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PRODUCTIVITY AND COMPETITIVENESS IN LUXEMBOURG: PRODUCTIVITY & THE CRISIS

The evolution of Total Factor Productivity in Luxembourg from 1995 to 2010 (LuxKlems Project)

MINISTÈRE DE L'ÉCONOMIE
ET DU COMMERCE EXTÉRIEUR
Observatoire de la compétitivité

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Productivity and competitiveness in Luxembourg: Productivity & the crisis

The evolution of Total Factor Productivity in Luxembourg from 1995 to 2010 (LuxKlems Project)

Chiara Peroni*

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Abstract

This report analyses patterns of labour productivity, Total Factor Productivity (TFP), efficiency and technical change for Luxembourg, EU member states and the US from 1995 to 2010. Malmquist productivity indices of TFP are constructed using a deterministic frontier approach (Data Envelopment Analysis - DEA), which permits to limit restrictive assumptions on economic behaviour. The report shows that labour productivity growth was weak in most of the countries analysed, due to a deterioration in TFP performances *vis-à-vis* sustained rates of capital accumulation. Both slow (or negative) technical progress and efficiency losses appear to have contributed to this outcome. The crisis appears to have exacerbated this tendency. The analysis of Luxembourgish industries reveals that structural shifts in Luxembourg's economy affected productivity trends. The most important was the continued relative decline in goods-producing industries in the face of sustained growth in services. The latter was led by telecommunication services and by financial activities. In services, however, strong inputs and output growth masked weaknesses in productivity performances.

KEYWORDS: Total Factor Productivity; production frontiers; DEA; Malmquist indices.

Résumé

Ce rapport présente l'évolution de la productivité du travail, de la productivité totale des facteurs (PTF) et de ses composantes : l'efficacité et le progrès technique. L'analyse porte sur la période 1995-2010 et compare les résultats du Luxembourg, des États membres de l'UE et des États-Unis. Les indices de productivité de Malmquist sont construits en utilisant l'approche déterministe d'enveloppement des données (Data Envelopment Analysis - DEA) qui permet de limiter les hypothèses trop contraignantes sur les comportements économiques. Les résultats montrent que la croissance de la productivité du travail a été faible dans la plupart des pays analysés. Cette faiblesse est due à une dégradation des performances relative de la PTF par rapport à la vitesse d'accumulation du capital. Le ralentissement (ou la diminution) du progrès technique et les pertes en efficacité contribuent simultanément à ce résultat. La crise a contribué à exacerber ces tendances. De plus, l'analyse conduite au niveau des branches d'activités luxembourgeoises révèle que les changements structurels en cours ont un impact important sur les tendances de la productivité. Le changement le plus marquant est le déclin relatif continu de la production industrielle accompagnant une croissance soutenue des services, cette dernière principalement induite par la dynamique des services de télécommunication et des activités financières. Toutefois, dans l'ensemble des branches de services, la croissance forte des *inputs* et de l'*output* masque la faiblesse des performances en termes de productivité.

Mots clés : Productivité Totale des Facteurs, Frontière de production, DEA, Indice de Malmquist

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Productivity ("productive efficiency") compares outputs against inputs used in producing those outputs (Farrell, 1957). Increases in productivity reflect an economy's ability to expand output by using inputs more efficiently, thus fostering general economic welfare. Productivity can be measured in various ways. This report presents synthesis productivity indicators from the LuxKlems database, produced using a frontier approach. It focuses on two widely used measures of productivity: labour productivity and Total Factor Productivity.

Labour productivity measures the amount of output produced by a worker. It is a determinant of countries' cost and price competitiveness. Increases in productivity permit to compensate workers with higher real wages without generating higher prices and business costs. Its main drivers are capital intensity and Total Factor Productivity (TFP). Capital intensity summarises the contribution of two inputs to production, namely capital equipment and labour. TFP, often regarded as an engine of economic growth, measures the amount of knowledge present in the economy and how well countries manage their inputs. Therefore, the evolution of productivity reflects both a country's economic conditions and its long-term structural changes. This is why productivity is often the focus of attention of economists and policy-makers.

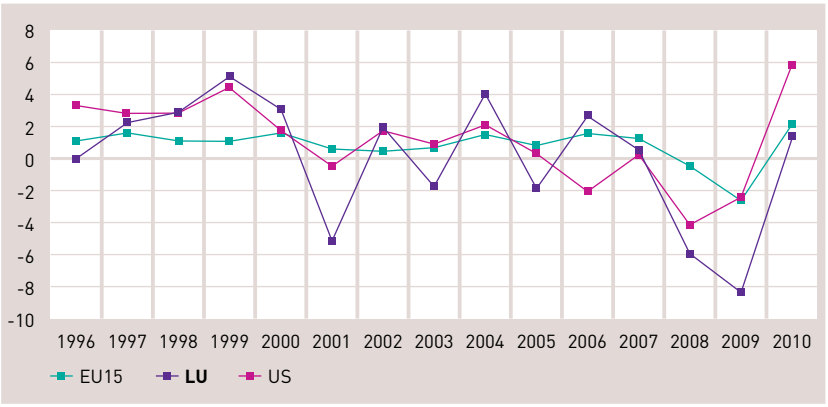
Figure 1 shows the evolution of labour productivity in the US, Europe and Luxembourg from 1995 to 2010. One can see that in the US, after the rapid growth of the second half of the 90s, productivity has slowed down. As a result, the productivity gap between the European countries and the US has been progressively narrowing since 2000, in what has been referred to as a 'race to the bottom' (OECD, 2010). One also observes the large fall in productivity that occurred in correspondence of the crisis, the concurrent decline of US productivity growth below the EU average, and the subsequent recovery. Productivity has been more volatile since the turn of the century. This volatility feature is particularly pronounced for Luxembourg, a small open economy with a predominant financial service industry. Clearly, the evolution of productivity provides a link and a perspective to analyse the effect of the recent financial crisis on the real economy.

The LuxKlems database provides data on output and inputs' use, productivity, efficiency gains and technical change for Luxembourg, at both industry- and national economy-level. These are compared against data for member states of the European Union and the US. LuxKlems uses a non-parametric deterministic frontier approach, known as Data Envelopment Analysis — DEA (Charnes *et al.*, 1978) — to construct Malmquist indices of productivity, interpreted as measures of TFP. The DEA method, based on the concept of production possibility sets, evaluates the performance of each economic units (countries/industries/firms) with reference to an efficient frontier, which identifies the best-practise technology using convex combinations of observed inputs and outputs. This approach has several advantages. Productivity measures are computed by using only the available data, while making minimal assumptions on the functional form of the technology (*sauf* returns to scale) or on market structure. Another advantage of DEA is that it takes into account different sources of TFP growth; in particular, it distinguishes the effect of efficiency changes (changes in how well production units use their inputs), also referred to as technological catch-up, from the effect of "pure" technical progress.

Despite being largely applied as an operational research tool, DEA is becoming popular in the field of economics, where it is used to assess performances at firm and industry level. The DEA method, however, is also capable of delivering interesting insights into countries' productivity performances. This is due to its benchmarking nature, which permits its flexible application to different problems/aggregation level. For example, using this approach, Fare *et al.* (2006) highlighted the role of TFP in the evolution and convergence of productivity per capita in EU countries. Other examples of country level analysis are Fare *et al.* (1994b); D. Margaritis and Grosskopf (2007); Badunenko *et al.* (2008). DEA nicely adapts to the analysis of small economies such as Luxembourg, where data availability is often problematic. In addition, it permits to avoid the assumption of market clearing in Luxembourg, an assumption that is not supported by the data (DiMaria, 2008; Peroni and Ferreira, 2011). (A more detailed discussion of the DEA method is available in the Technical Section of the Appendix to this report.)

This report gives a synthesis of the main results from the last performed update to the LuxKlems database. Accounts of previous versions of the database were given in the reports by DiMaria and Ciccone (2008) and Dubrocard *et al.* (2010). Source data are from Eurostat and Statec National Account. The remaining of this report is structured as follows. Section 1 uses the DEA frontier analysis to compare the performance of Luxembourg to other western European economies and the US. Then, Section 2 looks at the contribution of the different Luxembourg's industries to identify which ones are responsible for the observed evolution of productivity measures in this country. Section 3 gives concluding remarks. The Appendix has detailed tables of yearly changes for the main productivity variables from 2000 to 2010.

Figure 1
Labour productivity in the EU15 area, US, and Luxembourg



Sources: author's calculations from Eurostat and Statec data

1 International comparison

Labour productivity is an important determinant of an economy's price and cost-competitiveness. Another important measure of productivity, Total Factor Productivity (TFP hereafter), contains information on technical progress, a main driver of economic growth and contributor to overall competitiveness. In this light, it is interesting to compare Luxembourg's productivity performance to those of other countries. The DEA frontier approach provides an ideal framework to do so. This section analyses Luxembourg's labour and TFP at aggregate (national) level against a group of European countries (EU15) and the US over the period 1995-2010. The EU15 group comprises Austria, Belgium, Denmark, France, Finland, Germany, Greece, Italy, Luxembourg, Netherlands, Spain, Portugal, United Kingdom and Sweden.[1]

To interpret the data, we consider the decomposition of labour productivity into capital intensity and TFP. The first of these variables summarises the contribution of two inputs to production: capital stock and labour. The second variable, TFP, is often regarded as an engine of economic growth, as it measures the amount of knowledge present in the economy and how well countries manage their inputs. (TFP further decomposes into efficiency gains and technical changes.) This framework, first proposed by Kumar and Russell (2002), has become popular in the analysis of productivity trends. Kumar and Russell (2002) concluded that capital deepening was the driving force of economic growth. In contrast, Fare *et al.* (2006) and Badunenko *et al.* (2008) identified technical change as the main source of growth.

Here, the measures of TFP, technological shifts, and efficiency changes are given by Malmquist productivity indices. These indices give the best practice EU-US production frontier; individual countries are compared to this frontier. Note that, in a production frontier setting, the change in technology represents movements of the frontier, whereas efficiency changes correspond to movements towards/away from a given frontier; capital deepening describes movements along the frontier (the so-called scale effect).

Labour productivity growth is measured by the rate of growth of GDP per worker. For the DEA analysis, output is measured by real Gross Domestic Product (GDP), and capital stock and labour are the inputs to production. The labour input is measured by the number of workers (full time equivalent). This includes both resident and non-resident workers. GDP and employment series are from the Eurostat Economy and Finance database.[2] Estimates of capital stock are constructed using capital stock data from the EUKLEMS database and investment series from Eurostat.[3] Luxembourg data are from the Statec.

For ease of exposition, the graphs shown in this section present the time series of variables of interest for Luxembourg and its main commercial partners — the group of neighbouring countries — namely Germany, France and Belgium. The tables summarise average productivity performances of each country for the period 1995-2010. (Detailed tables with annual figures for selected years and all countries are given in the Appendix A.)

1 European averages, denoted as EU15, are given by Eurostat aggregates when available.

2 The series have been converted using the PPPs, which ensures comparability of aggregates across countries. PPPs allow researchers to express economic variables 'as if' they were recorded in a single common currency. This takes into account not only nominal exchange rates but also the different price levels (purchasing powers) across countries, and ensures that, for example, variables such as GDP reflect the actual size of an economy.

3 The EUKLEMS database provides an initial capital stock level (i.e. the last year available in the database for all countries) and capital stock series that allow us to compute depreciation rates. The initial stocks are then updated using yearly investment figures and the depreciation rate. Details on the method used to compute the capital stock are available on the 2010 report (Dubrocard *et al.*, 2010, page 24-25). EUKLEMS Database, March 2007, see Timmer *et al.* (2007); downloadable at www.euklems.net.

1.1 The evolution of inputs to production

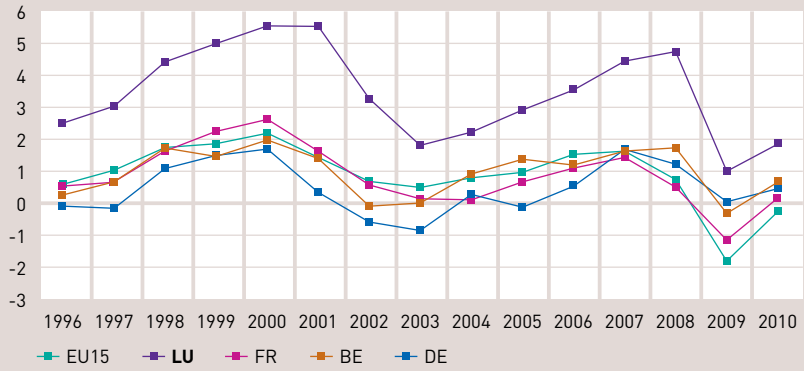
Before turning to the analysis of productivity figures, this section briefly overviews the evolution of output (GDP) and inputs to production. Table 1 gives (average) yearly growth rates of output, inputs, and productivity from 1995 to 2010. Overall, this was a period of remarkable economic expansion for Luxembourg. Real GDP grew at a rate of 3.4% per year, double the EU15 average. Employment increased even faster, well above the European average, while the stock of capital grew by nearly 4% yearly. (The prominence of Luxembourg as job creator is apparent in Figure 2, which plots Luxembourg's labour growth against those of neighbouring countries.) The recession marked an end to this long expansion, with a sharp fall in output (-7% in 2009, which followed -1.5% in 2008) and a severe contraction in jobs creation, in 2009 down to 1% from the 4.7% recorded in 2008. The positive rates of growth of employment recorded during the crisis indicate the possible presence of labour hoarding. This term refers to the failure of employment to adjust to the economic downturns, due to firms facing costly hiring process and shortages of firm-specific skills and, as a result, choosing to retain staff even if demand for products is insufficient to achieve a full use of resources. In 2010, however, employment growth was still low and well below the increase in production, which explains the recovery in labour productivity.[4]

Figures 2 and 4 show the deterioration and increased variability in GDP figures which occurred after 2000 in the *frontaliers* countries and the concurrent slow-down in employment creation. (Only Germany had comparable growth rates of employment and GDP pre- and post- 2000.) In neighbouring countries, the aggregates' time series evolution followed closely the European average, whereas Luxembourgish data were more volatile. Despite its high variability, the capital stock increased, on average, at sustained rates in this group of countries (Figure 3). Capital accumulation, however, slowed down in the years before the crisis and several countries experienced negative capital accumulation rates, which may be interpreted as an attempt at scaling down productive capacity in an uncertain business environment.[5] For Luxembourg, the data were characterised by large variations, so that it is difficult to discern a clear tendency, although one can see that capital accumulation was never below zero.

[4] Labour hoarding has been observed in several countries, and has been extensively discussed and analysed by economists. One can see, for example, the excellent discussion in Felices (2003) and references therein.

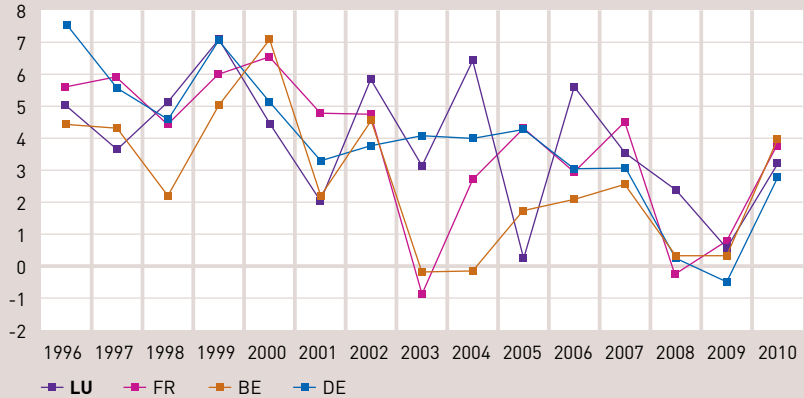
[5] Formally, a negative capital stock growth implies that the investment rate is lower than the depreciation rate.

Figure 2
Employment: yearly growth (%) 1995-2010



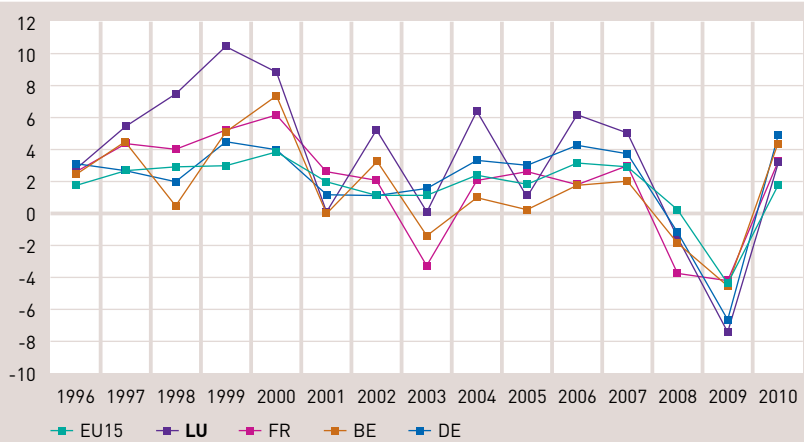
Sources: author's calculations from Eurostat and Statec data

Figure 3
Capital stock: yearly growth (%) 1995-2010



Sources: author's calculations from Eurostat, EUKLEMS, and Statec data

Figure 4
GDP: yearly growth (%) 1995-2010



Sources: author's calculations from Eurostat and Statec data

Table 1
GDP and inputs: annual growth (%) 1995-2010

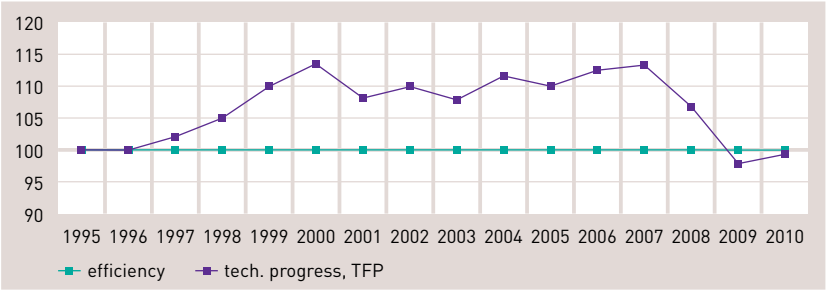
Countries	GDP	Labour	Capital
AT	2.05	0.93	3.81
BE	1.58	0.97	2.67
DE	2.04	0.47	3.85
DK	1.16	0.45	3.49
ES	2.01	2.18	5.11
FI	2.78	1.12	3.01
FR	1.84	0.85	3.71
GR	0.52	0.80	2.72
IE	3.81	2.45	6.88
IT	-0.06	0.81	3.19
LU	**3.44**	**3.45**	**3.88**
NL	2.21	1.27	3.51
PT	1.36	0.57	5.78
SE	2.14	0.61	2.77
UK	1.33	0.79	3.17
US	1.81	0.69	3.57
EU15	1.72	0.90	

Legend: Country codes are available in the Appendix D, Table 25.
Figures represent period averages of yearly percentage changes (geometric means).
Sources: author's calculations from Eurostat and Statec data

1.2 The evolution of productivity

In spite of the good overall macroeconomic performance, Luxembourg's productivity record was disappointing. Luxembourg featured on the efficient frontier for the entire period analysed, meaning that the country made a fully efficient use of inputs (last column in Table 2). This is certainly a positive feature of the data, but it also means that improvements in the country's competitiveness can be achieved solely through a sustained rate of technical progress. Technical progress, however, stagnated, which resulted in nearly-zero TFP growth (second last column, Table 2). This is shown in Figure 5, which depicts the evolution of Luxembourg's (cumulative) technical progress and efficiency indices against the base year (1995). One observes a big rise in TFP from 1995 to 2000, a subsequent period of stagnation, and the dramatic fall during the financial crisis. Despite signs of recovery, the crisis wiped out the technology gains realised in the 90s. Capital deepening was also modest. (Luxembourg, however, has the highest capitalisation among this group of countries).[6] As a result, labour productivity remained substantially stable over the period 1995-2010, in an international environment characterised by general productivity slow-down.

