68)
γ_1 (t)	-0.000 (-0.42)	0.018 (7)
γ_2 (t^2)	-0.002 (-5)	-0.003 (-3.31)
μ	0	0
σ_u^2	0.086 (10.89)	0.151 (8.15)
σ_v^2	0.000 (0.01)	0.003 (1.6)
Log-likelihood	118.10	28.16
Number of observations	237	237
LR test	81.97	20.20

Notes: The t-ratios are in parentheses. Intercept is not shown. The two equations have been estimated using a half-normal distribution on u_i.
(*) Elasticities evaluated at the sample means.

In the case of a half-normal model, the LR test has a mixed chi-square distribution with one degree of freedom. Since the critical value of the statistic at the 1‰ significant level is 9.5, the results of the test for both models indicate an outright rejection of the null hypothesis of no technical inefficiency.

Both sectors are more capital-intensive than labour-intensive. The manufacturing sector is the most capital-intensive one while the sector of business activities is the most labour intensive sector. The production function in the manufacturing sector exhibits increasing returns to scale (1.1) while the opposite holds true for the business sector services (0.79). The rate of technological progress at the sample means is somewhat less than 2% for the business sector services while for the manufacturing sector it is not statistically different from 0. Both sectors experience deceleration in the rate of technological progress. For the manufacturing sector, the bias of technical change is labour saving and capital neutral since δ_K is not statistically significant. For the business sector services, it is also labour saving but capital using.

There are a few things to say regarding the conditional levels of efficiency. First, it seems that the global crisis had a far greater effect on the manufacturing sector than on the business sector services.

In fact, the crisis slightly impacted efficiency in the business sector services while in some countries in the manufacturing sector the decrease in efficiency was significant (see Appendix B).

Table 5.2.2 displays the mean levels of technical efficiency reached in the two aggregated sectors by each country during the 1995-2014 period (note that for Belgium the period starts in 1999; for the Netherlands and Slovenia in 2000 and for Slovak Republic in 2004).

Table 5.2.2 Average technical efficiency across countries for the 1995-2014 period in the manufacturing sector and the business sector services

	Manufacturing sector	Business sector services
Austria	91.6%	66.7%
Belgium	86.5%	90.3%
Czech republic	62.7%	82.9%
Denmark	80.9%	79.2%
Finland	84.4%	60.2%
France	95.3%	89.5%
Germany	63.6%	70.5%
Greece	96.1%	71.5%
Italy	84.0%	73.3%
Luxembourg	89.8%	86.1%
Netherlands	83.5%	94.7%
Slovak Republic	68.7%	87.9%
Slovenia	61.3%	37.0%
Average (unweighted)	80.6%	76.2%

On average, technical efficiency is higher in the manufacturing sector (80.6%) than in the business sector services (76.2%) for the 1995-2014 period. However this does not hold true for Belgium, Czech Republic, Germany, the Netherlands and Slovak Republic.

In the manufacturing sector, Greece, France and Austria are in a leading position in terms of technical efficiency (96.1%; 95.3% and 91.6% respectively). Luxembourg also performs rather well (89.8%). In the business sector services, the Netherlands, Belgium and France are the leaders with respective average technical efficiency of 94.7%; 90.3% and 89.5%. They are followed by Slovak Republic (87.9%) and Luxembourg (86.1%). France and Luxembourg show good performances in both sectors.

In contrast, in the manufacturing sector the eastern countries (Slovenia, Czech Republic and Slovak Republic) and Germany lag far behind the leaders with respective average technical efficiency of 61.3%, 62.7%, 68.7% and 63.6%. In the business sector services Slovenia is at the very bottom of the ranking with an average efficiency of only 37%, followed by Finland (60.2%). Slovenia does not perform well in any of the sectors. The other two eastern countries are performant in the business sector services but not so much in the manufacturing sector.

The last part of this subsection deals with the TFPC and its components. Their mean annual growth rates for the 1995-2014 period are listed in table 5.2.3 (note that for Belgium the period starts in 1999, for the Netherlands and Slovenia in 2000 and for Slovak Republic in 2004).

*Table 5.2.3 Average annual rates of growth in technical efficiency, technical progress, scale efficiency and total factor productivity (in %) in the manufacturing sector and the business sector services**

	TEC	TC	SEC	**TFPC**
Austria				
Manufacturing sector	0.642	0.030	0.215	**0.887**
Business sector services	-1.039	2.120	-0.527	**0.554**
Belgium				
Manufacturing sector	-0.897	-0.406	0.223	**-1.079**
Business sector services	-0.915	1.708	-0.390	**0.404**
Czech Republic				
Manufacturing sector	3.265	-0.207	-0.032	**3.026**
Business sector services	-1.182	0.325	-0.455	**-1.312**
Denmark				
Manufacturing sector	-0.812	0.228	0.132	**-0.452**
Business sector services	-1.259	3.606	-0.614	**1.732**
Finland				
Manufacturing sector	0.975	0.181	0.117	**1.273**
Business sector services	-1.438	2.940	-0.980	**0.522**
France				
Manufacturing sector	0.388	-0.429	0.186	**0.146**
Business sector services	0.377	0.672	0.207	**1.256**
Germany				
Manufacturing sector	2.698	-0.672	0.077	**2.103**
Business sector services	1.030	0.130	0.246	**1.406**
Greece				
Manufacturing sector	0.118	0.067	0.028	**0.213**
Business sector services	-3.438	0.538	-0.288	**-3.188**
Italy				
Manufacturing sector	-0.047	-0.577	0.200	**-0.424**
Business sector services	-0.512	-0.060	0.374	**-0.197**
Luxembourg				
Manufacturing sector	-0.232	0.927	-0.070	**0.625**
Business sector services	1.788	4.105	-5.699	**0.194**
Netherlands				
Manufacturing sector	0.934	-0.640	0.105	**0.399**
Business sector services	-0.110	0.383	-0.072	**0.200**
Slovak Republic				
Manufacturing	4.205	-0.980	-0.045	**3.180**
Business sector services	0.345	-0.546	-1.814	**-2.015**
Slovenia				
Manufacturing sector	2.398	-0.238	0.023	**2.184**
Business sector services	-0.885	1.931	-2.332	**-1.286**
Average (unweighted)				
Manufacturing sector	1.049	-0.209	0.089	**0.929**
Business sector services	-0.557	1.373	-0.950	**-0.133**

*The results presented in table 5.2.3 are computed using the coefficients significant at the 10% level.

Just as with subsection 5.1, TFP growth has been affected by the global crisis. The adjustments were steeper in the manufacturing case.

On average, TFP growth is higher in the manufacturing sector than in the business sector services where it is negative. The technical change is much higher in the business sector services than in the manufacturing sector. Indeed, it is negative in the manufacturing sector. The manufacturing sector benefits from relatively high technical efficiency change while in the business sector services its impact is negative. The scale efficiency change has a large negative effect in the business sector services and is positive but less important in the manufacturing sector.

In the manufacturing sector the highest average annual rates of growth in TFP are found in the eastern countries and in Germany. These countries benefit from high growth rate of technical efficiency while the growth rate of technical change is negative. This implies that the countries which do not perform well in terms of efficiency experience more rapid productivity growth than the leading ones. Once again, this leads to convergence towards the leading countries (Gouyette and Perelman, 1997). Finland also experiences relatively high TFPC. In this country, the three components are positive. Luxembourg is the only country where the growth in TFP is mainly due to technical progress.

In contrast, Belgium, Denmark, and Italy have seen their TFP decrease over the years in the manufacturing sector. Belgium suffers from negative technical efficiency change and from negative technical change. In Denmark it is attributed to negative technical efficiency change and in Italy this is mainly due to negative technical change.

Regarding the business sector services, Denmark, Germany and France display the highest average annual rates of growth in TFP. Denmark benefits from high positive growth rate of technical progress despite the negative technical efficiency change. For Germany it is mainly due to gains in efficiency while for France the three components are positive. Austria, Finland, Belgium and the Netherlands also experience positive average annual growth rate of TFP. For all these countries, it is due to positive technical change higher than the sum of the negative technical efficiency change and scale efficiency change.

