Federal Planning Bureau
Kunstlaan/Avenue des Arts 47-49, 1000 Brussels
http://www.plan.be

WORKING PAPER 7-11

The determinants of industry-level total factor productivity in Belgium

April 2011

Bernadette Biatour, bbi@plan.be, Michel Dumont, dm@plan.be, Chantal Kegels, ck@plan.be

Abstract - In this Working Paper the impact of potential determinants of total factor productivity, i.e. the part of output that cannot be explained by the quantity of production factors, is estimated for Belgium using industry-level data for the period 1988-2007.

Abstract - In deze Working Paper wordt de impact van mogelijke determinanten van totale factorproductiviteit, d.w.z. het gedeelte van de output dat niet verklaard kan worden door de gebruikte hoeveelheid van de productiefactoren, geschat voor België, op basis van bedrijfstakgegevens voor de periode 1988-2007.

Abstract - Dans ce Working Paper, l'impact des déterminants potentiels de la productivité totale des facteurs, c'est-à-dire de la part de l'output qui ne peut pas être expliquée par la quantité de facteurs de production, est estimé pour la Belgique en utilisant des données sectorielles couvrant la période 1988-2007.

Jel Classification - C82, D24, F43, O47

Keywords - Total factor productivity, R&D, human capital, competition

Legal deposit - D/2011/7433/12
Responsible publisher - Henri Bogaert

Executive Summary

The share of the output of a company, industry or country that cannot be explained by the amount of capital, labour and other factors used for production is called total factor productivity (TFP). TFP growth is considered as a proxy for disembodied technological change, which, following the contributions to neoclassical economic growth theory is believed to be the predominant explanation of economic growth in developed countries. As total factor productivity is a residual, it is likely to be a biased indicator of technological efficiency due to measurement errors, omitted variables, aggregation and misspecification. If the heterogeneity in efficiency of capital goods and workers is taken into account, the TFP growth residual is often reduced dramatically, even to the extent that it suggests that almost all technological change is actually embodied in production factors (e.g. ICT in capital goods) and that there is hardly any disembodied technological change. In this paper, we dwell on the issues that make the measurement of TFP and its interpretation as an indicator of technological efficiency troublesome.

Despite the large list of problems involved in measuring total factor productivity, it is generally considered as a proxy of technological efficiency and, more in general, a major determinant of welfare. This warrants an analysis of the factors that may determine TFP. Research and Development (R&D) activities of firms, universities and research institutes are generally considered as the main determinant. Not only own R&D activities may affect innovation and productivity growth, but firms may also benefit from R&D performed by other domestic or foreign firms or research organisations. Empirical studies have shown the importance of these so-called spillovers for TFP and provide an argument for governments to stimulate R&D, e.g. through subsidies or fiscal support, as spillovers also imply that firms cannot fully appropriate all benefits resulting from their own R&D and may therefore invest too little in R&D from a macroeconomic point of view. Human capital, the diffusion of new technologies (e.g. ICT), international trade (as a channel for spillovers as well as a source of import competition or export opportunities), market regulation and competition are other determinants of TFP (growth) that have been put forward in the literature.

In this paper, we estimate the impact of these potential determinants on TFP for a panel of 21 industries in Belgium, over the period 1988-2007. Whereas Belgium appears to have been close to -if not at- the world frontier in terms of technological efficiency in the 1980s and 1990s, there are indications that its relative position has deteriorated recently. The results of our estimations show the need to account for heterogeneity between industries as to what determines total factor productivity. An obvious distinction is between manufacturing industries and services. For manufacturing industries, there is robust evidence of a positive impact of intra-industry R&D activities as well as positive domestic inter-industry R&D spillovers and foreign (knowledge) spillovers whereas in services only domestic (patent-weighted) R&D stocks are found to have had a statistically significant positive impact on TFP. However, even the group of manufacturing industries appears to be heterogeneous. The impact of intra-industry R&D investment is

only significantly positive for high-tech industries, the positive domestic inter-industry spill-overs only for medium-tech and high-tech industries and the foreign knowledge spillovers only for medium-tech industries. Estimation results suggest that the deregulation that occurred, over the period considered, in non-manufacturing industries has had a negative impact on TFP, which could indicate that deregulation in non-manufacturing industries so far did not result in increased competition or in downward pressure on the prices of intermediate inputs that may contribute to the productivity of downstream industries.

From an economic policy perspective, our results seem to justify public support for private sector R&D, e.g. through direct subsidies or fiscal incentives. However, these incentives should take into account the heterogeneity between industries. Own R&D activities should mainly be encouraged in high-tech manufacturing industries whereas for medium- and low-tech manufacturing and services, public support should be oriented more towards enhancing the absorptive capacity of companies and technology diffusion. Finally, it appears that policy makers should rethink the process of structural reforms in market services and utilities in such a way that deregulation will effectively increase competition and thereby provide a positive impact on the rest of the economy.

Synthese

Het gedeelte van de output van een bedrijf, bedrijfstak of land dat niet verklaard kan worden door de hoeveelheid kapitaal, arbeid en andere productiefactoren wordt totale factorproductiviteit (TFP) genoemd. De TFP-groei wordt beschouwd als een maatstaf van niet-belichaamde technologische vooruitgang, die volgens de bijdragen tot de neo-klassieke groeitheorie gezien wordt als de voornaamste verklaring van economische groei in de ontwikkelde landen. Aangezien totale factorproductiviteit echter een residu is, is het waarschijnlijk een vertekende maatstaf van technologische efficiëntie, als gevolg van meetfouten, niet-beschouwde variabelen, aggregatie- en specificatiefouten. Indien efficiëntieverschillen tussen kapitaalgoederen en werknemers in rekening worden gebracht, vermindert de berekende TFP-groei (residu van de groei) vaak vrij drastisch, soms zelfs in die mate dat de berekeningen suggereren dat alle technologische vooruitgang belichaamd wordt in de productiefactoren (bijv. ICT-kapitaalgoederen) en dat er nauwelijks niet-belichaamde technologische vooruitgang is. In deze paper staan we stil bij de verschillende problemen die de berekening van TFP en de interpretatie ervan als maatstaf voor technologische efficiëntie bemoeilijken.

Ondanks de lange lijst van problemen bij het meten van TFP, wordt die variabele algemeen beschouwd als een maatstaf voor technologische efficiëntie en meer algemeen als een belangrijke determinant van welvaart. Dat maakt het interessant om de determinanten van TFP te analyseren. Onderzoek en Ontwikkeling (O&O) van bedrijven, universiteiten en onderzoeksinstellingen wordt doorgaans gezien als de voornaamste determinant. Niet enkel de eigen O&O-activiteiten kunnen bijdragen tot innovatie en productiviteitsgroei, maar bedrijven kunnen ook voordeel halen uit O&O die wordt verricht door andere binnenlandse en buitenlandse bedrijven en onderzoeksinstellingen. Empirische studies hebben het belang van deze zogenaamde spillovers voor TFP aangetoond en leveren een argument voor de overheid om maatregelen te nemen ter stimulering van O&O, bijv. via subsidies of fiscale steun, aangezien spillovers ook impliceren dat bedrijven zich niet volledig de resultaten van hun eigen O&O-activiteiten kunnen toe-eigenen en daardoor minder in O&O zullen investeren dan vanuit macro-economisch standpunt optimaal is. Menselijk kapitaal, de verspreiding van nieuwe technologieën (bijv. ICT), internationale handel (zowel als een spillovermechanisme alsook als bron van invoerconcurrentie en exportopportuniteiten), marktregulering en concurrentie zijn andere determinanten van TFP-(groei) die in de literatuur worden beschouwd.

In deze paper wordt de impact van deze potentiële determinanten van TFP geschat voor een panel van 21 bedrijfstakken in België, voor de periode 1988-2007. Waar België zich in de jaren 1980 en 1990 nog dichtbij of zelfs aan de mondiale technologische grens bevond, zijn er aanwijzingen dat zijn relatieve positie er recent is op achteruitgegaan. Onze schattingsresultaten tonen aan dat het belangrijk is om rekening te houden met de heterogeniteit tussen bedrijfstakken wat de determinanten van totale factorproductiviteit betreft. Een voor de hand liggend onderscheid is dat tussen industriële bedrijfstakken en dienstensectoren. Voor de industrie zijn er overtuigende aanwijzingen voor een positieve impact van de O&O-activiteiten in de eigen bedrijfstak, maar ook voor positieve effecten van O&O van andere binnenlandse bedrijfstakken en van buitenlandse kennisspillovers. Voor dienstensectoren blijken enkel de binnenlandse O&O-activiteiten (gewogen via octrooien) een statistisch significant positieve impact op TFP te hebben gehad. Zelfs de groep van de industriële bedrijfstakken blijkt redelijk heterogeen te zijn. De impact van O&O in de eigen bedrijfstak was enkel significant positief voor hoogtechnologische bedrijfstakken en de positieve binnenlandse spillovers van andere bedrijfstakken enkel voor bedrijfstakken met een hoge of een gemiddelde O&O-intensiteit en buitenlandse kennisspillovers enkel voor bedrijfstakken met een gemiddelde O&O-intensiteit. De schattingsresultaten suggereren dat de deregulering die in de beschouwde periode heeft plaatsgegrepen in niet-industriële bedrijfstakken, een negatieve impact op TFP heeft gehad, wat erop kan wijzen dat die deregulering voorlopig niet heeft geleid tot meer concurrentie of tot een neerwaartse druk op de prijzen van intermediaire inputs die kunnen bijdragen tot de productiviteit van stroomafwaartse bedrijfstakken.

Wat het economisch beleid betreft, lijken onze resultaten overheidssteun voor O&O in de privésector, bijv. via directe subsidies of fiscale steun, te verantwoorden. Die maatregelen zouden echter rekening moeten houden met de heterogeniteit tussen bedrijfstakken. Eigen O&O-activiteiten zouden voornamelijk in hoogtechnologische industriële bedrijfstakken moeten worden aangemoedigd, terwijl in bedrijfstakken met een gemiddelde of lage O&O-intensiteit het beleid meer gericht zou moeten zijn op het versterken van de absorptiecapaciteit van bedrijven en de verspreiding van technologie. Tenslotte, lijkt het aangewezen om bij het uitstippelen van het beleid met betrekking tot structurele hervormingen in diensten- en nutssectoren na te denken over manieren om ervoor te zorgen dat deregulering effectief resulteert in meer concurrentie en daardoor een positieve impact heeft op de rest van de economie.

Synthèse

La part de l'output d'une entreprise, d'une branche d'activité ou d'un pays qui ne peut pas être expliquée par le montant de capital, de travail et des autres facteurs utilisés dans la production, est appelée productivité totale des facteurs (PTF). La croissance de la PTF est considérée comme une approximation du changement technologique non incorporé qui, suivant les contributions de la théorie néo-classique de la croissance, est supposé être l'explication majeure de la croissance économique des pays développés. Dans la mesure où la PTF est un résidu, il est probable qu'il s'agisse d'un indicateur de l'efficacité technologique biaisé par les erreurs de mesure, les variables omises, l'agrégation et la mauvaise spécification. Quand l'hétérogénéité de l'efficacité des différentes catégories de capital et de travail est prise en compte, la croissance du résidu PTF est souvent largement réduite, au point même de suggérer que la quasi-totalité du changement technologique est incorporée dans les facteurs de production (comme par exemple les TIC dans le capital) et qu'il n'y a quasi aucun changement technologique non incorporé. Dans cette contribution, nous analysons les raisons qui font de la mesure de la PTF et de son interprétation, un indicateur discutable de l'efficacité technologique.

Malgré la longue liste des problèmes liés à la mesure de la PTF, cette variable est généralement considérée comme une approximation de l'efficience technologique et plus généralement un déterminant important du bien-être, rendant intéressante une analyse des facteurs susceptibles de la déterminer. Les activités de recherche et de développement (R&D) des entreprises, des universités et des centres de recherche sont généralement considérées comme le principal déterminant de la PTF. Non seulement les activités propres de R&D peuvent affecter l'innovation et la croissance de la productivité mais les entreprises peuvent aussi bénéficier de la R&D réalisée par d'autres entreprises ou institutions de recherche domestiques ou étrangères. Des études empiriques ont montré l'importance de ces retombées, appelées spillovers, pour la PTF et fournissent aux gouvernements un argument pour stimuler la R&D à travers des aides directes ou fiscales, dans la mesure où la présence de ces spillovers implique que les entreprises ne sont pas en mesure de s'approprier la totalité des bénéfices résultant de leur propre R&D et peuvent dès lors être amenées à sous-investir dans ces activités d'un point de vue macro-économique. Le capital humain, la diffusion des nouvelles technologies (comme par exemple les TIC), le commerce international (comme canal pour les spillovers aussi bien que comme source de concurrence importée ou d'opportunités d'exportation), la régulation et la concurrence sont les autres déterminants de la (croissance) de la PTF généralement avancés dans la littérature.

Dans cet article, nous estimons l'impact de ces déterminants potentiels de la PTF à partir d'un panel de 21 branches d'activité belges sur la période 1988-2007. Alors que la Belgique semble avoir été proche de – si pas sur – la frontière technologique mondiale dans les années quatre-vingt et nonante, les données tendent à montrer une détérioration de sa position relative au cours des dernières années. Les résultats de nos estimations soulignent la nécessité de prendre en considération l'hétérogénéité des branches d'activité en ce qui concerne le rôle des déterminants de la PTF. Une distinction évidente est à opérer entre les branches de l'industrie manufacturière et celles des services. Pour les branches de l'industrie manufacturière, nous obtenons des indications robustes d'un impact positif de la R&D intra-sectorielle ainsi que de la présence de spillovers de la R&D intersectorielle domestique et de la R&D étrangère (« knowledge spillovers ») alors que pour les branches des services, seuls les stocks de R&D domestiques (pondérés par les brevets) ont un impact positif statistiquement significatif sur la PTF. Cependant, même le groupe des branches de l'industrie manufacturière présente de l'hétérogénéité. L'impact de la R&D intra-sectorielle n'est significativement positif que pour les branches high-tech, les spillovers intersectoriels domestiques ne sont détectables que pour les branches medium-tech et high tech et les « knowledge spillovers » étrangers que pour les branches medium-tech. De plus, les résultats des estimations suggèrent que la dérégulation qui a eu lieu au cours de la période considérée dans les branches d'activité non manufacturières a eu un impact négatif sur la PTF, ce qui pourrait indiquer que la dérégulation des branches non manufacturières n'a pas jusqu'à présent conduit à l'augmentation de la concurrence ou à des pressions suffisantes à la baisse des prix des intrants intermédiaires qui aurait pu contribuer à la croissance de la productivité des branches d'activité en aval.

Du point de vue de la politique économique, nos résultats apparaissent justifier un soutien public à la R&D du secteur privé, soit sous la forme d'aides directes, soit sous la forme d'incitants fiscaux. Cependant, ce soutien devrait prendre en considération l'hétérogénéité des branches d'activité. Les activités propres de R&D devraient principalement être encouragées dans les branches d'activité high-tech tandis qu'un soutien public davantage orienté vers l'amélioration de la capacité d'absorption et la diffusion du progrès technologique devrait s'adresser aux branches manufacturières medium- et low-tech ainsi qu'aux services. Finalement, il apparait que les décideurs politiques devraient repenser le processus de réformes structurelles des services marchands et des industries de réseaux de façon telle que la dérégulation augmente effectivement la concurrence et par là, stimule le reste de l'économie.

Contents

List of tables

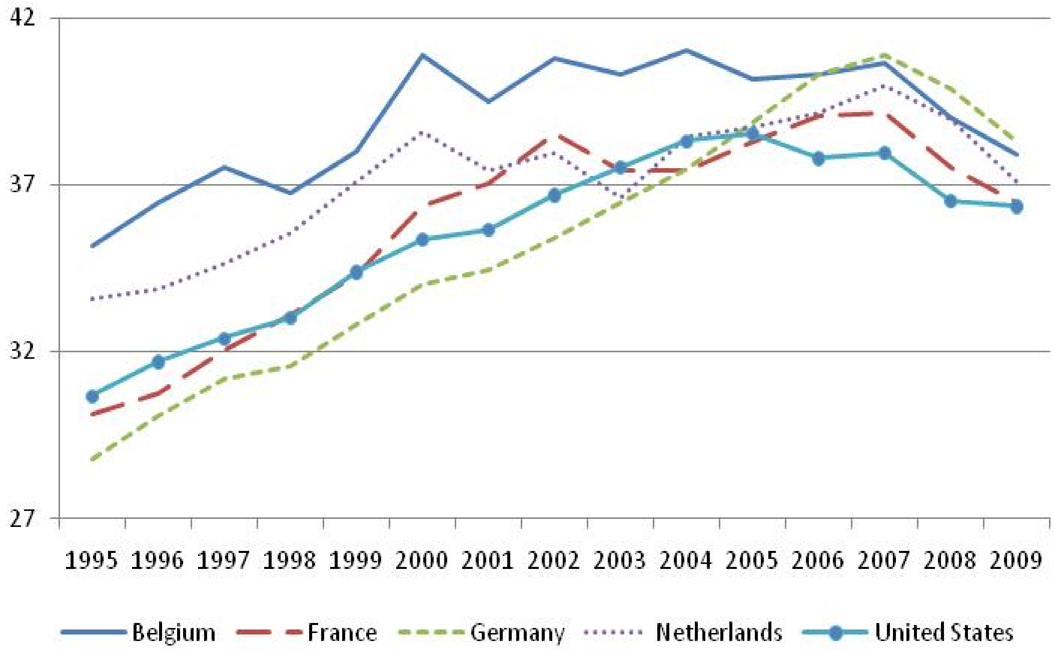
List of figures

1. Introduction

The determinants of national income or GDP have always been on the list of main research topics in economics. Early studies (Abramovitz 1956; Solow 1957 and Denison 1962) established that the larger part of growth in income per capita in developed economies was not explained by the accumulation of production factors (capital and labour) but by a residual, labelled as total factor productivity (TFP) growth. This finding has been confirmed in more recent studies (e.g. Islam 1995; Hall and Jones 1999 and Aiyar and Dalgaard 2005) but has been challenged by others (e.g. Jorgenson and Griliches 1967; Young 1995 and Jorgenson et al. 2005). Following Robert Solow's seminal contribution to neoclassical growth theory, TFP growth is generally considered as a measure of (disembodied) technological change and the assessment of the causes of economic growth tends to focus on the determinants of TFP. In contrast with traditional neoclassical growth theory, more recent contributions endogenize technological progress. In order to create or absorb knowledge, companies, industries or countries have to invest in human capital and research and development activities. New growth theories resulted in growing interest in the institutions that stimulate or hamper the creation, diffusion and absorption of new technologies, which may explain sustained cross-country differences in income per capita. A problem with the international comparison of TFP growth is that it does not take into account differences in the weights of sectors in the national economy. If in two countries, the same industries have equal TFP growth but a different economic weight, aggregate TFP growth will differ between the two countries without any growth differences at the industry level. This warrants a closer look at the evolution of TFP at the industry level. Possible differences between industries, e.g. technological regimes and distance to the technology frontier, should be accounted for when considering the determinants of TFP.

Graph 1 compares real GDP per hour worked between Belgium, France, Germany, The Netherlands and the US over the period 1995-2009, using EUROSTAT data. According to this measure, Belgium was more productive than the other four countries from 1995 up to 2007, with Belgian GDP per hour having decreased since the 2004 peak. However, GDP per capita in the US was higher than in Belgium due to the lower average number of hours per employed person and the substantially lower employment rate in Belgium. From the mid-1990s, France, Germany, The Netherlands and the US closed the productivity gap with Belgium, as the growth rate of GDP per hour worked in Belgium started to decrease. Whereas over the years 1995 up to 2002 GDP per hour increased, on average, by 2.2% every year, the growth rate fell to -1.0% between 2002 and 2009. This decrease in productivity coincided with positive employment growth. Although this negative correlation could indicate that part of the decreasing productivity growth in Belgium is due to the (necessary) rise in the employment rate, e.g. as a result of policy measures aimed at activating the unemployed, it may also be an indication of a drop in technological efficiency, relative to other countries.

Graph 1 Real GDP per hour worked 1995-2009 (constant 2009 prices, purchasing power parities)



Source: EUROSTAT

Section 1.1 provides a formal definition of total factor productivity. Section 1.2 discusses the methods and the difficulties involved in the measurement of TFP. In section 2, the main determinants of total factor productivity that have been put forward in the literature are discussed. Section 3.1 discusses the sources of the data used in the analysis and defines the variables used in the estimation. Section 3.2 provides an overview of the evolution by industry of the main variables and in section 3.3 we propose the econometric specification and discuss a number of econometric issues before reporting the results of our estimations. In section 4 conclusions are formulated.

1.1. The definition of total factor productivity

Consider a company, industry or country that uses labour L and capital K to produce output Q in year *t*[1]:

$$Q_t = A_t F(L_t, K_t) \tag{1}$$

Total factor productivity (TFP) or multifactor productivity (MFP), denoted by A, provides an indication of technological efficiency. If, for example, two companies use exactly the same amount (and quality) of production factors L and K, the company with the highest A will pro-

[1] To simplify notation, labour and capital are the only production factors that are considered. Output therefore denotes value added. If intermediate inputs are considered, e.g. energy and materials, output denotes gross output.

duce the highest output.

Equation (1) assumes that technological change is Hicks-neutral, i.e. that it increases the marginal product of capital and labour equally and thereby does not affect the distribution of income between the production factors. If technological change is not Hicks-neutral, the factor bias should be taken into account, e.g. $Q_t = F\left(a_t L_t, b_t K_t\right)$ and TFP growth equals the revenue share-weighted sum of the change in the input-specific shift parameters.

Growth in the level of technological efficiency over a given period, i.e. TFP growth, can be defined as the growth in output minus the growth in labour and capital, with input factors weighted by their output elasticity[2]:

$$\frac{dA_t}{A_t} = \frac{dQ_t}{Q_t} - \varepsilon^L \frac{dL_t}{L_t} - \varepsilon^K \frac{dK_t}{K_t} \qquad (2)$$

1.2. How to measure total factor productivity

As output elasticity is difficult to observe, Solow (1957) replaced it by the price (marginal product) of the input factors:

$$\frac{dA_t}{A_t} = \frac{dQ_t}{Q_t} - \frac{w_t L_t}{p_t Q_t}\frac{dL_t}{L_t} - \frac{r_t K_t}{p_t Q_t}\frac{dK_t}{K_t} \qquad (3)$$

Replacing factor prices for output elasticity imposes the strong assumption that factor markets are perfectly competitive. If the prices of assets such as ICT capital are partially driven by speculative bubbles, marginal cost may exceed marginal revenue. (Timmer et al. 2010) On the other hand, some assets may be priced below their marginal product due to market imperfections such as network externalities. (O'Mahony and Vecchi 2005) Similarly, wages may not reflect the marginal productivity of workers in some countries or industries as a result of labour market rigidities such as minimum wages or centralized wage negotiations. (Manning 2003)

Equation (3) is similar to a specification of a Divisia index, which does not require any assumption with regard to the specific form of the production function. The equation is expressed in continuous time which is not useful for practical reasons as most data are provided at given points in time (e.g. annually). TFP can therefore only be computed in discrete time. Diewert (1976) showed how a discrete-time Törnqvist index for TFP can be linked to a translog production function. (Hulten 2009)

The residual of output growth derived from a production function provides a primal measure of total factor productivity growth. Using a cost function, a dual measure of TFP growth can be

[2] The output elasticity of a production factor is defined as the percentage change in output for a given percentage change in input, e.g. for labour $\varepsilon^L = \frac{dQ_t}{dL_t} \Big/ \frac{Q_t}{L_t}$

computed as the share-weighted sum of the prices of production factors (e.g. user cost for capital and wages for labour). Under the assumption of constant returns to scale and perfect competition both measures of TFP should be equal. However, Aiyar and Dalgaard (2005) found substantial differences between both alternatives. Hall et al. (2009) discuss the differences between the primal and dual approach in some detail.