Figure 5
Luxembourg: efficiency and TFP/technical progress indices 1995-2010 (1995=100)



Sources: author's calculations from Eurostat and Statec data

Table 2 reports (average) rates of growth of labour productivity and its determinants from 1995 to 2010 for each country. One can see that labour productivity performance was weak in all countries. Its rate of growth was barely higher than 1% in 5 European countries (Austria, Finland, Germany, Ireland and Sweden). Labour productivity declined in Italy, Spain and Greece. In contrast, rates of capital accumulation were high, mainly reflecting low rates of employment growth (as seen in Section 1.1). This suggests that poor TFP performance was the likely source of the low productivity growth. In particular, efficiency losses and slow or even negative technical progress contributed to this outcome.

[6] The high capitalisation of Luxembourg's economy is explained by the relatively small workforce with respect to the country's capital stock. Kumar and Russell (2002) note that high capital/labour ratios often characterises high income (small) countries; in their study, Luxembourg share this feature with countries such as Norway and Switzerland. In Luxembourg, the high capitalisation is linked to the characteristics of its manufacturing sector and its historical development; in the service sector, it reflects the increasing importance of ICT and real estates. (Industries with highest capital stock per workers are the traditional heavy industries, public utilities and, among services, real estates, telecommunications and transport services.) Several studies also suggest a link between high capital stocks and favourable investment taxation in open economies (Sen and Turnovsky, 1990).

Table 2
Labour productivity and its components: average annual growth rates (%) 1995-2010

Countries	Y/L	K/L	TFP	Technical Progress	Efficiency Gains
AT	1.12	2.86	0.72	0.74	-0.02
BE	0.61	1.69	0.34	0.69	-0.35
DE	1.56	3.36	0.51	0.11	0.40
DK	0.71	3.03	-1.03	-1.06	0.03
ES	-0.17	2.87	-1.02	0.27	-1.29
FI	1.64	1.87	0.78	0.10	0.68
FR	0.98	2.83	0.44	0.57	-0.13
GR	-0.27	1.91	-1.62	-1.47	-0.16
IE	1.33	4.32	-1.06	-1.06	0.00
IT	-0.87	2.36	-1.76	-0.25	-1.51
LU	**-0.01**	**0.41**	**-0.05**	**-0.05**	**0.00**
NL	0.93	2.21	0.26	0.33	-0.07
PT	0.78	5.17	-4.14	-2.49	-1.69
SE	1.52	2.14	0.49	-0.88	1.38
UK	0.54	2.37	-1.71	-2.05	0.35
US	1.11	2.86	0.27	0.24	0.02
EU15	0.82				

Legend: Y/L denotes labour productivity; K/L capital intensity; TFP Total Factor Productivity. (Y denotes output (GDP); K capital stock; L employment. Country codes are available in the Appendix D, Table 25. Figures represent period averages of yearly percentage changes (geometric means).
Sources: author's calculations from Eurostat and Statec data

The data presented above, however, masks cyclical shifts that have occurred during the period analysed. Figures 6–8 present time series of labour productivity, capital accumulation and TFP components for Luxembourg and neighbouring countries. Tables 7–12 in Appendix A show annual growth rates from 2000 to 2010 for the same variables.

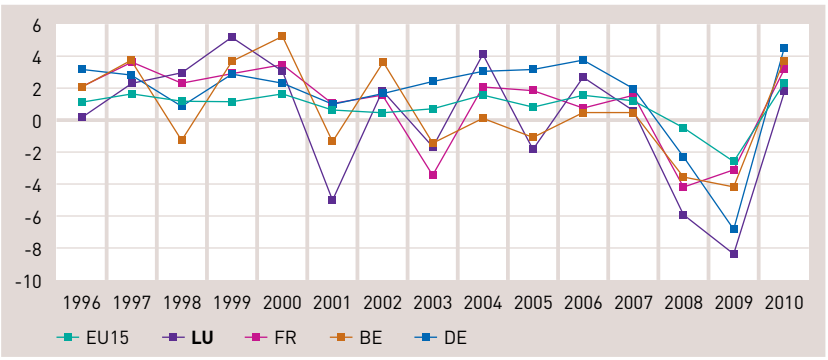
Figure 6 shows the evolution of labour productivity in selected countries (Luxembourg, Germany, France, and Belgium) against the European average. Overall, labour productivity deteriorated in the years post-2000 and became more volatile, with the possible exception of Germany. Its pattern followed closely the one of TFP. The *frontaliers* countries were severely hit by the recessions of 2001-2003 and 2007-2009, with a negative peak occurring in 2009. This evolution is confirmed by the annual figures in Table 7, Appendix A. Labour productivity declined in all countries during the recessions of 2001-2003 and 2007-2009, but this decline was dramatic in 2008 and 2009, with all countries recording negative rates of labour productivity growth in both years. This shows that the recession prompted by the financial crisis was more severe than the previous one.

The data show two important features of TFP evolution: 1) TFP figures were highly volatile in the last decade; 2) the productivity slowdown started well before the crisis in the countries considered. Figure 7 shows that the pattern of TFP growth in Luxembourg changed considerably before and after 2000. In the latter period, the variation in the data increased and overall performance worsened. (One can notice the two negative picks that occurred in correspondence of the 2001 and 2007-2009 crisis.) The TFP fell dramatically in all countries in 2008, and this indicator was still negative in 2009. This result was generated mainly by negative technical progress, that is, from the contraction of the production frontier. It is important to note, however, that rates of technical progress started deteriorating well before the crisis, as it is apparent in yearly data (Tables 10 and 12, Appendix A). Similarly, one observes that the recovery in labour and total factor productivity that occurred in 2010 was mainly due to technical gains. Finally, Figure 8 shows that Luxembourg's TFP performance was driven by technical progress, and that this was more volatile than in neighbouring countries, where patterns of technical progress were remarkably similar. In particular, German TFP performance, sustained by some efficiency gains, was less volatile.

Luxembourg featured on the best practice frontier for the entire period (Table 11, Appendix A). Other countries that made an efficient use of inputs were the US, which moved on the frontier in 1998, and the United Kingdom, on the frontier from 2004. Germany and Sweden made good efficiency gains, whereas Spain, Italy and Portugal suffered the biggest efficiency losses. (Portugal was on the frontier at the beginning of the period analysed, but fell below it in 1997.)[7]

Capital deepening was lower-than-average in a majority of countries already in 2007 (see Table 8). In 2008, 12 countries out of 16 had negative per capita capital accumulation rates. (In contrast, in 2009, only 5 countries had negative rates of capital deepening.) This pattern may be explained by firms attempting at scaling down capacity, and, at the same time, by the failure of employment to adjust to the downturn (the well-known 'labour hoarding'). The negative capital accumulation rates recorded during the crisis, however, did not match the dramatic fall in TFP and its components.

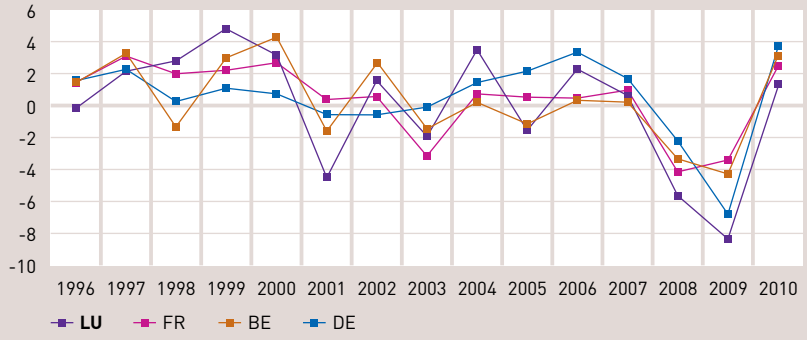
Figure 6
Labour productivity in the EU15 area, Luxembourg and neighbouring countries: yearly growth (%) 1995-2010



Sources: author's calculations from Eurostat and Statec data

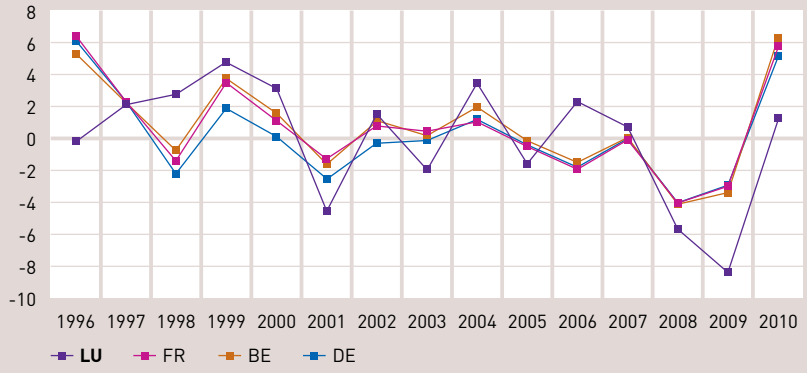
[7] Fare *et al.* (2006) and Kumar and Russell (2002) found similar results. Fare *et al.* (2006) analysed the same group of European countries plus Norway from 1965 to 1998. Kumar and Russell's database included OECD, developing and newly industrialised (NICs) countries for the period 1965-1990. These authors analysed the (cumulative) change in the tripartite decomposition indices in 1965 and 1990, and depicted technology frontiers for each of these years. Here, Luxembourg moves on the frontier in 1990, as a result of large efficiency gains and technological progress. Both studies used data from the Penn World Tables.

Figure 7
Total Factor Productivity: yearly growth (%) 1995-2010



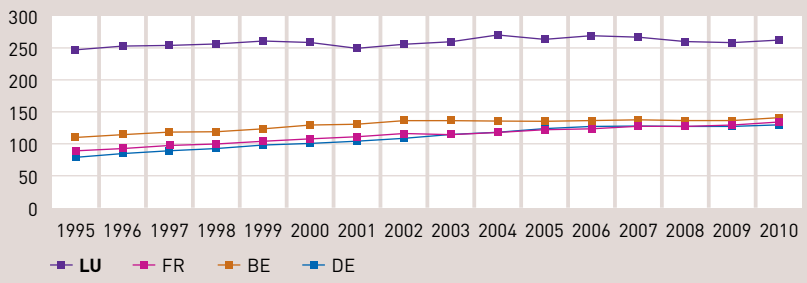
Sources: author's calculations from Eurostat and Statec data

Figure 8
Technical progress: yearly growth (%) 1995-2010



Sources: author's calculations from Eurostat and Statec data

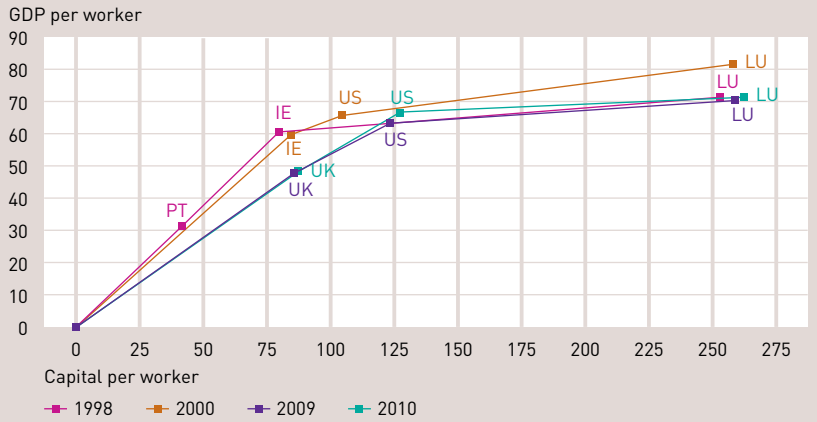
Figure 9
Capital intensity 1995-2010 (levels)



Sources: author's calculations from Eurostat, EUKLEMS, and Statec data

In summary, the analysis in this section shows a deterioration of countries' TFP performances which preceded the crisis. As a (rough) example, Figure 10 depicts the movement of the technological frontier from 1995 to 2010, by comparing output per capita and capital stock per capita in selected years. One observes the lowering of the frontier that occurred after 2000, and the slight recover in 2010. In 2009, at high level of capital intensity, the frontier is in about the same position as it was in 1995, whereas the area corresponding to low capitalisation has reduced substantially. (This may indicate that loss in efficiencies have been predominant in this area, and that the observed frontier is below the real technology frontier.) The deterioration of productivity performance is also apparent in Table 9 (Appendix A), which compares the position of the countries against the base year (1995). In 2010, only 7 European countries were better off than 1995.[8]

Figure 10
Production frontiers 1995-2010



Sources: author's calculations from Eurostat, EUKLEMS, and Statec data

Usually, the evolution of TFP is linked to the economic cycle, institutional and regulatory environments and ability to innovate. Regarding the first explanatory factor, it is often pointed out that TFP has hardly followed economic cycles in recent years. Many commentators cite rising business regulations as one of the causes of the productivity slowdown. Indeed, poor productivity growth may be partly explained by different degrees and intensity in the implementation of economic liberalisation programmes (Scarpetta *et al.*, 2002; Nicoletti and Scarpetta, 2003).[9] The results presented in this report, and in particular poor technological change figures, however, seem to indicate that a deterioration in the abilities of countries to innovate and adopt new technologies is another important cause of poor productivity growth.[10]

[8] Regression analysis confirms that changes in labour productivity were driven primarily by changes in TFP, and that technological changes are slightly more important than efficiency changes (results available from the author).

[9] One can also see the interesting blog at http://ftalphaville.ft.com/blog/2011/03/31/532611/the-uks-vanishing-productivity-and-the-datas-gone-too/. On the productivity effect of markets' liberalisation process, Fare *et al.* (2006) argue that, although frictions and adjustment costs related to deregulation and market-integration reforms should have been overcome, the high transaction costs involved by the process may explain the failure of EU countries to improve efficiency for the period pre-2000. In contrast, at industry level, Grifell-Tatje and Lovell (1996) find that productivity decreased following the deregulation in Spanish banking sector.

[10] The positive impact of indicators of innovation on TFP has been largely documented in the economic literature. One can see Peroni and Ferreira (2011) and references therein.

Another interesting feature of this analysis is that it identifies two group of countries in the EU: one sustained positive rates of TFP growth; another was characterised by overall negative TFP growth. Interestingly, this latter group includes the countries currently experiencing the sovereign debt crisis (with the exception of Denmark and the UK), possibly indicating long-term structural problems in those economies. This is also seen in the TFP indices in Table 9, Appendix A. Among the countries that were worse off in 2010 against 1995 we find those struck by the debt crisis. These relative positions were not altered significantly by the recession (cf. figures in 2006). The recession seems to have exacerbated the productivity decline in worse-off country, while slowing-down the growth in better-off country. These data features seem to support the presence of convergence "clubs" in the EU. It is difficult, however, to assess convergence due to the relatively short time horizon available. The analysis of the distribution of output percapita shows some evidence of emerging bi-modality and increased dispersion over the period analysed (graphs and data available from the authors).[11]

This analysis has been conducted at a high level of aggregation, whereas the importance of industry level analysis and sectoral patterns in explaining aggregate productivity is often pointed out in the literature. (D. Margaritis and Grosskopf, 2007, find that rather than economic restructuring and *between* sector effects, *within* industries effect provide a better explanation to aggregate productivity growth.) Thus, the next section looks in detail at the Luxembourgish economy, for which detailed industry-level data are available.

[11] The presence of convergence clubs in the EU and technical progress performance as a source of divergence has been previously documented in Fare *et al.* (2006). These authors conduct a standard distributional and cross-sectional analysis of convergence, along the analysis of the presence of common trends in clusters of countries using cointegration techniques.

2 Productivity in Luxembourg at industry level

The evolution of the Luxembourgish economy over the past 3 decades has been characterised by rapid economic growth, low unemployment and relatively low inflation.[12] During this time, Luxembourg has overtaken the US as the country with the highest level of GDP per capita among OECD countries. This rapid growth has not been uniform across industries, and is linked to the expansion of services and the decline of traditional heavy industries. The expansion of banking and financial activities that took place since the end of the 60s has made Luxembourg a major international financial centre. In recent years, however, the country's economic growth has been very volatile. This feature is explained by the size and degree of specialisation of the economy, which makes it especially exposed to international economic conditions. In the last decade, two recessions hit the country and its financial sector: the stock exchange crisis of 2001-2003, which followed the burst of the IT bubble, and the recession which followed the outbreak of the financial crisis in 2007-2008.[13]

In this context, it is important to look at productivity changes in the industries of Luxembourg. This helps to better understand the aggregate evolution of productivity and the impact of the crisis on the economy, because different economic activities contribute to aggregate outcomes in different ways, reflecting their specific characteristics and relative weight on the total economy. Moreover, productivity changes reflect not only economic cycles, but also long-term shifts in an economy. This becomes clearer at industry level.

