The evolution of technological inequalities: country effect vs. industry composition*

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Abstract

Using the EU-KLEMS database for 12 countries and 16 industries, our paper aims to analyze the differences in technological capital intensity (R&D capital stock as a percentage of GVA) between industries and the evolution of inequalities between the EU-11 and the U.S., as well as between EU countries. We use shift-share analysis and an inequality Theil index to break down these inequalities and to quantify the importance of either a country or a specialization effect. Results from the shift-share analysis show that there was a technological gap in the U.S. until the mid-90s linked to the greater accumulation of technological capital in most of the productive sectors considered, this being the main reason for the differences in technological innovation between the U.S. and the EU-11. However, since 1995 a change in productive specialization has occurred with a significant drop in the weight of lower technology-intensive sectors in the EU-11 economy, as well as a significant drop in the weight of some medium technology intensive sectors in the U.S., accounting for the reduction in the technological gap between the EU-U.S.. Results from the Theil index show that it is the differences in the productive structure of European countries which explain most of their differences in technological capital intensity.

Key words: R&D, shift-share, Theil index

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1. Introduction

Technological intensity effort has become a major economic policy objective of the more advanced countries given that it has a positive effect on their economies in terms of increased productivity and competitiveness. It is, therefore, logical to think that the disparities in the accumulation of technological capital among countries can help explain, in part, inequalities in productivity or income per capita.

In the specific case of the EU and U.S. economies, several studies show that since the mid-90s there has been a divergence process in per capita income and productivity, which may have contributed to the different investment effort in R&D and ICT. Van Ark et al. (2008) show that the European economy has experienced a divergence in productivity with regards to the U.S. economy since the mid-90s. Maudos et al. (2008) note that this divergence is not due to a change in the productive specialization of European economies towards less productive sectors, but rather is a general problem affecting all branches of production. Consequently, if the EU wants to reduce the gap in productivity with the U.S., it needs to accelerate productivity growth in all industrial sectors.

One of the reasons for the widening of the productivity gap between the U.S. and the EU since 1995 is that the EU has less knowledge and technological capital endowments than the U.S. However, whether this difference is determined by the sectoral composition of the EU and the U.S. (structural or specialization effect) or the intensity of R&D in each sector (country or intrinsic effect) has yet to be stressed. Our analysis therefore focuses on this aspect. In addition, this fact will be discussed from the point of view of time focusing on changes from the year 1995, when differences in productivity between the two economic areas began to be observed.

Although there have been several studies related to the economics of innovation[1], this paper takes an in-depth look at the differences in R&D between the EU and the U.S. at industry level. Our objective is to obtain more information on their innovation systems because, as mentioned below, despite there being a wide range of papers analyzing the role of R&D expenditure in companies and countries, sector analyses remains relatively unexplored.

[1] See the survey by Fagerberg and Verspagen (2009).

In this paper, we are interested in analyzing not only the differences and inequalities in R&D capital between these two economic areas, but also which sectors are more intensive in capital technology and if they are the same in both geographic areas. Therefore, we will find out whether the differences in technological intensity between the U.S. and EU are due to differences in investment effort or differences in product specialization which make a country specialized in sectors that are more or less intensive in R&D. This last point is particularly telling because being specialized in R&D dynamic sectors increases an economy's chances of success, while specializing in sectors of low technological intensity hinders the possibility of future development. To carry out this analysis, we use the EU-KLEMS database for 19 countries and 16 industries over the period 1980-2003.

Many studies use R&D expenditure as a proxy for innovation inputs. However, our paper uses R&D capital stock as a proxy for innovation, mainly because it is technological capital that is important when measuring a country's increase in production and productivity. The reason is that when companies develop new production processes or invent new products not only do they use the R&D expenditure in the current year but also their technical knowledge and experience accumulated over the years. It is therefore R&D capital stock and not current expenditure on R&D that will determine the scientific and technological base of the company that makes the investment effort. In addition, the relevant input in a production function is not spending on R&D but rather the accumulated technological capital stock.