TFP growth computed as a residual only provides an unbiased measure of (disembodied) technological change in the unlikely absence of measurement errors, omitted variables (e.g. unmeasured inputs related to R&D activities; investment in intangible assets and organisational change), aggregation bias or misspecification**.** This is the reason why Moses Abramovitz labelled TFP growth as a "measure of our ignorance about the causes of economic growth". Abramovitz (1956: p.11)

In what follows we discuss the main problems in the measurement and interpretation of total factor productivity growth.

If TFP growth is measured on the basis of gross output, the impact of intermediate production factors such as raw materials, energy and intermediate goods and services and their potential substitution for labour or capital is taken into account. Although this is theoretically more appropriate than considering value added, there are some practical reasons to prefer the use of value added to gross output (e.g. Hall et al. 2009) and the lack of data on gross output and intermediate inputs in volume often imply that TFP growth based on value added is the only feasible option.

Technological efficiency reflects the extent to which input quantities result in output, also expressed in terms of quantity. As data on output are given in value terms (sales, profits, value added), output should be deflated to obtain an indication of the volume that is produced. If innovation increases the quality of products, this could be accounted for in the deflator by equating price differences between similar products to differences in quality or by quantifying increases in some product characteristics, i.e. so-called hedonic prices. In principle the same correction should be applied if the products of some industries are used as inputs in other industries (e.g. ICT capital goods). So far, due to data availability, the use of quality-adjusted prices is not often applied in growth accounting. Hulten (2009)

Problems in measuring capital are well-known and were at the core of the Cambridge Capital Controversy between economists from the University of Cambridge (UK) and economists, like Paul Samuelson and Robert Solow, affiliated with the Massachusetts Institute of Technology (Cambridge, US). Joan Robinson and Piero Sraffa from the University of Cambridge pointed out the problem of circularity in the computation of the capital stock in value terms. Neo-classical economists computed this stock by multiplying the number of machines and buildings used for production with their respective prices. However, the determination of the equilibrium prices of capital goods implies knowledge of the value - and hence the prices - of capital goods. The problem is especially important when heterogeneous capital goods are aggregated into a single capital stock. Though the Cambridge Capital Controversy lasted almost two decades, the problem of how to compute capital has not been resolved satisfactorily. Solow (1957) acknowledged the validity of some of the arguments of Robinson (1953) and argued that if data are available it is better to use many precisely defined (capital) inputs. Given the problems involved in computing capital stocks, some scholars rely on the dual measurement of TFP (cost function) although this approach is also fraught with substantial measurement problems.

Jorgenson and Griliches (1967) argued that in order to avoid the aggregation bias due to changes in the composition of inputs, capital and labour should be decomposed (e.g. long-lived versus short-lived capital stock and workers by level of education). Inklaar et al. (2005) decomposed physical capital into six categories and distinguished an ICT component (software, computers and communications equipment) from a non-ICT component (equipment, structures and vehicles) and labour into a volume component (hours worked) and a component measuring labour composition, based on data by skill; age and gender. The procedure involved aggregation of two-digit industries and only the United States and four EU countries (France, Germany, the Netherlands and the United Kingdom) were considered, as few countries provide data on prices of computers and semiconductors needed to compute deflators that account for the increase in quality of ICT goods. In the EU KLEMS database which was used in our analysis, capital and labour have been decomposed (see section 3.1.1).

Although it seems more straightforward to express labour in physical terms than capital, e.g. number of workers or number of hours worked, TFP growth will also be biased if labour is considered as a single homogenous production factor. Denison (1974) computed an index of labour as a weighted aggregate of the hours worked by different age-sex groups. The average wage of each group is taken as weight, assuming that it is proportional to the marginal product (per hour worked) of a group. In a similar way, Denison constructed an index to reflect changes in the level of education. Denison found that when differences in productivity between workers are taken into account, TFP growth is reduced considerably. Young (1995) sparked a heated debate by stating that the strong economic growth witnessed in some East Asian countries like Hong Kong, Singapore, South Korea and Taiwan could be explained by factor accumulation rather than by technological change (TFP growth) when labour was distinguished by age, sex and level of education. Though this result was in line with Kim and Lau (1994) and confirmed in later studies, it has been challenged by others (e.g. Hsieh 2002; see Felipe 1999 for a survey on this issue).

Jorgenson and Griliches (1967) provided estimates of TFP growth corrected for several measurement errors[3]. Errors due to capacity utilization and aggregation in capital services and to a lesser extent the aggregation bias of labour substantially reduce TFP growth. After all corrections, changes in production factors (factor accumulation) appeared to explain the bulk of output growth in the US in the period 1945-1965**.** Jorgenson et al. (2005) reported more recent estimates of TFP for the United States as well as for Canada, France, Germany, Italy, Japan and the

[3] See for similar exercise for Belgium Biatour et al. (2007).

UK for three periods: 1980-1989; 1989-1995 and 1995-2001. According to these calculations growth in input per capita exceeded TFP growth in all countries considered except for Germany in the period 1989-1995 and Japan in the period 1995-2001 and TFP growth would have been negative for France and the UK over the years 1989-1995 and for Germany and Italy over the years 1995-2001. The impact of capital accumulation on output may be overstated if some of the investment in capital is induced by TFP growth. (Durlauf et al. 2005: p.605)

Looking at TFP growth by industry for the US over the period 1977-2000, Jorgenson et al. (2005) found TFP growth to be the main component of output growth for seven out of 41 industries considered, especially in two industries that produce IT equipment, i.e. computers and office equipment and electronic components. On the other hand, 16 out of 41 industries appeared to have witnessed a decrease in TFP over the period considered. The authors argue that this may be explained by the difficulty to account for changes in quality in output, especially concerning IT equipment and services.

There are good arguments to take into account the heterogeneity of production factors and possible measurement errors that may severely bias the computation of TFP growth. However, most of the corrections that have been applied rely on assumptions that may substitute some (measurement) errors for others, e.g. the assumption that wages fully reflect differences in efficiency between different groups of workers.

As capital is often considered to be quasi-fixed, i.e. it does not adjust instantaneously; troughs in the business cycle will often be characterized by low levels of capital utilization, as a result of which the residual computed with capital stock data will fluctuate pro-cyclically along with capacity utilization, blurring actual productivity changes. (Hulten 2000: p. 29) If firms, in order to retain workers with valuable skills or due to high severance indemnities, do not immediately lay off workers as sales growth slows down in times of economic recession, a phenomenon known as labour hoarding, the decrease in output will exceed the decrease in labour. This will be reflected in a decrease in TFP growth. Rotemberg and Summers (1990) report evidence in support of labour hoarding as an explanation of the established pro-cyclical pattern of measured TFP growth. Productivity in industries and countries appears to be more pro-cyclical the more important labour hoarding is. Wen (2004) provides more recent evidence of the importance of labour hoarding in explaining the pro-cyclical pattern of productivity growth.

To compute TFP growth, as shown in equation (3), the share of capital in value added has to be known. Given the difficulties in obtaining an estimate of the return to capital, the share of capital is simply assumed to be 1 minus the share of labour in most growth accounting exercises. This imposes constant returns to scale and perfect competition, both in product and in factor markets (i.e. there is no economic profit as value added equals the sum of labour and capital income). Estimations reported by Diewert and Fox (2008) suggest that productivity growth of US manufacturing industries over the period 1950-2000 could be explained by increasing returns to scale rather than by technological progress, which may also explain the pro-cyclical pattern in TFP growth. The article of Diewert and Fox clearly shows that distinguishing between non-constant returns to scale and imperfect market competition is not straightforward.

Basu et al. (2009) argued that although TFP growth is not a perfect proxy of technological change, it provides a good measure of welfare, which can be decomposed into three measures reflecting respectively technological change, aggregate distortions and allocation efficiency. Aggregate distortions relate for instance to the degree of competition and taxation whereas allocation efficiency reflects the extent to which the most productive firms have the highest (growth in) market shares. An analysis based on firm-level data for a group of five EU countries (Belgium, France, Italy, Spain and the UK) over the period 1998-2005 suggests that technological change explains the largest part of productivity growth. Aggregate distortions appear to have played an important role in Belgium, Italy and Spain whereas allocation efficiency was of minor importance in all countries considered. Basu et al. (2009) acknowledge that decomposition of TFP growth depends crucially on a number of assumptions, as different assumptions result in different decompositions.

Productivity growth can be calculated or estimated at different levels of aggregation, ranging from countries to individual plants. Whereas most early work in growth accounting considered productivity at the country level, more recent studies focus on industries or individual firms to avoid a potential aggregation bias due to heterogeneity across industries and firms and to provide insight into the determinants of productivity growth that are concealed at the more aggregate level. Bernard and Jones (1996 a, b) pointed out the important differences in TFP growth between six industries across 14 OECD countries over the period 1970-1987. The convergence between countries witnessed in terms of TFP growth appears to be the net aggregate effect of divergence in manufacturing counteracted by convergence in services. Changing industry shares explained some 20% of catch-up of countries with respect to the world technology frontier. International trade, which as an important channel of R&D spillovers tends to enhance catch-up of lagging industries (countries) could, as argued by Bernard and Jones (1996 a), also hamper convergence if it reinforces international specialization and productivity growth is to some extent industry-specific. Bosworth and Triplett (2004) and Jorgenson et al. (2005) assessed the degree of the industry-specific evolution of TFP, distinguishing ICT-producing; ICT-using and non-ICT industries. Bailey et al. (1992) was an early study in which plant-level data were used to establish the impact of differences between plants in growth in output and productivity, as well as firm entry and exit, on industry-level performance. A shift towards high-productivity plants and away from low-productivity plants explained a large part of aggregate productivity growth in US manufacturing over the years 1972 up to 1987. Entry and exit of firms did not appear to have mattered much for productivity growth as entrants and exits did not differ much in terms of productivity. Olley and Pakes (1996) found that productivity growth in the US telecommunications equipment industry could be explained by the reallocation of capital towards the most productive plants. Bartelsman et al. (2004) reported little difference in rates of firm entry and exit between industrial countries but the growth of entrants appeared to be more substantial in the United States than in EU countries, which according to the authors could indicate that barriers to firm growth rather than barriers to entry may explain differences between the EU and the United States. Firm-level studies are very demanding in terms of data availability and the estimation of productivity at the firm level is known to have specific problems (see e.g. Katayama et al. 2009). Bartelsman (2010) provides a good overview of the analysis of productivity growth at different levels of aggregation.

In traditional neoclassical growth theory, technological progress is considered to be exogenous and hence costless. This is rather unrealistic as it implies that companies and countries can absorb all existing knowledge without any effort. More recent growth theories (e.g. Romer 1986, 1990; Lucas 1988; Grossman and Helpman 1991 and Aghion and Howitt 1992, 1998) do not consider technological change as an exogenously determined residual but rather as the result of deliberate investment in human capital and research and development. R&D activities of other companies or countries may still provide benefits to others (spillovers) but investment is required to absorb external knowledge. Endogenous growth theories imply the inclusion of additional inputs in the production process:

$$Q_t = A_t F\left(L_t, K_t, H_t, RD_t^O, RD_t^X\right) \quad (4)$$

Human capital *H* reflects the skill level of workers (investment in education and training), RD^O is the own knowledge stock (investment in own R&D activities) and RD^X the knowledge stock of other companies, industries or countries, the latter capturing possible spillovers from external R&D activities. Although some scholars define TFP growth as the residual of output growth after subtraction of the growth in all production factors (R&D included), it is mostly defined as the residual after subtraction of traditional inputs like labour and capital.

Schankerman (1981) assessed the impact of double-counting of R&D investment on the estimates of TFP growth. If the capital and labour that are used in R&D activities are not subtracted from capital and labour used for production, TFP growth will be biased downward. If R&D activities are considered as intermediate inputs rather than as an investment, there is also an "expensing bias" which can be positive or negative. A growth accounting exercise for US manufacturing indicated that double-counting and expensing resulted in a net downward bias of 6% for the period 1958-1966 and 9% for the period 1967-1976. These results lend support to the view that double-counting of R&D expenditure provides an estimate of the excess gross rate of return to R&D above normal remuneration, which reflects the risk premium or market rent on R&D investment. The downward bias due to double-counting is apparently smaller when labour input is split up by level of qualification, due to the complementarity between high-skilled labour and R&D activities. (Hall et al. 2009)

As an alternative to computing TFP growth as a residual, a specification representing the production technology could be estimated econometrically, accounting for imperfect competition, non-constant returns to scale and factor-biased technological change. However, the results of these estimations have often been questioned for their robustness and sufficient data are needed for unrestricted specifications. As the production factors are the right-hand side variables, these regressions may moreover suffer from an endogeneity bias (see Durlauf et al. 2005 on the use of econometrics to study economic growth and cross-country income differences). Van Biesebroeck (2007) discussed the advantage and limitations of the different methods that can be used to calculate or estimate (firm-level) TFP. He compared the robustness of TFP calculated with the index number approach to the robustness of TFP measures derived from several econometric estimation procedures, considering heterogeneity in factor prices (e.g. wages); measurement error and heterogeneity in production technology across firms. When the assumption of a common production technology for all firms is relaxed, the index number approach outperforms the other procedures whereas parametric and semi-parametric methods do not provide very accurate estimates. Overall, the rather straightforward computation of TFP using the index number approach appears to result in reliable estimates unless measurement error is substantial. As argued by Van Biesebroeck (2007) but also by Basu et al. (2009), who provided results of (semi-) parametric estimation of TFP for Belgian industries for the period 1998-2005, no method can be singled out as performing best under all circumstances.

The long list of issues discussed in this section clearly point out the need for caution in the interpretation of total factor productivity (growth) as a measure of technological efficiency (change). Hulten (2009) rightly argued that growth accounting is a diagnostic technique that is likely to benefit more from reliable data than from sophisticated theory. Given this caveat, an analysis of TFP and its potential determinants at the level of industries is useful to provide some insight into the possible causes of the relative decrease in productivity that Belgium has witnessed in recent years.

2. The determinants of total factor productivity

This section enlists the main determinants of (industry-level) total factor productivity (growth) that have been put forward in the literature: R&D efforts, human capital, ICT investment, competition (product market regulation) and international trade.

Firms invest in R&D activities in the hope that these activities will result in product, process or organisational innovation, an increase in productivity, improved quality or reduced production costs of existing goods or more variety in final goods or intermediate inputs. In a review of the literature, Hall et al. (2009) range the rate of return to R&D activities between 20% and 30%. Including industry dummies in estimations tends to reduce the (statistical significance of) estimates which could be due to structural industry characteristics that are omitted from the estimations but could also reflect differences across industries in technological opportunities. (Hall et al. 2009: p. 19)

The (quasi-) public good nature of technological knowledge and the existence of R&D externalities are widely recognised in the academic literature. Griliches (1979) distinguished two categories of spillovers: rent spillovers and knowledge spillovers. The first category occurs when R&D intensive inputs are purchased from other industries at less than their full "quality" price, preventing the complete appropriation of the innovation rent by the innovator, e.g. due to strong competition. Knowledge spillovers are defined by Griliches (1979) as ideas borrowed by the research teams of industry *i* from the research results of industry *j* that provide a benefit to industry *i*'s innovation capacity. Poor patent protection, the inability to keep innovations secret, reverse engineering, imitation, meetings, conferences and mobility of (R&D) personnel are possible channels of knowledge spillovers and reflect the (partially) non-rival and non-excludable nature of knowledge.[4] Coe and Helpman (1995) provided one of the first empirical tests of the role of international R&D spillovers, as emphasized by Grossman and Helpman (1991). To estimate the impact of foreign R&D activities on domestic TFP growth, foreign R&D stocks were constructed as the weighted sum of R&D stocks of other countries. Coe and Helpman used bilateral import shares as weights as they considered international trade to be the main channel through which the results of foreign R&D activities spill over into domestic production. Most of later empirical studies confirmed the finding by Coe and Helpman (1995) that foreign R&D activities have a substantial positive impact on domestic productivity growth, with international trade but also FDI as main spillover channels (see Coe et al. 2009 and Keller 2009 for recent surveys). However, Higón (2007), finding no or even a negative impact of foreign R&D activities for a panel of eight UK manufacturing industries over the period 1970-1997, quoted similar findings in other studies as well as some arguments as to why spillovers may actually be negative, e.g. due to crowding out effects of competition from technologically superior (foreign) firms as argued by Aitken and Harrison (1999), due to the negative effects of successful com-

4 Sveikauskas (2007) and Hall et al. (2009) provide recent surveys of the literature on the impact of R&D on productivity.

petitors in a patent race as raised by Branstetter (2001) or because the new products that result from competitors' R&D activities may displace some of the products of a firm before all R&D expenditures has been recovered (e.g. Mohnen 1996).

Although spillovers may provide a valuable source of knowledge, not all firms are equally able to reap these benefits. Cohen and Levintahl (1990) defined absorptive capacity as the ability of firms to recognize and to use external knowledge. Own R&D activities and investment in human capital, are therefore not only important to create knowledge but also to enhance the capacity to absorb the knowledge created in external R&D activities.

In a recent panel study of 16 OECD countries, Luintel et al. (2010) established that R&D and human capital were the main determinants of productivity for the period 1982-2004. ICT investment, public infrastructure, exports of high-tech goods, inward and outward FDI stocks, the relative size of services in the economy and some measures of financial development were the other determinants found to explain cross-country differences in productivity. To the extent that macroeconomic and institutional characteristics do not differ between industries in the same country, they are less likely to explain much of cross-industry differences within countries.

Grossman and Helpman (1991) incorporated endogenous growth in an international framework in which some countries lead the innovation process by shifting the technology frontier whereas other countries try to catch up through imitation. Aghion and Howitt (2006) proposed a Schumpeterian model with creative destruction in which a country's (or industry's) growth performance will vary with its proximity to the world technology frontier. The further a country (industry) is behind the technology frontier, the faster it will grow, if it has institutions and policies that enhance catching up through technology transfer and imitation. As technologically lagging countries (industries) reduce the distance to the frontier, they have to develop institutions and policies that focus more on innovation than on imitation, notably in terms of increasing the skills of workers and own R&D efforts. In the model of Aghion and Howitt, competition (entry and exit) enhances innovation and productivity in countries (industries) that are close to the technology frontier, as incumbents will increase their investment in innovation (R&D) to escape the threat of entrants. In countries or industries that are far behind the technology frontier, the negative impact of competition on expected rents from innovation will reduce the incentive for laggards to innovate. The impact of competition on innovation depends on the distance to the technology frontier. The model clearly shows the need to allow for heterogeneity between industries (countries) when assessing the determinants of productivity. Aghion and Howitt (2006) argued that the growth rate differential between the EU and the US in the period 1995-2000 could be explained by the fact that the institutions and policies that were instrumental in the catching up of Europe after World War II were not attuned to the investment in innovation which became more crucial as Europe was closing the gap to the frontier (US). Similar arguments and conclusions were presented by Sapir et al. (2003).

Cameron et al. (2005) estimated the impact of R&D, human capital and international trade on productivity growth for a panel of 14 UK manufacturing industries over the period 1970-1992. They considered the distance to the frontier (US level) to distinguish between innovation and technology transfer. The positive effect of the distance to the technology frontier on productivity growth suggests conditional convergence in relative TFP. R&D appeared to be important for innovation but not for technology transfer (absorptive capacity). International trade played a more significant role for technology transfer. The results of Griffith et al. (2004) for a panel of industries for 12 OECD countries indicate a significant role for R&D in innovation but, in contrast with Cameron et al. (2005), also to absorb external knowledge (catch-up). The impact of human capital on productivity growth was statistically significant and substantial whereas the impact of international trade was found to be of minor importance.

Ortega-Argilés et al. (2009) assessed that the effect of R&D investment on productivity increases with R&D intensity. In a similar vein, Kumbhakar et al. (2009) found that R&D activities explain a small part of productivity growth in low-tech industries. In the latter industries, investment in fixed capital appears to be a more important determinant. Hall et al. (2009) point out that the estimates of R&D spillovers differ enormously when estimated separately by industry with the rate of return ranging from 0 to 100%.

Competition differs across industries and may have a substantial impact on productivity. Theoretical work on the link between productivity (innovation) and competition does not provide straightforward conclusions as two opposing mechanisms have been put forward. Competition may encourage investment in R&D by incumbent firms in order to escape competition. On the other hand, proponents of a Schumpeterian (Mark II) effect argue that the negative impact of competition on the expected rents from innovation will reduce investment in R&D. Aghion et al. (2005) have argued for an inverted-U relationship between innovation and product market competition, resulting from the trade-off between the escape effect and the Schumpeterian effect. Estimations for a panel of UK industries seem to confirm the inverted-U relationship between the citation-weighted number of patents (innovation) and the price cost margin (competition). Using data for a panel of 20 industries in 15 OECD countries, Bourlès et al. (2010) found evidence that market regulation that hampers competition in markets of intermediate goods (upstream industries) has negatively affected TFP growth in industries purchasing the intermediate goods over the period 1985-2007. This effect seems to be more important the closer a given industry is to the world productivity frontier. In an analysis of productivity in market services based on EU KLEMS data, Inklaar et al. (2008) found that the reduction of barriers to entry had a positive impact on productivity in the telecommunications industry but this effect was not found in other services industries. Schmutzler (2010) stated that empirical work on the link between innovation (productivity) and competition is not very conclusive.

Human capital is regarded as a major determinant of productivity growth in many endogenous growth models (e.g. Lucas 1988 and Romer 1990). If the quality of workers is accounted for in the index of labour input and differences in productivity between workers are fully reflected in relative wages, there will not necessarily be any effect of human capital on TFP growth unless there are externalities of human capital (see Cameron et al. 2005). Apergis et al. (2009) found a long-run relationship between TFP, R&D spillovers and human capital. The inclusion of human capital in a regression of TFP reduced the estimated effects of R&D spillovers.