This section analyses productivity changes, and associated technical and efficiency gains, in Luxembourgish industries from 1995 to 2010. Malmquist indices of productivity are computed for each industry at the NACE 2-digit level, using data from the National Accounts division at Statec. Service and manufacturing are analysed separately, and production frontiers are constructed for each group of industry. Each industry 's perfomance is evaluated by comparing gross output to three inputs: number of employees, capital stock, and intermediate inputs (energy, raw materials, and services) and compared to the relevant frontier. This is done to better reflect the structure of the Luxembourgish economy and the different weights of manufacturing and services on output and employment.[14] Computations are carried out assuming constant returns to scale.[15] To aid interpretation of results, Tables 26 and 27 in appendix D report each industry share on total employment and output of the corresponding group of activities.

Before turning to the detailed analysis of activities, we give a look at the overall evolution of labour productivity and TFP in service and manufacturing. Figure 11 compares annual labour productivity growth in manufacturing and service industries from 1995 to 2010. One can see that the recession of 2001-2003 ended the sustained productivity growth period which characterised the second half of the 90s. While services have rapidly recovered afterwards, manufacturing appears to have been struggling since then, alternating positive and negative growth rates. The financial crisis appears to have hit harshly both sectors of the economy, although the fall in manufacturing's productivity doubled the one of its counterpart. Thus, one can observe the decline of manufacturing *vis-à-vis* the growth of the services in disaggregated productivity measures.

12 Low inflation relatively to other European countries. Luxembourg experienced periods of high inflation during the 70s and first half of the 80s.

13 The evolution of Luxembourg from a steel-based to a service-based economy is effectively depicted in the *'Portrait économique et social du Luxembourg'* published by Statec (2003). In addition, the OECD economic study on Luxembourg (OECD, 2008) has an interesting discussion on the recent evolution of Luxembourg's financial sector.

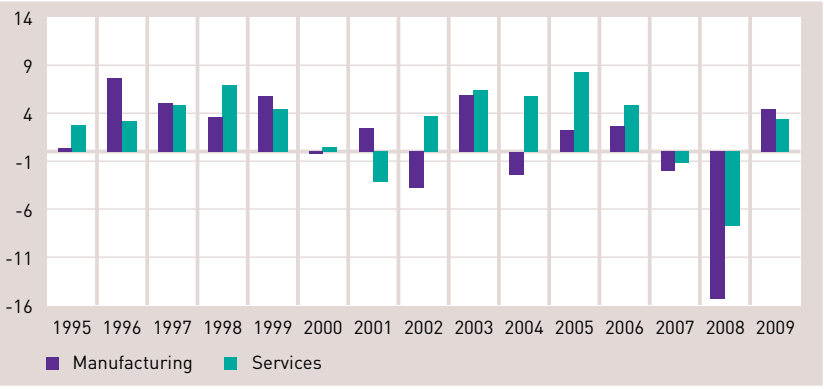
14 Manufacturing industries account for only about 20% of total value added in the economy. The structures of manufacturing and service industries are also quite different. Luxembourg's services are rather fragmented whereas manufacturing industries are often dominated by few big firms. The method used to compute the capital stock is discussed in DiMaria and Ciccone (2006a).

15 The validity of the assumption of constant returns to scale is discussed in DiMaria and Ciccone (2006b).

The sources of the dramatic fall in productivity recorded during the recessions of 2001-2003 and 2008-2009 can be traced to the decline in output and the sustained growth of the labour input. An explanation for the failure of employment to adjust to the economic downturns is that firms facing shortages of skilled labour, and as a result costly recruitment processes, choose to retain staff even if demand for goods/services is low.

Figure 12 depicts the overall evolution of Malmquist TFP indices in services and manufacturing (Tornqvist indices are included for comparison). In manufacturing, one can see that the great increase in productivity in the second half of the 90s was followed by a period of stagnation and by a fall during the last recession. Services' productivity increased until 2007, and subsequently declined in correspondence of the financial crisis. Both groups of industries had a small recovery in 2010. One also notice that the recent crisis was more severe than the 2001-2003 recession in terms of productivity losses.[16]

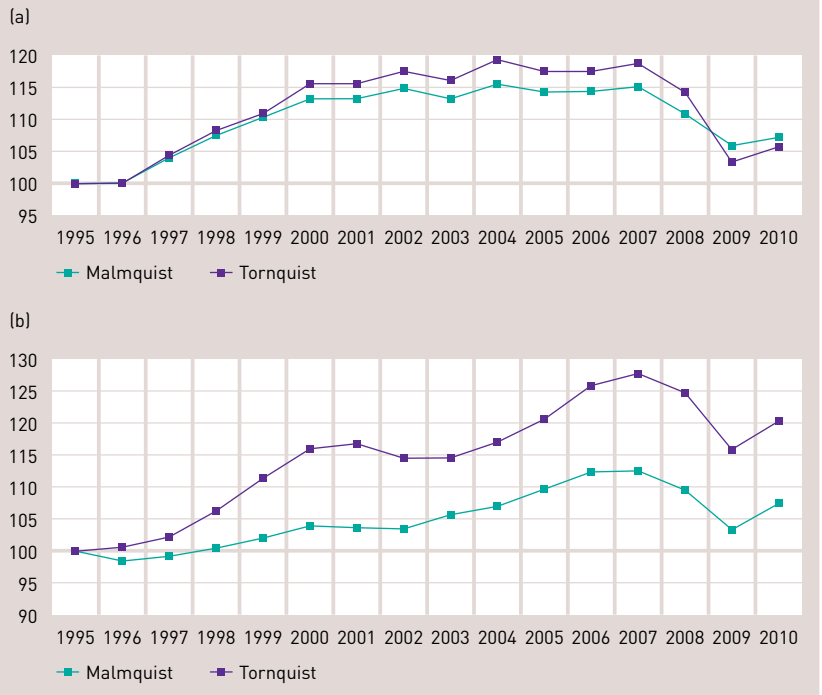
Figure 11
Labour productivity growth in Luxembourg in manufacturing and service industries: yearly changes (1995-2010)



Sources: author's calculations from Statec data

[16] Malmquist and Tornquist indices are close, indicating the same direction in productivity changes, which supports the hypothesis of constant returns to scale.

Figure 12
TFP growth in Luxembourg in manufacturing (a) and service industries (b): Malmquist and Tornqvist indices (1995-2010)



Sources: author's calculations from Statec data

2.1 Services

Service industries, characterised by the prominence of financial services, account for two third of the Luxembourgish economy. Luxembourg's financial services are highly specialised and dominated by banking activities. The last decade, however, saw a striking expansion of insurances and investment funds.[17] This expansion constituted the engine of growth of the Luxembourgish economy in the last decade. Several international institution, however, have often pointed out how growth in the financial sector is likely to slow down in future years (OECD, 2008; IMF, 2009). Thus, it is interesting to investigate the productivity performance of services and how this was affected by the crisis.

Factors growth in services had its focus on the financial services and new technologies (ICT)-related activities. Table 3 presents average yearly rates of growth of output, capital and labour inputs for service industries from 1995 to 2010. Production increased substantially in nearly all economic activities. (Only exceptions were car retail, R&D, recreational & cultural activities and sanitation.) Output expanded at striking rates in telecommunications (about 15% per year) and auxiliaries to financial intermediation and insurance (15.6%). Growth was also sustained in the other financial industries and related activities, such as business and IT services. Inputs use increased in all activities. Employment grew in all services, reaching 16% in ITs, and capital stock grew at rates higher than 5% per year in a majority of industries.[18] In the financial services, in 2010 employment in insurances and auxiliary activities was, respectively, 80% and 50% higher than in 2000, against an increase of 20% in financial intermediation.

In contrast to sustained input and output growth, labour productivity declined or failed to grow in many service industries, with some notable exceptions (Table 4). Postal and telecommunications services' labour productivity grew by 11% per year, reflecting the expansion of on-line services and satellite communications. (Luxembourg is home of world leaders companies in satellite communications and in the provision of on-line services.) Wholesale and retail industries' productivity also grew at sustained rates (about 6%). In the financial sector, output growth outpaced the increase in employment. As a result, labour productivity grew by nearly 4% per year in financial intermediation and 6.7% in auxiliaries to financial intermediation (it declined by -0.4% in the insurances).

Services' TFP performance was disappointing. TFP grew at positive rates in a handful of activities, namely telecommunications (2.3%) and some financial services, and was stable in transport services and retail. This result was generated by zero, or even negative, technical progress and efficiency losses.[19] (One can see Figure 13, which depicts the contributions of technical progress and efficiency to the TFP.) The financial sector confirmed its prominence with an average yearly increase of TFP by 2.7% and 4% in, respectively, auxiliary activities and insurances. This sustained growth was generated by positive rates of technical progress, as this industries made an efficient use of inputs. In contrast, TFP growth was lower in financial intermediation (a bare 0.5% yearly) as positive rates of technical progress were counter-balanced by efficiency losses. Telecommunications, real estate, and education were also efficient in inputs' use.

[17] In 2010 the financial industries accounted for about 50% of gross output and 15% of employment in services. Within financial services, financial intermediation has the largest shares of output and employment. The weight of the auxiliary activities has been growing in the last decade. The insurance industry is smaller but has also grown steadily since the EC savings taxation directive 2003/48/EC of 3 June 2003, which prompted a re-allocation of funds from banking to insurance products. International life insurance constitutes the largest share (about 80%) of premiums in this industry. Luxembourg is also an important center for re-insurance. Furthermore, a large part of service industries is related to the financial services; among those, business services accounted for 17% of services' employment in 2010. This information is provided in Table 27. One can also see Statec, *Note de Conjuncture*, no. 1, 2010, page 41.

[18] Capital stock grew by 24% in water transport, but one should note that these services do not correspond, by and large, to economic activities carried out on the national territory.

[19] A negative rate of technical progress corresponds to a lowering of the best practise frontier. This result is not uncommon in the literature on productivity in service industries (Grifell-Tatje and Lovell, 1996). Its interpretation is unclear and in the literature several explanations have been advanced, such as exogenous cost and demand shocks and changes in the institutional environment. On this issue, one can also see DiMaria and Ciccone (2008, page 28) and references therein.

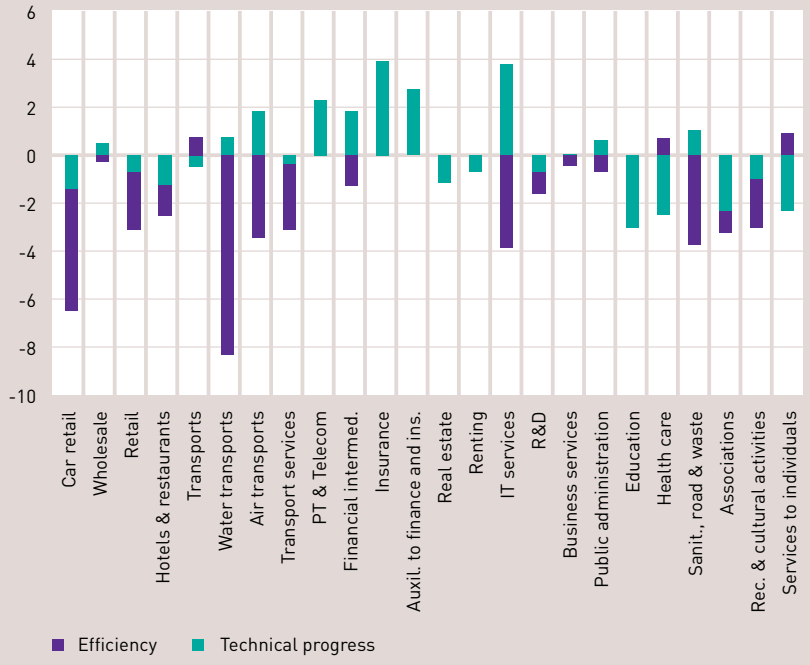
To gain insight in the impact of the financial crisis, Figure 14 compares TFP average growth rates in the period 1995-2006 against those recorded in 1995-2010. As a result of the financial crisis and subsequent recession, TFP growth fell dramatically in several activities, namely transport-related services, car retail and financial intermediation. In contrast, other financial industries and telecommunications productivity grew steadily also during the recession.[20] Business services, real estate, renting activities contracted less than public services.

To see this in more details, Tables 15—18 in the appendix report yearly growth rates of TFP, technical change and efficiency gains from 2000 to 2010. One observes that insurances and auxiliaries' TFP grew at a faster pace than financial intermediation after the stock exchange crisis of 2001-2003. Notably, the impact of the crisis on the TFP performance of the financial services was heterogeneous in terms of timing, sign and magnitude of the effects. The crisis hit harder the financial intermediation industry, with negative TFP growth recorded in all years from 2007 to 2009. TFP growth contracted in 2008 in the auxiliaries and in 2009 in the insurances.[21] Negative TFP growth stemmed from technical regress. The 2010 recovery was marked by a striking expansion of the best practice frontier in financial services. TFP in insurances and auxiliaries to financial intermediation grew by, respectively, 26 and 18%. Financial intermediation, however, suffered efficiency losses that weakened their TFP performance. Positive rates of technical progress characterised other activities related to the financial services, such as business and IT services, but their efficiency performance was disappointing, which suggests that these industries experienced difficulties in the adaptation of inputs' use to the economic cycle. One also see that telecommunications, auxiliaries to financial intermediation, real estate, and education have been steadily on the frontier since 2000. Business services were on the frontier until 2009. Insurances fell below the frontier in 2003, but were again on the frontier in 2007.

[20] In 2009, the government announced a plan of investment in national TC infrastructure, which may partly explain why TCs were not badly affected by the crisis.

[21] In 2007, the second largest world re-insurance company established itself in Luxembourg. Notably, this company has engaged in product innovation, with the creation of new insurance products.

Figure 13
TFP decomposition by service industry



Sources: author's calculations from Statec data

Table 3
Output and inputs in services: average annual growth (%) 1995-2010

Industries	Output	Labour	Capital
Car retail	0.46	3.30	6.57
Wholesale	7.96	1.62	6.03
Retail	7.77	1.62	5.84
Hotels & restaurants	0.81	2.57	6.22
Transports	5.46	4.24	3.80
Water transports	2.06	10.71	24.86
Air transports	5.65	5.24	7.95
Transport services	4.78	5.29	7.99
PT & Telecommunications	14.87	3.10	8.45
Financial intermediation	7.05	3.17	4.48
Insurance	6.31	6.78	0.47
Auxiliaries to fin. int. & insurance	15.63	8.32	7.84
Real estate	3.95	4.81	3.14
Renting & leasing	7.06	5.02	20.10
IT services	11.76	16.67	8.96
R&D	0.17	3.01	2.60
Business services	9.19	7.03	7.50
Public administration	3.40	3.08	4.24
Education	3.59	3.36	5.55
Health	6.14	5.52	9.42
Sanitation, road & waste	-1.27	3.66	1.87
Associations	4.44	3.26	9.67
Recreational & cultural activities	-3.95	4.24	5.87
Services to individuals	3.30	3.37	4.99

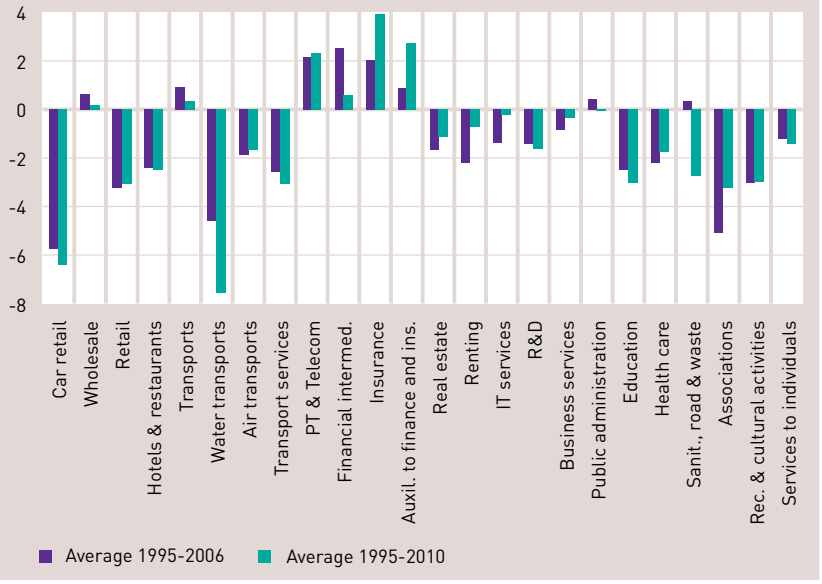
Sources: author's calculations from Statec data

Table 4
Labour productivity in services: average annual growth (%) 1995-2010

Industries	Y/L	K/L	TFP	Technical progress	Efficiency gains
Car retail	-2.75	3.16	-6.38	-1.39	-5.07
Wholesale	6.25	4.35	0.17	0.45	-0.28
Retail	6.05	4.15	-3.07	-0.72	-2.37
Hotels & restaurants	-1.71	3.56	-2.52	-1.26	-1.28
Transports	1.17	-0.42	0.30	-0.47	0.78
Water transports	-7.81	12.78	-7.59	0.78	-8.31
Air transports	0.39	2.57	-1.67	1.82	-3.43
Transport services	-0.49	2.56	-3.11	-0.38	-2.74
PT & Telecommunications	11.41	5.19	2.30	2.30	0.00
Financial intermediation	3.77	1.28	0.54	1.85	-1.28
Insurance	-0.44	-5.91	3.94	3.94	0.00
Auxiliaries	6.74	-0.45	2.72	2.72	0.00
Real estate	-0.82	-1.59	-1.17	-1.17	0.00
Renting	1.94	14.36	-0.73	-0.73	0.00
IT services	-4.21	-6.62	-0.26	3.78	-3.89
R&D	-2.76	-0.40	-1.64	-0.72	-0.94
Business services	2.01	0.43	-0.36	0.04	-0.41
Public admin.	0.31	1.13	-0.08	0.64	-0.71
Education	0.22	2.12	-3.06	-3.06	0.00
Health	0.59	3.70	-1.76	-2.44	0.69
Sanitation, road & waste	-4.76	-1.73	-2.74	1.02	-3.72
Associations	1.15	6.21	-3.24	-2.31	-0.96
Recr. & cultural activities	-7.86	1.56	-3.01	-1.00	-2.04
Services to individuals	-0.07	1.56	-1.46	-2.34	0.90