Luxembourg suffers from significant negative scale efficiency change in the business sector services but still displays positive average annual growth rate of TFP thanks to the positive changes in technical efficiency and technical progress. The case of Luxembourg is particular since it is a rather small country and the sector of the business activities plays a crucial role in its economy (see table 1.1). The use of a Translog function allows this country to display substantial negative output elasticity with respect to labour which results in significant decreasing returns to scale. The OECD (2015) stated that the competitive salaries in the financial sector in Luxembourg do not encourage qualified employees to work in other business lines. Thus, even if negative production elasticity with respect to labour may seem counterintuitive, a hypothesis could possibly be that there are too many workers in the sector of the business activities and that adding more workers in this sector decrease the productivity.

The eastern countries experience negative average annual rate of growth in TFP in the business sector services. Slovak Republic and Slovenia suffer from significant negative scale efficiency change but in Slovenia the technical progress is positive and its impact is important. Czech Republic displays important losses in technical efficiency.

The case of Greece is worthy of attention. As mentioned in subsection 5.1 the Greek economy was largely affected by the crisis that emerged in this country in late 2009. In fact, it seems that the impacts of this crisis were much larger in the business sector services than in the manufacturing sector. Indeed the TFP has decreased by more than 3% per year on average in the business sector services while in the manufacturing sector it has increased by 0.4%. The negative TFPC is mainly due to negative technical efficiency change.

The trend in the evolution of the growth rates of technical progress is exactly the same as that in subsection 5.1 in both sectors (see Appendix C). The speed of the rate of growth in technological progress is decreasing over the years. The growth rate levels differ across countries and according to the sector. In the manufacturing sector Luxembourg displays growth rates of technological progress above those in other countries. In the business sector services the highest rates of growth are found in Luxembourg, Denmark and Finland while the lowest come from Italy, Germany, Czech Republic, Greece and France.

Subsection 5.3 focuses on the results obtained for the four different industries, namely the pharmaceutical industry (C21); the transport equipment (C29-C30); the IT and other information services (J62-J63) and the scientific research and development (M72).

5.3 Pharmaceutical industry, transport equipment, IT and other information services and scientific research and development

For the purpose of this subsection equation (6) and (7) have been estimated. Table 5.3.1 summarizes the different parameters obtained (remember that the estimates for the transport equipment and the IT and other information services were got using binary variables).

These two equations have been estimated using half-normal models. The results of the LR test indicate that there is inefficiency in both cases. Estimating two different production functions as a single frontier was a way to avoid identification problems (Fecher and Perelman, 1992).

Table 5.3.1 Estimated parameters of stochastic production frontier in the four industries

	Pharmaceutical industry	Transport equipment	IT and other information services	Scientific research and development
α_H output elasticity with respect to labour (*)	0.584 (15.17)	-0.346 (-5.38)	0.127 (1.1)	0.455 (18.09)
α_K output elasticity with respect to capital (*)	0.616 (17.69)	0.183 (3.19)	-0.074 (-0.7)	0.510 (28.21)
α_{HK} $(x_{Hi}x_{Ki})$	-0.241 (-3.93)	0.522 (3.05)	0.604 (2.02)	-0.320 (-2.99)
α_{HH} $(x_{Hi}x_{Hi})$	0.181 (1.97)	-0.645 (-2.76)	-1.063 (-2.79)	0.747 (5.45)
α_{KK} $(x_{Ki}x_{Ki})$	0.126 (2.45)	-0.280 (-2.16)	-0.450 (-1.77)	0.028 (0.31)
δ_H $(x_{Hi}t)$	-0.014 (-2.55)	0.003 (0.27)	0.040 (6.59)	-0.034 (-10.56)
δ_K $(x_{Ki}t)$	0.018 (4.19)	-0.007 (-0.87)	-0.011 (-2.08)	0.028 (5.91)
γ_1 (t)	0.016 (5.92)	-0.008 (-1.92)	-0.011 (-2.94)	0.010 (4.36)
γ_2 (t^2)	-0.003 (-3.04)	-0.002 (-1.31)	0.002 (3.39)	-0.001 (-2.15)
μ	0		0	
σ_u^2	0.097 (8.14)		0.243 (14.21)	
σ_v^2	0.006 (2.84)		0.000 (0.02)	
Log-likelihood	97.53		-7.70	
Number of observations	404		404	
LR test	52.44		102.42	

Notes: The t-ratios are in parentheses. Intercept is not shown. The two equations have been estimated using a half-normal distribution on u_i.
(*) Elasticities evaluated at the sample means.

It appears from table 5.3.1 that these four industries are more labour-intensive than those in the previous subsections. Nonetheless, they are still more capital-intensive than labour-intensive except in the case of IT and other information services but these coefficients are not statistically different from those obtained in the scientific research and development. The most labour-intensive industry is the pharmaceutical industry. The most capital-intensive industry is the transport equipment. In the first two industries there are increasing returns to scale (1.2 and 1.04 respectively) while in the scientific research and development there are decreasing returns to scale (0.96) and thus it is also the case in the IT and other information services.

The rate of technological progress at the sample means is around 1% except in the IT and other information services where it is negative and close to 1‰. All the industries experience deceleration of the rate of technical change except the IT and other information services where there is acceleration. The technological biases in the pharmaceutical industry, the transport equipment and the scientific research and development are labour saving and capital using. In the IT and other information services, the bias of technical change is capital and labour using.

Table 5.3.2 presents the conditional mean levels of technical efficiency across countries in the four industries over the 1995-2014 period (note that for Belgium the period starts in 1999, for the Netherlands in 2000 and for Slovak Republic in 2004).

Table 5.3.2 Average technical efficiency across countries for the 1995-2014 period in the four industries

	Pharmaceutical industry	Transport equipment	It and other information services	Scientific research and development
Austria	82.3%	88.1%	69.8%	80.2%
Belgium	78.6%	85.6%	94.3%	64.2%
Czech Republic	69.7%	56.6%	53.5%	30.3%
Denmark	85.8%	86.8%	74.1%	68.9%
Finland	79.7%	75.2%	77.2%	61.1%
France	92.2%	78.3%	87.6%	59.0%
Germany	72.2%	86.1%	85.1%	89.5%
Greece	85.1%	75.7%	51.1%	60.5%
Italy	80.7%	87.3%	76.7%	89.6%
Netherlands	64.8%	85.1%	94.7%	70.3%
Slovak Republic	82.6%	75.6%	83.0%	53.5%
Average (unweighted)	79.4%	80.0%	77.0%	66.1%

The impact of the global crisis on technical efficiency is less easily identifiable at this level of disaggregation. The transport equipment is the only industry which seems to have been significantly impacted by the crisis.

On average the most efficient industry is the transport equipment (80%) followed very closely by the pharmaceutical industry (79.4%). The least efficient industry is the scientific research and development (66.1%).

No country has a leading position in several industries. Nevertheless Denmark performs well in the pharmaceutical industry as well as in the transport equipment while Italy shows good performances in the transport equipment and the scientific research and development.

Regarding the pharmaceutical industry, France is the leader in terms of efficiency (92.2%). Denmark (85.8%) and Greece (85.1%) come afterwards. In contrast, the Netherlands and Czech Republic lie at the bottom of the ranking with respective average technical efficiency of 64.8% and 69.7%.

For the transport equipment, Austria tops the other countries with average technical efficiency of 88.1%. Italy, Denmark, Germany and Belgium also perform well (87.3%, 86.8%, 86.1% and 85.6% respectively). Czech Republic, on the contrary, experiences the lowest average technical efficiency (56.6%).

In the IT and other information services, two countries are very close to each other in terms of efficiency, namely the Netherlands (94.7%) and Belgium (94.3%). Other countries also provide good performances: France and Germany with respective average technical efficiency of 87.6% and 85.1%. It is not the case for Greece and Czech Republic which experience respective average technical efficiency of 51.1% and 53.5%.