As other categories of capital goods, ICT equipment and software can contribute to productivity growth through capital deepening and TFP growth in ICT-producing industries (Oliner et al. 2007; Jorgenson et al. 2005). In addition, ICT may also generate productivity gains in other companies or industries through spillovers, although the presence and importance of these spillovers is the subject of some controversy in the economic literature. Two different types of ICT spillovers can be identified. (OECD 2004) First, as ICT is a general purpose technology, it may facilitate the reorganization of production at the level of firms, industries or the national economy, resulting in temporary acceleration of productivity growth (Van Leeuwen and van der Wiel 2003). ICT may also lead to greater efficiency in knowledge creation and enable firms to create new or better products or services, thereby increasing long term productivity growth (OECD 2002; Cohen et al. 2004). In OECD (2009) it is argued that the ICT industry is probably more important as a platform for innovation for the economy and society as a whole than for being a dynamic industry itself. Because processing, analysing and transferring information is fundamental to all economic activity - especially innovation - ICT advances have a fundamental impact on the nature of innovation itself. Network externalities are a second source of ICT spill-overs as the benefits of computer/internet usage increase when adopted by more users (Schreyer 2000). However, Basu et al. (2004) and Basu and Fernald (2006) pointed out that the short-run effect of ICT on TFP may be negative as reorganization and learning processes entail costs. Brynjolfsson and Hitt (2003) used data on U.S. firms over the period 1987-1994 to test for possible time lags in the impact of computers on output and productivity. They not only consider growth rates over one year but also differences over two and more years. The estimated impact of ICT on TFP growth rises as longer differences are considered, with the 7-year difference showing an impact that is five times as large as the 1-year difference. Econometric evidence of the effect of ICT investment on stock prices, reported by Brynjolffson, Hitt, and Yang (2002), suggests that as much as $9 of total investment is associated with $1 of ICT investment. In addition, as shown by van Ark and Inklaar (2005), the relation may be non-linear (U-shaped): the 'early normal returns' which are caused by the production and investment of IT are followed by periods of 'negative spillovers' that show up when firms develop capital complementarities. The empirical validation of spillovers is complicated by measurement problems which may cause a spurious link between TFP growth and ICT capital investment. As underlined by Oliner and Sichel (2002), if the quality adjustment used to estimate capital stocks were perfect, TFP would only pick up disembodied improvements. However, as investment data likely do not capture all quality improvements, the unmeasured part will be subsumed into TFP.

The econometric estimation of the impact of ICT on TFP is not straightforward, particularly at the industry level[5]. Some firm-level and industry-level analyses for the US suggest excess returns on investment in ICT capital relative to non-ICT capital (e.g. O'Mahony and Vecchi 2005) but other surveys conclude that the hypothesis of normal returns seems to hold (Stiroh 2004). Using Dutch data, van Leeuwen and van der Wiel (2003) conclude that, after accounting for ICT spillovers, the relatively high estimated elasticity of own ICT capital at the firm level is substantially reduced to levels that are more consistent with elasticity estimates for aggregated levels reported in growth accounting studies. Using a panel of international data covering nine market services over 1980-2004, Inklaar and Timmer (2008) failed to find a statistically significant link between ICT use and TFP growth. This result is confirmed in a more recent study, by Timmer et al. (2010), who even found a negative effect for Belgium. Based on country-level data, Venturini (2008) showed that both forms of technically advanced capital (R&D and IT) matter for long-run productivity growth. After controlling for either the domestic specialization in digital production or import penetration of high-tech goods, the national endowment of IT assets emerges as a robust source of spillovers. Luintel et al. (2010) using the ratio of ICT investment relative to GDP for a panel of 16 OECD countries showed that this non-R&D determinant has a significant positive impact on TFP.

In addition to being a channel for R&D spillovers, international trade may also affect productivity more directly through competitive pressure on domestic firms. Acharya and Keller (2008) estimated the impact of imports from the US on industry-level productivity in 16 countries, for 22 manufacturing industries over the period 1973-2002. In the short run, US imports have a positive pro-competitive effect on the productivity of domestic firms. In the long run, imports from the US appear to decrease productivity in domestic industries, by shifting profits from domestic to foreign firms. However, (high-tech) imports from the US result in R&D spillovers that counteract the negative impact through competition. Some empirical studies find indications that exporting raises the productivity of firms. The results of an analysis for Belgian manufacturing firms for the period 1998-2005 suggests that selection, i.e. the more productive firms in a given industry start exporting, is rather important whereas the evidence of a positive effect on productivity through exporting is not very robust. (Pisu 2008)

[5] Draca et al. (2007) provide a comprehensive survey of the empirical literature.

3. Estimation of the impact of the determinants of total factor productivity

In this paper, we assess the impact of determinants of total factor productivity for a panel of industries in Belgium. The econometric specification and the determinants that are used are in line with previous studies as discussed in section 2.

3.1. Econometric specification

In a number of recent papers the role of technology transfer for productivity growth is stressed for countries and industries that are behind the world technology frontier. Griffith et al. (2004) and Cameron et al. (2005) start from a first-order Autoregressive Distributed Lag (ADL) model that links the level of TFP of a given country (industry) i, $\ln TFP_i$ to the frontier TFP level, $\ln TFP^F$, i.e. the level of the country (industry) with the highest TFP of all countries considered:

$$\ln TFP_{i,t} = \alpha_1 \ln TFP_{i,t-1} + \beta_1 \ln TFP_t^F + \beta_2 \ln TFP_{t-1}^F + \varepsilon_{i,t} \tag{5}$$

From this ADL (1, 1) model Griffith et al. (2004) and Cameron et al. (2005) derive the following error correction model (ECM) specification, assuming long-run homogeneity, $(1-\alpha_1) = (\beta_1 + \beta_2)$:

$$\Delta \ln TFP_{i,t} = \beta_1 \Delta \ln TFP_t^F + (1-\alpha_1) \ln\left(\frac{TFP_{t-1}^F}{TFP_{i,t-1}}\right) + \varepsilon_{i,t} \tag{6}$$

If the coefficient of the second right-hand-side term, i.e. distance to the technology frontier, is positive, countries (industries) will witness higher productivity growth the further behind the technology frontier they are. The closer to the frontier, the smaller the role of technology transfer (imitation) for productivity growth and the more important innovation, e.g. as a result of own R&D activities, becomes. Griffith et al. (2004) and Cameron et al. (2005) included other determinants of TFP in specification (6) such as R&D, human capital and international trade as well as interaction terms of these variables with the distance to the frontier. The latter reflect the absorptive capacity of a given country (industry). To be able to absorb the knowledge produced by those at the technology frontier, own investment in R&D and human capital is needed.

Griffith et al. (2004) and Cameron et al. (2005) derive error-correction specification (6), by assuming long-run homogeneity in the parameters of specification (5). This provides a convenient econometric specification that links productivity growth to the distance to the frontier, as for instance proposed by Bernard and Jones (1996 a, b). However, there does not seem to be any overwhelming prior argument to impose long-run homogeneity. If the assumption is imposed when it does not hold, estimates of the long-run elasticity of the determinants will be biased. We have tested the hypothesis of long-run homogeneity $(1-\alpha_1) = (\beta_1 + \beta_2)$ in equation (5) using the Belgian industry-level data. The assumption was clearly rejected. Moreover, when we estimated specification (5) without imposing long-run homogeneity, i.e. with the lagged levels of $lnTFP_i$ and $lnTFP^F$ separately, only the coefficient of the lagged TFP level was statistically significant. The coefficient was negative, which suggests (conditional) convergence of TFP, i.e. those industries with the lowest TFP level witness the highest growth in TFP, but no convergence linked to the technology frontier, as the coefficients of the level as well as the growth of the TFP frontier were not significant. Given that the lagged TFP level is included with a negative sign in equation (6), a statistically significant positive effect of the distance to the frontier on productivity growth, appears to be explained predominantly by lagged TFP and not by the technology frontier. As a number of industries in Belgium were at - or close to - the technology frontier, it may be that the distance to the technology frontier was not relevant for productivity growth in Belgium over the period considered (see annex 6.5 for some graphical evidence on the link between distance to frontier and TFP growth and the initial TFP level and TFP growth).

Monte Carlo simulations (e.g. Stock and Watson 1993; Montalvo 1995 and Kao and Chiang 2000) have indicated that Dynamic Ordinary Least Squares (DOLS) generally results in estimates with a smaller bias than OLS and Fully Modified OLS, which are often used to estimate cointegration relationships. Kao et al. (1999) used dynamic Ordinary Least Squares (DOLS) to estimate the cointegration relationship between TFP and R&D and more recently Coe et al. (2009) have used DOLS to estimate the impact of domestic and foreign R&D on TFP for a panel of 24 countries over the period 1971-2004. A dynamic OLS specification can be specified as (e.g. Kao et al. 1999: p. 696):

$$\ln TFP_{i,t} = \alpha_i + \sum_{d=1}^{D} \beta_d \ln X_{i,t-1}^d + \sum_{d=1}^{D} \sum_{j=-L}^{F} \alpha_d \Delta \ln X_{i,t+j}^d + \varepsilon_{i,t} \tag{7}$$

As DOLS estimation focuses on the long-run (cointegration) relationship, the dependent variable is included in level rather than in growth. The most striking feature of DOLS is the inclusion of leads, in addition to lags, of the first differences of the determinants X^d. In Dynamic OLS estimation, the coefficients of the first differences are treated as nuisance parameters (e.g. due to serial correlation or endogeneity) rather than as economically meaningful estimates of short-run dynamics as in an error-correction framework (Stock and Watson 1993: p. 811).

3.2. Data

3.2.1. Data sources

The empirical analysis covers 24 Belgian industries (13 manufacturing industries, 7 services sectors and 4 other sectors) over the period 1987-2007. For these industries, we used data on TFP, R&D, ICT capital, human capital, market regulation, imports and exports.

TFP growth at the industry level is calculated following the growth accounting approach, using capital and labour services in order to take into account the improvement of quality over time. Data on inputs and outputs are taken from the EU KLEMS database (http://www.euklems.net/)

which provides detailed industry-level data for the EU Member States as well as for Australia, Canada, Japan, South-Korea and the United States. The volume of labour and capital services is estimated with a Törnqvist index that uses the average wage of each category of labour and the ex-post user cost of capital as weights to aggregate the different categories of hours worked and capital assets[6]. The use of services intends to improve the computation of the contribution of the production factors and hence of the TFP residual. To further refine the measurement of the TFP residual, hedonic prices are used for ICT capital inputs (computers, communication equipment and software) in order to take into account the frequent improvements in the quality of these assets[7].

The distance to the world technology frontier of industries has been computed considering annual TFP levels for all country-industry pairs. International comparison of productivity levels requires the use of purchasing power parities to convert all monetary variables to a common currency, taking into account differences in purchasing power between countries. Computation of TFP requires purchasing power parities (PPPs) for each industry and each variable included in the calculation of TFP, i.e. output as well as all inputs. The information needed to compute the TFP levels is described in detail by Inklaar and Timmer (2008). The authors have calculated comparative TFP levels for the benchmark year 1997 for 20 countries and 29 industries. The benchmark expresses the level of TFP for a given industry i in country j in terms of the level of TFP of this industry i in the United States (set equal to 1). Two estimations of TFP levels are available, one based on value added (VA) and the other based on gross output. Concerning the VA-based TFP level, two methods of deflation are used: a single deflated value added measure for which the PPPs for gross output are used to deflate value added and a double deflated measure obtained by independent comparisons of gross output and intermediate inputs with their specific PPPs. As double deflation provides a better estimation of the change in volume of value added, it is in principle more appropriate than single deflation. Indeed, considering an industry such as chemicals, in which prices of intermediate inputs (e.g. oil) fluctuate considerably and the opportunities to adjust output prices are limited due to strong competition, a single deflated measure would suggest a decrease in the volume of value added if input prices increase whereas a double deflated measure would provide a more stable volume of value added, as inputs are also deflated. Inklaar and Timmer (2008) only provide TFP levels for 1997. The time series needed for the econometric analysis are calculated by applying value added-based TFP growth rates relative to the level in the benchmark year 1997 (November 2009 release of the EU KLEMS database).

---

6 Hours worked are broken down by gender, age (3 categories), and level of educational attainment (3 categories). For capital assets, 9 categories are distinguished: 3 ICT assets (IT equipment, communication equipment and software) and 6 non-ICT assets (Products of Agriculture, hunting, forestry and fishing, Metal Products and Machinery, Transport equipment, Non-residential structures, Dwellings and Other products).

7 Since no hedonic price indices are available for ICT assets in Belgium, we used the US hedonic price indices. The method applied is proposed by Schreyer (2001). In order to make the harmonized price index of ICT goods in Belgium independent of the overall price levels in both countries, the price index differential of US ICT and non-ICT investment goods is used.

R&D stocks are computed according to the perpetual inventory method on the basis of R&D expenditures in constant prices. Data for the domestic R&D stocks are provided by the Belgian Science Policy Office and for foreign R&D stocks by the OECD (ANBERD database). Business R&D expenditures are expressed in constant US dollars (2000 PPPs prices). A number of assumptions have been made to fill missing values, e.g. average annual growth rates and proportionality factors.

Belgian inter-industry R&D stocks, included to estimate potential rent spillovers, were computed using weights derived from Supply and Use tables (SUT) from 1995 to 2005. Foreign R&D stocks were weighted using bilateral trade data by industry, provided by the National Bank of Belgium for the period 1995-2007 and by OECD (STAN) for the period before and SUT. Bilateral trade data are not available for services. Due to data availability, the number of trade partners considered for the construction of the Belgian foreign R&D stocks was restricted to 20 OECD countries, representing 85.7% of total Belgian imports in 2007: France, The Netherlands, Germany, Italy, United Kingdom, Ireland, Denmark, Greece, Portugal, Spain, Sweden, Finland, Austria, Poland, Czech Republic, Turkey, Norway, United States, Canada and Japan. To test for possible knowledge spillovers, Belgian and foreign R&D stocks were weighted on the basis of international patent citations matrices from 1990 to 2003, developed by UNU-MERIT in the framework of the Demeter project[8]. Canada, Norway and Turkey were not considered for the calculation of foreign R&D stocks, due to missing data. Inventors of both cited and citing patents are known by country and thus reflect the international flow of technological knowledge. Patents are classified using technology classes and industries according to the Yale/ OECD Concordance Table and aggregated by Demeter sectors.

The OECD considers two types of criteria to classify R&D expenditure by industry: by main activity or by product field. Allocating all R&D expenditures according to the principal activity of a firm may lead to a biased estimate of R&D spending, e.g. for large firms with important R&D activities in secondary activities. However, the advantage of this classification is its compatibility with industry-level National Accounts data. Data by product field are calculated by disaggregating the R&D expenditures of diversified firms into different activities. Belgium collects data both ways[9], contrary to most other countries. For Belgium, the two data series are used to estimate R&D stocks, for the other countries, when the two criteria are provided, the choice is made according to data availability.

Following the perpetual inventory method (Coe and Helpman 1995, Los and Verspagen 1999), the R&D stock of industry *i* at time *t* is equal to the new R&D expenditure at time *t* ($RD_{i,t}$) plus the R&D stock at time t-1 minus depreciation (with a depreciation rate of 15%)[10]:

---

8 European project which aimed to build a system of tools based on applied modelling that can be used for ex ante evaluation of research and innovation policies at sector and European level (http://demeter-project.eu).

9 R&D expenditures by industry according to the main activity are available over the period 1999-2007. Retropolations were made, based on the growth in R&D expenditures by product available over 1977-2007.

10 Many empirical studies assume an arbitrary annual depreciation rate of 10% to15%. Guellec and van Pottelsberghe (2001) mention that according to sensibility analysis, the results of the regressions do not change significantly with the chosen depreciation rate. Nadiri and Prucha (1996), applying a model of factor demand to estimate the deprecia-

$$R_{i,t} = RD_{i,t} + (1-\delta) \cdot R_{i,t-1} \tag{8}$$

The use of R&D stocks in a model expressed in logarithms allows for the direct estimation of the output elasticity with respect to different R&D stocks. This elasticity is assumed to be constant[11]. The coefficient of the industry-level R&D stocks in the TFP regression does not only capture the impact of the own R&D activities of firms but also the effects of competitors' R&D activities on TFP, i.e. intra-industry R&D spillovers.

To test for potential rent spillovers, inter-industry domestic stocks $\left(R_{i,t}^{inter}\right)$ for industry i are constructed as a weighted sum of the other industries' R&D stocks:

$$R_{i,t}^{inter} = \sum_{j=1, j \neq i}^{N} \frac{I_{ji,t}}{VA_{i,t}} \cdot R_{j,t} \tag{9}$$

where $R_{j,t}$ is the R&D stock of product j, $I_{ji,t}$ the domestic intermediate inputs from j to i and $VA_{i,t}$ value added of industry i.

Supply and use tables are product-by-industry matrices, i.e. $I_{ji,t}$ denotes the intermediate inputs of product j purchased by industry i. Given that, for Belgium, R&D expenditures are available by main activity and by product, the construction of R&D stocks by product j rather than by industry j is preferred with intermediate inputs as weight.

The foreign R&D stock $\left(R_{i,t}^{for}\right)$ for each Belgian industry i is constructed in a similar way:

$$R_{i,t}^{for} = \sum_{j=1}^{N} \sum_{k=1}^{K} \frac{I_{ji,t} \cdot \frac{M_{j,t}^{K}}{M_{j,t}}}{VA_{i,t}} \cdot R_{j,t}^{K} \tag{10}$$

where $R_{j,t}^{K}$ is the R&D stock of industry/product j in country K, $I_{ji,t}$ imported intermediate inputs of product j by industry i, $\frac{M_{j,t}^{K}}{M_{j,t}}$ the share of country K in total Belgian imports of products j and $VA_{j,t}$ the value added of industry i in Belgium. Due to data availability, imports from different countries are assumed to have the same industry-specific distribution[12]. Similar to domestic R&D stocks, the foreign R&D stock of industry i can be divided into two categories: an

tion rate of R&D for the US manufacturing sector, find a 12% depreciation rate. See Annex 6.1 for the estimation of the initial stock.

11 An alternative approach is also treated in the literature on R&D spillovers. By setting the depreciation rate to zero, stocks are replaced by R&D intensity (R&D expenditures over output or value added). In this model, estimated coefficients are constant rates of return. This alternative model allows the elasticity derived from the rates of return to vary across industries. If β is R&D elasticity, R is R&D stock with r = log (R) and RD is R&D expenditure:
$\beta \dot{r} = (\partial Q / \partial R)(R/Q)(\dot{R}/R) = \rho \, \dot{R}/Q = \rho \, (RD - \delta R)/Q \approx \rho \, RD/Q$

12 For instance, Belgian imports of chemical goods from Germany are distributed over Belgian industries in the same way as Belgian imports of chemical goods from the US.

intra-industry foreign stock that is the weighted sum of R&D stocks of industries *i* abroad and an inter-industry foreign stock that is the weighted sum of other industries' R&D stocks.

The construction of domestic and foreign R&D stocks using data on intermediate inputs permits to test for rent spillovers. However, knowledge spillovers may be associated with rent spillovers. Indeed, if an industry purchases intermediate inputs from another industry, they are more likely to be technologically similar and to benefit from each other's innovations (van Pottelsberghe, 1997). It is not possible to clearly distinguish the two categories of spillovers resulting from these economic transactions.

To test for potential knowledge spillovers, another type of domestic and foreign R&D stocks was constructed using international patent citations matrices[13]. A patent citation can be related to a knowledge flow from the cited country/industry to the citing country/industry. Using this information provides a domestic stock $\left(R_{i,t}^{dom,know}\right)$ and a foreign R&D stock $\left(R_{i,t}^{for,know}\right)$ for Belgian industry *i*, constructed in a similar way:

$$R_{i,t}^{dom(for),know} = \sum_{j=1}^{N} a_{ji,t} \cdot R_{j,t} \qquad (11)$$

where $R_{j,t}^{know}$ is the R&D stock of industry/country *j*, $a_{ji,t}$ is the number of citations from the cited country/sector *j* to the citing Belgian sector *i* divided by the total citations towards the Belgian industries.

The ICT variable denotes the share of ICT capital in total capital compensation (EU KLEMS database). For human capital, the share of high-skilled workers in the total number of hours worked (EU KLEMS database) was used, with high-skilled workers defined as workers with a university or two-cycle non-university tertiary degree.

The variable on market regulation follows the OECD method of knock-on effects of industry-level regulation upon other industries (Conway and Nicoletti 2006). It builds on the idea that the performance of an industry is not only affected by its own regulation, but also by the regulation of upstream industries (Bourlès et al., 2010):

$$REG_{jt} = \sum_{i=1}^{I} PMR_{it} \cdot L_{ijt} \qquad (12)$$

PMR is an indicator of the strictness of regulation in industry *i* and year *t*. L_{ijt} is the Leontief multiplier showing the output of industry *i* generated by one euro of demand for industry *j*'s products in year *t*. This includes direct sales from *i* to *j* and indirect sales via the production processes of other industries. Although the index for Belgium is available in the OECD database, it has been recalculated to make the best use of available domestic data and to concordat with the industry classification applied in this study (see Braila et al. 2010 and Bourlès et al. 2010 for details on the market regulation indicator).

---

13 Kindly provided by Huub Meijers (UNU-MERIT).

Although many industries may have specific regulation, the focus of PMR is on certain heavily regulated industries. For energy, certain transport industries, postal services and telecommunications, the time series have been taken from the ETCR database of the OECD (see Wölfl et al. 2009). For retail trade, a time series has been taken from Van der Linden (2010). For legal, architectural, accounting and engineering services no time series are available. Instead the RBSR database of the OECD holds observations for 1996, 2003 and 2008 (Conway & Nicoletti 2006). Time series were constructed by applying observations for 1996 to the period 1986-1996 and by interpolating for 1997-2007. All series were normalised and averages were taken where necessary.

Input-Output tables (NACE Rev.1) are available for 1995, 2000 and 2005 (Federal Planning Bureau 2010). A procedure like the one of RBSR has been applied to provide time series of Leontief multipliers: the 1995 multipliers for 1986-1995; interpolations for 1996-2004; the 2005 multipliers for 2005-2007. Leontief multipliers appear to be relatively stable over time. Before calculating the multipliers, Input-Output tables were aggregated from 60 to 36 industries. This is more detailed than the industry classification applied in this study, but makes better use of the detail of the PMR indicators. The regulation variable used in our analysis was derived from these REG variables, using weighted averages.

Industries that do not strongly depend on inputs from heavily regulated industries have a low score on the index. Industries that depend more substantially on inputs from heavily regulated industries have a higher score on the index, with the highest scores for the heavily regulated industries themselves.

Finally, we used the share of high-skilled workers in the total number of hours worked (from the EU KLEMS database) as a human capital variable, import intensity (imports/value added) to test for the impact of import competition and export intensity (exports/value added) to assess potential productivity gains of exporting. Both international trade variables were based on OECD STAN data.

3.2.2. Evolution of main variables by industry

As table A.1 in annex 6.3 shows, over the period considered, the largest industries in terms of nominal value added and hours worked were: Chemicals, Basic metals and Food products in manufacturing; Wholesale and retail trade and Renting of material and equipment and other business activities in market services and Construction.

Between 1987 and 2007, the share of market services in total value added and hours worked increased considerably, from 43.4% of value added in 1987 to 52.1% in 2007 and from 37.3% of total hours worked in 1987 to 44.9% in 2007. The relative importance of Renting of material and equipment and other business activities also increased substantially between 1987 and 2007.