Sources: author's calculations from Statec data

Figure 14
TFP growth rates in services: period averages comparison

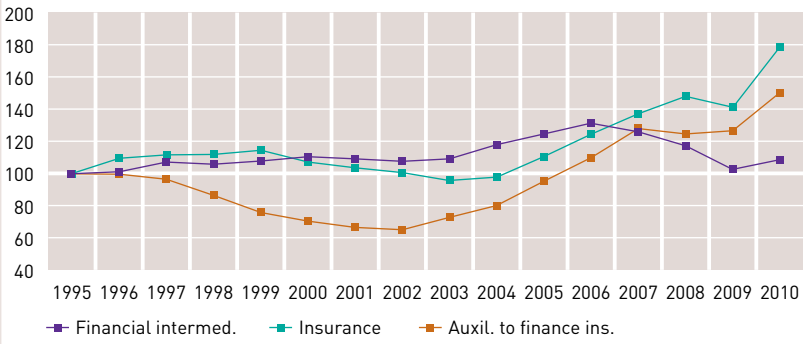


Sources: author's calculations from Statec data

Frame 1
The financial services

Given the predominance of financial activities in Luxembourg's services, Figure 15 focuses on the time series evolution of the TFP index (the index is set to 100 in 1995) for the activities involved in the provision of financial services. All financial services were hardly hit by the stock exchange crisis of 2001-2003. After a period of recovery, productivity declined again in correspondence of the 2007-2009 recession. Despite these common trends, one can observe marked differences in the response of each group of activities to the recessions and in overall TFP patterns. Insurances and activities auxiliaries to financial intermediation and insurance have become increasingly important in face of a decline in traditional financial intermediation. The TFP of the auxiliary activities grew steadily since 2002, stagnated in 2008 and 2009, and recovered in 2010. Insurances were also characterised by sustained growth in the last decade and a staggering recovery after the crisis. By contrast, financial intermediaries TFP decline started well before the crisis. Despite a slight recovery in 2009 and 2010, by the end of the period relative positions had changed and financial intermediation's TFP performance was dominated by insurances and auxiliaries. Technical progress was the main driver of such changes. In summary, the financial industry seems increasingly dominated by new type of financial services, with high innovation content.[22] The dynamism of the auxiliary activities is also reflected in the expansion of the number of funds and number of operators in this industry.[23]

Figure 15
TFP indices for the financial sector



Sources: author's calculations from Statec data

[22] A classification of the innovation content of the activities auxiliary to financial intermediation is available in O'Mahony and VanArk (2003). On this development one can also see the OECD Country Report on Luxembourg, 2008.

[23] The number of funds has nearly doubled since 2000. On the number of OPCs, cf. Statec, *Annuaire Statistique du Luxembourg*, 2010, page 409. Information on the number of enterprises is given by the Business Register (Statec, *Répertoire des Enterprises*, various years). One can see that the number of firms in the auxiliary category has nearly doubled in the decade, whereas the number of financial intermediaries and insurers has, respectively, remained stable and declined. In particular, the number of banks has steadily fallen in the last decade (cf. *Note de Conjoncture*, no 1 2007, p. 54).

2.2 Manufacturing

Tables 5 and 6 summarise the evolution of output, inputs and labour productivity in Luxembourg's manufacturing from 1995 to 2010. During this period, output and inputs' use grew in a majority of industries, albeit overall growth rates were much lower than in services. (Output and employment grew on average by, respectively, 2.5 and 1.5% per year against an increase of 7 and 4% per year in services). Productivity performances were weaker. The data, however, are characterised by high variation both across and within industries. This high variability, due to size effects, makes it difficult to discern clear patterns in the evolution of the variables. A few general tendencies are as follows: 1) the deterioration of the TFP performance, due to efficiency losses, and 2) the continued decline of Luxembourg's traditional heavy industry, largely dominated by the manufacturing of steel. (Output and inputs growth was modest or negative in both manufacturing of metals and fabricated metals; labour productivity fell in this latter industry by 2.5% per year, while TFP declined in the manufacturing of metals.)

Gross output and capital stock increased in all but three industries. Production increased in the manufacturing of wood products (11%), transport equipment (about 9%), and medical precision & optical instruments (9%). Among public utilities, the output of the electricity & gas industry increased on average by more than 5% per year. In construction, output grew by nearly 5% per year, while the output of Luxembourg traditional heavy industries declined (-1.3% in the production of metal). In general, output growth varied greatly across industries. (It ranged from minus 6% in clothing to 35% in office machinery and TC equipment.) Employment fell in 6 out of 21 industries, while it grew at sustained rates in manufacturing of wood (4.5%), textiles (3%), medical instruments (3.6%), transport equipments (5.5%), construction (approx. 3%) and recycling. The spectacular growth in the manufacturing of office and TC equipment should be interpreted with care, as it is largely due to the small size of this industry. This activity is constituted by a small number of firms and accounts for negligible shares of output and employment in manufacturing (Table 26).

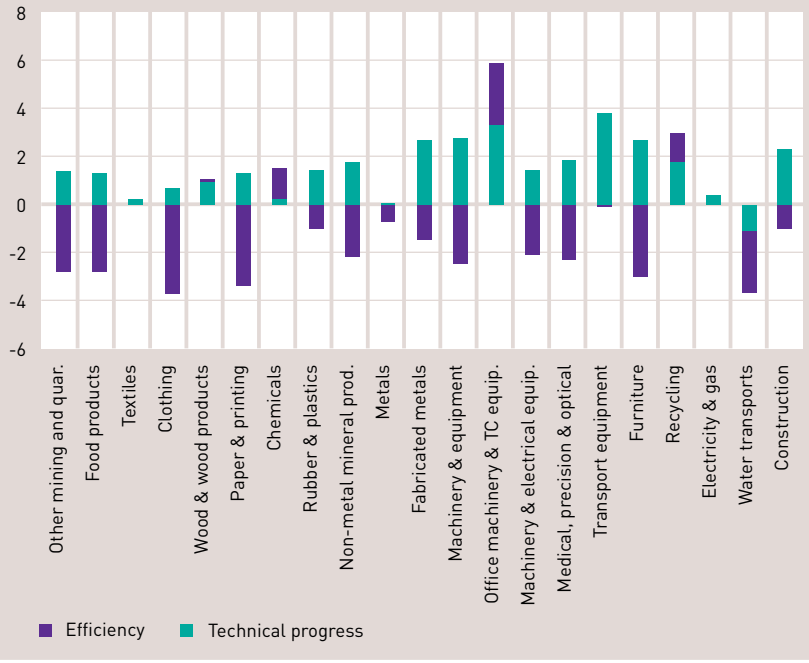
Labour productivity and TFP performances were generally poorer and varied greatly over industries (Table 6), growing at positive rates in some while declining in others. Labour productivity grew at rates faster than 5% in the manufacturing of wood product, chemicals and medical, precision & optical instruments. A growth rate of 3% was achieved by clothing, transport equipment, and production and distribution of electricity & gas. Productivity remained stable in a large number of industries, and fell markedly in fabricated metals. TFP performances were even poorer, as this figure declined in half of the Luxembourgish industries. This decline was driven primarily by efficiency losses. (Figure 16 depicts the two components of TFP growth, efficiency gains and technical progress for the period averages.) The public utilities (electricity & gas, water) and the manufacturing of textiles made an efficient use of inputs. The highest TFP gains were realised by transport equipment (3.8%) and recycling (3%).

Table 5
Output and input in manufacturing: average annual growth (%) 1995-2010

Industries	Output	Labour	Capital
Other mining and quarrying	0.15	-0.23	3.39
Food products	0.84	1.54	2.50
Textiles	3.48	3.33	0.14
Clothing	-3.98	-6.96	-4.57
Wood & wood products	11.00	4.59	6.93
Paper & printing	2.07	0.96	6.22
Chemicals	1.47	-3.66	-0.58
Rubber & plastics	1.56	1.64	1.05
Non-metal mineral products	0.23	-1.12	3.50
Metals	0.38	-2.20	0.06
Fabricated metals	-1.30	1.17	-0.29
Machinery & equipment	2.68	0.41	2.99
Office & TC equipment	36.08	23.51	6.69
Machinery & electrical equipment	4.04	0.80	3.28
Medical, precision & optical instr.	9.05	3.26	4.25
Transport equipment	8.93	5.54	3.13
Furniture	-3.07	-3.55	2.58
Recycling	1.43	2.29	5.48
Electricity & gas	5.69	1.86	4.45
Water dbn. & purification	0.30	0.05	2.50
Construction	4.67	3.02	2.27

Sources: author's calculations from Statec data

Figure 16
TFP decomposition by industry



Sources: author's calculations from Statec data

Table 6
Labour productivity in manufacturing: average annual growth (%) 1995-2010

Industries	Y/L	K/L	TFP	Technical Progress	Efficiency Gains
Other mining and quarrying	0.38	3.62	-1.52	1.31	-2.79
Food products	-0.69	0.95	-1.55	1.25	-2.77
Textiles	0.15	-3.09	0.19	0.19	0.00
Clothing	3.19	2.56	-3.09	0.64	-3.70
Wood & wood products	6.12	2.23	1.02	0.85	0.17
Paper & printing	1.10	5.21	-2.15	1.28	-3.39
Chemicals	5.33	3.20	1.53	0.23	1.30
Rubber & plastics	-0.07	-0.58	0.42	1.45	-1.02
Non-metal mineral products	1.37	4.67	-0.42	1.76	-2.14
Metals	2.63	2.31	-0.71	0.05	-0.75
Fabricated metals	-2.44	-1.45	1.09	2.61	-1.48
Machinery & equipment	2.26	2.57	0.17	2.73	-2.49
Office & TC equipment	10.18	-13.62	5.95	3.23	2.63
Machinery & electrical equipment	3.22	2.46	-0.71	1.42	-2.09
Medical, precision & optical instr.	5.61	0.96	-0.54	1.83	-2.32
Transport equipment	3.21	-2.29	3.67	3.81	-0.14
Furniture	0.49	6.35	-0.46	2.61	-2.99
Recycling	-0.84	3.12	2.99	1.75	1.22
Electricity & gas	3.76	2.54	0.37	0.37	0.00
Water dbn. & purification	0.25	2.45	-3.68	-1.09	-2.62
Construction	1.61	-0.73	1.23	2.29	-1.03

Sources: author's calculations from Statec data

Tables 21–24 in the appendix presents detailed TFP figures for the years 2000-2010. There, one can see that electricity & gas and textile manufacturing were on the frontier from 2000 to 2009, whereas transport equipment was on the frontier since 2005. Water and construction were on the frontier until 2008 but lost their position, due to efficiency losses, in the last two years. Table 21 presents the evolution of the TFP index in detail. If we fix at 100 the level of TFP in 1995, we observe that only half of the industries improved their position in 2010 (that is, they have an index greater than 100 in 2010) compared to the beginning of the period. In contrast, by 2006 a number of activities had improved their position.

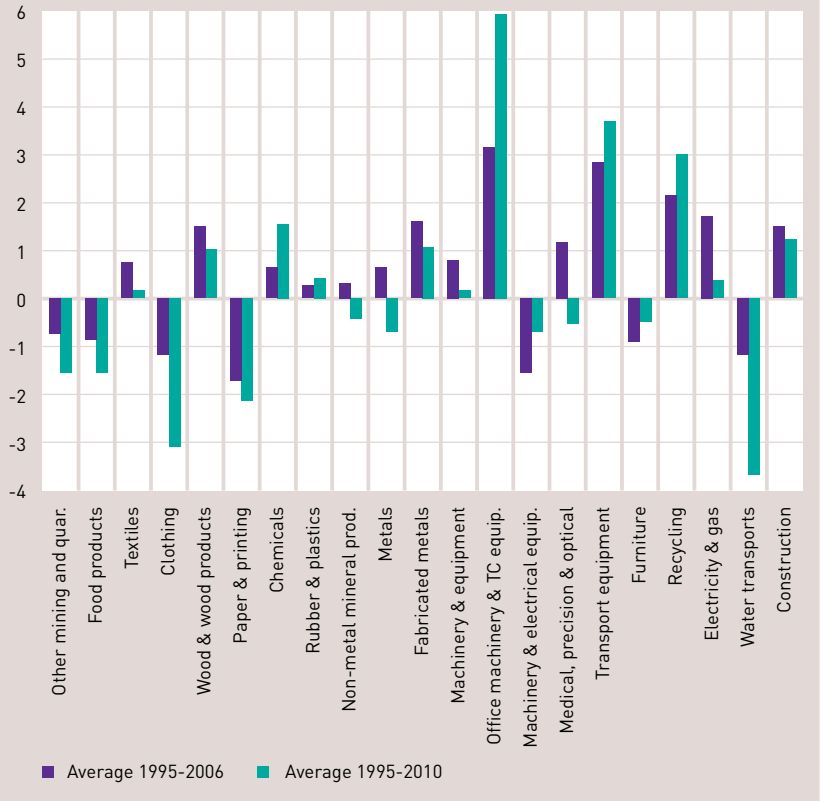
The detailed tables also reveal the data's high variability, which is recorded not only across but also within industries throughout the period analysed. This is due to the small size of the economy/industries and to the heterogeneous structure of Luxembourgish industries. These are often characterised by the presence of few big firms alongside a greater number of smaller firms.[24] As a result, the entry/exit of a producer (or even the fact that a plant becomes operational) causes large variations in the data. Moreover, TFP patterns are easily linked to firms' dynamics as new plants/firms are likely to employ more efficient technologies and to introduce some form of innovation compared to older ones.[25]

[24] In manufacturing and construction, only - respectively - 29 out of 987 and 16 out of 3151 firms employed more than 250 salary workers in 2010. Information on number and size of firms can be found in the various edition of the *Répertoire des Enterprises*, published yearly by Statec.

[25] Haltiwanger (2011) analyses the relation between the firms dynamics and TFP in the US, and highlights that the process of firms' creation and destruction is vital to productivity growth. Some older empirical evidence on the same issue is reviewed in Hahn (2001).

The productivity of manufacturing industries declined during both the recessions of the last decade, but the fall subsequent to the recent financial crisis was dramatic. (This was mainly linked to the fall in production of steel and other industrial products, due to the cyclical fall in demand, in an export-led economy.) To assess the effect of the financial crisis on this group of industries, Figure 17 compares average TFP growth rates for the period 1995-2010 to those recorded for the years 1995-2006. Clearly, the crisis caused a deterioration in TFP performances for all industries, with the exception of a few activities, namely transport equipments, recycling, chemicals and rubber products. One can also see this in Table 21 in the appendix, by comparing relative position in 2010 and 2006. In 2006, a majority of industries has improved their position compared to the beginning of the period, but only half of them had done so in 2010. In construction, an important industry often used as an indicator of economic health, output and inputs increased at sustained rates.[26] Productivity performance was poorer, as labour productivity grew by 1.6% per year, reflecting the fact that ouput grew faster than employment. TFP increased by a modest 1.2%, due to the concurrent effect of technical gains (2.3%) and efficiency losses (-1%). In particular, productivity indicators for this industry deteriorated substantially after the 2003 recession. Since then, TFP recorded positive growth rates only in 2007 and 2008, fell by nearly 6% in 2009, and recovered slightly in 2010 (TFP growth in 2010 was still negative, but decreased only by about 1%). This was the effect of big efficiency losses which displaced this industry from the best practice frontier in 2009.

Figure 17
TFP growth rates: period averages comparison



Sources: author's calculations from Statec data

[26] Construction accounts for about 10% of Luxembourg total employment and about 6% of the economy's value added.

3 Conclusions

This report presented the evolution of productivity in Luxembourg from 1995 to 2010 at national and industry level. At national level, the productivity performance of Luxembourg was evaluated against the one of a group of European countries and the US. The focus was on labour productivity and its main drivers, namely Capital deepening and Total Factor Productivity (TFP). The analysis used of production frontier methods, which allowed us to decompose the sources of TFP into technical changes and efficiency changes; this provided a valuable insight into the sources of productivity changes.

Main results can be summarised as follows:

- Overall, there was a deterioration in labour productivity, whose growth was weak in all the countries analysed. The source of this poor performance is found in negative TFP growth *vis-à-vis* sustained rates of capital accumulation. Both modest, or even negative, technical progress and efficiency losses appear to have contributed to this outcome. While the dramatic fall in productivity measures was generalised during the recent financial crisis, the slowdown in productivity started before the crisis. In particular, the 2001-2003 recession started the declining trend in productivity, which became concurrently more volatile.

- Luxembourg featured on the efficient frontier for the entire period, but TFP stagnated due to a deterioration in the country's technical progress performance. The recessions of 2001-03 and 2007-09 prompted a large fall in Luxembourg's labour productivity and TFP, due to the country's high exposure to external conditions. The source of this fall can be traced to the decline in output and the concurrent sustained growth of employment, pointing to a labour-hoarding phenomenon, and to the deterioration in the ability of the country to innovate at a sustainable rate.

- The analysis of productivity by industry helped to reveal features that were hidden in aggregate data. While peaks and troughs were mainly related to the economic cycle, structural shifts in Luxembourg's economy affected productivity trends in many industries. The most important was clearly the continued decline in goods-producing industries in the face of sustained growth in services. The latter was led by telecommunication and, most of all, financial services. Among financial industries, the activities auxiliaries to financial intermediation and insurance were the most dynamic. In face of sustained output and inputs growth, however, deterioration and weaknesses in productivity performances were also found in service industries. Other developments affected specific industries, and there were large differences in efficiency and technological progress across industries.

The analysis presented here has several limitations. The volatility in the data not only makes it difficult to attribute productivity changes to their various components, but also make historical observed patterns a poor guide to productivity trends. This is true for Luxembourg, where the economy's specialisation determines the country's high exposure to world economic conditions. At the disaggregate level it was difficult to assess sources of growth due to this data feature. Further limitations are the well known difficulties in the measurement of inputs, especially capital stock. difficulties exist also for the measurement of output for service industries and service-led economies. In particular, output measures are hard to interpret for financial intermediation (one can see Crespi *et al.*, 2006).