Finally in the scientific research and development, Italy and Germany are the leaders in terms of efficiency (89.6% and 89.5% respectively). The next performer is Austria with average technical efficiency of 80.2%. Contrariwise, in Czech Republic the average efficiency is only 30.3%. This is by far the lowest average level of technical efficiency. Slovak Republic does not perform very well either. Its average efficiency is 53.5%.

It may be worth mentioning that Czech Republic exhibits relatively bad performances in terms of efficiency in the four industries.

To end this section, table 5.3.3 shows the average annual rates of growth of technical efficiency, technical progress, scale efficiency and total factor productivity in the four different industries over the 1995-2014 period (note that this period starts in 1999 for Belgium, in 2000 for the Netherlands and in 2004 for Slovak Republic).

On average TFPC is positive in all the industries and the growth in productivity is the fastest in the pharmaceutical industry. The latter benefits mainly from positive technical progress. The positive TFPC in the transport equipment comes from positive technical change and positive efficiency change. In the IT and other information services, the growth in productivity is the slowest. This sector takes advantage of gains in efficiency. Finally, the scientific research and development industry benefits from positive technical change.

In the pharmaceutical industry, three countries have seen their productivity increase by more than 3% per year on average: Finland, Denmark and Italy. In Germany, France and Austria, it has increased by somewhat less than 3%. For Finland, Italy and Austria it is due mainly to positive technical change and to positive technical efficiency change. For France, Germany and Denmark it comes from positive technological progress. Greece and Slovak Republic exhibit negative growth in productivity in this industry. Both the technical efficiency change and the technical change are negative in these two countries.

In the transport equipment, Czech Republic displays the highest average growth rate of productivity (5.2%). Slovak Republic comes afterwards (3.8%). It is due in both countries to a positive growth in technical efficiency. In the case of Czech Republic, this confirms once again the phenomenon of convergence since this country presented the lowest average level of technical efficiency in this industry. Germany, France, Austria and the Netherlands also perform rather well. In the first three countries it comes mostly from technical change while in the Netherlands it is due to increases in efficiency. On the contrary, the productivity in Greece has decreased on average by 9% per year. It can be attributed to significant losses in technical efficiency and in technical change. The productivity is also decreasing in Denmark because of negative scale efficiency change, negative technical change and negative efficiency change.

*Table 5.3.3 Average annual rates of growth in technical efficiency, technical progress, scale efficiency and total factor productivity (in %) in the four industries**

	TEC	TC	SEC	**TFPC**
Austria				
Pharmaceutical industry	0.896	1.377	0.499	**2.772**
Transport equipment	0.541	1.153	0.265	**1.960**
IT and other information services	0.971	-1.132	0.225	**0.064**
Scientific research and development	1.848	-0.290	0.439	**1.997**
Belgium				
Pharmaceutical industry	-0.882	2.483	0.381	**1.982**
Transport equipment	-0.190	0.882	-0.157	**0.534**
IT and other information services	-0.845	-0.169	0.120	**-0.894**
Scientific research and development	3.263	2.806	-1.953	**4.116**
Czech Republic				
Pharmaceutical industry	-0.360	-0.571	1.212	**0.280**
Transport equipment	5.292	0.422	-0.509	**5.205**
IT and other information services	-1.066	-1.864	0.989	**-1.941**
Scientific research and development	0.398	1.406	0.244	**2.047**
Denmark				
Pharmaceutical industry	0.429	2.377	0.845	**3.650**
Transport equipment	-0.103	-0.310	-0.490	**-0.903**
IT and other information services	3.459	-0.790	-0.163	**2.506**
Scientific research and development	2.526	2.893	-0.190	**5.228**
Finland				
Pharmaceutical industry	1.236	2.015	0.549	**3.800**
Transport equipment	0.366	0.082	-0.168	**0.280**
IT and other information services	2.925	-1.723	0.468	**1.671**
Scientific research and development	-1.315	2.284	-0.249	**0.720**
France				
Pharmaceutical industry	-0.001	2.848	-0.014	**2.833**
Transport equipment	-0.496	2.772	0.006	**2.281**
IT and other information services	-1.707	4.006	-1.240	**1.060**
Scientific research and development	1.225	-0.780	0.186	**0.631**
Germany				
Pharmaceutical industry	-0.492	3.444	-0.114	**2.837**
Transport equipment	0.338	2.617	-0.223	**2.732**
IT and other information services	0.979	3.716	-2.576	**2.119**
Scientific research and development	-0.819	1.536	-0.113	**0.604**
Greece				
Pharmaceutical industry	-0.928	-2.176	1.161	**-1.943**
Transport equipment	-6.028	-2.742	-0.240	**-9.010**
IT and other information services	-5.198	-3.544	2.229	**-6.513**
Scientific research and development	-4.232	2.384	-1.543	**-3.391**

Table 5.3.3 (continued)

	TEC	TC	SEC	**TFPC**
Italy				
Pharmaceutical industry	1.946	1.307	-0.016	**3.237**
Transport equipment	-0.687	1.438	-0.050	**0.701**
IT and other information services	-2.516	3.943	-1.357	**0.070**
Scientific research and development	0.989	-2.130	0.986	**-0.155**
Netherlands				
Pharmaceutical industry	-0.105	2.092	-0.205	**1.782**
Transport equipment	1.131	0.347	-0.121	**1.357**
IT and other information services	-0.466	1.239	-0.193	**0.579**
Scientific research and development	-2.281	1.875	-0.161	**-0.567**
Slovak Republic				
Pharmaceutical industry	-0.663	-1.077	-0.039	**-1.779**
Transport equipment	3.851	-0.505	0.423	**3.769**
IT and other information services	5.706	-2.974	2.443	**5.176**
Scientific research and development	-2.612	-3.079	0.247	**-5.444**
Average (unweighted)				
Pharmaceutical industry	0.098	1.284	0.387	**1.768**
Transport equipment	0.365	0.559	-0.115	**0.810**
IT and other information services	0.204	0.064	0.086	**0.354**
Scientific research and development	-0.092	0.809	-0.192	**0.526**

*The results presented in table 5.3.3 are computed using the coefficients significant at the 10% level.

Regarding the IT and other information services, the growth in productivity is relatively rapid in Slovak Republic (5.2%). For Slovak Republic it comes from increases in efficiency and also from positive scale efficiency change which cancel the negative effect of technical change. Denmark, Germany and Finland also experience positive average annual growth rate of productivity. In the Nordic countries (Denmark and Finland) it is mostly due to gains in efficiency. Germany benefits mainly from technical progress and to a lesser extent from positive technical efficiency change while the scale efficiency change is negative. On the contrary, Greece, Czech Republic and Belgium have encountered a decrease in their productivity. Those countries suffer from both negative technical efficiency change and negative technical change. Note that however Greece and Czech Republic display a relatively high rate of growth in scale efficiency.

In the fourth industry, namely the scientific research and development, two countries show relatively fast growth in productivity: Denmark and Belgium. It can be explained by positive growth in technical efficiency and by positive technical progress for both countries. Czech Republic and Austria show good performances as well. The growth in TFP in Czech Republic comes from technological progress while Austria benefits from positive technical efficiency change. On the contrary, Slovak Republic, Greece, the Netherlands and Italy experience negative TFPC. The causes are different across countries. In Slovak Republic, it comes from negative technical efficiency change and negative technical change. Greece suffers from losses in technical efficiency but also from negative scale efficiency change. In the Netherlands it is mainly determined by negative efficiency change while in Italy it is caused by a negative technical change.

The Greek government debt crisis had major repercussions on the country judging by its low performances in these four industries. Slovak Republic performs rather well in the transport equipment and in the IT and other information services industries while in the two other industries its productivity has fallen significantly over the years.