The relative importance of manufacturing declined steadily over the period. This appears to have particularly been the case for Textiles, and to a lesser extent for Electrical and optical equipment, Transport equipment and Manufacturing (not elsewhere classified); recycling principally in terms of hours worked.

Table 1 shows TFP levels for the years 1987, 1997 and 2007 and the annual average growth rate between these years. Over the whole period considered, 10 out of 24 industries recorded on average an increase in TFP. These industries are Textiles, Wood, Rubber and plastics products, Basic metals, Machinery, Electrical and optical equipment, Electricity, gas and water supply, Construction, Post and telecommunications and Financial intermediation.

Table 1 TFP level and annual average growth rates (1987, 1997 and 2007) by industry

Industry	1987	1997	2007	1987-1997	1997-2007
Agriculture, hunting, forestry and fishing	0.51	0.74	0.68	3.73	-0.86
Mining and quarrying	2.08	1.51	1.44	-3.26	-0.41
Food products, beverages and tobacco	1.29	1.22	1.21	-0.54	-0.07
Textiles, textile products, leather and footwear	0.79	1.20	1.45	4.17	1.91
Wood and products of wood and cork	0.65	0.68	0.98	0.46	3.70
Pulp, paper, paper products, printing and publishing	1.38	1.31	1.49	-0.54	1.25
Coke, refined petroleum products and nuclear fuel	1.39	0.94	0.79	-3.86	-1.75
Chemicals and chemical products	1.76	1.68	1.47	-0.48	-1.32
Rubber and plastics products	3.85	5.02	7.46	2.64	3.96
Other non-metallic mineral products	1.67	1.94	1.82	1.50	-0.64
Basic metals and fabricated metal products	0.97	1.07	1.17	1.03	0.90
Machinery, not elsewhere classified (n.e.c.)	1.11	1.11	1.43	0.02	2.50
Electrical and optical equipment	0.62	0.71	0.91	0.25	2.52
Transport equipment	0.31	0.32	0.30	0.10	-0.69
Manufacturing (n.e.c.); recycling	1.64	1.60	1.82	-0.22	1.24
Electricity, gas and water supply	0.48	0.58	0.59	1.90	0.22
Construction	1.15	1.16	1.23	0.15	0.54
Wholesale and retail trade	2.06	1.55	1.38	-2.83	-1.15
Hotels and restaurants	0.93	0.82	0.75	-1.23	-0.97
Transport and storage	0.29	0.37	0.33	2.52	-1.15
Post and telecommunications	0.64	0.88	1.10	3.16	2.23
Financial intermediation	0.86	1.22	1.60	3.45	2.76
Real estate activities	1.06	1.03	0.94	-0.28	-0.93
Renting of material and equipment and other business activities	0.78	0.77	0.64	-0.20	-1.78

Source: Own computations based on EU KLEMS data.

By contrast, eight industries recorded a decrease in TFP over the periods 1987-1997 and 1997-2007: Mining, Food, Coke, Chemicals, Trade, Hotels and restaurants, Real estate activities and Renting of material and equipment and other business activities.

Some industries moved from a positive annual average growth rate over 1987-1997 to a negative growth rate over 1997-2007. This was the case for Agriculture, Other non-metallic mineral products, Transport equipment and Transport and storage, whereas two industries improved their TFP growth by moving from a negative growth over 1987-1997 to a positive growth over 1997-2007: Pulp, paper and Manufacturing (n.e.c) and recycling.

The TFP level of Rubber and plastics product was well above the TFP of other industries over the entire period.

The world technology frontier for a given industry in a given year is defined as the highest level of TFP, across the group of countries that are considered. This implies that the leading country for each industry may change over time, as shown in table 2 for the years 1987, 1997 and 2007. In 2007, the USA was the world leader in terms of TFP in only four out of the 24 industries in the list, e.g. Transport equipment and Business activities. In the same year, Belgium had the highest TFP level in Textiles, textile products, leather and footwear and in Rubber and plastics products. In 1987, Belgium was still TFP leader in five industries (e.g. Food products, beverages and tobacco but also in Chemicals and chemical products) and in 1997 in four industries.

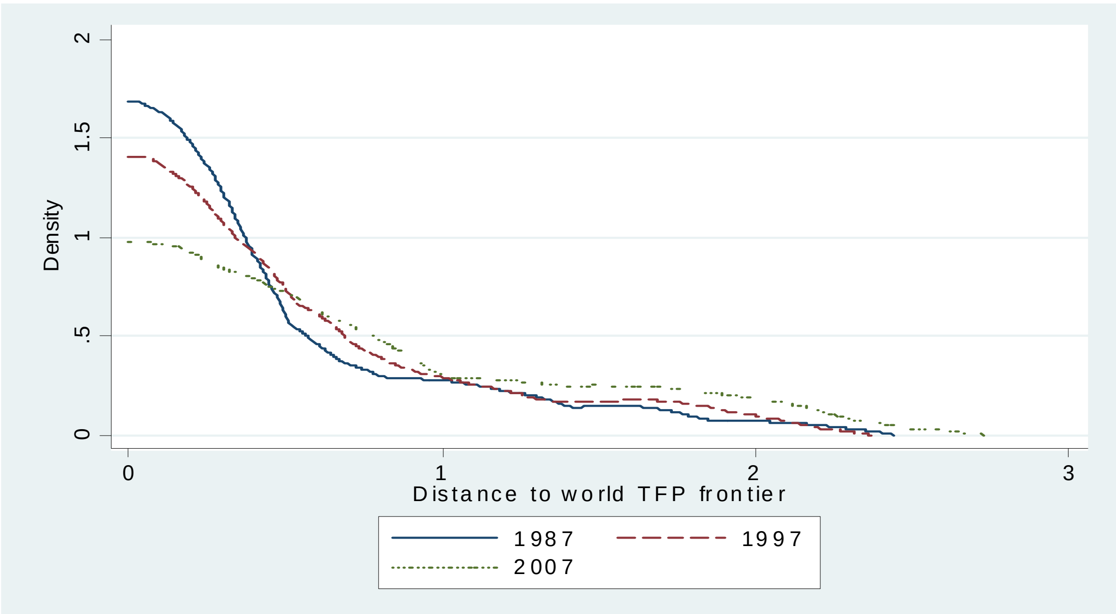
Table 2 Country with highest TFP level by industry (1987, 1997 and 2007)

Industry	1987	1997	2007
Agriculture, hunting, forestry and fishing	USA	USA	USA
Mining and quarrying	NLD	NLD	NLD
Food products, beverages and tobacco	BE	NLD	NLD
Textiles, textile products, leather and footwear	NLD	BE	BE
Wood and products of wood and cork	ESP	FIN	FRA
Pulp, paper, paper products, printing and publishing	BE	BE	FIN
Coke, refined petroleum products and nuclear fuel	UK	FRA	UK
Chemicals and chemical products	BE	FIN	NLD
Rubber and plastics products	BE	BE	BE
Other non-metallic mineral products	ITA	ITA	CZE
Basic metals and fabricated metal products	FRA	ITA	FIN
Machinery, not elsewhere classified (n.e.c.)	UK	HUN	HUN
Electrical and optical equipment	ITA	USA	SWE
Transport equipment	ITA	ITA	USA
Manufacturing (n.e.c.); recycling	UK	UK	UK
Electricity, gas and water supply	USA	SWE	SWE
Construction	AUS	FIN	AUS
Wholesale and retail trade	BE	BE	FIN
Hotels and restaurants	ESP	USA	USA
Transport and storage	NLD	NLD	NLD
Post and telecommunications	UK	SWE	SWE
Financial intermediation	ESP	AUS	ESP
Real estate activities	ITA	IRL	HUN
Renting of material & eq. and other business activities	USA	USA	USA

Source: Own computations based on EU KLEMS data.

The evolution over time of the world technology frontier differs between industries (see Annex 6.4 for a graphical illustration of the evolution of the world technology (TFP) frontier by industry). Three main categories of industries can be distinguished based on the growth of the frontier: Fast growing industries including Electrical and optical equipment (30t33), Post and telecoms (64), Machinery (29), Rubber and plastics products (25) and Chemicals (24); stagnant or declining industries including Mining and quarrying (C), Renting and business services (71t74), Hotels and restaurants (H), Trade (50t52), Wood (20), Coke, refined petroleum products (23) and Manufacturing n.e.c. (36t37) and finally a group of industries that have witnessed slow growth. The group of fast growing industries is characterised by a rapid increase in the dispersion of TFP level across countries, measured by the standard deviation, particularly since the second half of the 1990s. By contrast, industries in the stable or declining group are characterised by stable or increasing convergence across countries. This kind of contrasting convergence patterns across industries is also confirmed by Bernard and Jones (1996 b) and by Timmer et al. (2010). Graph 2 shows the distribution of the distance to the world TFP frontier across Belgian industries in 1987, 1997 and 2007. In line with the evolution of GDP per hour worked shown in graph 1 and the list of world leaders in table 2, Belgium appears to have fallen behind over the period considered as more industries have witnessed an increase in the gap with regard to the TFP frontier.

Graph 2 Kernel density plot of distance to world technology frontier of Belgian industries (1987-1997-2007)



Note: The kernel density plot provides a non-parametric estimate of the underlying density function of the distance of Belgian industries to the world TFP frontier in the three respective years. As the distance to frontier has a lower bound of zero, the STATA procedure kdens was used with the reflection option.

Table 3 shows the R&D intensity and the industry-level R&D stocks by industry (classified according to main activity)[14] over the period 1987-2007. It appears that R&D activity is highly concentrated in a small number of knowledge intensive manufacturing industries: Chemicals and chemical products, Electrical and optical equipment and, at a considerably distance, Machinery (not elsewhere classified), Transport equipment, Rubber and plastics products (R&D intensity), Basic metals and fabricated metal products (R&D stocks), Renting of material and equipment and other business activities (R&D stocks). The non-manufacturing sectors recorded particu-

14 For Belgium, R&D expenditures by industry according to the main activity are available over the period 1999-2007. Retropolations were made, based on the growth in R&D expenditures by product available over 1977-2007.

larly low levels of R&D intensity. Most industries witnessed an increase in R&D intensity and R&D stocks. Electrical and optical equipment recorded a strong decrease in R&D intensity as well as in the R&D stock.

Table 3 R&D intensity (R&D expenditure in % of value added) and industry-level R&D stocks (millions constant (2000) PPP US dollars)

	R&D Intensity			R&D stocks		
Industry	1987	1997	2007	1987	1997	2007
Agriculture, hunting, forestry and fishing	0.35	0.68	1.08	71.7	134.3	138.4
Mining and quarrying	0.00	0.48	0.61	0.0	10.4	15.7
Food products, beverages and tobacco	0.60	1.02	1.48	172.6	313.7	552.5
Textiles, textile products, leather and footwear	0.96	1.93	2.64	155.4	273.6	332.8
Wood and products of wood and cork	0.57	0.88	0.59	24.1	34.2	34.7
Pulp, paper, paper products, printing and publishing	0.53	1.13	0.41	90.0	226.4	149.4
Coke, refined petroleum products and nuclear fuel	1.45	2.96	0.83	111.6	217.6	153.6
Chemicals and chemical products	9.54	10.91	15.17	3204.4	4875.1	7162.8
Rubber and plastics products	1.22	4.78	5.54	67.1	362.0	557.5
Other non-metallic mineral products	1.62	2.71	1.93	199.5	306.4	322.9
Basic metals and fabricated metal products	2.85	2.27	1.98	1361.3	1071.1	1117.1
Machinery, not elsewhere classified (n.e.c.)	5.21	5.85	7.13	699.2	954.0	1314.5
Electrical and optical equipment	28.53	22.38	19.82	6995.7	5976.1	5124.6
Transport equipment	1.95	3.07	5.31	528.0	738.1	988.1
Manufacturing (n.e.c.); recycling	0.35	1.97	1.16	27.6	109.4	128.9
Electricity, gas and water supply	0.01	0.05	0.11	2.8	12.6	28.7
Construction	0.35	0.78	0.36	181.0	320.9	345.2
Wholesale and retail trade	0.00	0.11	0.20	6.2	146.9	411.9
Hotels and restaurants	0.00	0.05	0.03	6.0	9.1	16.2
Transport and storage	0.01	0.24	0.08	3.0	125.7	183.7
Post and Telecommunications*	0.00	0.38	2.12	0.0	84.3	617.2
Financial intermediation	0.15	0.26	0.51	82.1	158.3	321.7
Real estate activities	0.23	0.01	0.00	256.5	79.9	19.0
Renting of material &equipment and other business activities	0.54	1.74	2.29	395.0	1793.3	4795.1

Source: Own computations based on OECD data.

(*) “Post and telecommunications” is reduced to telecommunications for R&D expenditures.

Between 1987 and 2007, the R&D stock increased substantially in some industries, especially in industries with small R&D stocks at the beginning of the period considered, i.e. Mining, Electricity, Trade, Transport and storage, Post and Telecommunications but also in industries with a high initial stock, e.g. Rubber and plastics products and Renting of material and equipment and other business activities.

Table 4 Inter-industry domestic R&D stocks and foreign R&D stocks (I/O-weighted) (millions constant (2000) PPP US dollars)

	Inter-industry domestic stocks			Foreign stocks		
Industry	1987	1997	2007	1987	1997	2007
Agriculture, hunting, forestry and fishing	309.7	464.7	1043.3	1496.1	2339.0	2651.4
Mining and quarrying	207.5	393.1	615.9	1052.1	1466.9	1389.7
Food products, beverages and tobacco	174.5	622.5	1148.8	1583.0	1899.0	3995.6
Textiles, textile products, leather and footwear	629.9	982.4	1170.9	6414.7	9796.7	12325.2
Wood and products of wood and cork	558.4	816.1	1030.9	1760.0	2168.4	4508.3
Pulp, paper, paper products, printing and publishing	160.6	364.0	1024.7	1503.8	2189.4	2985.1
Coke, refined petroleum products and nuclear fuel	2373.5	892.6	4582.8	34360.2	46753.1	42126.0
Chemicals and chemical products	46.3	214.4	715.1	16397.8	26867.0	30841.3
Rubber and plastics products	2144.5	3077.6	1562.3	14283.2	22430.5	19005.4
Other non-metallic mineral products	218.1	449.7	723.4	1516.0	2105.9	3461.5
Basic metals and fabricated metal products	133.6	344.0	699.5	4538.3	5065.3	5098.3
Machinery, not elsewhere classified (n.e.c.)	344.2	373.9	882.1	14463.3	18073.5	15493.6
Electrical and optical equipment	179.6	206.6	738.8	27558.7	30510.8	25362.2
Transport equipment	259.1	547.3	758.2	95481.2	102753.2	121152.6
Manufacturing (n.e.c.); recycling	406.9	489.6	1568.4	1492.7	1789.5	7814.4
Electricity, gas and water supply	137.8	259.5	562.8	2298.8	2283.8	460.3
Construction	276.9	534.1	862.5	1658.5	1697.0	1827.5
Wholesale and retail trade	90.4	460.6	819.3	1391.9	1801.0	3917.2
Hotels and restaurants	179.8	537.7	1110.7	176.5	316.7	490.8
Transport and storage	100.4	367.2	547.8	874.2	1283.1	883.4
Post and telecommunications*	21.3	140.8	514.6	49.0	71.5	1963.0
Financial intermediation	25.1	165.0	620.3	303.0	392.4	54.7
Real estate activities	60.1	88.6	177.7	32.5	44.9	43.2
Renting of material &equipment and other business activities	62.4	108.3	102.2	805.6	974.0	662.9

Source: Own computations based on OECD data.

(*) The industry "Post and telecommunications" is reduced to telecommunications for R&D expenditures.

Table 4 shows inter-industry domestic R&D stocks and foreign R&D stocks by industry in 1987, 1997 and 2007. At the end of the period, inter-industry domestic stocks are particularly high in Coke, Rubber and plastics and in Other manufacturing (n.e.c) and recycling. Rubber and plastics, having a high stock at the beginning of the period, is the only industry that witnessed a decrease of its inter-industry domestic stock due to the lesser use of R&D-intensive domestic intermediate inputs. Coke, refined petroleum products and nuclear fuel is the industry using most domestic intermediate inputs relative to value added and so can benefit more from the R&D in the other industries. All other industries recorded an increase in the inter-industry domestic stock, with the increase being important in three industries with small initial stocks: Telecommunications, Chemicals and chemical products and Wholesale and retail trade.

Foreign R&D stocks were particularly high in Transport equipment, which uses a lot of imported intermediate inputs from R&D intensive industries. To a lesser extent, Coke, Chemicals and Electrical and optical equipment also had substantial foreign R&D stocks. All manufacturing industries recorded an increase in their foreign R&D stock, with the exception of Electrical and optical equipment. The increase of foreign R&D stocks is particularly important in Manufacturing n.e.c. and recycling. In services sectors, foreign R&D stocks are generally lower than in manufacturing, which to some extent can be explained by the fact that, due to the availability of imports data, only the spillovers from the manufacturing towards services can be taken into account. Telecommunications, which at the beginning of the period had a small foreign R&D stock, witnessed strong growth over the period.

Table 5 Inter-industry domestic R&D stocks and foreign R&D stocks (patent-weighted spillovers) (millions constant (2000) PPP US dollars)

	Inter-industry domestic stocks			Foreign stocks		
Industry	1987	1997	2007	1987	1997	2007
Agriculture, hunting, forestry and fishing	0.7	0.1	1.5	36.4	39.0	76.7
Mining and quarrying	0.0	0.0	0.0	4.7	4.7	5.7
Food products, beverages and tobacco	2.3	1.8	6.3	117.5	203.6	427.2
Textiles, textile products, leather and footwear	3.2	5.2	4.0	297.6	411.6	455.5
Wood and products of wood and cork	14.4	20.0	32.6	1729.2	2467.5	3079.7
Pulp, paper, paper products, printing and publishing	8.9	10.9	16.5	610.9	652.5	965.3
Coke, refined petroleum products and nuclear fuel	0.5	1.5	0.7	97.1	99.8	96.6
Chemicals and chemical products	22.8	25.2	28.6	10561.3	15764.7	18618.3
Rubber and plastics products	15.8	17.9	20.3	1628.7	1612.2	2153.3
Other non-metallic mineral products	3.8	4.1	4.4	420.1	402.2	507.4
Basic metals and fabricated metal products	4.9	5.2	7.0	508.5	786.8	928.3
Machinery, not elsewhere classified (n.e.c.)	38.2	61.5	66.1	6552.4	12004.4	12379.2
Electrical and optical equipment	13.4	20.4	43.0	10515.2	25354.6	29118.6
Transport equipment	2.2	3.5	8.1	816.1	2122.5	2096.1
Manufacturing (n.e.c.); recycling	14.4	20.0	32.5	1729.2	2467.5	3079.7
Electricity, gas and water supply	0.0	0.0	0.0	1.5	1.2	3.5
Construction	0.2	0.1	1.3	15.9	13.9	33.4
Wholesale and retail trade	0.0	0.0	0.1	2.1	4.6	4.9
Hotels and restaurants	0.0	0.0	0.0	0.0	0.0	0.0
Transport and storage	0.0	0.0	0.0	2.2	4.8	1.9
Post and telecommunications*	0.0	0.0	0.0	0.9	1.7	0.5
Financial intermediation	0.0	0.0	0.0	1.3	3.2	1.3
Real estate activities, renting of material & equipment and other business activities	0.5	1.2	0.3	32.4	43.4	22.7

Source: Own computations based on OECD data.

(*) The industry “Post and telecommunications” is reduced to telecommunications for R&D expenditures.

Table 5 shows, for the Belgian industries, the inter-industry domestic and foreign R&D stocks, based on patent citations, over the period 1987-2007. The largest stocks are found in manufacturing industries. Inter-industry domestic stocks and foreign stocks are particularly high in Machinery (not elsewhere classified) and Electrical and optical equipment. Chemicals and chemical products and to a lesser extent Wood, Rubber and plastics products and Manufacturing (not elsewhere classified) and recycling also have large foreign R&D stocks and high inter-industry domestic stocks.

The strongest growths in inter-industry domestic stocks are observed in Electrical and optical equipment, in Transport equipment and in Construction. The strongest growths in foreign stocks are observed in Electrical and optical equipment, in Transport equipment and in Food products, beverages and tobacco. Strong growths over the period considered are often associated with small stocks in 1987.

In empirical studies, different measures of ICT capital are used, in line with the improvement of available data, e.g. ICT investment as a share of total investment or ICT capital compensation as a share of total capital compensation. In this paper, we opt for this most recent measure as it constitutes the best way to take into account the quality improvement in ICT equipment.

Table 6 ICT capital compensation as a share of total capital compensation (in %)

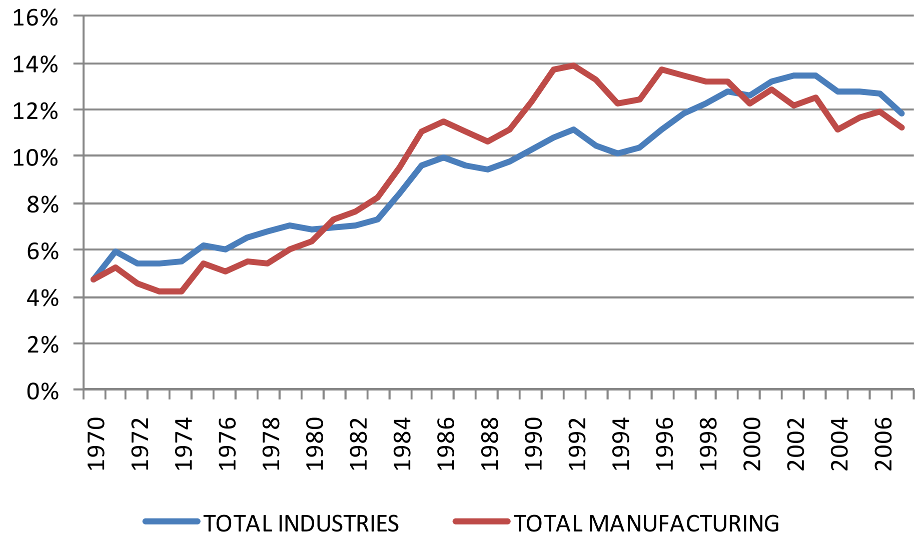
Industry	1987	1997	2007
Agriculture, hunting, forestry and fishing	2.4	1.5	0.3
Mining and quarrying	3.0	3.1	3.3
Food products, beverages and tobacco	6.2	6.7	8.6
Textiles, textile products, leather and footwear	11.0	11.9	8.8
Wood and products of wood and cork	9.2	7.3	4.4
Pulp, paper, paper products, printing and publishing	19.0	21.5	14.9
Coke, refined petroleum products and nuclear fuel	15.6	12.0	15.6
Chemicals and chemical products	5.9	11.8	15.2
Rubber and plastics products	10.8	8.1	6.0
Other non-metallic mineral products	5.1	5.2	4.9
Basic metals and fabricated metal products	9.3	13.6	6.7
Machinery, not elsewhere classified (n.e.c.)	17.0	15.0	10.8
Electrical and optical equipment	38.5	39.3	25.4
Transport equipment	6.5	8.1	16.0*
Manufacturing (n.e.c.); recycling	13.3	7.5	4.6
Electricity, gas and water supply	2.6	3.5	8.5
Construction	4.5	5.1	4.4
Wholesale and retail trade	12.7	15.2	13.3
Hotels and restaurants	12.6	13.0	7.6
Transport and storage	10.9	12.9	7.3
Post and telecommunications	27.7	47.7	30.3
Financial intermediation	32.3	31.5	23.0
Real estate activities	3.1	1.7	3.7
Renting of material &equipment and other business activities	13.6	17.7	25.9

Source: Own calculations based on EU KLEMS data.
* 2006 i.s.o.2007 (no capital compensation in 2007 because of the redundancy payments made following the closure of production facilities).