This analysis points to TFP as the main source of productivity growth, in line with Fare *et al.* (2006), but it is mainly descriptive, and more research is needed to find an explanation for this finding. There is some evidence that productivity performance is related to firm dynamics, but at present too few observations are available for a meaningful assessment of this evidence. (The link between firms dynamics and productivity is at the center of an OECD-led project which will exploit data at firm level and hopefully shed some light on this issue.) Moreover, it is clear that the financial services in Luxembourg are related to other industries and the evaluation of productivity trends may be improved if the information content of such links was taken into account.

Computations

Computations of the productivity indices in this report have been carried out using the SAS macro klems, developed by J. Ciccone and C.H. Di Maria.

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Appendix

A Tables: international comparison

Table 7
Labour productivity yearly growth (%) 2000-2010

Countries	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
AT	4.42	-3.14	3.86	0.75	2.97	-1.25	2.52	0.15	-3.13	-4.79	2.57
BE	5.22	-1.43	3.51	-1.45	0.08	-1.11	0.46	0.42	-3.60	-4.21	3.67
DE	2.30	0.94	1.66	2.42	3.04	3.15	3.71	1.96	-2.35	-6.86	4.36
DK	3.88	-2.37	2.05	-2.02	4.38	-1.87	1.47	-0.42	-4.68	-3.98	6.06
ES	-0.10	-1.78	0.79	-3.29	-1.27	-2.28	1.13	1.09	-1.87	1.52	3.25
FI	4.16	-2.22	1.34	0.49	7.28	0.22	2.46	3.69	-3.62	-6.45	6.55
FR	3.41	1.03	1.51	-3.46	2.03	1.83	0.71	1.54	-4.27	-3.12	3.07
GR	4.53	3.59	2.45	-0.38	0.73	-2.24	1.02	-0.70	-1.07	-5.27	-1.95
IE	1.22	-3.02	2.72	0.50	1.72	-1.10	0.63	3.78	-5.32	3.69	10.87
IT	1.40	-0.53	-5.99	-3.16	-1.28	-0.31	1.09	1.83	-2.31	-5.11	0.00
LU	3.03	-5.15	1.96	-1.76	4.07	-1.88	2.61	0.56	-5.97	-8.40	1.42
NL	3.43	-3.10	-0.32	-2.59	4.98	1.89	1.96	2.17	-2.65	-5.67	5.36
PT	1.49	-2.17	-0.59	-0.76	0.03	4.63	1.39	2.30	-3.11	-0.10	4.95
SE	3.86	-4.54	2.03	2.37	7.44	-1.20	2.88	2.81	-4.87	-7.22	5.51
UK	5.54	1.60	0.80	-0.98	3.03	-0.53	0.49	-1.37	-4.19	-6.30	1.79
US	1.74	-0.45	1.72	0.92	2.12	0.28	-2.05	0.27	-4.13	-2.41	5.81
EU15	1.60	0.60	0.46	0.66	1.54	0.80	1.56	1.22	-0.51	-2.62	2.12

Sources: author's calculations from Eurostat, Statec data

Table 8
Capital deepening (%) 2000-2010

Countries	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
AT	5.54	0.40	5.89	3.05	3.46	-0.58	1.71	-0.61	-1.88	0.66	1.82
BE	4.98	0.88	4.67	-0.23	-1.08	0.31	0.89	0.94	-1.38	0.69	3.26
DE	3.36	3.03	4.39	4.99	3.71	4.42	2.46	1.35	-0.92	-0.54	2.30
DK	5.03	0.68	5.21	0.69	5.05	-0.82	2.67	2.10	-0.36	2.93	5.48
ES	1.82	1.18	4.49	-0.29	1.41	0.29	3.47	3.66	2.15	8.49	5.49
FI	2.65	-1.00	2.93	1.86	6.35	0.49	1.14	2.16	-1.39	3.68	4.65
FR	3.83	3.23	4.19	-1.13	2.62	3.59	1.84	3.11	-0.80	1.99	3.72
GR	6.27	5.43	5.31	-0.05	2.16	0.38	1.41	0.53	2.03	-0.64	3.85
IE	2.84	1.56	4.97	4.44	5.04	2.37	3.54	6.06	2.55	12.78	10.24
IT	3.32	2.38	-2.08	0.74	0.68	2.68	2.63	3.76	1.66	1.45	0.13
LU	-1.00	-3.29	2.51	1.29	4.21	-2.60	1.98	-0.86	-2.26	-0.46	1.37
NL	4.26	-0.90	2.98	-0.16	4.99	2.50	1.66	1.57	-1.11	-0.12	5.26
PT	7.36	4.23	5.86	5.68	2.79	7.51	2.94	2.87	-0.58	3.67	4.17
SE	2.83	-2.80	2.10	2.34	5.52	-0.77	2.77	4.18	-0.15	-0.10	2.39
UK	6.26	3.51	2.80	0.04	3.80	1.22	1.91	0.51	-0.75	-0.01	2.14
US	3.49	3.73	4.24	2.03	2.22	1.82	-0.38	2.08	-1.13	2.10	3.80

Sources: author's calculations from Eurostat, Statec data

Table 9
TFP indices 2000-2010 (1995=100)

Countries	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
AT	100	113.54	109.90	113.10	113.42	116.20	114.85	117.41	117.73	114.45	108.86	111.35
BE	100	111.11	109.35	112.33	110.73	111.00	109.72	110.06	110.33	106.63	102.04	105.23
DE	100	106.10	105.49	104.92	104.81	106.32	108.61	112.24	114.16	111.66	104.08	107.89
DK	100	101.85	99.11	98.60	96.26	97.46	96.20	95.79	93.99	89.82	84.37	85.58
ES	100	98.58	96.42	95.34	92.34	90.36	88.12	86.92	85.74	83.45	83.72	85.70
FI	100	115.19	113.07	112.86	112.28	116.01	115.86	117.72	120.50	117.33	107.50	112.41
FR	100	111.88	112.30	112.94	109.41	110.25	110.87	111.35	112.46	107.81	104.17	106.76
GR	100	92.82	93.34	92.90	92.58	91.89	89.59	89.62	88.67	86.48	82.32	78.25
IE	100	99.27	95.21	94.31	92.04	90.67	88.23	86.62	86.21	80.12	78.11	85.27
IT	100	99.11	97.61	92.78	89.48	87.97	86.07	85.39	84.67	81.71	76.67	76.58
LU	100	113.47	108.21	109.95	107.85	111.64	109.92	112.45	113.23	106.86	97.95	99.27
NL	100	110.86	107.59	106.20	103.54	105.68	106.26	108.04	110.04	107.33	101.31	104.01
PT	100	73.04	68.55	64.37	60.45	58.82	57.25	56.39	56.08	54.65	52.66	53.05
SE	100	114.96	111.24	112.33	113.21	117.47	116.70	117.78	117.65	112.04	104.03	107.65
UK	100	94.32	92.58	90.77	89.85	89.40	88.01	87.04	85.49	82.43	77.25	77.18
US	100	111.08	109.14	109.50	109.69	111.01	110.43	108.35	107.63	103.71	100.18	104.09

Legend: 1995=100.
Sources: author's calculations from Eurostat, Statec data

Table 10
TFP % yearly growth 2000-2010

Countries	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
AT	3.44	-3.20	2.91	0.29	2.45	-1.16	2.23	0.27	-2.78	-4.89	2.29
BE	4.30	-1.59	2.72	-1.42	0.24	-1.15	0.31	0.24	-3.35	-4.30	3.12
DE	0.76	-0.57	-0.54	-0.10	1.44	2.16	3.33	1.71	-2.19	-6.79	3.66
DK	1.66	-2.69	-0.52	-2.37	1.25	-1.30	-0.42	-1.88	-4.43	-6.07	1.43
ES	-0.63	-2.19	-1.13	-3.14	-2.15	-2.48	-1.36	-1.35	-2.68	0.32	2.36
FI	3.45	-1.83	-0.19	-0.52	3.33	-0.13	1.61	2.36	-2.64	-8.37	4.56
FR	2.66	0.37	0.57	-3.13	0.77	0.56	0.44	0.99	-4.13	-3.38	2.48
GR	-0.90	0.56	-0.47	-0.35	-0.74	-2.51	0.04	-1.06	-2.46	-4.82	-4.94
IE	-0.77	-4.09	-0.95	-2.40	-1.48	-2.69	-1.83	-0.48	-7.05	-2.51	9.16
IT	0.24	-1.52	-4.95	-3.55	-1.70	-2.15	-0.80	-0.85	-3.49	-6.17	-0.11
LU	3.19	-4.64	1.61	-1.91	3.51	-1.54	2.30	0.69	-5.63	-8.34	1.35
NL	2.75	-2.95	-1.30	-2.50	2.06	0.55	1.68	1.85	-2.47	-5.61	2.67
PT	-5.46	-6.14	-6.10	-6.10	-2.69	-2.67	-1.51	-0.55	-2.55	-3.64	0.75
SE	2.58	-3.23	0.98	0.78	3.77	-0.65	0.92	-0.11	-4.77	-7.15	3.47
UK	-0.68	-1.85	-1.95	-1.02	-0.50	-1.56	-1.10	-1.79	-3.58	-6.28	-0.09
US	0.67	-1.75	0.33	0.17	1.21	-0.52	-1.88	-0.66	-3.64	-3.40	3.90

Sources: author's calculations from Eurostat, Statec data

Table 11
Efficiency gains (% yearly growth) 2000-2010

Countries	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
AT	1.91	-1.77	1.75	0.07	0.42	-1.00	3.63	0.20	1.43	-1.46	-3.82
BE	2.66	0.02	1.56	-1.58	-1.72	-1.04	1.84	0.21	0.80	-0.98	-2.94
DE	0.64	2.02	-0.24	0.06	0.27	2.54	5.26	1.75	1.92	-3.98	-1.35
DK	1.59	0.49	-0.54	-1.17	2.01	0.44	0.98	-0.49	-1.02	-1.46	-0.47
ES	-1.58	-0.03	-1.10	-2.72	-2.34	-1.17	0.28	-0.27	1.01	3.48	-3.53
FI	2.48	0.46	0.17	0.05	2.76	1.01	3.39	3.37	0.74	-5.10	0.51
FR	1.53	1.63	-0.21	-3.56	-0.29	1.11	2.39	1.04	-0.12	-0.42	-3.04
GR	-0.06	4.73	-0.32	1.43	1.04	-0.66	1.21	0.47	1.12	0.50	-6.02
IE	0.00	0.00	0.00	0.00	0.00	-0.80	-0.49	0.92	-3.78	1.24	3.04
IT	-0.25	0.72	-4.64	-2.73	-1.31	-0.59	0.74	0.49	-0.13	-2.05	-2.25
LU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NL	1.45	-1.88	-1.38	-2.14	1.26	1.14	3.67	1.97	1.57	-2.49	-1.19
PT	-3.95	-1.71	-4.04	-4.34	-1.96	-0.96	-0.12	1.35	0.95	2.81	1.09
SE	2.51	0.05	0.77	2.84	5.30	1.33	2.21	1.36	-1.35	-2.34	1.95
UK	0.91	2.79	0.20	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00
US	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Sources: author's calculations from Eurostat, Statec data

Table 12
Technical progress (% yearly growth) 2000-2010

Countries	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
AT	1.50	-1.46	1.14	0.22	2.02	-0.16	-1.34	0.07	-4.16	-3.48	6.35
BE	1.59	-1.61	1.15	0.16	2.00	-0.11	-1.50	0.03	-4.12	-3.36	6.25
DE	0.12	-2.54	-0.31	-0.16	1.16	-0.37	-1.83	-0.03	-4.03	-2.92	5.07
DK	0.06	-3.16	0.02	-1.22	-0.75	-1.73	-1.39	-1.40	-3.44	-4.68	1.92
ES	0.96	-2.16	-0.02	-0.43	0.20	-1.32	-1.64	-1.08	-3.65	-3.05	6.11
FI	0.94	-2.29	-0.36	-0.56	0.55	-1.13	-1.72	-0.97	-3.35	-3.45	4.03
FR	1.12	-1.24	0.79	0.45	1.06	-0.54	-1.90	-0.05	-4.02	-2.97	5.69
GR	-0.84	-3.98	-0.15	-1.76	-1.76	-1.86	-1.16	-1.53	-3.54	-5.29	1.15
IE	-0.77	-4.09	-0.95	-2.40	-1.48	-1.91	-1.34	-1.39	-3.40	-3.70	5.94
IT	0.49	-2.22	-0.32	-0.84	-0.39	-1.57	-1.52	-1.33	-3.37	-4.21	2.18
LU	3.19	-4.64	1.61	-1.91	3.51	-1.54	2.30	0.69	-5.63	-8.34	1.35
NL	1.28	-1.09	0.09	-0.37	0.80	-0.58	-1.93	-0.11	-3.97	-3.20	3.90
PT	-1.58	-4.51	-2.15	-1.84	-0.74	-1.73	-1.39	-1.87	-3.46	-6.28	-0.34
SE	0.06	-3.28	0.21	-2.00	-1.46	-1.95	-1.25	-1.45	-3.47	-4.92	1.49
UK	-1.58	-4.51	-2.15	-1.84	-0.50	-1.56	-1.10	-1.79	-3.58	-6.28	-0.09
US	0.67	-1.75	0.33	0.17	1.21	-0.52	-1.88	-0.66	-3.64	-3.40	3.90

Sources: author's calculations from Eurostat, Statec data

B Tables: service industries

Table 13
Services: labour productivity yearly growth (%) 2000-2010

Industry	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
31	-4.92	1.60	-5.82	-0.97	-7.99	-8.11	-3.41	-8.74	-4.49	-8.24	-4.79
32	4.14	4.70	2.40	12.84	3.62	0.59	16.18	9.59	35.20	-10.25	-4.22
33	1.03	-0.59	3.70	-6.62	3.40	-1.34	30.44	28.51	2.18	16.01	17.12
34	-2.58	-0.19	-0.81	-6.22	-2.62	-1.31	-2.34	-0.41	-1.45	-4.97	-5.22
35	4.24	-1.63	-0.12	-3.82	6.75	1.42	3.77	0.21	0.86	-5.17	3.23
36	-10.62	-3.81	-0.26	-5.52	-27.36	-28.60	40.32	-24.67	20.04	-20.84	2.42
37	-0.06	-4.47	0.27	-5.04	11.22	9.54	-7.16	3.10	-7.44	-11.65	7.90
38	-11.87	-7.49	-17.57	-5.92	21.67	-17.83	8.03	-4.01	7.23	-0.78	11.75
39	13.38	8.23	11.02	5.18	4.87	5.40	25.38	16.39	16.24	21.37	-1.00
40	6.99	-0.98	-2.64	0.16	10.93	8.24	11.27	3.84	-5.01	-12.55	3.00
41	-10.98	-11.11	-3.96	-6.73	1.01	11.01	0.51	1.37	4.30	-5.05	12.53
42	8.92	-8.67	-7.54	22.30	18.44	29.32	15.60	3.21	-11.52	-6.77	25.04
43	1.42	3.37	8.78	-5.47	-2.58	-2.63	-8.25	1.99	-2.60	5.44	-1.62
44	25.65	4.01	-11.19	-14.48	8.77	-8.56	23.05	14.40	7.60	36.43	-15.38
45	-1.04	-6.16	-11.39	133.94	41.22	-17.09	-11.84	-20.63	-13.97	-16.91	-0.52
46	-17.31	-8.94	-3.06	-10.17	-11.56	-7.08	-4.74	3.77	-0.92	31.48	-2.41
47	-4.35	12.90	-1.21	12.98	5.93	1.82	4.45	3.31	8.30	-5.87	-0.25
48	1.87	1.33	-1.34	-1.15	0.76	0.17	-0.13	1.35	2.26	-2.05	1.21
49	0.86	-0.49	-2.48	-0.48	-1.12	-1.74	0.86	1.59	0.14	1.57	0.46
50	-3.15	2.53	-1.57	1.53	3.39	-0.80	-0.04	1.50	-2.72	-3.97	-2.47
51	-1.34	-8.03	4.93	-8.77	4.60	1.15	-2.91	-2.62	-33.97	-3.86	-8.77
52	0.14	13.56	-2.60	-10.78	1.95	-7.97	2.05	-0.14	15.78	2.96	0.58
53	-11.26	-6.27	6.45	-8.96	-21.79	5.29	-37.06	-3.00	7.39	-15.75	-3.90
54	2.25	0.67	-3.07	1.04	2.03	-2.37	-0.48	-2.27	15.60	-2.48	-8.43