A few words may be needed regarding the evolution of the rates of technical progress over the years (see Appendix D). Different trends emerge from the different industries. For the pharmaceutical industry and the transport equipment, the evolution of the speed of the technical progress follows the same pattern as in subsection 5.1 and 5.2; that is to say that that the speed of technological progress is decreasing. For the pharmaceutical industry, the highest growth rates are found in Germany, Belgium, France and the Netherlands while the lowest rates come from Greece, Czech Republic and Slovak Republic. In the case of transport equipment, France and Germany display the highest growth rates while they are always negative in Greece.

For the IT and other information services the tendency is different. Indeed, the speed of growth in technical progress is increasing; going, for some countries, from negative to positive growth rates of technical change. This is due to the γ_2 coefficient which is positive in this sector and thus indicates acceleration in the rate of technological progress. France, Italy and Germany display the highest rates of growth while in Greece and Slovak Republic the growth rates remain negative during the whole period.

In the scientific research and development industry, the trend in the growth of technological progress is less clear. In Denmark and Belgium the rates of growth are the highest and they are negative in Slovak Republic, Italy and France. It is questionable whether the data in this sector is reliable. This industry produces a particular type of output which may be difficult to measure.

The next section of this report tries to identify the main determinants of productivity growth and then to test their effect on TFPC.

6. Determinants of productivity growth

This section borrows largely from Fecher and Perelman (1992) and Perelman (1995).

Before trying to explain the differences in productivity growth, a note of caution should be formulated. There exist a lot of variables for which it has been demonstrated that they affect productivity growth. However in this study, only five of them are controlled for due to the availability of data. In addition, only 882 of the 1387 observations are usable.

The analysis presented in this section follows a two-stage methodology. That is to say that in the first stage the productivity estimates are obtained as described in section 4 and then, they are regressed on a set of independent variables. Only the growth in productivity will be studied and not the level of efficiency. Indeed, there are stochastic frontier models that allow the inefficiency effect (u_i) to be expressed as an explicit function of a vector of variables which may influence the efficiency of an observation. Thus, it corresponds to a single-stage estimation. Such models were proposed by

Kumbhakar, Ghosh and McGukin (1991); Reifschneider and Stevenson (1991) and Battese and Coelli (1995). Therefore, the estimates obtained using a two-stage procedure are likely to be less efficient than those produced using the aforementioned models (Coelli, 1996).

Many authors have worked on determinants of productivity. For example, Eichler, Grass, Blöchliger and Ott (2006) chose indicators from four policy areas: innovation, taxation, regulation and accessibility to test their impact on productivity growth. Loko and Diouf (2009) used different categories of factors, namely macroeconomic factors; trade openness and knowledge spillovers; labour quality; institutional factors and sectoral composition of output that can be represented by one or more variables to test this relationship.

This research settles for five different variables that are likely to influence total factor productivity growth (TFPC):

- The first variable refers to research and development (R&D) expenditure. A large number of studies on the contribution of R&D outlays to productivity growth have been carried out so far (Griliches, 1998). The impact of R&D expenses on TFPC may however be ambiguous. Indeed, R&D expenses can be converted with time into new and more effective production technologies. As a result, it will shift up the production frontier and increase the rate of technical change. In the meantime, it will cause a decrease in technical efficiency for countries which cannot adapt to this technical progress. Furthermore, it takes time for these expenses to affect production processes (OECD, 2011). Therefore, the indicator used in this study is the lagged ratio of R&D outlays to the value added: $\left(\frac{R\&D}{VA}\right)_{-1}$. Data on R&D comes from the OECD's ANalytical Business Enterprise Research and Development (ANBERD) database which presents annual data on Research and Development expenditures by industry (OECD, 2017). The R&D expenses are carried out by the business enterprise sector exclusively. The value added data is from the STAN database.

- The second variable is the rate of growth in output. The relation between the growth in output and the growth in productivity is known as Kaldor's second Law or Verdoorn's law and can be expressed as follows: a faster growth in output causes a faster growth in productivity (McCombie, 2013). Indeed, a faster growth in output can be seen as increases in demand that will influence TFPC through the capacity utilisation (Jajri, 2007). This will have a stimulating effect on production processes making them more efficient. Nevertheless, this relation should be tested with caution since, as pointed out by Castiglione (2011), there is a problem of bias due to the simultaneity between the two variables. The growth rate of value added (ΔVA) is used as explanatory variable. The data comes from the STAN database.

- The next variable is a measure for trade openness. Trade openness is expected to have a positive impact on TFPC. This can be attributed on one side to international competition that puts more pressure on countries therefore leading them to become more 'efficient' to "stay on course". On the other side, countries can benefit from technology spillovers brought in by the foreign states. For Jajri (2007), it can also be due to larger scale of operations. In order to meet the demand for exports, the countries will have to increase their production capacity and hence they will be able to enjoy the benefits of economies of scale. For Fecher and Perelman (1992), a high ratio of imports could indicate the presence of inefficiencies in the country. While it is difficult to obtain a good measure for trade openness, Perelman (1995) suggested to use the ratio of total imports (M) and exports (X) over the total value of production (TPV) plus the imports: $\left(\frac{X+M}{TPV+M}\right)_{-1}$. It is also introduced with a lag of one year. Nevertheless, Islam (2005) expressed reservations about this measure. Indeed, this ratio largely relies on the size and location of a country rather than on its trade policies. Data on imports and exports comes from STAN Bilateral Trade Database by Industry and End-use category (BTDIxE). It provides values of imports and exports of goods broken down by industrial sectors and by end-use categories (OECD, 2017). The production data originates from the STAN database.

- The fourth variable as defined by Perelman (1995) is the growth rate of the ratio of gross investments to capital stock: $\Delta\frac{I}{K}$. As stated by Millemaci and Ofria (2012), new investments introduce new capital goods and thus technical progress. Fecher and Perelman (1992) also emphasized that, just as in the R&D case, it can lead to decreases in efficiency if countries are not able to adopt many changes in a short period of time. The STAN database provides data on investment and capital stock.

-The last variable is technical efficiency. As mentioned in section 5, the countries which displayed low levels of technical efficiency are usually those which benefit from high productivity growth rates. This is the so-called catching-up process. Therefore, the effect on TFPC is expected to be negative. The lagged levels of technical efficiency, $(TE)_{-1}$, are used and are those derived as explained in section 4.

Table 6.1 presents the estimates obtained firstly by OLS and then by OLS weighted by state population for the different sectors.

Three of the variables have the expected signs: the growth in output, the capital formation and the catching-up process. The Kaldor-Verdoorn relationship is thus validated. Nonetheless the high magnitude of the coefficients (except in the pharmaceutical industry) and their significance for both methods of estimation should put a bug in one's ear about the spurious relation between TFPC and growth in output. These results are exactly the same as those found by Fecher and Perelman (1992).

New investments seem to have a positive impact on productivity growth. The coefficients for the aggregation of all economic activities, the manufacturing sector, the business sector services and the scientific research and development are all positive and significant. The effect of this variable is rather high in the first three sectors while it is moderate in the last one. However, the coefficient for the pharmaceutical industry is negative but becomes insignificant when weighted OLS is used. The coefficient for the IT and other information services turns out to be positive and significant when weighted OLS is used; its effect is among the lowest.

Finally the catching-up hypothesis is proven by the negative and significant estimated coefficients except for the aggregation of all industries; the transport equipment and the IT and other information services where the coefficients are not significant. When using weighted OLS, the coefficient for the business sector services becomes insignificant. Overall, the effect of technical efficiency is rather low. However in the pharmaceutical industry the impact of this coefficient is more important.