As table 6 shows, the accumulation of ICT is characterized by a high degree of cross-industry heterogeneity, in levels as well as in growth. Not surprisingly, ICT industries (Electrical and optical equipment and Post and telecommunications) had the highest ratio of ICT compensation over the period, but the ratio decreased substantially between 1997 and 2007. The ratio is particularly low for Agriculture; Mining and quarrying and Real estate activities.

Graph 3, covering a longer period, shows the difference in pattern of ICT diffusion between manufacturing industries and services industries. For manufacturing, ICT accumulation mainly occurred during the 1980s, reaching a peak in 1992, whereas in services, it occurred later, explaining the continuing increase in the ratio for total industries until 2003.

Graph 3 ICT capital compensation as a share of total capital compensation, 1970-2007 (in %)



Note: Own calculations based on EU KLEMS data

3.3. Estimation

Due to the unreliability of some data, three industries were not considered in the estimation: Agriculture, hunting, forestry and fishing; Mining and quarrying and Real estate activities. For the same reasons, the first year of our observations (1987) was also excluded. This leaves us with a panel of 21 industries over the period 1988-2007.

All variables appear to be stationary in first differences (see annex 6.6 on the stationarity of time series). The results of the panel unit root tests indicate that a regression in levels may suffer from spurious regression. To avoid this problem, we applied Dynamic OLS, as specified by equation (7).

We have estimated DOLS specification (7), including two lags and one lead for the first differences of the explanatory variables. To account for possible heteroskedasticity and autocorrelation we used the Feasible Generalized Least Squares procedure for panels in Stata (XTGLS) with a panel-specific AR(1) process. To test for the stationarity of the time series we used two types of panel unit root tests (XTUNIT in Stata), the test proposed by Im et al. (2003) and the combination of four tests proposed by Choi (2001). Both show that all variables are non-stationary in levels although there are some indications of stationarity for a number of R&D stocks.

Table 7 shows the results for a panel regression of all 21 industries, i.e. manufacturing, construction, utilities and market services. The second column shows the results of a specification in which inter-industry and foreign R&D stocks using input-output weights as well as stocks based on patent data are included to test for rent and knowledge spillovers respectively. Due to the strong correlation between most R&D stocks, which may bias the results, we also did estimations considering the input-output weighted R&D stocks (column 3) and the patent-based R&D stocks (column 4) separately. All R&D stocks are expressed in logarithms, as is TFP. The coefficients of the R&D stocks can therefore be interpreted as constant elasticity estimates, i.e. a coefficient of 0.5 suggests that an increase by 10% in the given R&D stock will result in an increase by 5% in TFP. The ICT variable is also expressed in logarithms but the market regulation indicator, which is a bounded variable, is not. The specification in which all R&D stocks are considered indicates statistically significant positive domestic inter-industry rent spillovers and foreign knowledge spillovers. Both effects appear to be robust when considering input-output stocks and patent-based stocks separately. The negative impact of the domestic intra-industry R&D stock and the foreign inter-industry R&D stock in the rent spillovers specification (column 3) is not statistically significant when patent-based R&D stocks are controlled for. As will be shown in the regressions for separate groups of industries, the effects of R&D on TFP differ substantially between manufacturing industries and the group of construction, utilities and services. A finding in table 7 that appears to be more robust over all industries is the negative coefficient of the ICT variable, which is significantly negative in most of the specifications that were considered. Although this result is somewhat surprising, it is in line with the negative effect of ICT reported for Belgium by Inklaar and Timmer (2008).

Table 7 Dynamic OLS estimation of the determinants of TFP for a panel of Belgian industries (1988-2007)

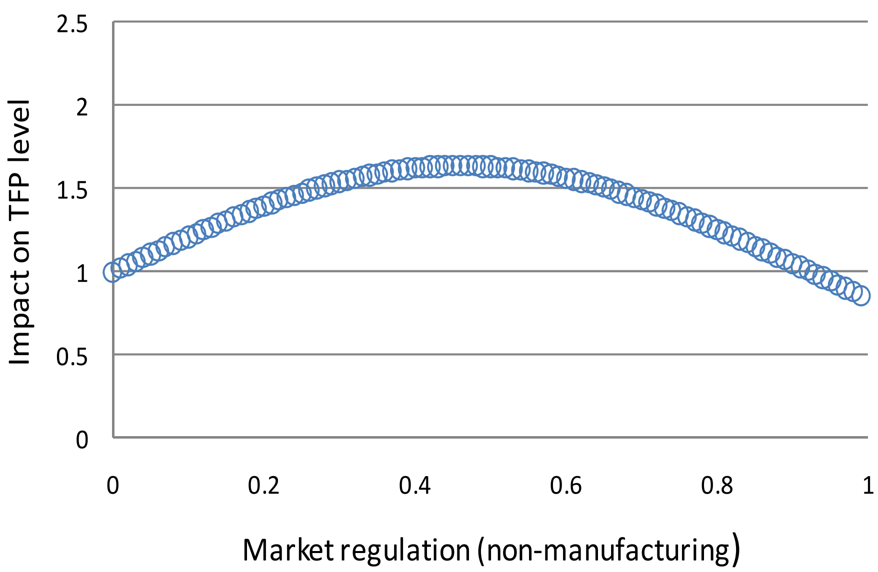
Dependent variable: $\ln TFP_{i,t}$	All	Rent	Knowledge
Domestic intra-industry R&D	-0.02 (-0.79)	-0.10 (-4.81) ***	-0.00 (-0.10)
Domestic inter-industry R&D (I/O-weighted)	0.08 (3.36) ***	0.14 (8.75) ***	-
Domestic R&D (patent-weighted)	0.01 (0.75)	-	0.02 (1.49)
Foreign intra-industry R&D (I/O-weighted)	0.00 (0.08)	0.00 (0.14)	-
Foreign inter-industry R&D (I/O-weighted)	0.00 (0.17)	-0.05 (-3.74) ***	-
Foreign R&D (patent-weighted)	0.11 (3.01) ***		0.10 (3.37) ***
ICT	-0.19 (-4.25) ***	-0.21 (-5.11) ***	-0.17 (-3.64) ***
Market regulation	2.14 (4.94) ***	2.94 (8.63) ***	1.71 (4.64) ***
Market regulation^2	-2.32 (-6.12) ***	-3.29 (-11.17) ***	-2.10 (-6.24) ***
Number of observations	288	336	288

Note: The table shows the results of a Dynamic Ordinary Least Squares, see equation (7), in which two lags and one lead have been included for the first differences of the explanatory variables. The coefficients of first differences, which in DOLS are considered as nuisance parameters, are not reported for reasons of clarity. For the same reason, the industry-specific intercepts (fixed effects) that have been included in the estimation, are not reported. The estimation accounts for potential heteroskedasticity and autocorrelation (XTGLS procedure in STATA).
***, ** and * denote significance at 1%, 5% and 10% respectively.

As stressed in section 2, the statistically significant negative coefficient of ICT should not be interpreted as absence of a positive contribution of ICT. The contribution of ICT to capital formation has been taken into account in the calculation of the TFP measure that was used in our estimations. The ICT variable therefore only reflects possible (network) externality effects.

Another result of table 7 that appears to be robust over industries is the positive coefficient of the market regulation variable and the negative coefficient of its squared term, which corroborates previously reported evidence of an inverted-U relationship between competition and TFP.

Graph 4 Relationship between market regulation in non-manufacturing industries and TFP



Note: Graph based on coefficient estimates for market regulation in column 2 of table 7.

However, considering that the market regulation variable -included as a proxy for competition in non-manufacturing industries- was bounded between 0.02 and 0.14 for manufacturing industries and that the mean value for the other industries was 0.25, the bulk of observations are found to the left (downward-sloping) part of the inverted-U, as shown in graph 4, based on the estimated coefficients for the market regulation variable and its squared term (column 2 in table 7). This seems to suggest that the impact of the deregulation that occurred in Belgium, over the period 1988-2007, so far failed to increase competition or at least did not induce a positive impact on the productivity of industries.

Estimation for the panel of all industries, i.e. imposing common coefficients for the determinants of TFP, is likely to ignore cross-industry heterogeneity. We have therefore replicated the Dynamic OLS estimation for manufacturing industries and services separately. The results of these estimations, again considering all R&D stocks as well as input-output weighted and patent-based R&D stocks separately, are shown in table 8 for manufacturing industries and for services, construction and utilities in table 9. The results clearly indicate the need to discriminate between manufacturing and services. Table 8 provides robust indications of a statistically significant positive impact of intra-industry R&D on TFP in manufacturing industries whereas in services the impact is found to be negative or not statistically significant (column 2 in table 9). The elasticity of TFP with regard to intra-industry R&D for manufacturing industries falls within the margin of 0.01 to 0.25 reported in the review by Hall et al. (2009).

The positive domestic inter-industry rent spillovers are robust for manufacturing industries but are only statistically significant for the group of services, construction and utilities in the rent spillovers specification (column 3 in table 9) whereas the positive foreign knowledge spillovers found in table 7, only appear to apply to manufacturing industries. The negative foreign inter-industry R&D spillovers in the specification in which input-output R&D stocks are considered separately (column 3 in table 7), is also found to be statistically significant for services, construction and utilities (column 3 in table 9) but for manufacturing industries the coefficient is actually positive and statistically significant (column 3 in table 8). For services, construction and utilities the positive domestic knowledge spillovers appear to be the only effect of R&D activities that is found to be robust.

Table 8 Dynamic OLS estimation of the determinants of TFP for a panel of Belgian manufacturing industries (1988-2007)

Dependent variable: $\ln TFP_{i,t}$	All	Rent	Knowledge
Domestic intra-industry R&D	0.14 (2.52) **	0.14 (2.42) **	0.17 (2.94) ***
Domestic inter-industry R&D (I/O-weighted)	0.08 (3.65) ***	0.11 (7.26) ***	
Domestic R&D (patent-weighted)	-0.06 (-1.47)		-0.05 (-1.06)
Foreign intra-industry R&D (I/O-weighted)	0.00 (0.05)	0.00 (0.07)	
Foreign inter-industry R&D (I/O-weighted)	0.04 (1.16)	0.07 (2.62) ***	
Foreign R&D (patent-weighted)	0.17 (2.97) ***		0.23 (3.60) ***
ICT	-0.23 (-3.85) ***	-0.26 (-4.58) ***	-0.16 (-2.23) **
Market regulation	10.61 (3.86) ***	11.83 (4.43) ***	9.67 (2.89) ***
Market regulation^2	-32.363 (-2.26) **	36.98 (2.62) ***	41.20 (-2.28) **
Number of observations	208	208	208

Note: The table shows the results of a Dynamic Ordinary Least Squares, see equation (7), in which two lags and one lead have been included for the first differences of the explanatory variables. The estimation only considers the manufacturing industries. The coefficients of first differences, which in DOLS are considered as nuisance parameters, are not reported for reasons of clarity. For the same reason, the industry-specific intercepts (fixed effects) that have been included in the estimation, are not reported. The estimation accounts for potential heteroskedasticity and autocorrelation (XTGLS procedure in STATA).
***, ** and * denote significance at 1%, 5% and 10% respectively.

Table 9 Dynamic OLS estimation of the determinants of TFP for a panel of Belgian services, construction and utilities (1988-2007)

	All	Rent	Knowledge
Domestic intra-industry R&D	-0.03 (-0.60)	-0.11 (-5.60) ***	-0.04 (-1.68) *
Domestic inter-industry R&D (I/O-weighted)	-0.02 (-0.34)	0.14 (7.23) ***	
Domestic R&D (patent-weighted)	0.03 (2.02)**		0.03 (2.09) **
Foreign intra-industry R&D (I/O-weighted)			
Foreign inter-industry R&D (I/O-weighted)	0.03 (1.24)	-0.05 (-3.66) ***	
Foreign R&D (patent-weighted)	0.02 (0.54)		0.04 (1.49)
ICT	-0.16 (-2.80) ***	-0.25 (-5.85) ***	-0.16 (-2.93) ***
Market regulation	1.83 (4.57) ***	2.89 (10.77) ***	2.11 (10.80) ***
Market regulation^2	-2.32 (-7.34) ***	-3.20 (-13.36) ***	-2.60 (-12.85) ***
Number of observations	80	128	80

Note: The table shows the results of a Dynamic Ordinary Least Squares, see equation (7), in which two lags and one lead have been included for the first differences of the explanatory variables. The estimation only considers the services, construction and utilities. The coefficients of first differences, which in DOLS are considered as nuisance parameters, are not reported for reasons of clarity. For the same reason, the industry-specific intercepts (fixed effects) that have been included in the estimation, are not reported. The estimation accounts for potential heteroskedasticity and autocorrelation (XTGLS procedure in STATA).
***, ** and * denote significance at 1%, 5% and 10% respectively.

To test the robustness of our estimation results, we re-estimated the specification with all R&D stocks for manufacturing industries (column 2 in table 8), including additional potential determinants of TFP like human capital (share of high-skilled workers in the total number of hours worked), imports and exports (expressed in intensity, i.e. relative to value added). This specification has been estimated with our preferred TFP measure, i.e. accounting for the heterogeneity of capital and labour, but also with a more basic TFP that does not account for heterogeneity and a TFP measure that accounts for possible imperfect market competition (so-called TFP ex ante). Table A.2 in annex 6.7 compares the results of these three alternative estimations. The positive impact of domestic intra-industry R&D and the positive foreign R&D spillovers appear to be very robust over the three alternative TFP measures. The negative coefficient of the domestic patent-weighted R&D stocks (knowledge spillovers) is only statistically significant in the estimation with the benchmark TFP. On the other hand, due to the inclusion of three additional determinants, the negative coefficient of ICT is no longer statistically significant in the estimation with the benchmark TFP, though it is in the estimation with the basic TFP and the ex ante TFP, albeit only at 10% for the latter. The coefficient of the human capital variable is positive but only statistically significant (at 10%) in the estimation with the basic TFP. This result indicates the need to account for differences in the qualification of workers, as in the calculation of our benchmark TFP. As our benchmark TFP accounts for the effects of qualification on output, the lack of a statistically significant coefficient for the share of high-skilled workers in the number of hours worked is an indication of the absence of externalities of human capital and not of the absence of a positive contribution of human capital. The positive impact of export intensity on TFP may indicate the potential productivity benefits of exporting, although the lack of statistical significance in the estimation with TFP ex ante seems to suggest that it could as well reflect an export premium (mark-up) rather than a positive contribution of exporting to technological efficiency.

The link between TFP and its determinants may depend on the technological regime of a given industry, as characterised by appropriability conditions, technological opportunities and other industry characteristics (e.g. Castellaci 2007). Following Verspagen (1997), Ortega-Argilés et al. (2009), Kumbhakar et al. (2009) and Nishioka and Ripoll (2011), who have reported evidence that the impact of R&D activities on productivity increases with the R&D intensity of industries, we have ranked industries by average R&D intensity and considered three groups: low-tech, medium-tech and high-tech manufacturing industries[15]. Due to the small number of services for which data are available, a further distinction for services is not feasible.

[15] Ranked by increasing average R&D intensity (based on average over the period): **Low-tech** (Wood and products of wood and cork; Pulp, paper, products of paper, printing and publishing; Food, beverages and tobacco and Manufacturing (n.e.c.); recycling); **Medium-tech** (Textiles, textile products, leather and footwear; Other non-metallic mineral products; Coke, refined petroleum and nuclear fuel; Basic metals and fabricated metal products and Transport equipment); **High-tech** (Rubber and plastics; Machinery n.e.c., Chemicals and chemical products and Electrical and optical equipment).

Table 10 Dynamic OLS estimation of the determinants of TFP for a panel of Belgian manufacturing industries grouped by R&D intensity (1988-2007)

Dependent variable: $\ln TFP_{i,t}$	All	Rent	Knowledge
Low-tech manufacturing			
Domestic intra-industry R&D	-0.14 (-1.17)	-0.03 (-0.46)	-0.29 (-5.49)***
Domestic inter-industry R&D	0.04 (0.60)	0.09 (1.83)*	
Domestic R&D (patent-weighted)	0.01 (0.21)		0.02 (0.53)
Foreign intra-industry R&D	-0.35 (-3.15)***	-0.43 (-4.05)***	
Foreign inter-industry R&D	-0.01 (-0.18)	-0.02 (-0.39)	
Foreign R&D (patent-weighted)			0.13 (1.30)
ICT	0.03 (0.29)	-0.01 (-0.08)	-0.03 (-0.32)
Market regulation	-21.27 (-1.42)	-32.46 (-3.02)***	-30.98 (-3.21)***
Market regulation^2	104.36 (1.12)	185.16 (2.61)***	151.37 (2.44)***
Medium-tech manufacturing			
Domestic intra-industry R&D	0.03 (0.39)	-0.15 (-1.46)	0.20 (1.68)*
Domestic inter-industry R&D	0.21 (2.36)**	0.16 (1.63)*	
Domestic R&D (patent-weighted)	-0.37 (-5.91)***		-0.19 (-2.30)**
Foreign intra-industry R&D	0.84 (4.84)***	0.20 (1.07)	
Foreign inter-industry R&D	0.63 (4.10)***	0.51 (2.90)***	
Foreign R&D (patent-weighted)			0.56 (5.36)***
ICT	-0.08 (-0.62)	-0.49 (-4.21)***	0.01 (0.07)
Market regulation	-13.57 (-2.20)**	11.75 (1.85)*	17.32 (6.46)***
Market regulation^2	148.92 (4.14)***	-10.03 (-0.29)	-79.90 (-5.31)***
High-tech manufacturing			
Domestic intra-industry R&D	0.13 (1.80) *	0.41 (6.23)***	0.64 (7.43)***
Domestic inter-industry R&D	0.18 (17.58)***	0.18 (18.15)***	
Domestic R&D (patent-weighted)	-0.09 (-2.15)**		0.28 (2.50)***
Foreign intra-industry R&D	0.29 (15.70)***	0.24 (11.75)***	
Foreign inter-industry R&D	-0.00 (-0.03)	-0.05 (-1.36)	
Foreign R&D (patent-weighted)			0.01 (0.11)
ICT	-0.64 (-20.66)***	-0.65 (-25.98)***	-0.25 (-4.47)***
Market regulation	-56.22 (-11.53)***	-46.81 (-8.09)***	4.86 (0.35)
Market regulation^2	478.82 (13.65)***	434.93 (9.97)***	33.15 (0.32)
Number of observations	208	208	208

Note: The table shows the results of a Dynamic Ordinary Least Squares, see equation (7), in which two lags and one lead have been included for the first differences of the explanatory variables. The coefficients of first differences, which in DOLS are considered as nuisance parameters, are not reported for reasons of clarity. For the same reason, the industry-specific intercepts (fixed effects) that have been included in the estimation, are not reported.
***, ** and * denote significance at 1%, 5% and 10% respectively.

In table 10, we report the results of a Dynamic OLS estimation in which the coefficients have been estimated specific to each of the three groups of manufacturing industries ranked by R&D intensity. Including all R&D stocks (input-output-weighted and patent-based) provides elasticity estimates that are way out of bound and overall seem very unreliable, probably due to substantial collinearity.

For this reason, the specification reported in column 2 does not include the foreign patent-based R&D stocks, which appears to pose the most problems in terms of collinearity. In line with

Verspagen (1997), Ortega-Argilés et al. (2009), Kumbhakar et al. (2009) and Nishioka and Ripoll (2011), we find that the impact of industry-level R&D increases with R&D intensity. Only for high-tech industries is the (positive) effect of domestic intra-industry R&D robust over all three specifications. The elasticity of TFP with respect to domestic intra-industry R&D for high-tech industries in the specification with all R&D stocks (column 2) falls within the 0.02-0.25 range reported by Hall et al. (2009) whereas in the specification with input-output-weighted R&D stocks and patent-based R&D stocks considered separately the elasticity is somewhat higher, which suggests that the omission of either type of R&D stocks may result in the overestimation of the impact of intra-industry R&D. The negative coefficient for low-tech industries of domestic intra-industry R&D and the positive coefficient for medium-tech industries of domestic intra-industry R&D in the specification with patent-based R&D stocks (column 4) are not statistically robust. For high-tech industries there is robust evidence of positive domestic inter-industry and foreign intra-industry rent spillovers. Domestic knowledge spillovers appear to have been negative for medium-tech and high-tech industries although this result is only robust for medium-tech industries, as for high-tech industries the specification with only patent-based R&D stocks even suggests statistically significant positive domestic knowledge spillovers. For medium-tech industries, all foreign spillovers are positive and statistically significant except foreign intra-industry rent spillovers in the specification with input-output-weighted R&D stocks. The results seem in line with the finding by Verspagen (1997) that domestic spillovers are more important for high-tech industries and foreign spillovers for industries with a lower R&D intensity. The robust indications of negative foreign intra-industry rent spillovers in low-tech industries (column 2 and 3) could indicate, as discussed in section 2, crowding out effects from foreign firms or the negative effects of successful foreign firms in patent races exceed the potential benefits of R&D activities of foreign competitors in low-tech industries.

4. Conclusions

In this working paper, we estimated the impact of the determinants of total factor productivity (TFP) for Belgium, using industry-level data for the period 1988-2007. Despite well-known problems in calculating or estimating TFP and in interpreting TFP growth as a measure of disembodied technological change, it is generally considered as an indicator of technological efficiency and more generally a major determinant of welfare. Macroeconomic as well as industry-level data show that Belgium was close to or even at the world technological frontier in the 1980s and 1990s. However, productivity (growth) slowed down more recently, resulting in the deterioration of the relative position of Belgium.

We regressed TFP on potential determinants like intra- and inter-industry R&D stocks (domestic and foreign), ICT investment, market regulation, human capital and international trade for a panel of manufacturing industries, services sectors, construction and utilities. Using so-called Dynamic Ordinary Least Squares, our focus was on long-run effects, accounting for possible spurious correlation in regressions with non-stationary time series. The strong correlation between several determinants of TFP, e.g. between the different R&D stocks but also between R&D stocks and human capital, hamper the unbiased simultaneous assessment of the contribution of individual variables.