In this context, our paper attempts to answer the following questions: Which of these economic areas is more intensive in technological capital? Which productive sectors are more technologically advanced? Are the most intensive sectors in R&D the same in both countries? Are the differences between the two areas caused by the fact that there has been little investment in R&D or that they are specialized in low technology intensive sectors? Has there been a process of divergence or convergence over time between the technological intensity of both countries? And if there is convergence, what causes it? Have differences between countries been reduced within the same sector? Or has the composition of production changed in such a way that the initially more backward country has changed its specialization towards more technologically advanced sectors?

In order to answer these questions, we conduct a shift-share analysis that allows us to decompose the differences in technological capital between economic areas into several components: a first component reflecting the importance of country effect (i.e. the part of R&D capital stock change that would occur in the absence of changes or differences in specialization); a second component including the effect of a country's sectoral specialization; and a third component quantifying the interaction between them. Identifying these differences can help implement economic policies aimed at strengthening innovation.

Finally, in addition to exploring the origin of the differences in technological capital intensity between the U.S. and EU countries, we also analyze how inequalities among EU countries have evolved. To this end, we use the Theil index which also decomposes the inequalities into two terms: a within-group inequality term and a between-group inequality component. Using the country variable as a reference in one case and the industry variable in another, the construction of the Theil index indicates that it is the productive structure of European countries that explains most of the differences in technological intensity

This work contributes to the economic literature in several respects. First, it presents a general overview of the differences in R&D capital stock between the U.S. and EU. Second, although many studies focus on the effects of technological innovation, most of them discuss the issue from the standpoint of the company or country, with less emphasis on analyzing the distribution of technological innovation from the industry point of view. Thirdly, it applies a methodology (shift-share analysis) which, as far as we know, has not been used in the field of technological innovation to quantify the weight of sectoral and spatial characteristics when explaining differences between countries. And fourthly, it uses the Theil index to analyze how the inequalities in technological capital intensity among EU countries have evolved.

The paper is organized as follows. The second section reviews the literature with a special emphasis on works exploring the sectoral analysis. The third section describes the data used, along with the most important aspects of the shift-share analysis methodology and the inequality Theil index. In the fourth section, the results obtained are discussed and finally, the main conclusions and some policy implications are presented at the end of the paper.

2. Review of the literature

There is an increasingly common belief that inequalities between countries could be caused by different patterns of technological development. Given that rapid technological growth facilitates the incorporation of high-skill jobs and higher income levels, this development is essential for countries.

Although many studies emphasize the positive effects generated by R&D activities, the bulk of the literature has focused on analyzing this issue from the standpoint of the company or the country, being less empirical evidence from the sectoral point of view. For this reason, we focus our analysis on the sectoral differences between economic areas (in particular the U.S. and EU) and their influence on technological innovation.

When we focus on characteristics of a sector to explain differences in innovation between countries, we find that throughout the economic literature there are different contributions regarding sectoral differences in innovation. Pol, Carroll and Robertson (2002) provide a typology of economic sectors called "systems approach to innovation". They distinguish between "enabling sectors" consisting of companies manufacturing new products that promote efficiency, not only in their own sector but also in other sectors, and "recipient sectors" consisting of companies merely receiving innovations from other sectors.

Another economic branch asserts that a source of sectoral innovation is "technological regimes", representing the intrinsic characteristics of the technology used by one sector and the learning process in which the innovative activity is involved. In this vein, Malerba and Orseningo (1997) and Evangelista and Mastrostefano (2006), point out that the cross-industry differences in innovation activities can be explained by the differences in technological regimes, characterized by differences in technological opportunity or the probability of completing significant technological advances. They could also be explained by differences in the appropriability of benefits from innovation, differences in the degree of technical knowledge accumulation and differences in the accessibility of businesses to the scientific basis or knowledge of a sector. Thus, those technological regimes characterized by high technological opportunities but low appropriability of resources and a poor scientific basis basically coming from its own environment (universities or research centers), will consist of small innovative companies with a high level of competition between themselves, with low industrial concentration and low barriers to entry. By contrast, those technological regimes characterized by a high degree of technological opportunities, appropriability of resources and technological cumulativeness by the companies themselves, will be characterized by the concentration of innovation in large companies with significant barriers to entry.