Table 6.1 Determinants of productivity growth

		Unweighted OLS							
Sectors	Explanatory variables	$\left(\frac{R\&D}{VA}\right)_{-1}$	ΔVA	$\left(\frac{X+M}{TPV+M}\right)_{-1}$	$\Delta\frac{I}{K}$	$(TE)_{-1}$	Constant	n	R^2
Aggregation of all economic activities		0.016*** (5.83)	0.810*** (9.5)	-0.032** (-2.26)	0.189*** (4.81)	-0.020 (-0.91)	-0.011 (-0.63)	201	0.725
Manufacturing sector		0.130 (1.11)	0.695*** (15.92)	-0.016 (-1.22)	0.118*** (3.88)	-0.057*** (-2.81)	0.041** (2.4)	125	0.790
Business sector services		0.740 (0.96)	0.568*** (3.69)	-1.334* (-1.95)	0.127** (2.05)	-0.038* (-1.7)	0.022 (1.11)	110	0.428
Pharmaceutical industry		0.136 (1.18)	0.130*** (4.23)	-0.027 (-1.42)	-0.090*** (-3.19)	-0.146*** (-2.68)	0.133*** (2.84)	105	0.378
Transport equipment		-0.041 (-0.43)	0.457*** (10.03)	0.012 (0.42)	-0.007 (-0.2)	-0.058 (-1.32)	0.044 (0.87)	124	0.515
IT and other information services		-0.008 (-0.04)	0.477*** (9.42)	-0.115** (-2.43)	0.003 (0.12)	-0.013 (-0.39)	0.011 (0.33)	93	0.545
Scientific research and development		-0.014 (-0.35)	0.635*** (11.09)	-0.008 (-0.32)	0.016** (2.51)	-0.077*** (-2.63)	0.053** (2.08)	124	0.547

		Weighted OLS by state population							
Sectors	Explanatory variables	$\left(\frac{R\&D}{VA}\right)_{-1}$	ΔVA	$\left(\frac{X+M}{TPV+M}\right)_{-1}$	$\Delta\frac{I}{K}$	$(TE)_{-1}$	Constant	n	R^2
Aggregation of all economic activities		0.016*** (6.33)	0.752*** (9.19)	-0.049*** (-3.94)	0.142*** (3.69)	-0.013 (-0.7)	-0.003 (-0.17)	201	0.762
Manufacturing sector		0.029 (0.28)	0.753*** (21.14)	-0.018 (-1.55)	0.205*** (6.31)	-0.041*** (-2.85)	0.037*** (2.81)	125	0.896
Business sector services		0.115 (0.21)	0.496*** (4.23)	-1.054** (-2.02)	0.131*** (2.83)	-0.015 (-0.81)	0.011 (0.75)	110	0.486
Pharmaceutical industry		-0.063 (-0.7)	0.235*** (5.48)	-0.027* (-1.83)	-0.058 (-1.65)	-0.121** (-2.56)	0.140*** (3.28)	105	0.367
Transport equipment		-0.024 (-0.27)	0.519*** (13.64)	0.007 (0.29)	0.020 (0.47)	-0.069 (-1.55)	0.063 (1.14)	124	0.659
IT and other information services		0.043 (0.18)	0.495*** (8.73)	-0.159*** (-3.36)	0.063* (1.9)	-0.046 (-1.35)	0.040 (1.42)	93	0.536
Scientific research and development		-0.043 (-1.13)	0.696*** (10.18)	0.007 (0.35)	0.019* (1.88)	-0.071*** (-2.97)	0.048** (2.16)	124	0.510

Notes: t-statistics are in parentheses. *** P < 0.01; ** P < 0.05; * P < 0.1.

Regarding the R&D expenditures, only one coefficient is positive and significant in both models: that for the aggregation of all economic activities. Its magnitude is relatively low. All the other coefficients are not statistically different from 0 meaning that at more disaggregated levels of activities, R&D outlays do not play a role in productivity growth.

The trade openness factor has a counterintuitive effect: its impact is negative. Indeed, its coefficient is negative and significant in the aggregation of all economic activities, the business sector services, the IT and other information services and also in the pharmaceutical industry when the weighted OLS model is used. Its effect is really important in the business sector services, moderate in the IT and other information services and rather low in the pharmaceutical industry and in the aggregation of all industries. While it is not difficult to explain a positive relation between trade openness and productivity, the opposite is not so obvious. It might be the consequence of an improper measure of trade openness.

7. Conclusion

In this research productivity growth was studied in 13 European countries for the aggregation of all economic activities, in the manufacturing sector and in the business sector services over the 1995-2014 period. Four industries were also surveyed in 11 of these countries. The use of stochastic frontiers allowed for the decomposition of productivity growth into technical efficiency change (catching-up), technical change (frontier shift) and scale efficiency change (change in the scale of operations). There is no general rule to explain productivity growth across countries: some of them benefited from technical progress (Denmark, Finland, the Netherlands and Austria) while others took advantage of gains in efficiency (France, Germany). Luxembourg enjoyed both of them. In the eastern countries, Italy and Greece the growth of productivity was negative. It is puzzling to see such differences across these countries since they should have access to the same technology, are open to trade and are located in the same area. For Färe, Grosskopf and Margaritis (2006), this can be attributed to the individual country regulatory and institutional environment.

The sector of business activities plays an increasingly important role in the countries' economies judging by its rising share in the gross value added. Employment and investments are also augmenting in this sector. It appeared yet that average productivity growth and technical efficiency are higher in the manufacturing sector than in the business sector services. The manufacturing sector enjoyed significant gains in efficiency while the technical progress was rather high in the sector of business activities. The latter sector may need more time to adapt to the ongoing technical and economic evolutions.

Some evidence of convergence was found especially in the manufacturing sector where the eastern countries and Germany converged towards the leading countries.

All the four industries reviewed displayed positive growth in productivity. The pharmaceutical industry and the "scientific research and development" industry took advantage of technological progress while "the IT and other information services" industry benefited mostly from gains in efficiency.

Regarding the last part of this research that consisted in testing the relation of growth in productivity to a set of explanatory variables, innovation did not have the expected impact on productivity growth nor did the trade openness. Indeed, innovation only mattered in the aggregation of all economic sectors and the trade openness negatively influenced the productivity growth. However new investments seemed to play an important role in the growth in productivity. The catching-up process was confirmed especially in the pharmaceutical industry where its impact was the largest.

Nevertheless, these results call for further investigation. The Translog production function is initially a very flexible functional form. As no restriction was imposed on the structure of production, it sometimes yields results which are not desirable from an economic point of view, for instance negative output elasticities or negative technological change. Another way to conduct this research would be to take intermediate consumption as an input in the production process.

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Appendix A: STAN industry list