Sources: author's calculations from Statec data

Table 14
Services: capital deepening (%) 2000-2010

Industry	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
31	-0.40	-0.11	4.87	3.67	8.84	6.32	5.34	3.01	0.77	5.24	0.19
32	0.83	1.86	6.06	8.00	8.70	3.28	9.58	5.34	2.22	6.98	-0.09
33	3.97	2.05	7.40	5.15	5.36	5.76	5.22	3.12	1.31	3.79	0.61
34	3.33	3.66	4.69	3.92	2.39	5.08	2.19	2.14	0.57	2.52	-1.14
35	-4.18	-4.26	-4.34	-2.79	5.91	9.06	-2.68	-2.26	-1.44	3.40	1.99
36	40.31	-12.04	47.95	-20.94	1.78	-25.67	30.52	9.77	124.18	24.63	11.11
37	-3.29	5.97	8.44	-3.34	8.43	-1.10	-9.15	-0.65	-1.17	-2.91	-4.10
38	-3.86	-4.63	10.38	1.94	4.49	0.37	10.48	-0.06	-3.59	6.18	5.72
39	6.14	4.95	4.59	1.80	5.96	4.61	5.55	6.94	2.99	-2.66	0.03
40	0.51	-0.63	3.07	0.68	3.99	-0.35	-3.60	-3.06	7.63	-0.29	-0.99
41	-13.65	-12.05	-3.33	-0.58	-1.03	3.95	-5.70	1.16	-8.99	-7.75	-7.61
42	22.58	4.63	3.22	-3.50	-6.52	-9.30	-16.14	-25.37	-16.72	-11.62	-10.50
43	-4.15	-1.42	3.82	-4.55	0.30	-2.89	-8.15	-1.92	-2.44	10.45	0.52
44	-1.27	38.38	24.85	27.00	29.70	35.60	23.71	15.80	7.73	7.01	-2.52
45	-21.58	-22.34	-7.97	22.23	69.77	49.95	-0.76	-7.81	-12.12	-17.01	-24.88
46	-10.48	-1.73	3.09	-4.48	3.62	-0.52	-0.71	-0.59	0.79	31.93	-12.48
47	-8.29	-2.22	12.12	47.88	4.14	11.29	-4.70	-7.18	-11.75	-1.00	-4.56
48	0.25	2.44	-0.52	-1.02	-0.03	1.21	4.67	2.80	0.74	-1.37	4.17
49	-1.45	-0.89	0.84	4.25	3.24	3.49	3.90	2.13	1.33	0.66	2.93
50	2.80	-1.01	0.63	10.02	8.14	2.26	4.30	4.11	-1.28	-3.53	-2.36
51	-5.63	-3.14	1.75	-0.98	0.13	-1.25	0.56	0.89	0.01	-2.61	-0.81
52	8.81	15.79	27.98	50.98	-8.85	3.63	7.39	4.41	-2.38	-6.00	-5.00
53	-3.39	3.26	-0.73	7.06	2.95	6.95	1.96	-0.95	3.21	-2.89	2.36
54	0.15	0.70	-1.29	1.24	0.46	2.23	0.70	-0.32	0.48	-0.66	-1.22

Sources: author's calculations from Statec data

Table 15
Services: TFP indices 2000-2010 (1995=100)

Industry	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
31	100	91.23	88.90	82.95	62.44	60.26	54.47	52.12	47.67	42.45	38.44	37.19
32	100	97.48	104.39	104.82	101.72	101.86	105.91	106.69	108.69	108.04	95.72	102.55
33	100	101.54	101.59	99.44	87.51	88.06	84.91	69.70	70.84	66.12	65.32	62.62
34	100	94.06	92.69	92.03	86.36	83.95	81.28	76.67	73.19	72.52	69.01	68.15
35	100	110.89	108.56	109.62	104.45	107.36	109.46	110.24	107.93	107.52	102.90	104.66
36	100	78.69	77.32	73.97	83.39	67.52	63.41	59.55	46.57	35.62	31.54	30.60
37	100	83.36	79.60	78.73	78.47	79.84	85.16	81.24	81.55	74.28	75.28	77.72
38	100	96.11	93.25	87.42	79.24	79.27	76.20	74.83	72.03	72.17	62.86	62.30
39	100	115.44	109.20	126.95	123.31	131.93	131.39	126.27	128.98	131.03	142.14	140.64
40	100	110.60	109.05	107.52	109.59	118.29	124.42	131.35	126.08	117.48	102.74	108.42
41	100	107.36	103.02	100.86	95.92	97.86	110.86	124.90	137.11	148.33	141.48	178.50
42	100	70.75	66.72	65.03	72.63	79.98	95.29	110.03	128.33	124.42	126.87	149.57
43	100	91.92	89.08	93.33	82.93	80.39	83.43	82.89	89.77	87.40	81.57	83.87
44	100	111.25	100.76	92.84	87.36	88.96	74.69	78.36	78.89	85.94	98.07	89.53
45	100	91.86	96.10	94.43	115.91	107.34	82.83	85.97	87.84	98.23	93.13	96.22
46	100	85.33	83.75	75.37	72.78	77.89	83.79	85.11	86.10	85.97	80.13	77.98
47	100	95.54	93.25	96.17	90.32	89.45	89.05	91.00	94.83	89.69	92.48	94.68
48	100	102.29	105.99	103.21	102.18	104.57	101.52	104.44	102.13	98.63	98.61	98.87
49	100	91.14	89.09	84.90	80.16	77.12	78.76	75.68	71.84	67.70	62.37	62.78
50	100	88.36	91.16	85.76	83.21	82.17	78.52	78.16	77.46	77.79	74.80	76.57
51	100	108.27	105.20	107.05	104.41	106.49	109.22	103.30	98.53	75.07	69.35	65.90
52	100	88.31	77.66	70.95	55.17	59.78	55.98	56.18	56.82	60.51	59.59	61.00
53	100	83.83	83.66	81.00	79.92	75.20	76.92	71.36	69.75	66.61	62.88	63.19
54	100	97.80	95.91	93.96	93.06	89.70	90.66	87.02	83.96	72.82	75.29	80.23

Sources: author's calculations from Statec data

Table 16
Services: TFP yearly growth (%) 2000-2010

Industry	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
31	-0.94	-2.56	-6.69	-24.73	-3.49	-9.62	-4.31	-8.53	-10.96	-9.44	-3.25
32	-0.75	7.09	0.42	-2.95	0.13	3.97	0.74	1.88	-0.60	-11.40	7.13
33	5.98	0.05	-2.12	-12.00	0.63	-3.58	-17.91	1.63	-6.66	-1.22	-4.12
34	-1.35	-1.45	-0.71	-6.16	-2.79	-3.18	-5.67	-4.54	-0.92	-4.84	-1.24
35	2.75	-2.09	0.97	-4.72	2.79	1.95	0.72	-2.09	-0.38	-4.29	1.71
36	-15.81	-1.74	-4.33	12.73	-19.04	-6.09	-6.08	-21.80	-23.52	-11.45	-3.00
37	-0.85	-4.51	-1.10	-0.32	1.74	6.67	-4.60	0.38	-8.92	1.35	3.24
38	3.59	-2.98	-6.25	-9.35	0.05	-3.88	-1.80	-3.74	0.20	-12.90	-0.90
39	13.27	-5.41	16.26	-2.87	6.99	-0.41	-3.90	2.15	1.59	8.48	-1.05
40	2.71	-1.40	-1.41	1.93	7.94	5.18	5.57	-4.01	-6.82	-12.55	5.53
41	-6.27	-4.04	-2.10	-4.90	2.02	13.29	12.66	9.78	8.18	-4.62	26.17
42	-6.99	-5.70	-2.53	11.69	10.11	19.15	15.47	16.63	-3.05	1.97	17.89
43	16.25	-3.09	4.77	-11.15	-3.06	3.78	-0.65	8.29	-2.63	-6.67	2.82
44	24.11	-9.43	-7.86	-5.90	1.83	-16.05	4.92	0.68	8.93	14.11	-8.70
45	1.08	4.61	-1.73	22.75	-7.40	-22.83	3.79	2.17	11.84	-5.20	3.32
46	-5.32	-1.85	-10.01	-3.43	7.02	7.57	1.58	1.17	-0.16	-6.78	-2.69
47	2.38	-2.39	3.13	-6.08	-0.96	-0.45	2.20	4.21	-5.43	3.12	2.38
48	-3.93	3.62	-2.62	-0.99	2.34	-2.92	2.87	-2.21	-3.43	-0.02	0.27
49	2.65	-2.24	-4.71	-5.58	-3.79	2.13	-3.91	-5.08	-5.76	-7.88	0.67
50	-7.88	3.16	-5.91	-2.98	-1.25	-4.44	-0.46	-0.90	0.43	-3.84	2.36
51	2.93	-2.83	1.76	-2.47	2.00	2.57	-5.42	-4.62	-23.82	-7.62	-4.97
52	-5.21	-12.06	-8.64	-22.24	8.36	-6.36	0.36	1.14	6.50	-1.52	2.37
53	-12.11	-0.20	-3.18	-1.33	-5.91	2.29	-7.23	-2.26	-4.50	-5.61	0.51
54	0.79	-1.93	-2.03	-0.96	-3.61	1.07	-4.01	-3.52	-13.26	3.39	6.55

Sources: author's calculations from Statec data

Table 17
Services: technical progress (% yearly growth) 2000-2010

Industry	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
31	-0.94	-2.56	-6.69	-5.70	-0.04	1.19	0.17	1.60	-4.66	-0.80	6.51
32	6.08	-6.94	-5.19	-3.62	0.13	3.97	0.74	1.88	3.34	-3.52	23.92
33	0.01	-3.28	-6.38	-7.94	-2.63	0.26	-0.11	2.04	-0.68	-1.72	20.14
34	4.88	-5.94	-7.36	-4.99	-0.37	0.87	-0.29	1.34	-3.51	-0.88	5.85
35	12.24	-7.53	-6.19	-5.10	0.70	0.38	-1.73	0.59	-3.25	3.08	5.10
36	20.03	-2.63	-5.27	-0.46	2.68	-0.66	-2.37	-1.30	1.58	12.03	-3.04
37	13.30	-2.16	-4.85	4.33	2.35	0.73	1.37	5.00	1.75	2.70	13.75
38	15.07	-8.21	-5.87	-4.76	0.64	0.10	-2.35	-0.19	-3.09	5.04	4.81
39	13.27	-5.41	16.26	-2.87	6.99	-0.41	-3.90	2.15	1.59	8.48	-1.05
40	-2.39	-1.40	-1.41	1.93	7.94	15.04	1.65	-1.02	-8.86	-6.77	20.64
41	-6.27	-4.04	-2.10	4.13	16.20	0.73	1.60	9.78	8.18	-4.62	26.17
42	-6.99	-5.70	-2.53	11.69	10.11	19.15	15.47	16.63	-3.05	1.97	17.89
43	16.25	-3.09	4.77	-11.15	-3.06	3.78	-0.65	8.29	-2.63	-6.67	2.82
44	24.11	-9.43	-7.86	-5.90	1.83	-1.97	-10.15	0.68	8.93	14.11	-8.70
45	1.08	4.61	-1.73	22.75	-7.40	15.44	0.25	9.37	4.71	-3.49	27.11
46	7.23	-7.07	-5.21	-3.78	0.26	1.72	-0.01	1.56	-3.60	-0.26	10.78
47	2.38	-2.39	3.13	-6.08	-0.96	-0.45	2.20	4.21	-5.43	3.12	8.83
48	10.56	-4.00	10.28	-6.67	4.09	-0.34	-5.95	0.35	5.84	1.13	-2.43
49	2.65	-2.24	-4.71	-5.58	-3.79	2.13	-3.91	-5.08	-5.76	-7.88	0.67
50	0.60	-2.79	-5.96	-6.99	-2.84	-0.28	-1.32	-0.11	-3.69	-3.84	3.39
51	12.64	-5.04	14.77	-6.90	6.26	-1.26	-7.80	-0.34	6.64	1.30	-2.80
52	0.83	-2.52	-5.49	-4.63	-1.91	-0.93	-2.03	-1.30	-3.24	-2.37	2.13
53	17.50	-4.23	-10.81	-5.15	-0.66	0.16	-1.47	-1.34	-2.71	10.27	-3.05
54	0.69	-2.71	-5.86	-7.36	-2.82	-0.28	-1.25	0.14	-4.96	-1.89	4.79

Sources: author's calculations from Statec data

Table 18
Services: efficiency gains (% yearly growth) 2000-2010

Industry	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
31	0.00	0.00	0.00	-20.18	-3.44	-10.68	-4.47	-9.98	-6.61	-8.70	-9.17
32	-6.44	15.08	5.92	0.69	0.00	0.00	0.00	0.00	-3.82	-8.17	-13.55
33	5.97	3.44	4.55	-4.40	3.35	-3.83	-17.81	-0.40	-6.02	0.51	-20.19
34	-5.94	4.77	7.18	-1.23	-2.44	-4.02	-5.40	-5.80	2.69	-4.00	-6.70
35	-8.45	5.88	7.63	0.40	2.08	1.56	2.49	-2.66	2.97	-7.15	-3.23
36	-29.86	0.92	0.99	13.25	-21.15	-5.46	-3.79	-20.77	-24.71	-20.96	0.04
37	-12.49	-2.40	3.94	-4.46	-0.60	5.90	-5.89	-4.40	-10.49	-1.31	-9.25
38	-9.98	5.70	-0.41	-4.83	-0.59	-3.97	0.56	-3.57	3.40	-17.08	-5.45
39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	5.22	0.00	0.00	0.00	0.00	-8.57	3.85	-3.02	2.24	-6.20	-12.53
41	0.00	0.00	0.00	-8.67	-12.21	12.48	10.89	0.00	0.00	0.00	0.00
42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44	0.00	0.00	0.00	0.00	0.00	-14.36	16.76	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00	-33.15	3.53	-6.58	6.81	-1.77	-18.71
46	-11.70	5.62	-5.06	0.36	6.74	5.75	1.59	-0.39	3.57	-6.54	-12.16
47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-5.93
48	-13.11	7.94	-11.70	6.08	-1.68	-2.59	9.38	-2.54	-8.76	-1.14	2.77
49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	-8.43	6.12	0.05	4.32	1.64	-4.17	0.87	-0.79	4.27	0.00	-1.00
51	-8.62	2.32	-11.34	4.75	-4.01	3.88	2.58	-4.29	-28.56	-8.81	-2.24
52	-5.99	-9.78	-3.33	-18.47	10.47	-5.48	2.44	2.47	10.07	0.87	0.23
53	-25.20	4.21	8.55	4.02	-5.28	2.13	-5.84	-0.93	-1.84	-14.40	3.66
54	0.10	0.80	4.06	6.91	-0.81	1.36	-2.80	-3.65	-8.73	5.38	1.68

Sources: author's calculations from Statec data

C Tables: manufaturing industries

Table 19
Manufacturing: labour productivity yearly growth (%) 2000-2010

Industry	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
8	6.03	-1.67	0.50	-15.41	-2.39	-10.15	17.29	7.04	-9.09	-5.65	-4.74
9	4.67	0.00	-0.17	-4.09	3.31	5.88	-11.55	-1.01	1.76	-2.94	-5.17
10	18.37	-1.49	-27.91	-1.10	14.91	-9.24	0.26	-2.10	-2.46	-33.91	35.31
11	-5.18	19.62	33.50	4.40	-3.11	-41.03	6.91	6.68	4.19	9.39	6.26
13	-2.39	-6.06	3.44	6.35	13.58	-3.32	1.59	-1.69	-14.91	1.06	11.54
14	-3.05	6.60	2.12	2.48	17.45	-1.38	-4.39	3.73	6.04	33.32	-40.01
16	8.33	10.49	19.53	-0.16	-7.76	0.69	24.58	28.81	-11.89	-18.70	33.83
17	36.56	4.03	1.58	-8.38	9.14	8.92	5.35	5.97	-8.89	-35.14	28.82
18	5.29	2.67	-6.19	-3.39	14.56	3.99	1.63	1.58	-0.16	-12.60	3.45
19	3.86	-2.73	7.77	1.88	10.84	-8.66	14.81	2.42	4.58	-29.53	4.32
20	2.01	-12.36	2.17	-7.05	5.94	-25.62	26.00	-5.83	-16.17	-21.38	10.13
21	0.79	2.76	0.45	-4.38	-3.80	-2.68	8.07	8.89	-11.08	-16.76	25.41
22	44.33	-16.66	-38.32	6.54	-43.35	54.92	55.86	105.46	19.84	-11.36	17.64
23	4.03	21.90	-15.84	5.84	7.94	-2.81	31.52	7.29	10.69	-5.88	-9.58
24	5.72	1.59	1.02	-7.31	142.76	16.35	-32.12	9.09	-29.88	-21.10	39.58
25	-6.46	-1.03	5.15	12.63	15.17	12.67	13.68	30.84	10.56	-36.58	-10.44
26	10.98	-11.75	-22.56	3.54	-0.73	4.46	-6.18	-3.08	2.04	-5.82	-2.92
27	-7.75	-6.91	-11.53	17.72	12.07	13.20	-5.92	-11.93	3.33	-18.10	2.95
28	9.69	31.00	10.33	-4.37	19.35	16.11	-3.82	10.84	-3.12	-27.28	1.41
29	-12.09	-3.85	13.89	-0.73	-3.36	-15.55	4.65	23.31	5.49	-9.36	-9.56
30	5.06	0.02	5.56	-5.74	-3.58	-0.86	-0.76	3.77	2.38	0.02	-2.31

Sources: author's calculations from Statec data.