Econometric results show that R&D is an important determinant, either R&D accumulated inside the industry (intra-industry) or R&D accumulated by other domestic or foreign industries (inter-industry). This impact is more pronounced for manufacturing than for other industries (services, construction and utilities). There is robust evidence of a positive impact of domestic intra- and inter-industry R&D stocks and of foreign (knowledge) spillovers for manufacturing industries. For services, construction and utilities, only domestic (patent-weighted) R&D stocks are found to have a statistically significant positive impact on TFP.

We also find strong indications for the need to account for substantial heterogeneity across industries as to which factors affect TFP. When a breakdown of manufacturing industries by R&D intensity is considered, for high-tech industries, there is robust evidence of a positive impact of domestic and foreign intra-industry and domestic inter-industry R&D stocks. For medium-tech industries, domestic and foreign inter-industry R&D stocks and foreign knowledge spillovers have a positive impact on TFP. However, domestic knowledge spillovers appear to be negative which might be an indication of the negative effect of domestic competitors' R&D activities. We find no significant positive impact of R&D stocks for low-tech industries.

The results for a variable reflecting so-called knock-on effects of market regulation in non-manufacturing industries on other industries suggest that the deregulation that occurred in Belgium, over the period considered, has had a negative impact on TFP. This could indicate - in line with more anecdotic evidence- that deregulation in market services and utilities so far did not result in increased competition or at least not in downward pressure on the prices of intermediate inputs that would contribute to productivity growth in downstream industries.

5. References

Abramovitz, M. (1956), 'Resource and Output Trends in the United States since 1870', *American Economic Review* 46, 5-23.

Abramovitz, M. (1993), 'The Search for the Sources of Growth: Areas of Ignorance, Old and New', *The Journal of Economic History 53(2)*, 217-243.

Acharya, R.C. and W. Keller (2008), Estimating the Productivity Selection and Technology Spillover Effects of Imports, NBER Working Paper 14079.

Aghion, P., N. Bloom, R. Blundell, R. Griffith and P. Howitt (2002), 'Competition and Innovation: An Inverted-U relationship', *The Quarterly Journal of Economics* 120(2), 701-728.

Aghion, P. and P. Howitt (1992), 'A Model of Growth through Creative Destruction', Econometrica. 60(2), 323-351.

Aghion, P. and P. Howitt (1998), *Endogenous Growth Theory*, MIT Press, Cambridge (MA).

Aghion, P. and P. Howitt (2006), 'Joseph Schumpeter Lecture Appropriate Growth Policy: A Unifying Framework', *Journal of the European Economic Association* 4(2-3), 269-314.

Aitken, B.J. and A.E. Harrison (1999), 'Do Domestic Firms Benefit from Direct Foreign Investment? Evidence from Venezuela', *American Economic Review* 89(3), 605-618.

Aiyar, S. and C.-J. Dalgaars (2005), 'Total Factor Productivity Revisited: A Dual Approach to Development Accounting', *IMF Staff Papers* 52(1), 82-102.

Apergis, N., C. Economidou and I. Filippidis (2009), 'International Technology Spillovers, Human Capital and Productivity Linkages: Evidence from the Industrial Sector', *Empirica* 36 (4), 365-387.

Baily, M.N., C. Hulten, D. Campbell, T. Bresnahan and R. E. Caves (1992), 'Productivity Dynamics in Manufacturing Plants', *Brookings Papers on Economic Activity: Microeconomics* 1992, pp. 187-267.

Barbieri, L. (2009), 'Panel Unit Root Tests under Cross-Sectional Dependence: An Overview', *Journal of Statistics: Advances in Theory and Applications* 1(2), 117-158.

Bartelsman, E.J. (2010), 'Searching for the Sources of Productivity from Macro to Micro and Back', *Industrial and Corporate Change* 19(6), 1891-1917.

Bartelsman, E., J. Haltiwanger and S. Scarpetta (2004), *Microeconomic Evidence of Creative Destruction in Industrial and Developing Countries*, Policy Research Working Paper 3464, The World Bank.

Basu S., Fernald, J. G., Oulton, N., and S. Srinivasan, (2004), 'The Case of the Missing Productivity Growth: Or, Does Information Technology Explain Why Productivity Accelerated in the

United States but not the United Kingdom?' in M. Gertler and K. Rogoff (eds) *NBER Macroeconomics Annual 2003*. Cambridge, MA: MIT Press, 9-63.

Basu, S. and J. Fernald, (2006), 'Information and Communications Technology as a General-Purpose Technology: Evidence from U.S. Industry Data", Working paper 2006-29, Federal Reserve Bank of San Francisco.

Basu, S., L. Pascali, F. Schiantarelli and L. Serven (2009), *Productivity, Welfare and Reallocation: Theory and Firm-Level Evidence*, NBER Working Paper 15579.

Bernard, A. B. and C.I. Jones (1996 a), 'Productivity across Industries and Countries: Time Series Theory and Evidence', *The Review of Economics and Statistics* 78(1), 135-146.

Bernard, A. B. and C.I. Jones (1996 b), 'Comparing Apples to Oranges: Productivity Convergence and Measurement across Industries and Countries', *American Economic Review* 86(5), 1216-1238.

Biatour, B., Bryon, G. and C. Kegels (2007), 'Capital services and total factor productivity measurements: impact of various methodologies for Belgium', WP 3-07, Federal Planning Bureau, Brussels.

Bosworth, B.P. and J.E. Triplett (2004), *Productivity in the U.S. Services Sector: New Sources of Economic Growth*, Brookings Institution Press.

Bourlès, R., G. Cette, J. Lopez, J. Mairesse and G. Nicoletti (2010), *Do Product Market Regulations in Upstream Sectors Curb Productivity Growth? Panel Data Evidence for OECD Countries*, NBER Worling Paper 16520.

Braila, C., Dekker, R., Kleinknecht, A., Micevska, M., Rayp, G., Sanyal, S. and J. Van Der Linden (2010), *Productmarkthervorming, collectief arbeidsmarktoverleg en het innovatievermogen van de Belgische ondernemingen*, Eindverslag Programma "Samenleving en Toekomt", Federaal Wetenschapsbeleid, Brussel.

Branstetter, L.G. (2001), 'Are Knowledge Spillovers International or Intranational in Scope? : Microeconometric Evidence from the U.S. and Japan', *Journal of International Economics* 53 (1), 53-79.

Brynjolfsson, E. and L.M. Hitt (2003), 'Computing Productivity: Firm-Level Evidence', *The Review of Economics and Statistics* 85(4), 793-808.

Brynjolffson, E., Hitt, L. M., and Yang, S. (2002), 'Intangible Assets: Computers and Organizational Capital'. Brookings Papers on Economic Activity: Macroeconomics, 1, 137-99.

Cameron, G., J. Proudman and S. Redding (2005), 'Technological convergence, R&D, trade and productivity growth', *European Economic Review* 49, 775-807.

Castellacci, F. 2007, 'Technological Regimes and Sectoral Differences in Productivity Growth', *Industrial and Corporate Change* 16(6), 1105-1145.

Choi, I. (2001), 'Unit Root Tests for Panel Data', *Journal of International Money and Finance* 20, 249-272.

Coe, D. T. and E. Helpman (1995), 'International R&D Spillovers', *European Economic Review* 39(5), 859-887.

Coe, D. T., E. Helpman and A.W. Hoffmaister (2009), 'International R&D Spillovers and Institutions', *European Economic Review* 53(7), 723-741.

Cohen D., P. Garibaldi and S. Scarpetta (eds), (2004), The ICT Revolution Productivity Differences and the Digital Divide, A report for the Fondazione Rodolfo Debenedetti in Association with the William Davidson Institute, Oxford University Press, Oxford.

Cohen, W.M. and D.A. Levinthal (1990), 'Absorptive Capacity: A New Perspective on Learning and Innovation', *Administrative Sciences Quarterly* 35, 569-596.

Conway, P. and G. Nicoletti (2006), *Product Market Regulation in the Non-Manufacturing Sectors of OECD Countries: Measurement and Highlights*, OECD Economics Department Working Paper 530, Paris.

Corrado, C.A., C.R. Hulten and D.E. Sichel (2006), *Intangible Capital and Economic Growth*, NBER Working Paper11948.

Denison, E.F. (1962), *The Sources of Economic Growth in the United States and the Alternatives before Us*, Committee for Economic Development, New York.

Denison, E.F. (1974), *Accounting for United States Economic Growth 1929-1969*, The Brookings Institution, Washington (DC).

Dickey, D.A. and W.A. Fuller (1979), 'Distribution of the Estimators for Autoregressive Time Series with a Unit Root', *Journal of the American Statistical Association* 74, 427-431.

Diewert, W. E. (1976), 'Exact and Superlative Index Numbers', *Journal of Econometrics* 4(2), 115-145.

Diewert, W. E. and K.J. Fox (2008), 'On the Estimation of Returns to Scale, Technical Progress and Monopolistic Markups', *Journal of Econometrics* 145(1-2), 174-193.

Draca M., R. Sadun and J. Van Reenen,(2007), 'Productivity and ICTs: a Review of Evidence', in: R. Mansell, C. Avgerou, D. Quah and R. Silverstone (eds.), *The Oxford Handbook of Information and Communication Technologies*, Oxford University Press, Oxford, 100-47.

Durlauf, S. N., P. A. Johnson and J.R.W. Temple (2005), 'Growth Econometrics', in: P. Aghion and S.N. Durlauf (eds.), *Handbook of Economic Growth 1*, North-Holland, Amsterdam.

Federal Planning Bureau (2010), *Input- Output tables for Belgium for 2005*, Brussels.

Felipe, J. (1999), 'Total Factor Productivity Growth in East Asia: A Critical Survey', *The Journal of Development Studies* 34(5), 1-41.

Griffith, R., S. Redding and J. van Reenen (2004), 'Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries', *Review of Economics and Statistics* 86 (4), 883-895.

Griliches, Z. (1979), 'Issues in Assessing the Contribution of Research and Development to Productivity Growth', *Bell Journal of Economics* 10(1), 92-116.

Grossman, G.M. and E. Helpman (1991), *Innovation and Growth in the Global Economy*, MIT Press, Cambridge (MA).

Guellec D. and B. Van Pottesberghe (2001), 'R&D and Productivity Growth - Panel Data Analysis of 16 OECD Countries', *OECD Economic Studies* 33, 103-126.

Hall, R.E. and C.I. Jones (1999), 'Why Do Some Countries Produce So Much More Output Per Worker Than Others?', *The Quarterly Journal of Economics* 114(1), 83-116.

Hall, B.H., J. Mairesse and P. Mohnen (2009), *Measuring the Returns to R&D*, NBER Working Paper 15622.

Higón, D.A. (2007), 'The Impact of R&D Spillovers on UK Manufacturing TFP: A Dynamic Panel Approach', Research Policy 36(7), 964-979.

Hsieh, C.T. (2002), 'What Explains the Industrial Revolution in East Asia? Evidence from the Factor Markets', *American Economic Review* 92, 502-526.

Hulten, C. R. (2000), *Total Factor Productivity: A Short Biography*, NBER Working Paper No. 7471

Hulten, C. R. (2009), *Growth Accounting*, NBER Working Paper No. 15341.

Im, K. S., M. H. Pesaran and Y. Shin (2003), 'Testing for Unit Roots in Heterogeneous Panels', *Journal of Econometrics* 115, 53-74.

Inklaar, R., M. O'Mahony and M. Timmer (2005), 'ICT and Europe's productivity performance: Industry-level growth account comparisons with the United States', *Review of Income and Wealth* 51(4), 505-536.

Inklaar, R. and M. Timmer (2008), *GGDC Productivity Level Database: International Comparison of Output, Inputs and Productivity at the Industry Level*, EU KLEMS Working Paper 40.

Inklaar, R., M. Timmer and B. Van Ark (2008), 'Market Services Productivity across Europe and the US', Economic Policy 23(53), 139-194.

Islam, N. (1995), 'Growth Empirics: A Panel Data Approach', *The Quarterly Journal of Economics* 110(4), 1127-1170.

Jorgenson, D.W. and Z. Griliches (1967), 'The Explanation of Productivity Change', *Review of Economic Studies* 34 (99), 249-280.

Jorgenson, D.W., M.S., Ho and K.J. Stiroh (2005), *Productivity: Information Technology and the American Growth Resurgence*, MIT Press, Cambridge (MA).

Kao, C., and M.-H. Chiang (2000), 'On the Estimation and Inference of a Cointegrated Regression in Panel Data', *Advances in Econometrics* 15, 179-222.

Kao, C., M.-H. Chiang and B. Chen (1999), 'International R&D Spillovers: An Application of Estimation and Inference in Panel Cointegration', *Oxford Bulletin of Economics and Statistics* 61(0), 691-709.

Katayama, H., L. Shihua and J.R. Tybout (2009),'Firm-Level Productivity Studies: Illusions and a Solution', *International Journal of Industrial Organization* 27, 403–413.

Keller, W. (2009), *International Trade, Foreign Direct Investment, and Technology Spillovers*, NBER Working Paper 15442.

Kim, J.-I., and L.J. Lau (1994), 'The Sources of Economic Growth of the East Asian Newly Industrialized Countries', *Journal of the Japanese and International Economies* 8, 235-271.

Kumbhakar, S.C., R. Ortega-Argilés, L. Potters, M. Vivarelli and P. Voigt (2009), *Corporate R&D and Firm Efficiency: Evidence from Europe's Top R&D Investors*, IZA Discussion Paper 4657, Institute for the Study of Labor (IZA).

Luintel, K. B., M. Khan and K. Theodoridis (2010), *How Robust is the R&D-Productivity Relationship? Evidence from OECD Countries*, Cardiff Economics Working Paper E2010/7, Cardiff University, Cardiff Business School.

Lucas, R. (1988), 'On the Mechanics of Economic Development', *Journal of Monetary Economics* 22(1), 3-42.

Manning, A. (2003), *The Real Thin Theory: Monopsony in Modern Labour Markets*, CEP Discussion paper dp 0564, Centre for Economic Performance, LSE.

Mohnen, P. (1996), 'R&D Externalities and Productivity Growth, STI Review 18, 39-66.

Montalvo, J.G. (1995), 'Comparing Cointegrating Regression Estimators: Some Additional Monte Carlo Results', *Economics Letters* 48(3-4), 229-234.

Nadiri M.I and I.R. Prucha (1996), 'Estimation of the depreciation rate of physical and R&D capital in the U.S. total manufacturing sector', *Economic Inquiry* 34, 43-56.

Nishioka, S. And M. Ripoll (2011), *Productivity, R&D, and International Technology Diffusion at the Industry Level*, mimeo.

OECD (2002), "Economic Outlook", n°72, OECD, Paris.

OECD (2004), *The Economic Impact of ICT: Measurement, Evidence and Implications*, OECD, Paris.

OECD (2009), *Innovation Strategy*, OECD, Paris.

O'Mahony, M. and M. Vecchi (2005), 'Quantifying the Impact of ICT Capital on Output Growth: A Heterogeneous Dynamic Panel Approach', *Economica* 72(288), 615-633,

Oliner, S.D. and D.E. Sichel (2002), 'Information Technology and Productivity: Where are we now and where are we going?', *Economic Review* issue Q3, Federal Reserve Bank of Atlanta, 15-44.

Oliner, S.D., D.E. Sichel and K.J. Stiroh (2007), 'Explaining a Productive Decade', *Brookings Papers on Economic Activity* 38(1), 81-152.

Olley, G.S and A. Pakes (1996), 'The Dynamics of Productivity in the Telecommunications Equipment Industry', *Econometrica* 64(6), 1263-1297.

Ortega-Argilés, R., L. Potters and M. Vivarelli (2009), *R&D and Productivity: Testing Sectoral Peculiarities Using Micro Data*, Working Papers 2009-3, Institute for Prospective and Technological Studies, Joint Research Centre, Sevilla.

Pedroni, P. (1999), 'Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors', Oxford Bulletin of Economics and Statistics 61(S1), 653–670.

Pisu, M. (2008), *Export Destinations and Learning-by-Exporting : Evidence from Belgium*, Research series 200809-23, National Bank of Belgium.

Robinson, J. (1953), 'The Production Function and the Theory of Capital', *Review of Economic Studies* 21, 81-106.

Romer, P.M. (1986), 'Increasing Returns and Long-Run Growth', *Journal of Political Economy* 94(5), 1002-1037.

Romer, P.M. (1990), 'Endogenous Technological Change', *Journal of Political Economy* 98(5), 71-102.

Rotemberg, J. And L.H. Summers (1990), 'Inflexible Prices and Procyclical Productivity', *The Quarterly Journal of Economics.* 105(4), 851-874.

Sapir, A., P. Aghion, G. Bertola, M. Hellwig, J. Pisani-Ferry, B. Lange, J. Viñals, H. Wallace, M. Buti, M. Nava and P. Smith (2003), *An Agenda for a Growing Europe: Making the EU System deliver*, European Commission, Brussels.

Schankerman, M. (1981), 'The Effects of Double-Counting and Expensing on the Measured Returns to R&D', *Review of Economics and Statistics* 63 (3), 454-459.

Schmutzler, A. (2010), T*he Relation between Competition and Innovation- Why is it such a Mess?*, Socioeconomic Institute Working Paper No. 0719, University of Zurich.

Schreyer, P. (2000), *The contribution of information and communication technology to output growth: a study of the G7 countries*, OECD STI Working Papers 2000/2.

Schreyer, P. (2001), *Computer price indices and international growth and productivity comparisons*, OECD Statistics Directorate, National accounts division.

Solow, R. (1957), 'Technical Change and the Aggregate Production Function', *Review of Economics and Statistics* 39, 312-320.

Solow, R. (2005), 'Reflections on Growth Theory', in: P. Aghion and S.N. Durlauf (eds.), *Handbook of Economic Growth 1*, North-Holland, Amsterdam.

Stiroh K. J. (2004), 'Reassessing the Impact of IT in the Production Function: A Meta analysis and Sensitivity Tests', Mimeo, New York Federal Reserve.

Stock, J.H. and M.W. Watson (1993), 'A Simple Estimator of Cointegrating Vectors in Higher Order Integrated Systems, *Econometrica* 61(4), 783-820.

Sveikauskas, L. (2007), *R&D and Productivity Growth: A Review of the Literature*, BLS Working Paper 408, U.S. Bureau of Labor Statistics.

Timmer M., R. Inklaar, M. O'Mahony and B. van Ark (2010), *Economic Growth in Europe: A Comparative Industry Perspective*, Cambridge University Press, Cambridge.

van Ark, B. and R. Inklaar (2005), 'Catching up or Getting Stuck? Europe's Trouble to exploit ICT's Productivity Potential', Research Memorandum GD-79, Groningen Growth and Development Centre, University of Groningen.

Van Biesebroeck, J. (2007), 'Robustness of Productivity Estimates', *Journal of Industrial Economics* 55(3), 529-569.

Van Der Linden, J. (2010), *Concurrentie in de Belgische Distributie*, Working Paper No.15-10, FPB, Brussels.

Van Leeuwen G. and H. van der Wiel (2003), *Do ICT spillovers matter? Evidence from Dutch firm-level data*, Centraal PlanBureau Working Paper No 26.

Van Pottelsberghe de la Potterie, B. (1997), 'Issues in assessing the impact of interindustry R&D spillovers', *Economic Systems Research* 9(4), 331-56.

Venturini F. (2008), "Information Technology, Research & Development, or both? What really drives a nation's productivity", Quaderno di Ricerca n. 321, Department of Economics, Polytechnic University of Marche.

Verspagen, B. (1997), 'Estimating International Technology Spillovers using Technology Flow Matrices,' *Review of World Economics* (Weltwirtschaftliches Archiv) 133(2), 226-248.

Wen, Y. (2004), 'What Does It Take to Explain Procyclical Productivity?', *The B.E. Journal of Macroeconomics* 4(1), 1-38.

Westerlund, J. (2007), 'Testing for Error Correction in Panel Data', *Oxford Bulletin of Economics and Statistics* 69(6), 709–748.

Wölfl, A., I. Wanner, T. Kozluk and G. Nicoletti (2009), *Ten Years of Product Market Reform in OECD Countries: Insights from a Revised PMR Indicator*, Economics Department Working Paper No.695, OECD, Paris.

Young, A. (1995), 'The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growth Experience', *The Quarterly Journal of Economics* 110(3), 641-680.

6. Annexes

6.1. Construction of the initial R&D stock

The initial R&D stock is constructed. Considering an average annual growth rate of R&D investment,

$$R_t = RD_t + (1-\delta)RD_{t-1} + (1-\delta)^2 RD_{t-2} + (1-\delta)^3 RD_{t-3} + ...$$
$$R_t = RD_t + (1-\delta)\lambda RD_t + (1-\delta)^2 \lambda^2 RD_t + (1-\delta)^3 \lambda^3 RD_t + ..$$
$$R_t = \frac{RD_t}{1-\lambda(1-\delta)}$$

where

R_t = R&D capital stock at time t.

RD_t = R&D investment at time t.

δ = Depreciation rate (constant over time).

$\lambda = \frac{1}{1+\eta}$ and η is the average annual growth rate of RD_t.