Finally, differences in innovation arising from intra-sectoral characteristics have been analyzed in a broad context that considers the influence that government institutions can have on each sector, as well as the relationship of each productive sector with universities, the role of suppliers and users as sources of opportunity for innovation, etc.

For example, it is known that some governments have pursued policies of R&D tax credit in order to encourage a greater level of investment in R&D, with some of these policies giving tax relief according to the R&D intensity. In this context, we can place all studies analyzing the role played by technological spillovers in innovation itself. For example, Audretsch and Feldman (1996), Bottazzi and Peri (2003), Malerba et al. (2007) and Gumbau and Maudos (2009) have found important sources of localized spillovers.

The first of these papers suggests that location and proximity have a direct impact on innovation. More specifically, these authors distinguish between the transmission of information and the transmission of knowledge. They indicate that, although the cost of transmitting information may not vary with distance, the cost of transmitting knowledge does increase with distance, given that the transmission of knowledge requires continuous contacts and interaction between agents. They also conclude that spillovers differ from industry to industry, therefore generating different patterns of innovative behaviour across sectors. Bottazzi and Peri (2003) believe that the proximity to other agents' innovation is significant and consider that spillovers are located within a very limited radius (300 km). Meanwhile, Gumbau and Maudos (2009) analyze the importance of different spillovers, such as technological inputs of other agents weighted by spatial distance or commercial relationship, when explaining the differences in patenting among Spanish regions and find significant sources of spillovers. Finally, Malerba et al. (2007) conclude that national and international spillovers have different effects across sectors; thus, in the chemical sector the elasticity of new knowledge to national inter-sectoral external resources is comparable to that of R&D, while the elasticity to international resources is at least twice as large. By contrast, in the electronics sector the effect of national and international spillovers is similar to the effect of R&D. Finally, in the machinery sector national inter-sectoral external resources do not appear to have any positive impact on new knowledge creation, while international sources of knowledge do contribute to new knowledge creation with an elasticity equal to that of R&D.

The differences between innovation systems are also determined by differences between countries in terms of the legal and institutional framework, innovation policies, support systems for innovation, relationships between those involved in the process of innovation, education systems, relationships between universities or vocational training centres with firms, knowledge spillovers from other firms in the country, etc.

Empirically, several authors have conducted comparisons of innovation systems across countries. Van Reenen (1997) argues that the slower growth of expenditure on R&D in the UK compared to other countries is due to the relative low weight of knowledge intensive sectors such as pharmaceutical and computer software industries, as well as the presence of tax incentives in R&D. In the same vein, Iorwerth (2005) noted that the low intensity of R&D in Canada with respect to the U.S. is mainly due to industry composition. Another study by Ciupeaga et al. (2006) also explores the reasons for Europe’s delay with respect to the USA in the area of knowledge investments and shows that the European private R&D investment deficit is mainly due to a sectoral composition effect. Mancusi (2003) examines the empirical dynamics of countries' technological specialization finding that, in all the technology fields analyzed, innovation activities are performed by relatively few countries and the degree of concentration is fairly stable over time. He also finds that Electronics have the highest degree of geographical concentration but there are several small countries among those specialized. Likewise, Dosi, Llerena and Silos Labini (2005) argue that the differences in innovation performance between the U.S. and EU depend simply on the intensity of R&D expenditure. Moreover, they emphasize that the EU has structural delays in terms of advanced science and innovation, although it has some strengths in physical sciences and engineering. Above all, the authors consider that there is clearly a significant corporate business weakness. Finally, Helmers et al. (2009) also point to the increased spending on R&D of the U.S. in all productive sectors of the economy as the main reason for the gap between the U.S. and EU.