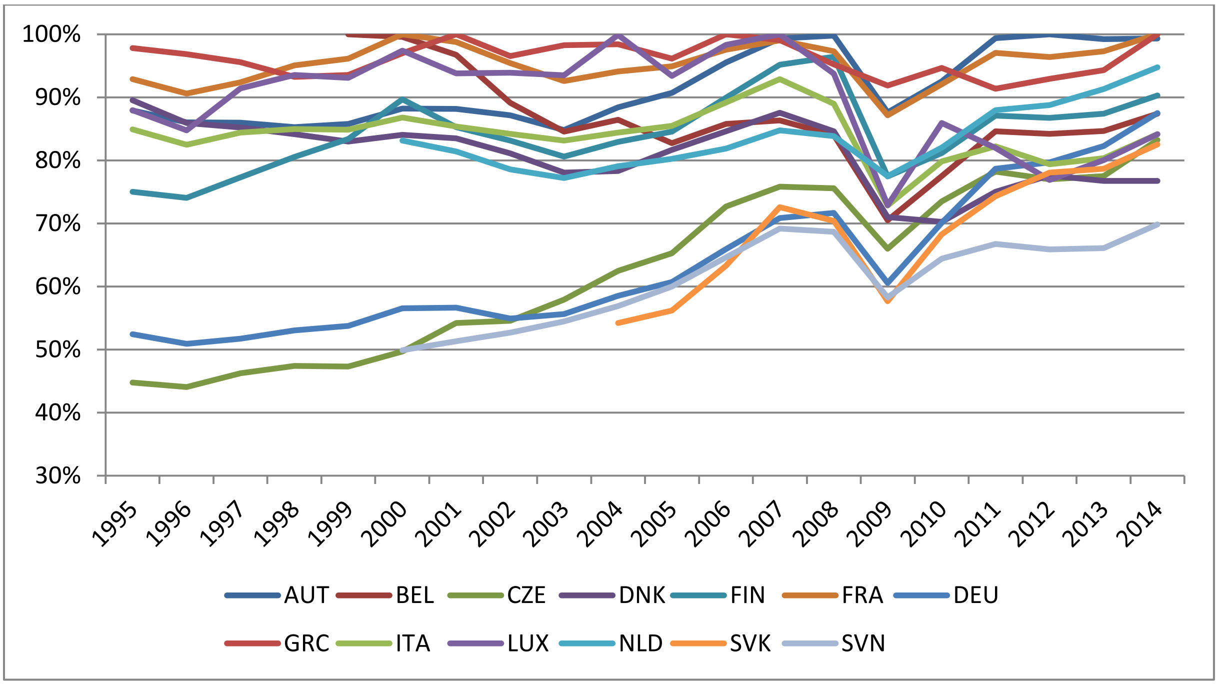
TOTAL	**01-99**
Agriculture, hunting, forestry and fishing [A]	**01-03**
Agriculture, hunting and forestry	01-02
Crop and animal production, hunting and related service activities	01
Forestry and logging	02
Fishing and aquaculture	03
Mining and quarrying [B]	**05-09**
Mining and quarrying of energy producing materials	05-06
Mining and quarrying except energy producing materials	07-08
Mining support service activities	09
Manufacturing [C]	**10-33**
Food products, beverages and tobacco [CA]	10-12
....Food products and beverages	10-11
........Food products	10
........Beverages	11
....Tobacco products	12
Textiles, wearing apparel, leather and related prodcuts [CB]	13-15
....Textiles and wearing apparel	13-14
........Textiles	13
........Wearing apparel	14
....Leather and related products	15
Wood and paper products, and printing [CC]	16-18
....Wood and products of wood and cork, except furniture	16
....Paper and paper products	17
....Printing and reproduction of recorded media	18
Chemical, rubber, plastics, fuel products and other non-metallic mineral products	19-23
....Coke and refined petroleum products [CD]	19
....Chemical and pharmaceutical products	20-21
........Chemicals and chemical products [CE]	20
........Basic pharmaceutical products and pharmaceutical preparations [CF]	21
....Rubber and plastics products, and other non-metallic mineral products [CG]	22-23
........Rubber and plastics products	22
........Other non-metallic mineral products	23
Basic metals and fabricated metal products, except machinery and equipment [CH]	24-25
....Basic metals	24
........Iron and steel	241+2431
........Non-ferrous metals	242+2432
....Fabricated metal products, except machinery and equipment	25
........Manufacture of weapons and ammunition	252
.... Manufacture of other fabricated metal products; metalworking service activities	25X
Machinery and equipment	26-28
....Electrical, electronic and optical equipment	26-27
........Computer, electronic and optical products [CI]	26
........Electrical equipment [CJ]	27
....Machinery and equipment n.e.c. [CK]	28
Transport equipment [CL]	29-30
....Motor vehicles, trailers and semi-trailers	29
....Other transport equipment	30
........Building of ships and boats	301
........Air and spacecraft and related machinery	303
........Military fighting vehicles	304
........Railroad equipment and transport equipment n.e.c.	302+309
Furniture; other manufacturing; repair and installation of machinery and equipment [CM]	31-33
....Furniture, other manufacturing	31-32
........Manufacture of medical and dental instruments and supplies	325
....Repair and installation of machinery and equipment	33
Electricity, gas and water supply; sewerage, waste management and remediation activities [D-E]	**35-39**
Electricity, gas, steam and air conditioning supply [D]	**35**
Water supply; sewerage, waste management and remediation activities [E]	**36-39**
....Water collection, treatment and supply	36
....Sewerage, waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	37-39
Construction [F]	**41-43**

Wholesale and retail trade; Repair of motor vehicles and motorcycles; Transportation and storage; Accommodation and food service activities [G-I]	**45-56**
Wholesale and retail trade, repair of motor vehicles and motorcycles [G]	**45-47**
....Wholesale and retail trade and repair of motor vehicles and motorcycles	45
....Wholesale trade, except of motor vehicles and motorcycles	46
....Retail trade, except of motor vehicles and motorcycles	47
Transportation and storage [H]	**49-53**
....Land transport and transport via pipelines	49
....Water transport	50
....Air transport	51
....Warehousing and support activities for transportation	52
....Postal and courier activities	53
Accommodation and food service activities [I]	**55-56**
Information and communication [J]	**58-63**
Publishing, audiovisual and broadcasting activities [JA]	58-60
....Publishing activities	58
........Publishing of books, periodicals and other publishing activities	581
........Software publishing	582
....Audiovisual and broadcasting activities	59-60
Telecommunications [JB]	61
IT and other information services [JC]	62-63
....Computer programming, consultancy and related activities	62
....Information service activities	63
Financial and insurance activities [K]	**64-66**
Financial service activities, except insurance and pension funding	64
Insurance, reinsurance and pension funding, except compulsory social security	65
Activities auxiliary to financial service and insurance activities	66
Real estate, renting and business activities [L-N]	**68-82**
Real estate activities [L]	**68**
Professional, scientific and technical activities; administrative and support service activities [M-N]	**69-82**
Professional, scientific and technical activities [M]	**69-75**
....Legal and accounting activities; activities of head offices; management consultancy activities; architecture and engineering activities; technical testing and analysis [MA]	69-71
........Legal and accounting activities; activities of head offices; management consultancy	69-70
..........Legal and accounting activities	69
..........Activities of head offices; management consultancy activities	70
........Architectural and engineering activities; technical testing and analysis	71
....Scientific research and development [MB]	72
....Advertising and market research; other professional, scientific and technical activities; veterinary activities [MC]	73-75
........Advertising and market research	73
........Other professional, scientific and technical activities; veterinary activities	74-75
..........Other professional, scientific and technical activities	74
..........Veterinary activities	75
Administrative and support service activities [N]	**77-82**
Rental and leasing activities	77
Employment activities	78
Travel agency, tour operator, reservation service and related activities	79
Security and investigation activities; services to buildings and landscape activities; office administrative, office support and other business support activities	80-82
Public administration and defence; compulsory social security; education; human health and social work activities [O-Q]	**84-88**
Public administration and defence; compulsory social security [O]	**84**
Education [P]	**85**
Human health and social work activities [Q]	**86-88**
....Human health activities [QA]	86
....Residential care and social work activities [QB]	87-88
Arts, entertainment, repair of household goods and other services [R-U]	**90-99**
Arts, entertainment and recreation [R]	**90-93**
....Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities	90-92
....Sports activities and amusement and recreation activities	93
Other service activities [S]	**94-96**
....Activities of membership organizations	94
....Repair of computers and personal and household goods	95
....Other personal service activities	96
....Activities of households as employers; undifferentiated activities of households for own use [T]	**97-98**
Activities of extraterritorial organizations and bodies [U]	**99**