6.2. List of industries

Industry	Nace codes	Description
AtB	01,02,05	Agriculture, hunting, forestry and fishing
C	10t14	Mining and quarrying
DA	15t16	Food products, beverages and tobacco
DBtDC	17t19	Textiles, textile products, leather and footwear
DD	20	Wood and products of wood and cork
DE	21t22	Pulp, paper, paper products, printing and publishing
DF	23	Coke, refined petroleum products and nuclear fuel
DG	24	Chemicals and chemical products
DH	25	Rubber and plastics products
DI	26	Other non-metallic mineral products
DJ	27t28	Basic metals and fabricated metal products
DK	29	Machinery, not elsewhere classified (n.e.c.)
DL	30t33	Electrical and optical equipment
DM	34t35	Transport equipment
DN	36t37	Manufacturing (n.e.c.); recycling
E	40t41	Electricity, gas and water supply
F	45	Construction
G	50t52	Wholesale and retail trade
H	55	Hotels and restaurants
I –trans.	60t63	Transport and storage
I – com.	64	Post and telecommunications
J	65t67	Financial intermediation
K-estate	70	Real estate activities
K-bus.	71t74	Renting of material and equipment and other business activities

6.3. Tables and graphs of evolution of main variables by industry

Table A.1 Nominal value added and hours worked by industry (share in total, %)

Industry	Value Added			Hours worked		
	1987	1997	2007	1987	1997	2007
Agriculture, hunting, forestry and fishing	2.1	1.6	0.9	2.5	1.9	1.8
Mining and quarrying	0.5	0.2	0.1	0.6	0.1	0.1
Food products, beverages and tobacco	2.8	2.6	2.1	3.0	2.6	2.2
Textiles, textile products, leather and footwear	1.6	1.2	0.7	2.7	1.6	0.9
Wood and products of wood and cork	0.4	0.3	0.3	0.4	0.4	0.4
Pulp, paper, paper products, printing and publishing	1.6	1.6	1.2	1.6	1.4	1.1
Coke, refined petroleum products and nuclear fuel	0.4	0.6	0.7	0.2	0.2	0.2
Chemicals and chemical products	3.7	3.9	3.1	2.3	2.1	1.8
Rubber and plastics products	0.7	0.7	0.7	0.8	0.7	0.6
Other non-metallic mineral products	1.1	1.1	0.8	1.1	1.0	0.8
Basic metals and fabricated metal products	3.4	2.9	2.8	3.9	3.0	2.6
Machinery, not elsewhere classified (n.e.c.)	1.4	1.2	1.2	1.5	1.2	1.1
Electrical and optical equipment	1.8	1.8	1.1	2.3	1.6	1.1
Transport equipment	2.2	1.8	1.1	2.0	1.8	1.3
Manufacturing (n.e.c.); recycling	0.7	0.6	0.5	1.2	0.9	0.6
Electricity, gas and water supply	3.6	3.0	2.1	1.0	0.8	0.7
Construction	4.9	4.9	5.2	5.7	6.2	5.9
Wholesale and retail trade	13.4	12.0	13.0	15.3	14.5	13.7
Hotels and restaurants	1.3	1.5	1.6	2.6	2.8	2.6
Transport and storage	4.4	5.5	5.8	5.9	5.7	5.3
Post and telecommunications	2.1	2.5	2.5	2.5	2.5	2.0
Financial intermediation	6.5	6.1	5.6	4.1	3.9	3.2
Real estate activities	9.3	9.8	9.8	0.3	0.5	0.6
Renting of material and equipment and other business activities	6.5	10.3	13.8	6.6	12.0	17.5

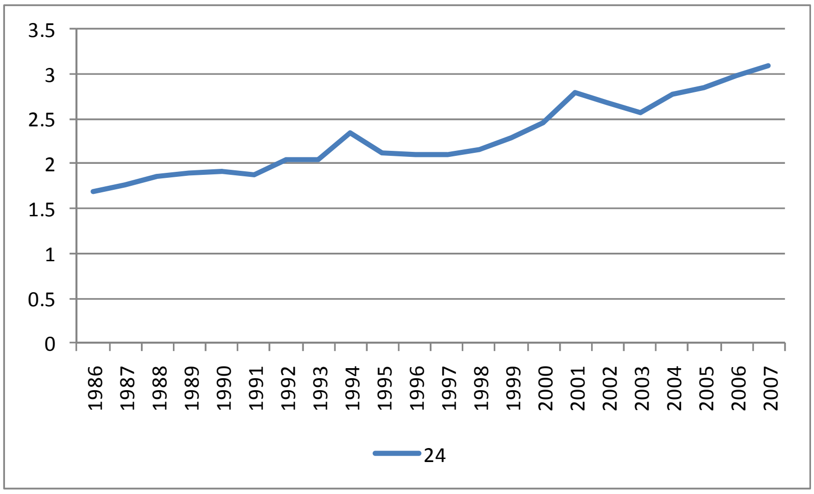
Source: EU KLEMS database.

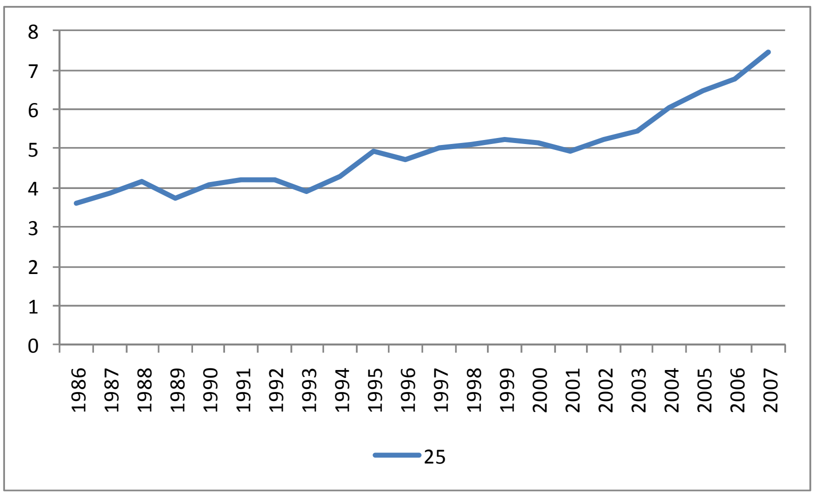
6.4. The world technology frontier

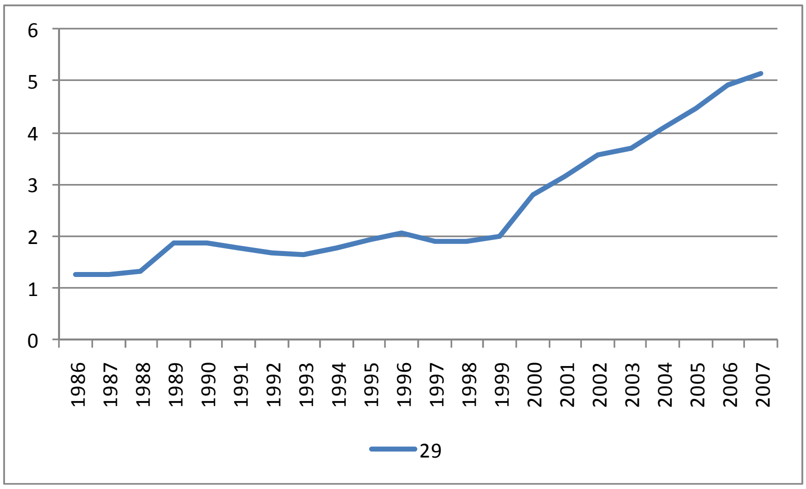
The following graphs show the evolution of the world technology (TFP) frontier for the industries taken into account in the analysis over the period 1986-2007. The industries are grouped into three categories according to the growth of the world frontier: Fast growing industries including Electrical and optical equipment (30t33), Post and telecoms (64), Machinery (29), Rubber and plastics products (25) and Chemicals (24); Stagnant or declining industries including Mining and quarrying (C), Renting and business services (71t74), Hotels and restaurants (H), Trade (50t52), Wood (20), Coke, refined petroleum products (23) and Manufacturing n.e.c. (36t37) and finally a group of industries that have witnessed slow growth. See annex 6.2. for the industry description of the NACE codes.

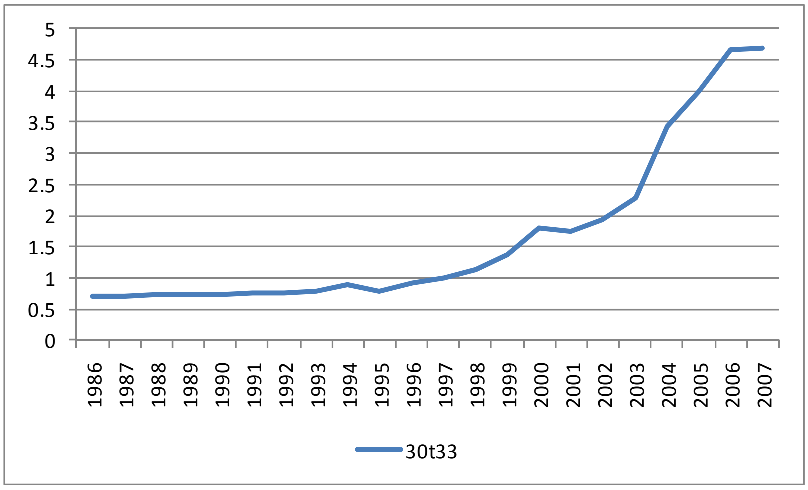
Graph A.1 World technological frontier by industry

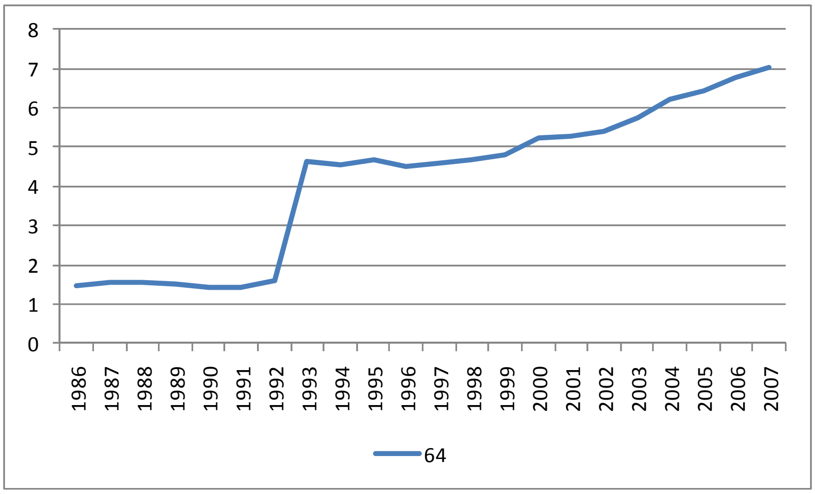
A. Fast growing industries



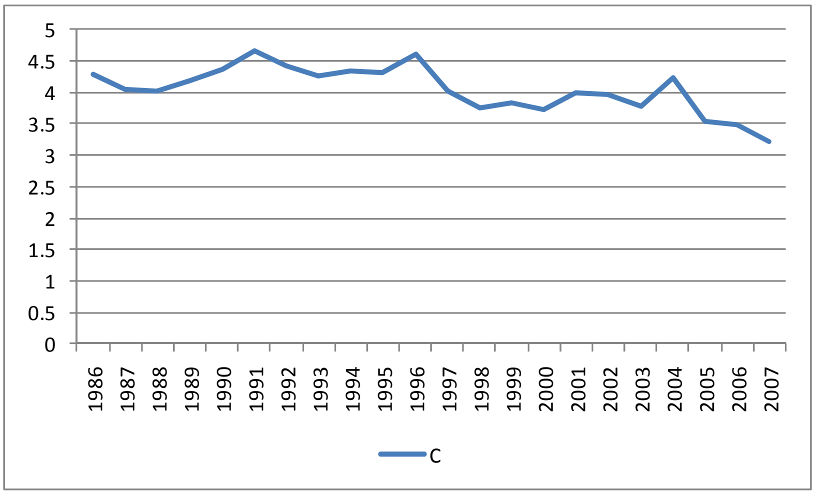


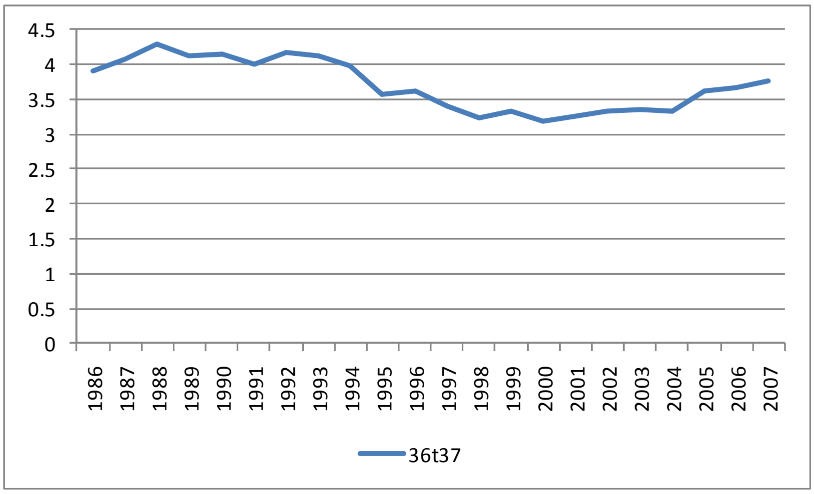

6
5
4
3
2
1
0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
29

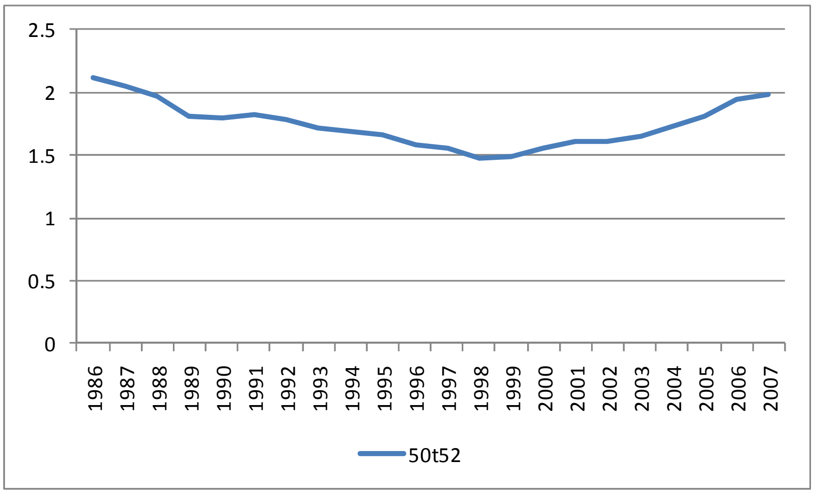

5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
30t33

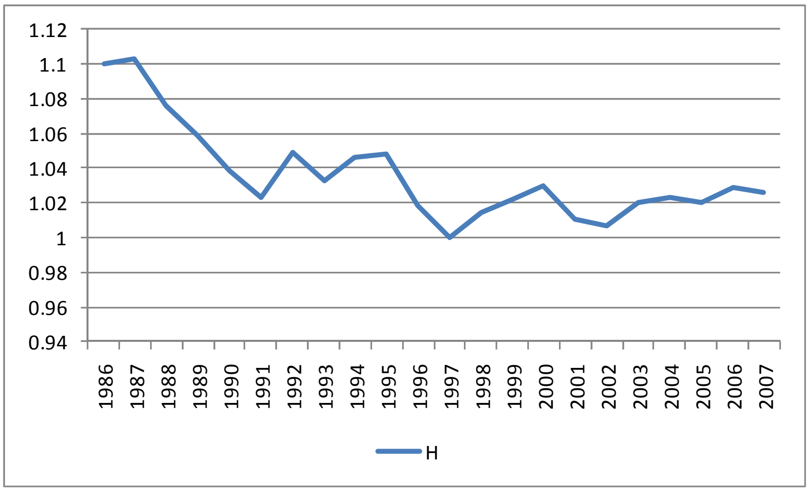

8
7
6
5
4
3
2
1
0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
64

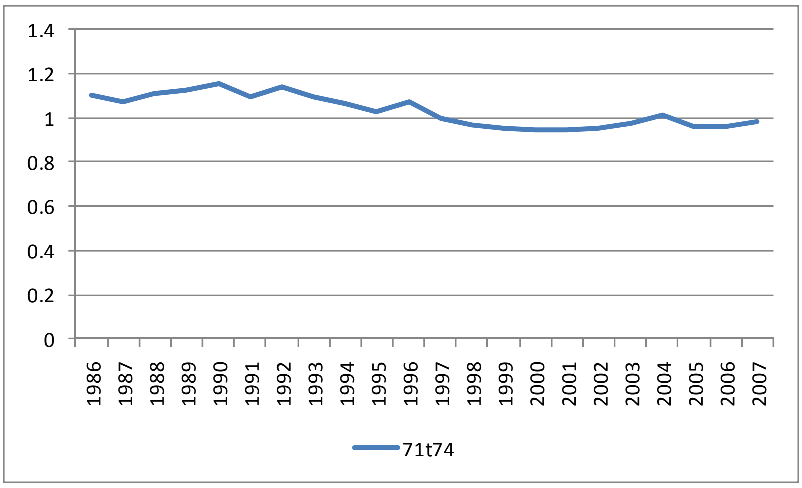
B. Declining industries

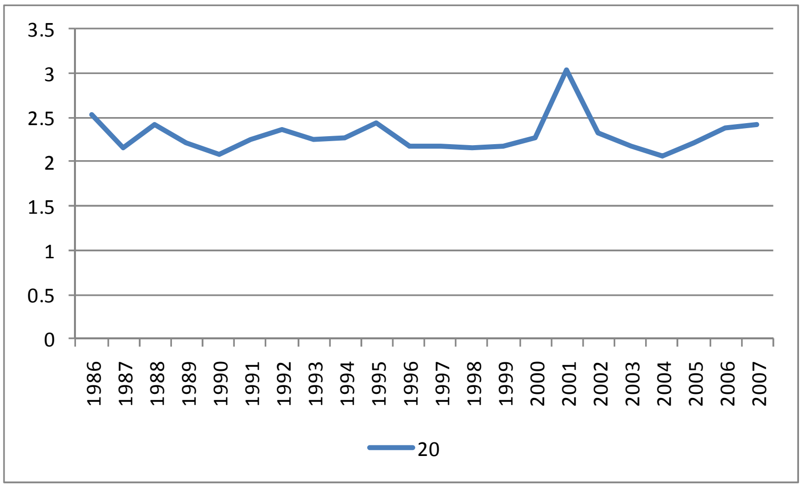


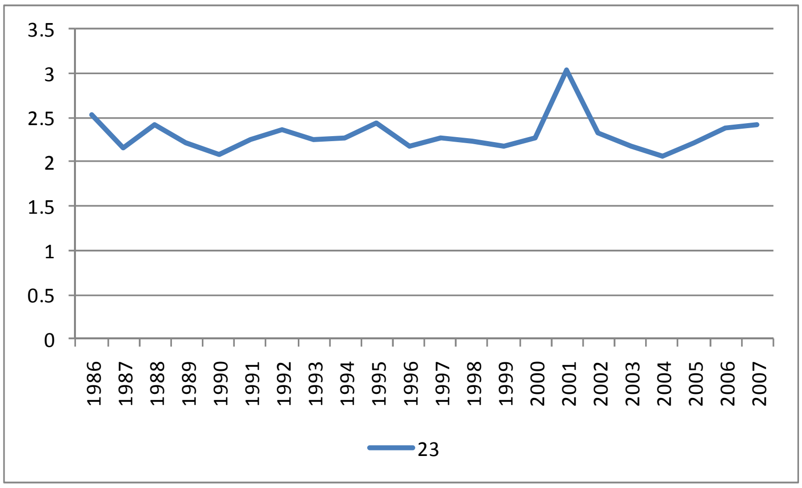




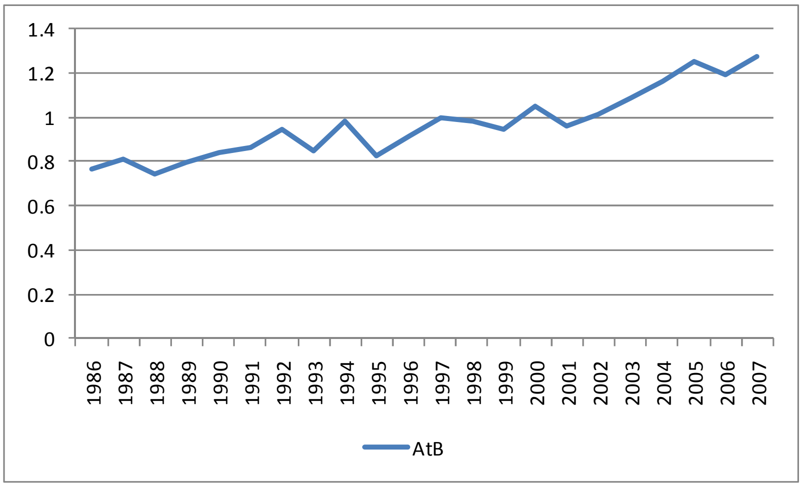

1.12
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
H

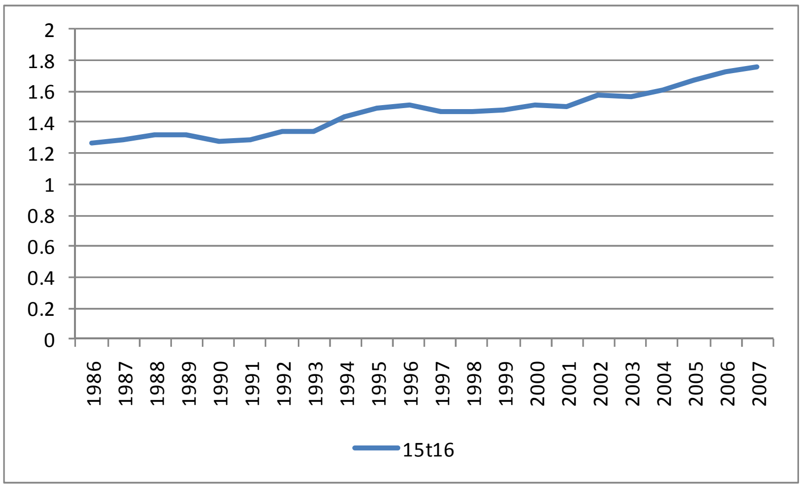

1.4
1.2
1
0.8
0.6
0.4
0.2
0
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
71t74