Table 20
Manufacturing: capital deepening (%) 2000-2010

Industry	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
8	-0.97	4.36	-0.14	-1.10	2.17	3.30	4.74	1.03	3.15	10.33	11.38
9	5.12	-1.56	-1.73	-2.51	-0.34	2.51	2.36	6.01	4.87	1.81	1.18
10	22.51	3.25	-35.92	-3.93	12.85	-10.86	-1.54	-2.42	2.80	-18.60	6.59
11	3.83	-11.94	-4.59	-1.71	-4.74	4.67	1.33	-1.73	-12.90	-4.75	-3.93
13	-2.07	9.72	1.53	-12.43	1.24	0.63	4.55	-1.44	-4.16	5.33	4.64
14	0.08	6.86	10.80	6.05	2.53	4.83	-0.73	10.92	1.92	37.95	-21.52
16	-5.82	1.65	3.68	-5.56	2.38	9.41	27.33	29.85	-6.64	18.86	-5.67
17	12.06	0.20	4.89	-15.23	0.21	1.67	5.82	7.13	4.10	-17.94	13.79
18	-0.83	5.64	12.59	9.59	5.52	6.28	4.58	12.94	2.21	4.87	8.03
19	-1.65	-1.12	5.90	-4.68	6.08	5.43	2.90	4.48	2.14	9.04	-6.91
20	-9.95	-3.32	2.57	-3.85	-0.97	0.40	-1.13	-2.41	-2.79	5.31	-1.62
21	-5.09	2.63	9.05	-3.88	-0.48	3.12	1.05	0.31	-2.38	-0.29	7.31
22	-4.35	6.08	-20.37	301.01	-54.67	15.40	-20.01	-50.25	-8.40	-14.83	-14.79
23	-5.14	4.25	-7.91	-2.80	-3.43	1.54	2.10	-1.03	1.21	1.06	1.03
24	0.37	-1.56	7.51	-4.17	-5.12	4.75	8.36	1.86	1.65	2.29	-4.98
25	-3.32	6.20	2.58	-10.55	-11.62	-2.25	-2.64	-6.34	-6.94	-2.84	-0.16
26	16.49	-10.36	-11.04	188.40	2.91	1.84	-8.20	-4.47	0.82	7.06	-3.27
27	6.06	12.29	14.38	-4.53	3.48	-0.50	-1.09	-5.19	-7.25	2.24	9.82
28	5.98	3.96	-0.01	5.09	5.64	3.19	-3.15	2.37	2.21	7.58	-4.24
29	2.13	-1.01	16.03	2.65	0.27	-0.12	3.77	3.21	7.68	-5.10	-0.22
30	-2.61	-3.62	-3.16	-4.02	-0.26	-0.34	-1.61	-2.27	-2.33	6.28	3.79

Sources: author's calculations from Statec data

Table 21
Manufacturing: TFP indices 2000-2010 (1995=100)

Industry	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
8	100	107,22	92,93	96,87	95,25	92,95	91,24	92,00	89,96	81,33	80,90	79,51
9	100	93.62	91.12	92.24	91.23	92.76	95.62	90.99	87.87	80.22	81.75	79.06
10	100	122.81	119.23	105.06	104.53	113.21	108.47	108.76	109.81	105.93	77.04	102.85
11	100	61.03	65.48	83.61	76.86	70.85	81.22	87.86	90.73	95.96	61.38	62.46
13	100	123.80	121.65	130.11	122.71	127.36	124.23	117.54	111.18	103.74	106.59	116.40
14	100	90.85	87.90	87.79	84.99	86.03	84.29	82.64	82.70	84.11	92.38	72.15
16	100	101.57	103.33	110.04	106.39	104.42	101.62	107.36	117.25	114.74	98.51	125.62
17	100	106.80	104.55	109.03	104.48	101.48	105.90	103.22	106.41	99.61	95.67	106.47
18	100	102.82	99.56	93.12	91.66	99.99	103.46	103.72	101.94	97.71	94.03	93.83
19	100	120.72	117.37	116.97	124.40	117.56	117.64	107.21	118.96	116.77	86.11	89.91
20	100	128.70	116.24	120.08	112.00	119.07	103.67	119.24	114.90	110.85	114.20	117.73
21	100	105.77	107.76	105.10	100.34	101.33	104.26	109.04	111.82	105.25	102.75	102.60
22	100	135.81	136.09	118.98	94.91	122.81	176.25	140.70	217.63	208.52	201.93	237.82
23	100	91.10	91.06	85.73	87.12	91.00	90.11	84.44	88.90	95.19	93.98	89.93
24	100	118.59	116.42	119.52	114.95	133.39	147.38	113.75	118.30	99.16	91.19	92.21
25	100	109.85	104.85	108.81	129.06	132.64	142.52	136.24	175.58	188.61	172.40	171.76
26	100	110.10	103.21	84.80	93.23	96.23	98.12	90.59	101.91	98.24	96.28	93.39
27	100	113.51	112.63	122.26	115.79	120.02	133.58	126.51	114.80	119.63	168.12	155.55
28	100	107.19	110.29	109.08	108.87	116.80	121.68	120.50	118.09	108.73	107.40	105.66
29	100	99.82	97.80	98.19	108.32	105.07	86.22	88.14	88.16	80.12	75.85	56.98
30	100	112.86	114.69	120.13	116.79	116.07	117.26	117.80	122.94	128.72	121.22	120.17

Sources: author's calculations from Statec data

Table 22
Manufacturing: TFP % yearly growth 2000-2010

Industry	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
8	8.11	-13.32	4.24	-1.67	-2.41	-1.84	0.83	-2.22	-9.60	-0.52	-1.72
9	-4.56	-2.67	1.22	-1.09	1.67	3.08	-4.83	-3.44	-8.71	1.91	-3.29
10	7.94	-2.92	-11.88	-0.50	8.30	-4.19	0.27	0.97	-3.53	-27.28	33.51
11	-1.86	7.30	27.69	-8.07	-7.81	14.64	8.17	3.27	5.77	-36.04	1.77
13	5.50	-1.74	6.96	-5.69	3.79	-2.45	-5.39	-5.41	-6.69	2.74	9.21
14	1.41	-3.25	-0.13	-3.18	1.22	-2.02	-1.96	0.08	1.69	9.84	-21.90
16	-2.66	1.74	6.49	-3.32	-1.85	-2.68	5.65	9.21	-2.14	-14.15	27.52
17	3.97	-2.11	4.29	-4.18	-2.87	4.36	-2.52	3.09	-6.40	-3.95	11.29
18	-1.11	-3.18	-6.47	-1.57	9.09	3.47	0.24	-1.71	-4.15	-3.77	-0.21
19	1.96	-2.77	-0.34	6.35	-5.50	0.07	-8.86	10.95	-1.84	-26.26	4.42
20	10.37	-9.68	3.30	-6.73	6.32	-12.93	15.01	-3.64	-3.52	3.02	3.09
21	2.72	1.89	-2.47	-4.53	0.98	2.90	4.58	2.55	-5.87	-2.38	-0.15
22	9.20	0.21	-12.58	-20.22	29.39	43.52	-20.17	54.68	-4.19	-3.16	17.77
23	-6.17	-0.04	-5.85	1.62	4.46	-0.98	-6.29	5.28	7.07	-1.27	-4.31
24	6.65	-1.83	2.66	-3.82	16.05	10.48	-22.81	4.00	-16.18	-8.04	1.12
25	2.96	-4.55	3.77	18.61	2.77	7.45	-4.40	28.87	7.42	-8.59	-0.37
26	11.79	-6.26	-17.83	9.94	3.22	1.96	-7.68	12.50	-3.60	-1.99	-3.01
27	2.46	-0.77	8.55	-5.29	3.65	11.31	-5.30	-9.25	4.21	40.53	-7.48
28	4.49	2.90	-1.10	-0.20	7.29	4.17	-0.97	-2.00	-7.93	-1.23	-1.62
29	8.72	-2.02	0.41	10.31	-3.00	-17.94	2.23	0.02	-9.12	-5.32	-24.88
30	2.81	1.62	4.74	-2.78	-0.62	1.03	0.46	4.36	4.70	-5.82	-0.87

Sources: author's calculations from Statec data

Table 23
Manufacturing: technical progress (% yearly growth) 2000-2010

Industry	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
8	7.63	-10.07	0.67	-0.60	3.49	8.19	-5.76	44.68	-27.20	14.64	-1.10
9	2.26	-6.01	0.61	1.32	5.11	6.43	-5.95	46.29	-27.76	12.68	-2.19
10	7.94	-2.92	-11.88	-0.50	8.30	-4.19	0.27	0.97	-3.53	-21.00	22.91
11	2.21	-6.49	11.01	-2.18	-1.51	18.10	-12.42	9.90	-0.62	24.91	-8.22
13	6.94	-5.98	-0.03	-2.15	2.45	1.19	-1.79	11.78	-1.87	-9.13	18.51
14	2.06	-6.51	0.46	0.58	3.43	4.14	-2.93	43.30	-18.73	0.61	6.96
16	6.92	-6.15	-0.55	-2.59	2.42	1.30	-1.48	4.29	-2.14	-12.13	24.59
17	7.00	-9.22	0.93	-1.52	3.17	3.80	-2.75	29.15	-8.94	9.94	-0.32
18	2.12	-6.24	0.12	-0.70	3.27	5.76	-3.94	41.66	-20.59	11.52	-0.32
19	6.87	-5.69	-0.55	-2.36	2.34	0.78	-1.38	7.42	-1.84	-18.77	26.92
20	2.00	-2.54	1.35	-2.35	2.36	3.90	0.09	35.87	-24.14	11.46	-2.11
21	2.80	-2.35	0.02	-2.04	3.11	3.72	-2.43	37.61	-14.09	9.16	-0.08
22	4.46	-7.86	3.18	1.79	-1.37	25.02	-14.89	45.08	-4.19	-3.16	17.77
23	2.90	-7.68	3.43	4.48	4.85	5.96	-4.69	34.66	-11.46	7.50	-0.48
24	3.58	-8.76	5.22	5.83	1.97	10.48	-6.64	33.87	-18.60	10.92	-1.18
25	3.59	-8.49	5.03	5.94	2.77	7.45	-4.40	28.87	12.35	5.70	-0.40
26	1.93	-5.75	2.84	-0.10	-1.47	14.88	-13.35	31.02	-21.35	44.08	-9.76
27	6.87	-8.47	8.55	-2.10	2.61	8.77	-5.30	37.85	-27.04	32.13	-7.48
28	4.49	2.90	-1.10	-0.20	7.29	4.17	-0.97	-2.00	-7.93	-1.23	-1.62
29	8.72	-2.02	0.41	10.31	-3.00	-17.94	2.23	0.02	-9.12	15.36	-8.20
30	2.81	1.62	4.74	-2.78	-0.62	1.03	0.46	4.36	4.70	3.85	5.07

Sources: author's calculations from Statec data

Table 24
Manufacturing: efficiency gains (% yearly growth) 2000-2010

Industry	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
8	0.44	-3.62	3.55	-1.08	-5.71	-9.27	6.99	-32.41	24.18	-13.23	-0.62
9	-6.67	3.56	0.61	-2.38	-3.27	-3.15	1.18	-33.99	26.38	-9.56	-1.13
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-7.95	8.63
11	-3.98	14.74	15.02	-6.02	-6.40	-2.93	23.51	-6.03	6.42	-48.79	10.89
13	-1.34	4.51	6.99	-3.62	1.31	-3.60	-3.66	-15.37	-4.91	13.06	-7.85
14	-0.64	3.49	-0.59	-3.74	-2.14	-5.91	1.00	-30.16	25.13	9.18	-26.99
16	-8.96	8.40	7.08	-0.74	-4.17	-3.93	7.23	4.72	0.00	-2.30	2.35
17	-2.83	7.83	3.33	-2.70	-5.86	0.53	0.23	-20.18	2.79	-12.64	11.65
18	-3.16	3.27	-6.58	-0.87	5.63	-2.17	4.36	-30.62	20.70	-13.71	0.11
19	-4.59	3.09	0.21	8.92	-7.66	-0.71	-7.59	3.29	0.00	-9.21	-17.73
20	8.20	-7.33	1.92	-4.48	3.87	-16.20	14.91	-29.08	27.18	-7.57	5.31
21	-0.08	4.34	-2.50	-2.54	-2.07	-0.79	7.19	-25.48	9.56	-10.57	-0.07
22	4.53	8.75	-15.27	-21.63	31.19	14.79	-6.21	6.62	0.00	0.00	0.00
23	-8.82	8.27	-8.98	-2.74	-0.38	-6.55	-1.68	-21.82	20.93	-8.16	-3.85
24	2.97	7.59	-2.43	-9.12	13.80	0.00	-17.32	-22.31	2.97	-17.09	2.33
25	-0.61	4.31	-1.20	11.96	0.00	0.00	0.00	0.00	-4.38	-13.52	0.03
26	9.67	-0.54	-20.10	10.05	4.76	-11.24	6.54	-14.14	22.56	-31.97	7.48
27	-4.13	8.41	0.00	-3.26	1.01	2.33	0.00	-34.17	42.82	6.36	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-17.93	-18.18
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-9.31	-5.65

Sources: author's calculations from Statec data

D Tables: legend

Table 25
Country codes

Code	Country name
AT	Austria
BE	Belgium
DE	Germany
DK	Denmark
ES	Spain
FI	Finland
FR	France
GR	Greece
IE	Ireland
IT	Italy
LU	Luxembourg
NL	Netherlands
PT	Portugal
SE	Sweden
UK	United Kingdom
US	United States
EU15	European Union (15 countries)

Table 26
Manufacturing industries: codes and shares on manufacturing total output and employment

Code	Industry name	Output Share (%)	Employment share (%)
8	Other mining and quarrying	0.40	0.41
9	Food products	5.10	6.75
10	Textiles	5.36	2.03
11	Clothing	0.02	0.05
13	Wood & wood products	1.47	0.80
14	Paper & printing	3.39	3.22
16	Chemicals	3.05	0.98
17	Rubber & plastics	8.10	6.30
18	Non-metal mineral products	4.20	3.29
19	Metals	12.95	7.66
20	Fabricated metals	5.13	6.49
21	Machinery & equipment	4.97	3.71
22	Office machinery & TC equip.	0.45	0.19
23	Machinery & electrical equip.	0.91	0.94
24	Medical, precision & optical	2.51	2.60
25	Transport equipment	0.76	0.80
26	Furniture	0.18	0.38
27	Recycling	0.41	0.45
28	Electricity & gas	5.82	1.86
29	Water distribution & purification	0.37	0.55
30	Construction	34.46	50.55

Output and employment shares are percentage shares over totals for manufacturing.
Data refer to 2010.
Sources: author's calculations from Statec data

Table 27
Service industries: codes and shares on services total output and employment

Code	Industry name	Output Share (%)	Employment share (%)
31	Motor vehicles retail & repair	0.51	3.27
32	Wholesale	4.92	5.75
33	Retail	3.50	7.68
34	Hotels & restaurants	1.13	6.14
35	Land transports, storage	1.98	5.74
36	Water transports	0.03	0.07
37	Air transports	1.82	1.50
38	Transport services	0.43	1.33
39	PT & Telecommunications	6.30	1.86
40	Financial intermediation	39.17	10.77
41	Insurance	3.87	1.21
42	Activities auxiliaries to financial intermediation and insurance	15.78	3.16
43	Real estates activities	4.54	1.41
44	Renting & leasing	0.74	0.34
45	IT services	1.57	2.93
46	R&D	0.38	0.92
47	Business services	5.32	17.04
48	Public administration	2.79	6.75
49	Education	1.52	6.04
50	Health & social work	2.51	11.19
51	Sanitation, road & waste	0.15	0.67
52	Associations	0.18	0.85
53	Recreational & cultural activities	0.66	1.81
54	Services to individuals	0.20	1.56

Output and employment shares are percentage shares over totals for services.
Data refer to 2010.
Sources: author's calculations from Statec data

E Technical section

This section briefly outlines some key methodological concepts and ideas underlying the empirical results of this LuxKlems report. The method used here to evaluate key indicators of the Luxembourg's economy, such as Total Factor Productivity (TFP), labour productivity and capital intensity, is non-parametric. This permits to avoid assumptions on the form of the production function and on structure of the economy which are often not realistic, and to better adapt the analysis to the specific structure of the Luxembourgish economy. This approach, which offers an alternative to the growth accounting framework, nicely integrates index number theory, often employed by statistical offices to measure productivity, with measures of input/output efficiency expressed in terms of distance functions.

In general terms, the concept of productivity refers to the ability of an economy to convert inputs into outputs (Mawson *et al.*, 2003). Among measures of productivity, Total Factor Productvity (TFP) considers aggregate output and aggregate inputs (see Hulten, 2002). TFP is a useful indicator of the performance of an economy (or firms, industries, etc.) for several reasons:

1. it allows researchers to compute measures of operating efficiency, that is, to quantify the gap between the actual level of output and the level of output permitted by the existing technology;

2. it provides a measure of the economic role of factors others than capital and labour, such as intangible inputs (for example, social and human capital), and technical progress and innovation, whose importance is increasingly recognised by economists and policy makers alike.

The measurement of TFP is often performed in the context of the growth accounting framework based on the Solow model (Solow, 1957). This requires the specification of a production function which defines the level of output obtainable given available inputs and technology. A specific example of production function, the Cobb-Douglas is widely used in the literature and is adopted here *for ease of illustration*:

$$Q_t(K_t, L_t) = A_t K_t^{\alpha} L_t^{1-\alpha}; \qquad (1)$$

Here, Q, L, K denote, respectively, output, labour, and capital at time t; A is a factor that changes over time; the parameter α measures the elasticity of output with respect to capital.[27] One should note that this Cobb-Douglas function defines a Constant Return to Scale (CRS) technology, one for which changes in *all* inputs lead to a proportional change in output.[28] The rate of growth of the economy, g, is obtained by considering how equation (1) changes with respect to time. This leads to the following equation:

$$g = \frac{\Delta Q}{Q} = \frac{\Delta A}{A} + \alpha \frac{\Delta K}{K} + (1-\alpha)\frac{\Delta L}{L}; \qquad (2)$$

Thus, economic growth can be decomposed into the change in A and the changes in labour and capital input. In this framework, the TFP compares total output to total inputs:

$$TFP = Q / (K^{\alpha} L^{1-\alpha}); \qquad (3)$$

[27] α is a measure of the share of capital input on output, and can be written as $\alpha = f_k \frac{K}{Q}$, where $Q = f(K, L)$ denotes the production function and f_k the marginal productivity of capital. Similarly, one can show that $(1-\alpha)$ represents the elasticity of output with respect to labour input.

[28] Mathematically, the CRS assumption corresponds to homogeneity of degree 1 in the production function. One can show this as follows: $Q_t(\lambda K_t, \lambda L_t) = A_t(\lambda K)_t^{\alpha}(\lambda L)_t^{1-\alpha} = \lambda\left[A_t K_t^{\alpha} L_t^{1-\alpha}\right] = \lambda Q_t(K_t, L_t)$; thus, when all inputs are multiplied by a factor λ, output is also increased by λ.

From equation (3) one derives the rate of growth of the TFP, in an analogous manner to equation (1). TFP growth gives the difference between changes in output and changes in measured inputs:

$$\frac{\Delta TFP}{TFP} = \frac{\Delta Q}{Q} - \alpha \frac{\Delta K}{K} + (1-\alpha)\frac{\Delta L}{L}; \qquad (4)$$

The rate of growth of the TFP is thus that part of economic growth which does not stem directly from changes in input utilisation. Comparing equation (4) to equation (2), one can see that the rate of growth of A is equivalent to TFP growth, which offers an interpretation for A in terms of technological progress. One should note, however, that there is no agreement in the literature on the interpretation of A, which is often referred to as the "Solow residual".[29]

The preceding growth accounting framework is based on two crucial assumptions on the structure of the economy: 1) Constant Return to Scale (CRS), and 2) Perfect Competition.[30] These assumptions have been called into question by an ever-growing theoretical and empirical literature. (One could argue that, in the last 40 years, developments in the economic analysis have been devoted to the study of departures from the paradigm defined by the above assumptions.) There is also some evidence that the assumption of perfect competition is untenable for the economy of Luxembourg (DiMaria, 2008; Peroni and Ferreira, 2011).