3. Data and methodology

3.1. The data

We use the sector information from the EU-KLEMS database for the period 1980-2003 to conduct our analysis. This allows us to compare the economies of the U.S. with 11 European countries for which data are available: Austria, Denmark, Finland, France, Germany, Greece, Italy, the Netherlands, Spain, Sweden and the UK**.** The study has been performed for the various industries that appear in the above-mentioned publication: Electrical and optical equipment; Food products, beverages and tobacco; Textiles, textile products, leather and footwear; Manufacturing nec, recycling; Wood and products of wood and cork; Pulp, paper, paper products printing and publishing; Coke, refined petroleum products and nuclear fuel; Chemicals and chemical products; Rubber and plastic products; Other non-metallic mineral products, Basic metals and fabricated metal products; Machinery, nec; Transport equipment, Electricity, gas and water supply, Construction; and Market services. Although EU-Klems does not provide separate information on the ICT sector, it is included in the Market Services sector. The following sectors were not considered due to lack of information in the database: Agriculture, hunting, forestry and fishing; and Mining and quarrying. As public services are not included, the sector analyzed is therefore the private sector.

In the EU-KLEMS database, R&D data have been compiled at industry level. This allows for industry-level analyses, which are indispensable given the substantial inter-industry differences in technological dynamism characterizing developed countries. The data on annual R&D expenditures are taken from the "OECD Research and Development in Industry Database". The common Perpetual Inventory Method was used to construct R&D stocks using the R&D expenditures data.

3.2. Decomposition of the technological gap between the U.S. and EU: country effect vs. industry effect

In order to analyze the relative importance of country effect and specialization effect when explaining the differences and evolution in the technological effort of the US and EU, the shift-share analysis is applied to the "R&D capital stock / gross value added (GVA)" ratio. The property of this methodology is to decompose a variable into a number of components. In general, in the two shift-share analyses conducted, the variable is decomposed into three parts: a first component which reflects the importance of a country effect, i.e. the part of the variable's progress that would occur in the absence of variations or specialization differences; a second component that reflects the effect of specialization; and a third component called interaction effect.

To this end, the two shift-share analyses, detailed below, are applied to the R&D capital stock/GVA ratio, named as (K / Y) in which *A* and *B* are the two economic areas to be analyzed (U.S. and EU-11, respectively), *t* the year, *j* the sector and θ measures the specialization or production structure approximated by the weight of the GVA in each sector *j* in total.

a) Analysis of the specialization contribution to the differences in (K/Y) between countries in each year during the period 1980-2003.

$$\frac{K^A{}_t}{Y^A{}_t}-\frac{K^B{}_t}{Y^B{}_t}=\sum_{j=1}^{J}\theta^B{}_{jt}\left(\frac{K^A{}_{jt}}{Y^A{}_{jt}}-\frac{K^B{}_{jt}}{Y^B{}_{jt}}\right)+\sum_{j=1}^{J}\left(\theta^A{}_{jt}-\theta^B{}_{jt}\right)\frac{K^B{}_{jt}}{Y^B{}_{jt}}+\sum_{j=1}^{J}\left(\theta^A{}_{jt}-\theta^B{}_{jt}\right)\left(\frac{K^A{}_{jt}}{Y^A{}_{jt}}-\frac{K^B{}_{jt}}{Y^B{}_{jt}}\right)$$

(1)

As shown in the above expression, the difference between the U.S. and the EU technological effort can be decomposed into three components. The first component is the *country effect* corresponding to the difference in technological intensities between country *A* and *B,* which would exist if there were no differences in specialization. It therefore provides the effect associated with the technological effort in each sector. The second component is the *specialization effect* and measures the differences in (K/Y) due to different composition of output. And the third is the *interaction effect* as a result of country *A* being specialized in relative terms in sectors that tend to have greater technological intensity in comparison to country *B*. Note that if the productive specialization of A and *B* were the same, the last two terms would be zero, and thus only the technological intensity differences can account for the difference at aggregate level in the (K/Y) ratio.