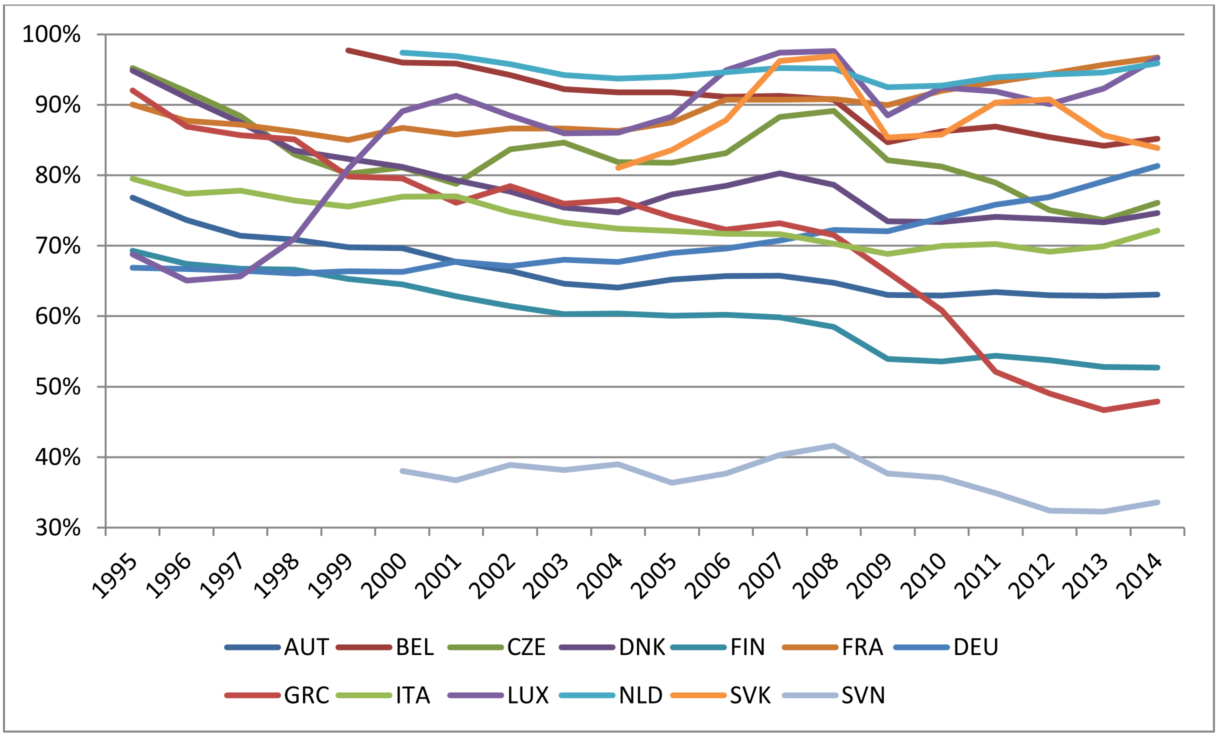
Source: OECD

Appendix B: Evolution of technical efficiency across countries in the manufacturing sector and the business sectors services between 1995 and 2014

1. Evolution of technical efficiency levels across countries <u>in the manufacturing sector</u> between 1995 and 2014

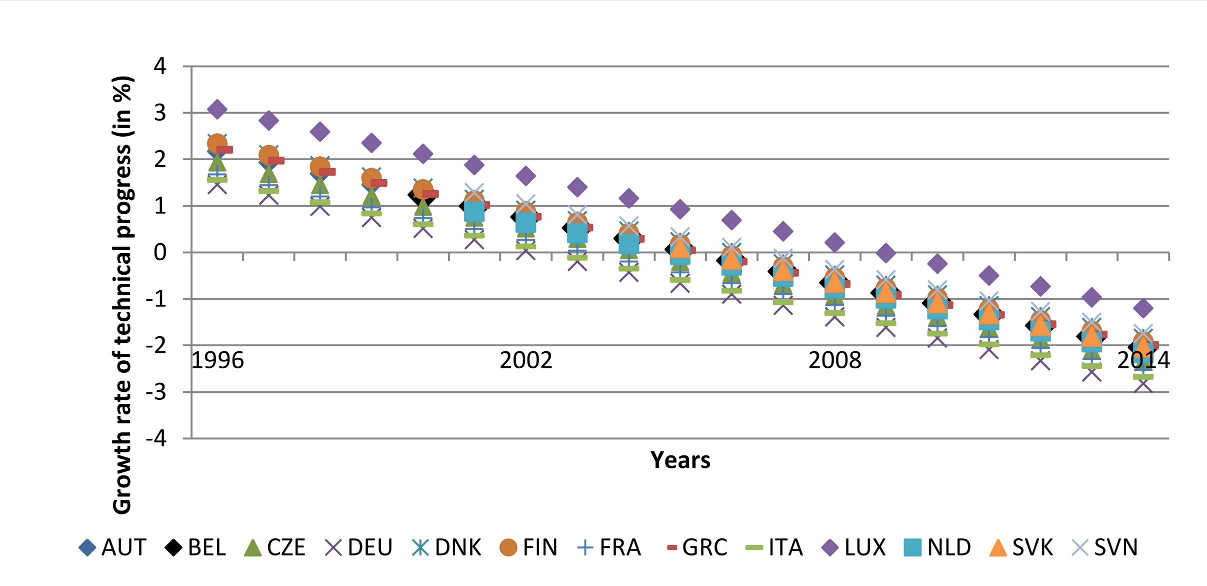


2. Evolution of technical efficiency across countries <u>in the business sector services</u> between 1995 and 2014

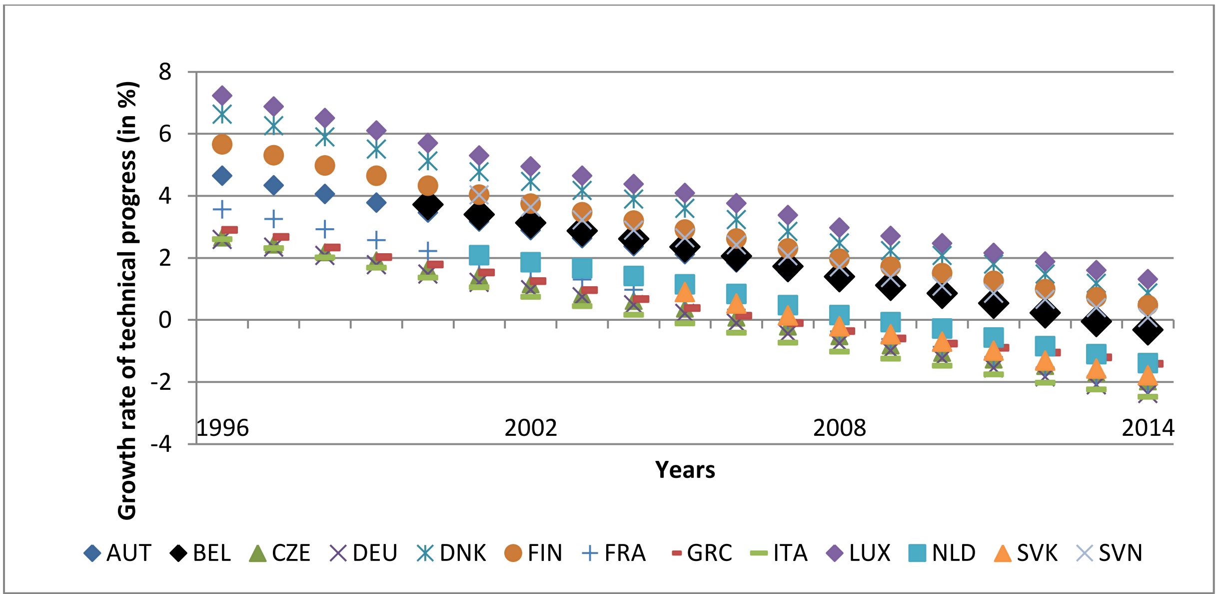


Appendix C: Evolution of the growth rates of technical progress across countries in the manufacturing sector and the business sector services between 1995 and 2014

1. Evolution of the growth rates of technical progress across countries in the manufacturing sector between 1995 and 2014