The need of measures of production more general than the parametric production functions used in the growth accounting framework is also widely recognised. Carlaw and Lipsey (2004) summarise some of the difficulties with an approach to measure productivity based on production functions: 1) the approach requires a time invariant production function 2) the aggregation of production functions over units, in order to produce an economy-wide measure, depends crucially on the perfect competition assumption. The problem of the existence of an aggregate production function, and its consequences on the validity the Solow's model and the neo-classical growth accounting framework, is discussed at length in Felipe and Fisher (2003), Felipe and McCombie (2005) and Felipe and McCombie (2007).

This motivates the use of the alternative methodology based on production frontiers and distance measures, which makes TFP computations more robust to the validity of economic hypothesis such as CRS and perfect competition. This is because no assumptions on the form of the production function are made when specifying the technology and the productivity measure. As a result, computations rely only on the data available and do not require the econometric estimation of the parameters of a production function. The application of the method of production frontier is critically and comparatively assessed in DiMaria and Ciccone (2006a).

Section E.1 presents a general setting based on production sets, which allows an alternative representation of technology and production outcomes. Section E.2 shows how this setting is applied to the derive productivity indices. Finally, Section E.4 gives some practical examples to clarify the theory outlined in the first two section.

[29] One can see, for example, Carlaw and Lipsey (2004). These authors give an account of the debate on productivity measurement, and offer an interesting interpretation of TFP.

[30] Notice that the assumption of perfect competition implies that inputs earn their marginal productivity. In practical implementation of growth accounting, this permits to avoid the estimation of the parameters α (and $1-\alpha$) which can be measured instead using data on the share of capital on income.

E.1 The distance function approach

This section presents an approach to measure the efficiency of economic units based on the concepts of production sets and of *distance function*. It starts by defining technology in terms of feasible input/output sets. (This contrasts to the growth accounting framework, which uses parametric production functions based on specific assumptions on agents economic behaviour and on the structure of the economy.) Then, it introduces the concept of distance function, and shows how it can be applied to study the *relative* efficiency of economic units. This is based on the seminal work of Farrell (1957), which introduced the concept of productive efficiency.

In what follows, the units object of the analysis (firms, sectors, etc.) are referred to as Decision Making Units (DMUs). We also assume that such DMUs produce a single output, denoted by y, using a vector of input $\mathbf{x} \in R_+^N$. (This can be generalised to the case where output is a vector rather than a scalar.)

The production possibility set in period t, S_t, describes all feasible input/output vectors as follows:

$$S_t = \{(\mathbf{x}_t, y_t) : \mathbf{x}_t \; can \; produce \; y_t\}; \qquad (5)$$

Here, the set S represents all feasible input/output vectors $(\mathbf{x}, y)$ such that using $\mathbf{x}$ one can produce y. The boundary of S gives the maximum output obtainable from a given amount of inputs using the available technology. This boundary is usually referred to as the *production frontier*. DMUs operating on the frontier are said to be efficient because they make full use of the inputs. As a result, we can define an output distance function, defined on $\mathbf{x}$ and y, which describes all DMUs operating in the economy/sector in terms of their *relative* position to the frontier, as follows:

$$D^t(\mathbf{x}_t, y_t) = inf\{\theta : (x_t, \frac{y_t}{\theta}) \in S_t, \theta \geq 0\}; \qquad (6)$$

The distance function D gives the *infimum* of the set of real numbers θ, where θ is such that the input/output combination $(\mathbf{x}_t, y_t)$ belongs to the production possibility set S. This *infimum* is the lowest bound of the set θ. Perhaps it is easier to think at D as the reciprocal of the largest factor by which one should increase output in order to reach the production frontier, given the vector of input $\mathbf{x}$. (Figure 1 in Section E.4 present a graphical example of the production set and frontier for a constant return to scale, single output/single input unit.) The distance function D takes the value of 1 for those DMUs on the boundary of S, so that $D^t(\mathbf{x}_t, y_t^*) = 1$, where y_t^* denotes optimal output; conversely, D is less than 1 for those DMUs below the frontier. Larger values of D are associated to units closer to the frontier. [31]

The following presents two distance functions which will be used in the next section to derive the measure of productivity change. These are, respectively, the distance function in period $t+1$ based on the technology available in t, and the distance function in t based on the technology available in $t+1$:

$$D^t(\mathbf{x}_{t+1}, y_{t+1}) = inf\{\theta : (\mathbf{x}_{t+1}, \frac{y_{t+1}}{\theta}) \in S_t, \theta \geq 0\}, \qquad (7)$$

$$D^{t+1}(\mathbf{x}_t, y_t) = inf\{\theta : (\mathbf{x}_t, \frac{y_t}{\theta}) \in S_{t+1}, \theta \geq 0\}; \qquad (8)$$

[31] DiMaria and Ciccone (2006a) introduce the distance function approach adopted in the drafting of the LuxKlems report. Fare *et al.* (1994a) give an extensive presentation of this approach. One can also see Mawson *et al.* (2003), who give a clear and accessible outline of alternative methods for the measurement of productivity. Deaton (1979) presents a synthesis of the use of distance functions in economic theory with an application to consumption behaviour; interestingly, this author points out that distance functions can be viewed as index numbers.

One can see that $D^t(\mathbf{x}_{t+1}, y_{t+1})$ measures the required adjustment in output, for input $\mathbf{x}_{t+1}$, for the DMU to be on the frontier defined by S_t. *Viceversa*, $D^{t+1}(\mathbf{x}_t, y_t)$ gives the increase in output required for the unit to be on the frontier of S_{t+1}.

By comparing input utilisation to output, the distance function approach offers a measure of productivity and relative efficiency of an economic unit. It also offers a mean of comparing two (or more) different units in terms of their position to the frontier, and, in principle, to study the evolution of the units' performance when the structure of technology changes. The use of distance functions to construct productivity indices is outlined in the following section.

E.2 The Malmquist "index"

Caves *et al.* (1982) propose to construct productivity indices using the distance function approach, developing an idea first suggested by Malmquist (1953). These authors define the Malmquist productivity index as follows:

$$M^{t+1} = \frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)}; \qquad (9)$$

This index compares two distance functions, computed using output and inputs from the periods t and $t+1$, using the structure of technology in t. In practice, the Malmquist index tells how much a unit could produce in $t+1$, using the inputs available in $t+1$, if it used the technology available at time t. Clearly, it is also possible to write the same index using S^{t+1} as reference technology instead of S_t. To avoid the arbitrary choice of a reference technology, Fare *et al.* (1994b) propose to use a geometric average of the Malmquist indices obtained using both S_t and S_{t+1} production possibility sets:

$$M^{t,t+1} = \left[\left(\frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)}\right)\left(\frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}}; \qquad (10)$$

Equation (10) considers how much a unit could produce using the inputs available in $t+1$, if it used the technology at time t, and how much a unit could produce using the inputs available in t, if it used the technology available in $t+1$, and takes the geometric mean of the answers to these two questions. If, for example, the output resulting from the use of inputs in $t+1$ were halved when using as reference technology S_t, and the output from the use of inputs in were doubled when using as reference technology S_{t+1}, the index above would show that a substantial technology progress has occurred from period t to $t+1$. One of the advantages of this approach is that it is possible to decompose the index of Malmquist into efficiency gains and technical progress. This is done by rewriting equation (10) as follows:

$$M^{t,t+1} = \underbrace{\frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)}}_{efficiency\ gains}\underbrace{\left[\left(\frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)}\right)\left(\frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}}}_{technical\ progress}; \qquad (11)$$

The first term of the product above represents, for each unit, the evolution of its distance to the frontier from period t to period $t+1$ keeping technology constant, thus measuring the gain in efficiency made by the unit. The second term is, once again, a geometric mean of distance function indices that considers also the change in the frontier taking place from period t to $t+1$. Clearly, changes in the frontier (i.e., the structure of the technology) can be viewed as effects of technical progress.

E.3 Computation

The method presented in previous sections is appealing for several reasons:

1. It does not require the specification of a production function;[32]

2. It does not require assumptions on the market structure (i.e. perfect competition), and it permits different specifications of the returns to scale technology;[33]

3. To compute productivity at time t (or $t+1$), one only needs observations on inputs, outputs, and technology over two periods, say, t and $t+1$;

The distance function approach is based on the idea of a level of technical efficiency which cannot be exceeded by the operating units, and which might not be attained. This level of technical efficiency is represented by the production frontier. So, one needs a method to compute/estimate the production frontier. To this purpose, DiMaria and Ciccone (2006a) propose to use Data Envelopment Analysis (DEA). The DEA technique was first introduced by Charnes *et al.* (1978), and later developed by Caves *et al.* (1982) and Banker *et al.* (1984). Fare *et al.* (1994a) present the theoretical foundation of the DEA approach, while Coelli *et al.* (2005) provide an accessible introduction to efficiency measurement.

DEA provides a mean to compute distance functions, and to practically evaluate the efficiency performance of economic units. This exploits the fact that distance functions are reciprocal's of Farrell's efficiency measures. (An accessible introduction to DEA is provided by Coelli *et al.*, 2005.) The idea is, in very general terms, to select the most efficient unit for each observed combination of input (that is, the unit which produces the highest amount of output), and to construct the frontier by joining the set of points represented by those efficient units. The distance functions are computed by solving the following mathematical linear program:

$$max_{\lambda,\Phi}\lambda_0 \qquad (12)$$

$$s.t.\sum_{j=1}^{J} x_{ij}\varphi_j \le x_{i0}, \quad \text{for every } i$$

$$-\sum_{j=1}^{J} y_j\varphi_j + \lambda_0 y_0 \le 0$$

$$\Phi, \lambda \ge 0$$

[32] In practice, as in the measurement of productivity in the context of index number theory, there is no need to specify a functional form of the production function.

[33] Note that this setting requires assumptions on return to scale. However, results are robust to such assumptions. This issue is discussed in some details in DiMaria and Ciccone (2006c).

Here, the subscripts i and j index, respectively, inputs and DMUs; Φ is a vector (J x 1) of coefficients for the DMUs; λ is a score to be maximized. (The subscript indicates that the problem is solved with respect to a reference DMUs.) Intuitively, the problem above seeks the biggest possible expansion of the output of DMU_0, while remaining within the feasibility set. (So that this expansion is equal or higher a linear combination of other DMUs output and the amount of inputs used in producing that output does not exceeds a combination of inouts use by other units.) The solution to the problem above gives a score for each DMU, λ_0^* ; the efficiency measure for DMU_0 is then equal to the reciprocal of such score: $E_0 = 1/\lambda_0^*$. This also provides an estimate of the distance of DMU_0 to the frontier. The DMUs with a score equal to 1 will define the efficient frontier. [34]

Clearly, the above avoids the use of a tightly specified production function for which parameters should be estimated, but it is complicated to implement and computationally intensive. Biesebroeck (2007) shows that DEA is optimal among productivity measurement methods when technology is heterogeneous and returns to scale are not constant. A problem of aggregation, however, poses also for the production frontier approach. Zelenyuk (2006) considers aggregating Malmquist productivity indices over individual decision making units (firms, countries, etc.) into a group Malmquist productivity index. DiMaria and Ciccone (2006a) discuss the application of aggregated Malmquist indices to the case of Luxembourg.

E.4 Examples

This section illustrates some of the concepts presented in the previous section using two examples. The first example presents a production possibility set and a distance function in the case of a single input/single output unit, and a constant return to scale (CRS) technology. The second example aims to clarify the link between the Malmquist productivity index and the measurement of TFP. (One should note that this is for illustrative purposes and can be generalised to the case of increasing and decreasing return to scale and multi-input/output vectors.)

Example 1

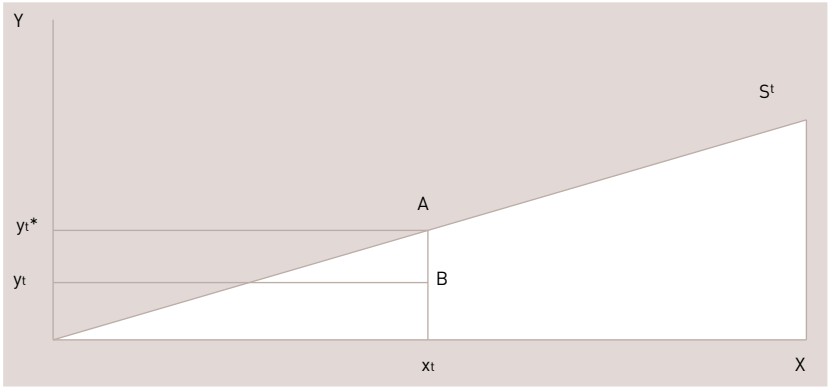
Consider an economic unit which produces a single output using a single input. (This example is based on the graphical illustrations in Mawson *et al.*, 2003 .) Consider Figure 18, where the input is measured on the X axis and the output in the Y axis. The straight line S^t represents the production frontier and the white area the production possibility set in period t . (Note that it is not possible for the unit to operate at a point above the frontier.) Given a level of input equal to x_t , the unit can operate on every point on the line which starts from x_t and is perpendicular to the X axis. If it is efficient, it will operate at point A, on the frontier. If it is not efficient, the combination input/output will be the one represented, say, by point B, below the frontier but belonging to the production possibility set. The distance function is given by actual output divided by optimal output:

$$D^t = \frac{y_t}{y_t^*}; \qquad (13)$$

[34] The formulation of problem (12), also referred to as the envelopment form, represents the dual of a non-linear fractional problem. Charnes *et al.* (1978) show how the original problem, which minimises a ratio of input on output, can be transformed into a linear score problem. The latter formulation reduces the dimensionality of the problem as it includes I (number of inputs) rather than J (number of DMU) constraints. The optimisation problem presented here is an output-oriented version, it is also possible to formulate the problem as an input-oriented one. In the latter case, we seek the biggest possible reduction in inputs' use, while keeping output levels constant.

(Here, y denotes actual output and y^* optimal output.) To see this, we proceed as follows. Recall, form Section E.1, that the parameter θ in equation (6) represents the largest factor by which we should increase output to place the unit on the frontier, i.e. to achieve point A. The reciprocal of $theta$ gives the distance function. At point B, the output produced is y_t , which should be multiplied by the factor θ to reach the optimal level y_t^* : $y_t\theta = y_t^*$. Thus, solving for the reciprocal of θ , we obtain the distance function above.[35]

Figure 18
Production frontier: constant return to scale



Source: Mawson *et al.*, 2003.

Example 2

The following example is based on DiMaria and Ciccone (2008). Let us assume that the technology frontier is given by the production function $y_t^* = A_t F(\mathbf{x}_t)$. (Here, there is one output but more than one input. A is constant over the DMUs but varies over time.) The distance function is then defined as:

$$D^t = \frac{y_t}{A_t F(\mathbf{x}_t)} \tag{14}$$

Substituting the distance function above into equation (10), and cancelling out equal terms, one gets:

$$_{t,t+1} = \left[\frac{\dfrac{y_{t+1}}{A_t F(\mathbf{x}_{t+1})}}{\dfrac{y_{t+1}}{A_{t+1} F(\mathbf{x}_{t+1})}} \frac{\dfrac{y_t}{A_t F(\mathbf{x}_t)}}{\dfrac{y_t}{A_{t+1} F(\mathbf{x}_t)}} \right]^{\frac{1}{2}} \tag{15}$$

$$= \frac{\dfrac{y_{t+1}}{F(\mathbf{x}_{t+1})}}{\dfrac{y_t}{F(\mathbf{x}_t)}}; \tag{16}$$

[35] One can see that the distance function of equation (13) can also be written as $D^t = y_t / \beta x_t$, where β denotes the slope of the straight line representing the frontier. Alternatively, using the notation of Section 2, one could write $D^t(x_t, y_t) = inf\{\theta : y_t / \theta \leq \beta x_t\}$. Notice also that the function $y = \beta x$ represents a CRS technology, as, for example, if input doubles then output doubles as well.

One can see that the right-hand side of equation (16) coincides with the definition of TFP growth (cf. equations (3) and (4) and let $F(\mathbf{x}) = L^{(1-\alpha)}K^{\alpha}$). Similarly, the Malmquist productivity index can also be written as follows:

$$M^{t,t+1} = \frac{A_{t+1}}{A_t}; \tag{17}$$

As a result, one can see that the Malmquist index reflects technical progress. (Any value of the index below one denote technical regress.)

Consider now the case of a Cobb-Douglas technology with capital and labour as inputs, such as the one defined in equation (1), expressed in *per capita* terms. Let $F(\mathbf{x}) = L^{(1-\alpha)}K^{\alpha}$ and $y = Q$. The production frontier is then given by:

$$q_t = A_t f(k_t) = A_t k^{\alpha}; \tag{18}$$

Here, both output and capital input are expressed in *per capita* terms and are defined as follows: $q_t = Q_t / L_t$, and $k_t = K_t / L_t$, where Q, L, K denote, respectively, output, labour and capital inputs.[36] The distance function for this Cobb-Douglas technology is as follows:

$$D^t = \frac{y_t}{A_t k^{\alpha}}; \tag{19}$$

Using the distance function above, one can show that the change in labour productivity, $q = Q / L$, can be written as follows (DiMaria and Ciccone, 2008):

$$\frac{q_{t+1}}{q_t} = \underbrace{\left(\underbrace{\frac{k_{t+1}}{k_t}}_{\text{capital intensity}} \right)^{\alpha} \frac{\frac{Q_{t+1}}{A_{t+1}F(L_{t+1})}}{\frac{Q_t}{A_t F(L_t)}}}_{\text{efficiency gains}} \underbrace{\sqrt{\frac{\frac{Q_{t+1}}{A_t F(L_{t+1})}}{\frac{Q_{t+1}}{A_{t+1}F(L_{t+1})}} \frac{\frac{Q_t}{A_t F(L_t)}}{\frac{Q_t}{A_{t+1}F(L_t)}}}}_{\text{technical progress}} \tag{20}$$

One can see that the change over time of labour productivity is the product of a function of capital intensity and the Malmquist productivity index. So, the expression above provides a nice link between changes in labour productivity and TFP.

[36] Equation (18) is obtained by dividing both sides of equation (1) by L.

F Figures and Tables

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