b) Contribution of structural change or change in specialization to growth of (K/Y) for each country

$$\frac{K_T}{Y_T}-\frac{K_0}{Y_0}=\sum_{j=1}^{J}\theta_{j0}\left(\frac{K_{jT}}{Y_{jT}}-\frac{K_{j0}}{Y_{j0}}\right)+\sum_{j=1}^{J}\left(\theta_{jT}-\theta_{j0}\right)\frac{K_{j0}}{Y_{j0}}+\sum_{j=1}^{J}\left(\theta_{jT}-\theta_{j0}\right)\left(\frac{K_{jT}}{Y_{jT}}-\frac{K_{j0}}{Y_{j0}}\right)$$

(2)

The first term is the *intra-sectoral effect* representing the growth of technological intensity in each sector and therefore growth in the (K/Y) ratio, although it does not change the specialization. The second term is the *static sectoral effect* which measures the changes in (K/Y) due to changes in productive specialization, and the third is the *dynamic sectoral effect* which reflects growth caused by the interaction between changes in productive specialization and the growth of technological intensity in each sector. The sign of the latter depends on whether the reallocation has been made in sectors with greater growth in (K/Y) - in which case it would be positive - or in sectors with lower growth -and thus the third component would be negative-.

3.3. The evolution of inequalities in the technological intensity of EU member countries: country vs. specialization effect

After analyzing the source of inequalities in the technological intensity between the U.S. and EU, it is interesting to examine the possible heterogeneity within the EU countries.To do this, we use the Theil Inequality index which has the property of being additively decomposable. We decompose the inequality in the technological intensity among the industries and countries of the EU into a between effect and a within effect. In particular, we construct two Theil indexes: one which measures internal or within-group inequality (in this case internal inequality within each country or industry) and another which measures between-group inequality (external inequality between countries or between sectors).

The Theil index is defined by:

$$T(\beta) = \frac{1}{\beta(\beta-1)} \sum_i p_i \left[\left(\frac{x_i}{\mu} \right)^{\beta} - 1 \right] \tag{3}$$

where x_i is the study variable (*K/Y*), μ the weighted average of x_i, p_i the weight of each individual i in the total sample and β a factor measuring the sensitivity of the index to transfers between individuals with high levels of x_i to individuals with low ones. We assume β =0, so that Eq. (3) becomes

$$T(0) = -\sum_i p_i \log\left(\frac{x_i}{\mu} \right) \tag{4}$$

The total sample is separated into G groups, and we assume that each group represents a percentage p_g of the total sample and that the weighted average of variable x_i of each grouping is μ_i. The decomposition property of the family of Theil indexes then allows us to express the previous equation in the following manner:

$$T(0) = \sum_{g=1}^{G} p_g T_g(0) + T_0(0) \tag{5}$$

where

$$T_g(0) = -\sum_{i \in n_g} \frac{p_i}{p_g} \log\left(\frac{x_i}{\mu_g} \right) \tag{6}$$

is the internal inequality (within groups) index of each grouping and

$$T_0(0) = -\sum_g p_g \log\left(\frac{\mu_g}{\mu} \right) \tag{7}$$

is the external inequality (between groups) index between grouping. Thus, we compute the decomposition of the Theil index defined by Eqs. (3)-(7) for the technological intensity *K/Y* for each industry of each country. We use as weights (p_i and p_g) the share in value added of each sector in the sample.

To analyze whether there are more differences between countries than industries, we compute two Theil inequality indexes for the *K/Y* ratio. If we take the group "industry" as a reference in the construction of the index, a high relative weight of the between component will mean that the main source of inequalities is productive specialization, while if the index is constructed taking the group "country" as reference, a high weight of the within component will strengthen the message that specialization is the main source of inequalities.

It is clearly interesting to compute the Theil index over time to see, firstly, whether there has been a reduction or increase in the technological intensity differences within the different sectors and EU countries. And secondly what causes convergence/divergence by looking at the temporal evolution of the relative importance of the between and within effect in the two constructed indexes.