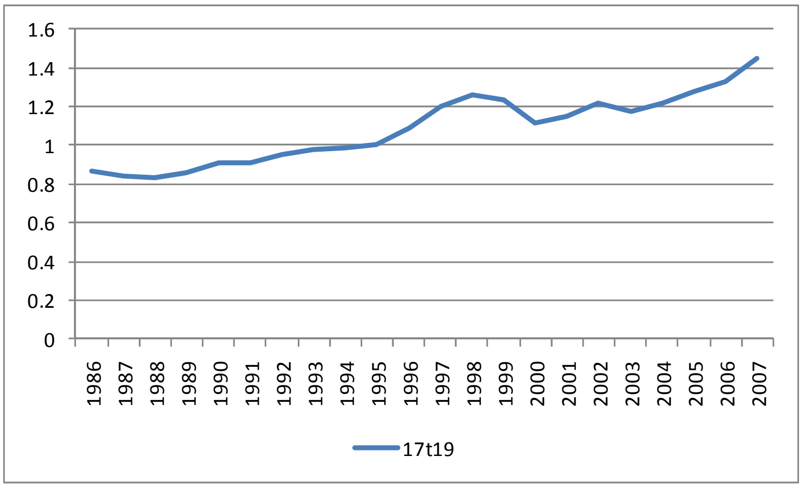

3.5
3
2.5
2
1.5
1
0.5
0
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
20

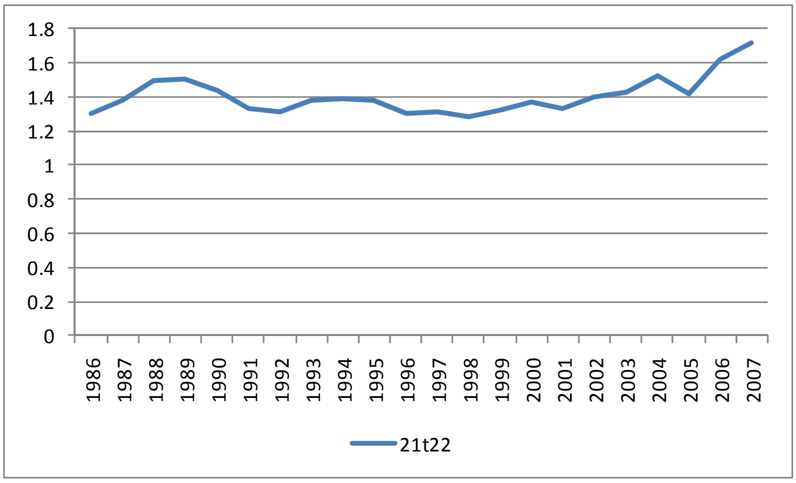


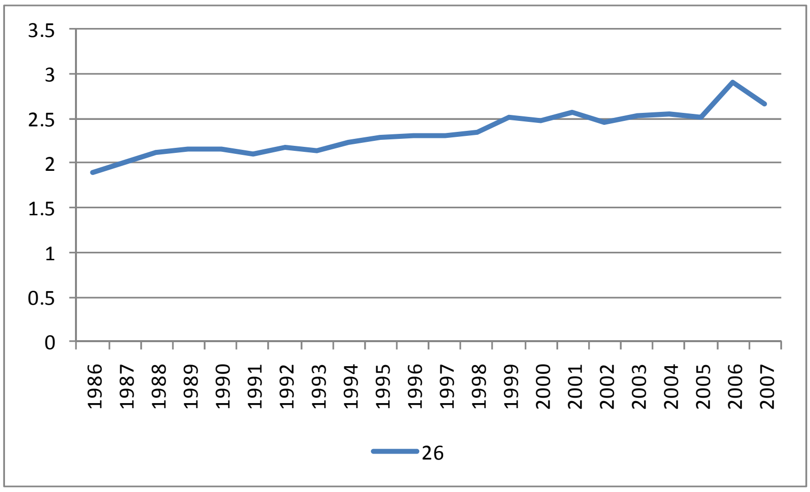
C. Moderate growing industries

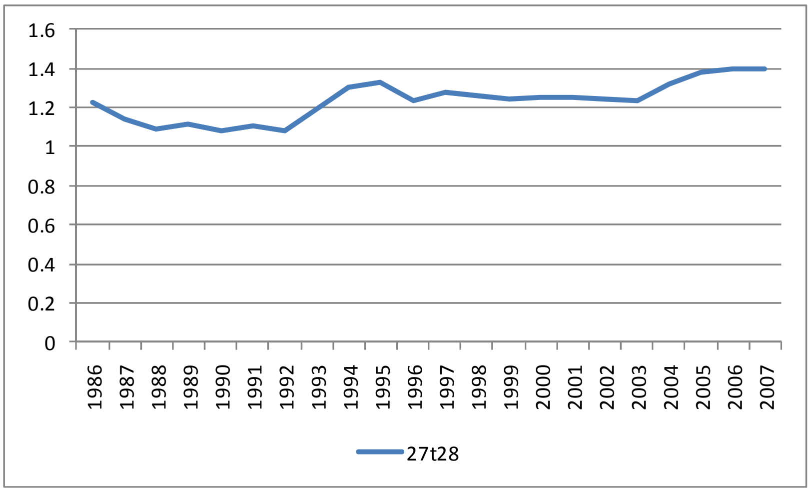


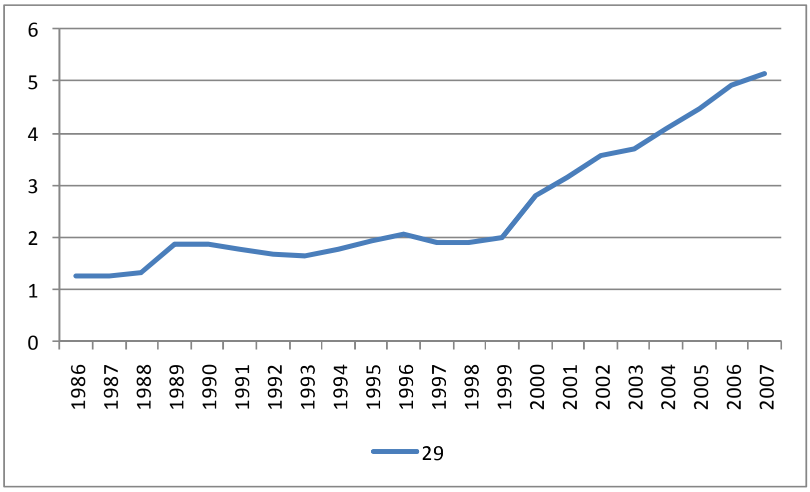


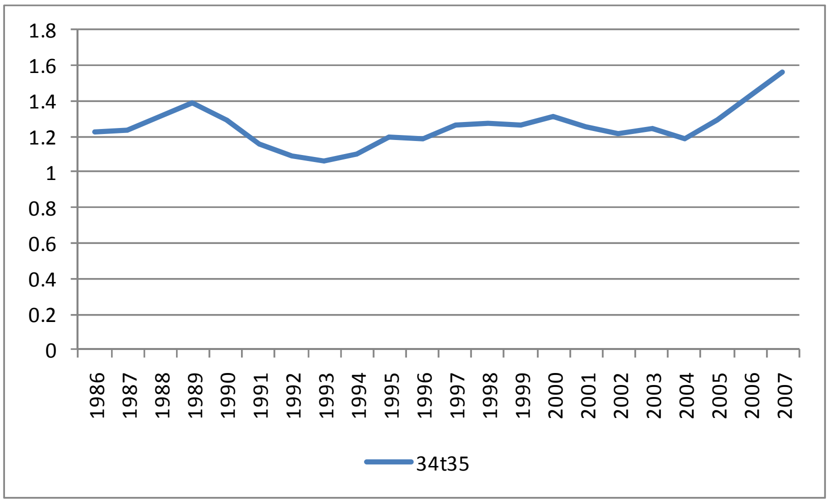

1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
17t19

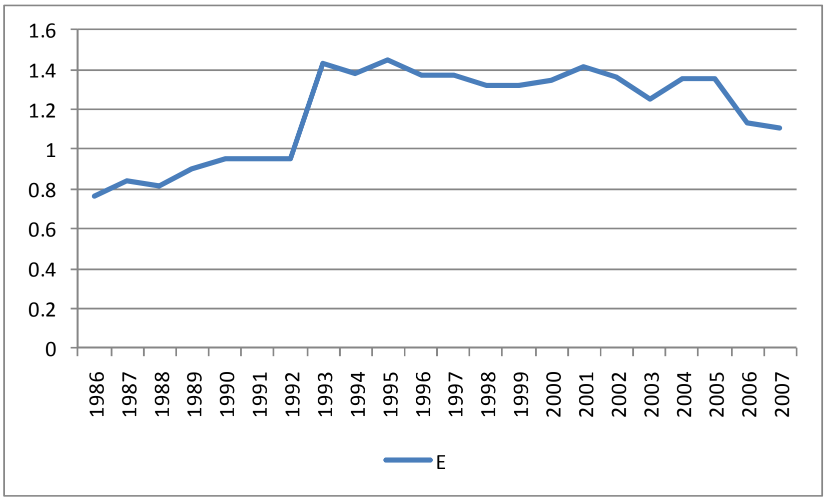

1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
21t22

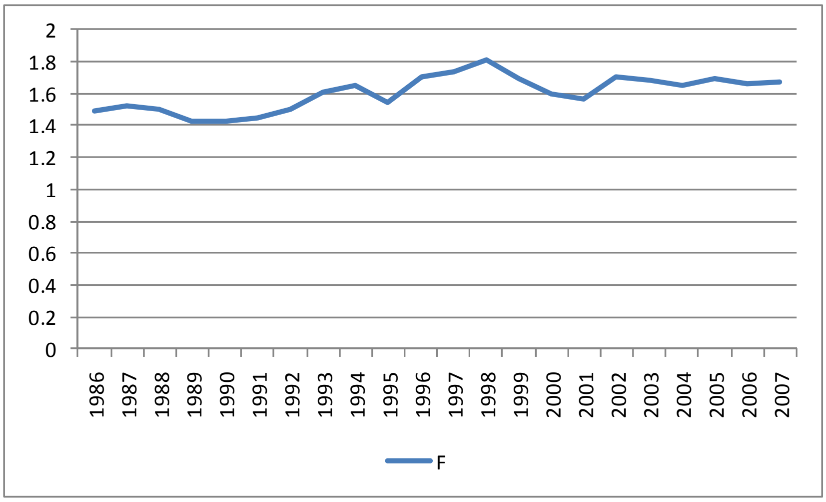

3.5
3
2.5
2
1.5
1
0.5
0
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
26

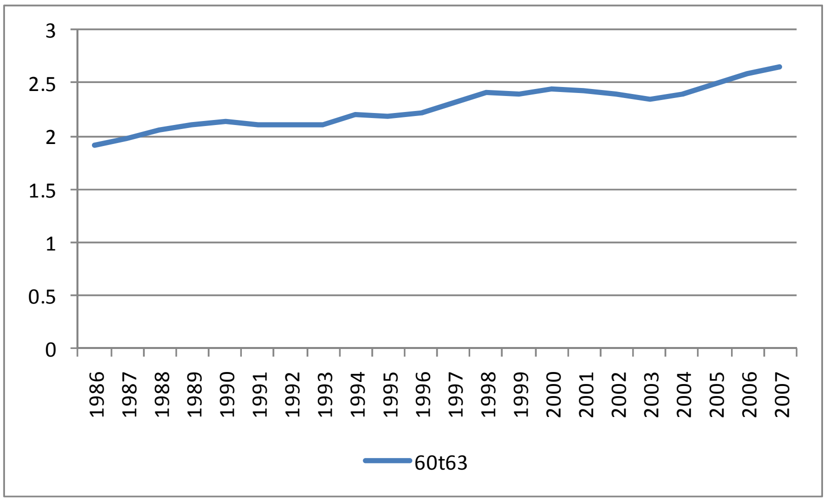

1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
27t28

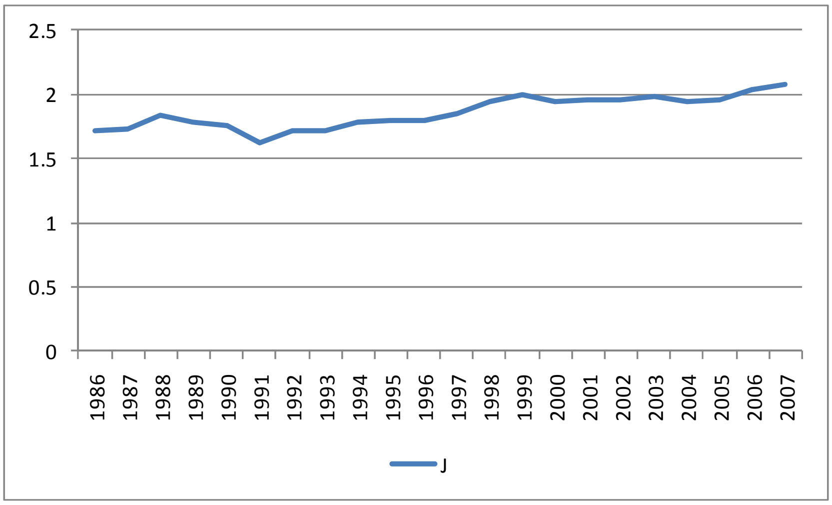

6
5
4
3
2
1
0
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
29

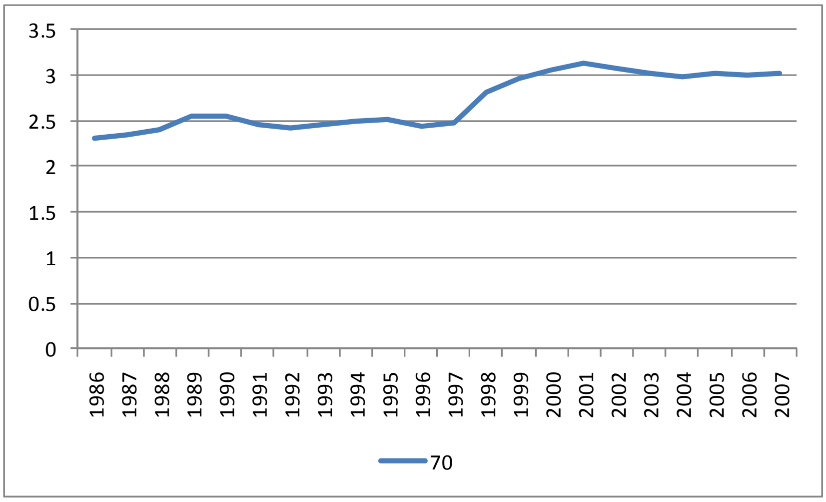

1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
34t35


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
E


2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
F


3
2.5
2
1.5
1
0.5
0
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
60t63

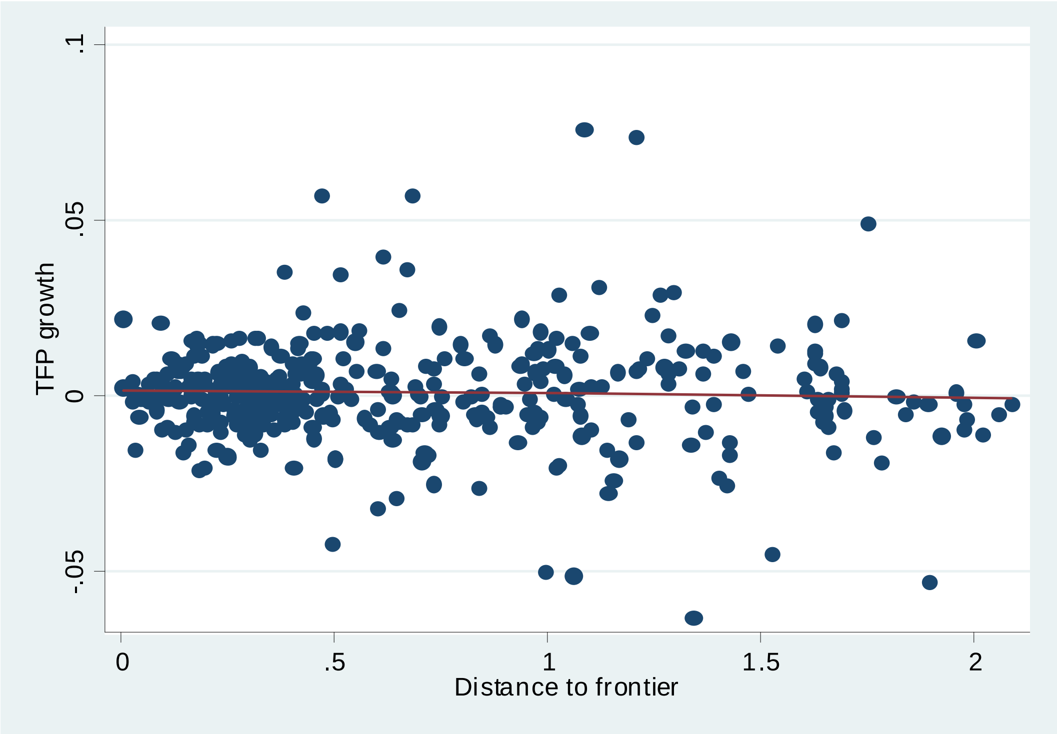




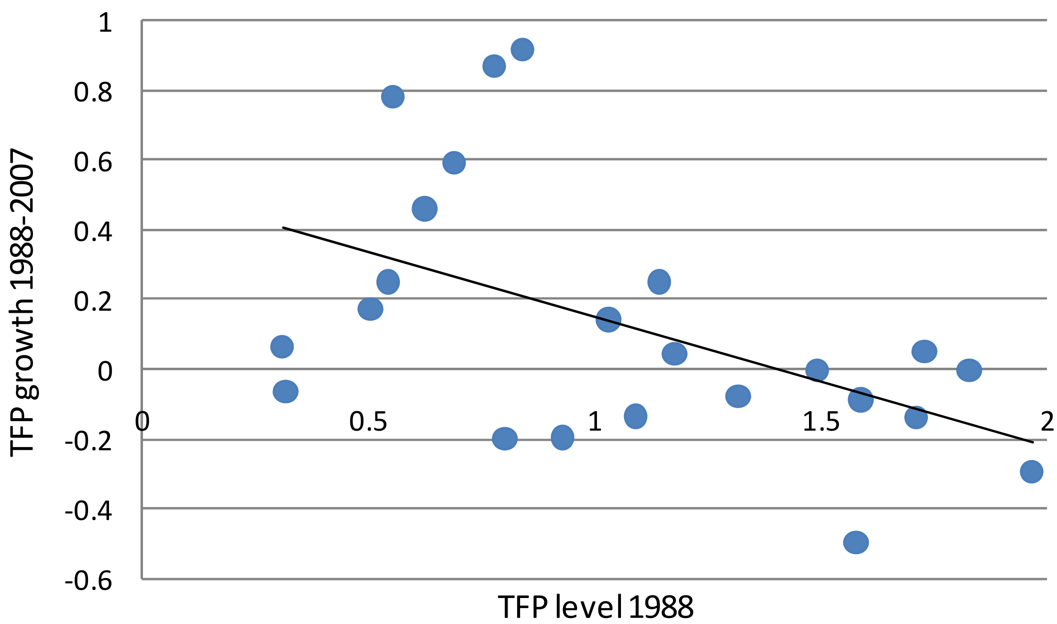
6.5. TFP growth relative to the distance to the world TFP frontier and the initial TFP level

As Graph A.1 shows, there is no link between the distance to the world frontier and TFP growth for Belgian industries over the period 1988-2007. On the other hand, graph 5 provides indications of (conditional) convergence, i.e. industries with a low TFP level in 1988, relative to other Belgian industries, witnessed stronger growth than industries that had a higher TFP level. Rubber and plastics is not included in graph A.2 as it stands out with a TFP level that was more than twice as large in 1988 than the industry with the second highest TFP level (Wholesale retail and trade).

Graph A.2 Distance to the World technology frontier and TFP growth for Belgian industries (1988-2007)



Graph A.3 TFP level in 1988 and TFP growth over the period 1988-2007 for Belgian industries



6.6. Stationarity of time series

Many economic variables show a trend over time, e.g. GDP or income per capita. Regression of time series may suffer from spurious correlation, i.e. correlation between variables due to a common or opposing trend rather than as a result of any underlying economic relationship. To avoid results being driven by the non-stationarity of variables it should be assessed whether there is any true long-run correlation (so-called cointegration) between the variables of interest. A first step in cointegration analysis consists in establishing the order of integration of the time series. The order of integration of a time series reflects the level at which the variable is stationary. If the time series of a variable is stationary in level, it has an order of integration zero. If the series is stationary after differencing once it has an order of integration 1. If the series has to be differenced *n* times before turning stationary it has order of integration *n*. A time series is said to be non-stationary if it contains a unit root. Dickey and Fuller (1979) proposed a unit root test which consisted in an Ordinary Least Squares estimation of the following specification:

$$Y_t = \rho Y_{t-1} + \varepsilon_t \quad \varepsilon_t \sim N\left(0, \sigma^2\right)$$

If $|\rho| < 1$ the time series is said to be stationary whereas if $|\rho| >= 1$ it is not stationary. To assess whether a time series is stationary or not, Dickey and Fuller proposed to test the hypothesis that the time series has a unit root (ρ =1), i.e. is not stationary. Rejection of the null hypothesis provides an indication that the time series is stationary. A constant can be added to (5) to test whether the time series drifts and a variable reflecting the number of years to test for a deterministic trend. An Augmented Dickey-Fuller test solves the problem of autocorrelation that may bias the original Dickey-Fuller test. Several other unit root tests have been proposed that tackle other econometric problems with the original Dickey-Fuller test. If a panel is used, i.e. time series for a cross section of units (firms, industries, countries) rather than time series for a single unit, panel unit root tests have to be used. These tests pose a number of problems specific to a panel structure and have only been developed rather recently. Existing panel unit root tests mainly differ with respect to the restrictions that are imposed on the cross-section dimension of the panel. The first generation of panel unit root tests assumed independence across the units that are considered. Second generation tests have relaxed this assumption. A recent survey on panel unit root tests is provided by Barbieri (2009).

If the time series of all variables appear to be non-stationary in levels but stationary after differencing, a regression in first differences could be considered to avoid spurious correlation. This is rather crude as differencing removes relevant information contained in the levels of variables. A more appropriate method is an error-correction model (ECM), in which the short-run dynamics are distinguished from the long-run dynamics (cointegration relationship). ECM is most often estimated by an Ordinary Least Squares (OLS) regression of the first difference of the dependent variable on the lagged levels of the dependent variables and the explanatory variables for which a long-run relationship is tested, as well as on the first differences of the explanatory variables. The coefficients of the variables in levels provide an indication of the cointegration relationship. For a cointegration relationship to exist all variables should be integrated of the same order and the residual of the ECM specification should be stationary. Westerlund (2007) argued that tests that are based on testing for the stationarity of the residuals of a static regression, e.g. Pedroni (1999), often fail to reject the null hypothesis of no cointegration. Westerlund proposed four panel cointegration tests that establish whether the error correction term in a conditional ECM is significant or not. Simulations indicate that these tests are more powerful than residual-based tests of panel cointegration.

6.7. Robustness tests of the estimation for manufacturing industries

Table A.2 Dynamic OLS estimation of the determinants of TFP for a panel of Belgian manufacturing industries (1988-2007) – Robustness tests (cf. Table 5, p. 36)

Dependent variable:	TFP (benchmark)	TFP (basic)	TFP (ex ante)
Domestic intra-industry R&D	0.31 (4.90)***	0.27 (4.43)***	0.30 (4.92)***
Domestic inter-industry R&D (I/O-weighted)	**-0.02 (-0.49)**	**-0.00 (-0.06)**	**-0.00 (-0.05)**
Domestic R&D (patent-weighted)	-0.09 (-1.98)**	-0.06 (-1.38)	-0.04 (-0.89)
Foreign intra-industry R&D (I/O-weighted)	-0.00 (-0.12)	0.02 (0.64)	0.04 (1.29)
Foreign inter-industry R&D (I/O-weighted)	0.05 (1.55)	0.07 (1.92)*	0.02 (0.61)
Foreign R&D (patent-weighted)	0.17 (2.55)***	0.19 (2.92)***	0.19 (2.96)***
ICT	-0.11 (-1.61)	-0.20 (-2.87)***	-0.14 (-1.79)*
Market regulation	19.27 (6.20)***	18.32 (5.96)***	19.40 (6.30)***
Market regulation^2	-84.90 (-4.93)***	-79.81 (-4.74)***	-81.04 (-4.95)***
Share high-skilled workers	0.02 (1.21)	0.03 (1.70)*	0.02 (1.04)
Imports	-0.04 (-1.51)	-0.02 (-0.69)	0.01 (0.47)
Exports	0.10 (3.27)***	0.08 (2.71)***	0.00 (0.13)
Number of observations	208	208	208

Note: The table shows the results of Dynamic Ordinary Least Squares estimations that test the robustness of the results for manufacturing industries as reported in table 5. Three additional potential determinants are included: the share of high-skilled workers in the total number of hours worked, import and export intensity. Column 2 shows the results of the estimation with our benchmark TFP, column 3 the results of an estimation with a TFP measure (basic) that does not account for heterogeneity in capital and labour and column 4 the results of a TFP measure (ex ante) that accounts for possible imperfect market competition. To measure TFP ex-ante, exogenous rates of return are used to estimate capital services. The estimation accounts for potential heteroskedasticity and autocorrelation (XTGLS procedure in STATA).
***, ** and * denote significance at 1%, 5% and 10% respectively.