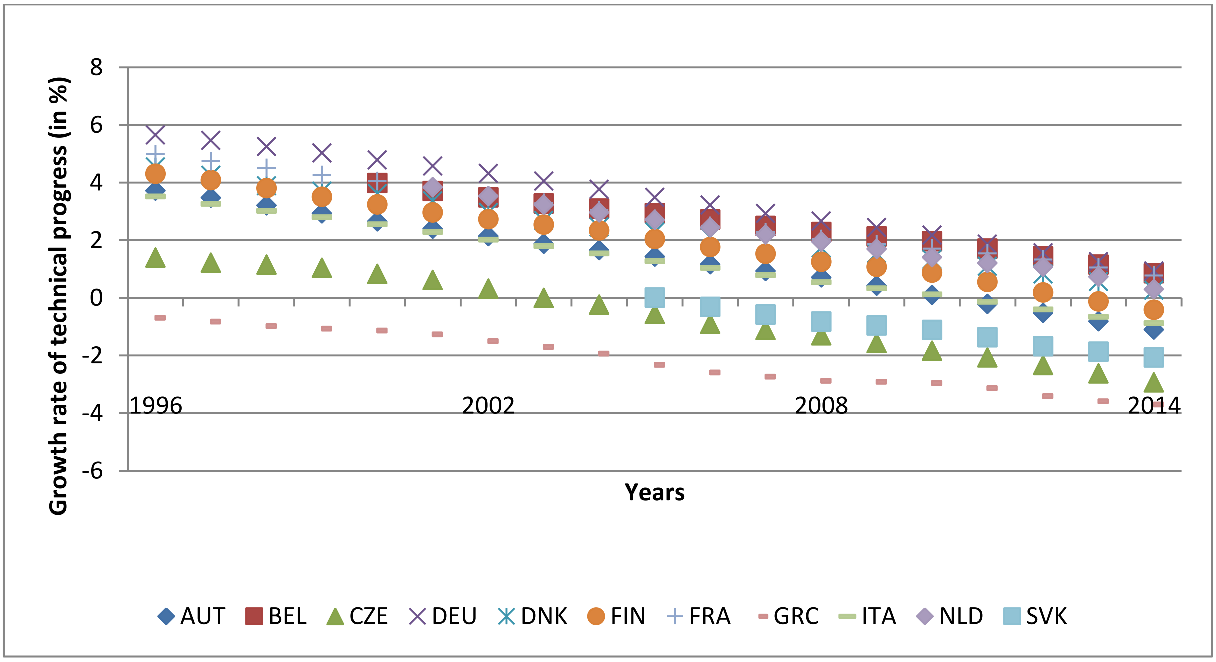


2. Evolution of the growth rates of technical progress across countries in the business sector services between 1995 and 2014

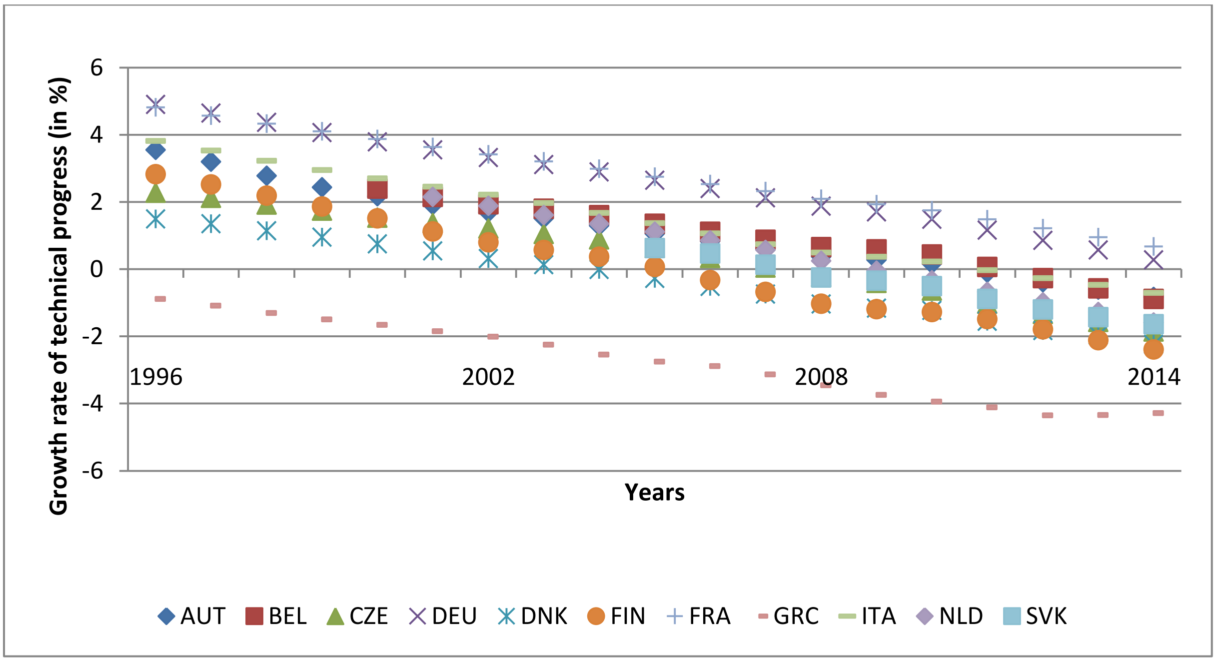


Appendix D: Evolution of the growth rates of technical progress across countries in the four industries between 1995 and 2014

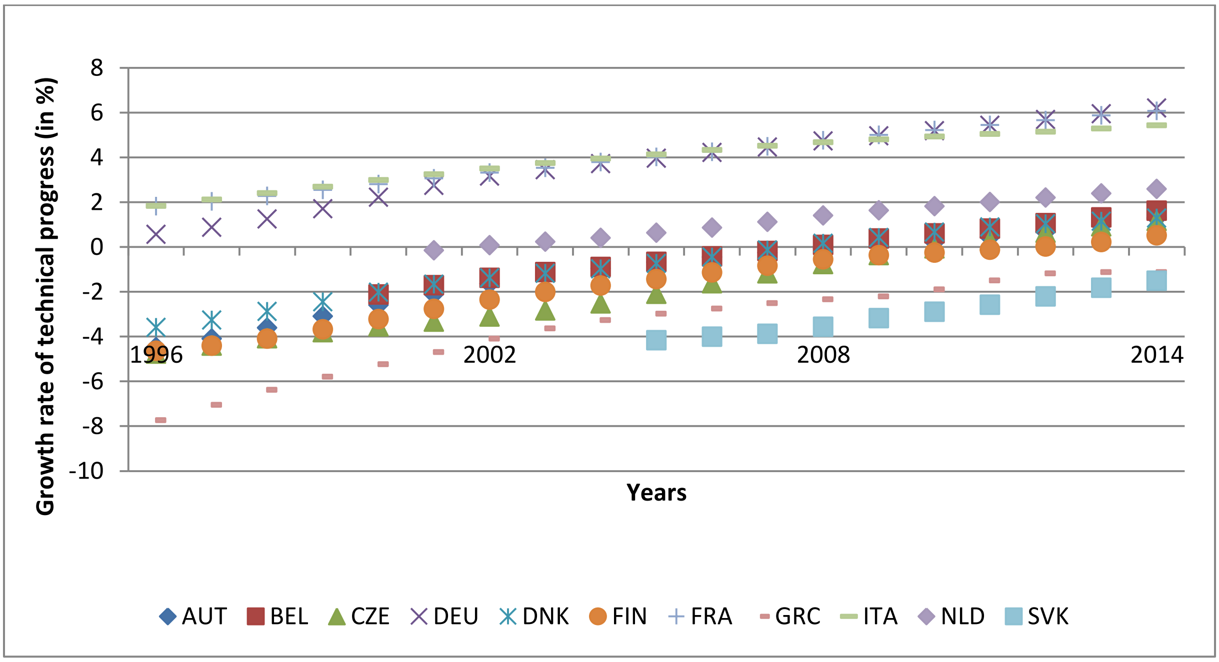
1. Evolution of the growth rates of technical progress across countries in the pharmaceutical industry between 1995 and 2014



2. Evolution of the growth rates of technical progress across countries in the transport equipment between 1995 and 2014



3. Evolution of the growth rates of technical progress across countries in the IT and other information services between 1995 and 2014



4. Evolution of the growth rates of technical progress across countries in the scientific research and development between 1995 and 2014