4. Results

4.1. Explaining the differences between USA and EU

So as to compare EU-11 and U.S. economies, figure 1 presents the technological capital intensity of each country measured by the percentage that R&D capital stock represents in the private sector regarding its gross value added (K/Y). The graph shows that although the U.S. economy had a higher technological intensity in the first year analyzed (1980), the gap has been closing since the early 90s. Specifically, as illustrated in table 1, the technological capital stock of the U.S. Market Economy represented 28% of its value added in 1980, compared to a value of 23% in the EU-11. However, in 2003, both economies presented practically the same value.

Using OECD data for 36 industries, authors like Jerkin and van Es (2007) argue that the differences between the EU and the U.S. in R&D expenditure are very low when only the manufacturing sector is considered. And Landmark, Turtle and Ulbricht (2008), using European Commission microdata, Eurostat, OECD and EU-Klems statistics, conclude that the intensity in R&D of private firms is similar. However, Erik and van Es (2007) show that the sectoral contribution of the gap between the EU and the U.S. is very low. They explain this gap by the low technological intensity of main sectors such as the services sector, while Lindmark, Turlea and Ulbrich (2010) consider that the sectoral composition is very different. Furthermore, Mathieu and van Pottelsberghe de la Potterie (2008), using data from 20 manufacturing sectors and 10 European countries between 1991 and 2002, conclude that the sectoral composition is the cause of the lower intensity of European R&D.

In view of the different studies, we now focus on examining the R&D distribution by sector and geographic area. To this end, table 1 and figure 2 illustrate the ratio of R&D capital stock / GVA in the years 1980, 1990, 1995 and 2003 for each sector in both economies. It is noted that the U.S. economy is more intensive in technological capital in all sectors and for all years except in the three following sectors: Chemicals and chemical products; Machinery, nec; and Electricity, gas and water supply. Less investment effort in R&D and, thus, lower technological capital stock (relative to GVA) of the EU-11 in most areas would therefore be the first explanation for the gap observed between the EU and U.S..

In addition, it can also be noted that at the beginning as well as at the end of the period, the most intensive sectors in technology are Electrical and optical equipment; Transport equipment; and Chemical and chemical products, of which Europe only stands out in the latter sector. Therefore, the U.S. make greater R&D investments in two of the three most technologically advanced sectors. This could mean that less effort in R&D in Europe is not the sole cause of the technological gap existing in many of the years considered in the sample between the EU and U.S.. That is, productive specialization may also have a key role to play. However, if this were the case, the output of the technologically advanced EU industries would be lower than the U.S..

Finally, there is a third significant fact: although less intensive in technological capital, the EU-11 reduces the gap with the U.S. in the fields in which this country is more intensive in R&D (Electrical and optical equipment; and Transport equipment) and maintains a distance with the U.S. in those sectors in which EU-11 had come to be more intensive in R&D (Chemicals and chemical products; Machinery, nec; and Electricity, gas and water supply). It is this latter aspect in particular that contributes to the convergence in (K/Y) between the two economic areas. The U.S. also makes a significant effort in R&D in other less technology-intensive sectors such as Textiles, textile products, leather and footwear with a 51% growth in (K/Y) during the period 1980-2003; Pulp, paper, paper products, printing and publishing with 27.3% growth in technological effort over the same period; and Machinery, nec with 30% growth in technological effort during the same period. Meanwhile, the EU-11 reduces the rate of growth in (K/Y) in all sectors during the period except in the Market Services sector where intensity in knowledge has increased some 94.3%. However, in the same period, the U.S. increased intensity in technological effort in this sector by 219.1%.

To analyze the importance of sectoral specialization in explaining the technological intensity differences between the U.S. and the EU, table 2 presents the percentage structure of private GVA for the U.S. and EU and shows several facts: first, the weight of the Electrical and optical equipment sector in GVA is lower in the EU than in the U.S., with this difference being particularly significant between 1990 and 1995. However, in both the U.S. and EU-11, the weight of this sector decreases in the total Market economy at the end of the period. Second, there are limited differences between the U.S. and EU-11 in the Chemicals and chemical products; and Transport equipment sectors, being favorable to the U.S. in one year and to the EU-11 in another year. Third, the largest weight of the Machinery, nec sector in the EU-11 in all the years considered is noteworthy. This fact is relevant given that although this sector is not among the most technology-intensive, it is one of the sectors in which the EU-11 is more intensive in R&D investment than the USA. Fourth, the table illustrates the largest weight of Market Services in the U.S., with its intensity in knowledge increasing by 219% over the period analyzed. Finally, it should also be noted that two of the less intensive sectors in (K/Y) - Construction; and Wood and products of wood- represent the largest weight in the GVA of the EU-11.

In order to quantify accurately the extent to which higher expenditure or specialization accounts for the technological gap between the EU and USA, table 3 presents a first shift-share analysis indicating several aspects. In 1980 the difference in innovation capacity was 27.3% higher in the U.S, with the country effect explaining more than 100% of the difference. That is, if production specialization would have been the same in both regions, the intensity of American innovation would have been even greater, its technological intensity ratio being 30.4% above the EU instead of 27.3%. Thus, there is a technological breakthrough for the U.S. in most of the productive sectors considered.

In 1995 the weight of the country effect is greatly reduced, accounting for 63.8% of the total gap. Therefore, if production specialization would have been the same in the two areas in 1995, the technological capitalization of the U.S. would have been 15.7% higher. But the picture changes completely in 2003 when differences in the technological intensity between the U.S. and EU practically disappear, reaching only 0.04%. The country effect is very high in relative terms but if the specialization of both areas would have been the same, the technological intensity of the U.S. would have been only 2.3% higher than the EU.

Consequently, since 1995 there has been a strong convergence between the two economies in the accumulation of technological capital. This is mainly because the U.S. reduces technological intensity much more than the EU in high technology intensive sectors, such as Electrical and optical equipment; Transport equipment; and Chemicals and chemical products. This is also the case in medium technology intensive sectors like

Coke, refined petroleum products and nuclear fuel; Rubber and plastic products; Manuacturing nec; and Other non-metallic mineral products. By contrast, the EU maintains its position in these sectors and reduces technological intensity more than the U.S. in low technology intensive sectors like Basic metals and fabricated metal products; Pulp, paper, paper products printing and publishing; Textiles, textile products, leather and footwear; Electricity, gas and water supply; and Construction.

Given that the specialization effect is negative in 1980, the U.S. was more specialized than the EU in less technologically advanced sectors during that year. In particular, the increased specialization in these sectors subtracted 3.2 percentage points from its distance in technological effort with regard to the EU.

By contrast, the effect is positive and accounts for 21% of the differences in the technological intensity between the two countries in 1995, while the specialization effect is again negative and of high magnitude up to 2003. This data can be explained by the biggest drop in the weight represented by low technology intensive sectors in the EU-11 economy (Food products, beverages and tobacco; Electricity, gas and water supply; and Construction) and by the biggest drop in the weight represented by medium technology intensive sectors in the U.S. economy (Machinery, nec; Rubber and plastic products; Basic metals and fabricated products; o Pulp, paper, paper products, printing and publishing).

Although the EU-11 shows a favorable specialization effect, the major impact of the U.S. national effect determines that the interaction effect or competitive effect is favorable to the U.S. in any year analyzed. This fact shows that it is not the increased specialization of the U.S. in technology intensive sectors, but the bulk of technological effort in all its productive structure that determines the increased competitiveness of the U.S. economy in technology.

The second shift-share carried out (table 4) focuses on analyzing how structural change or change in specialization contributes to the growth of (K/Y) in the U.S. and EU-11 economies. The results show that for the entire period 1980-2003, the reduction of technological intensity in the U.S. is more significant than in the EU, with an average annual reduction rate of 2.28% and 1.24% respectively.

The intra-industry effect is negative both in the U.S and the EU, which implies that although specialization in production has not changed over time, technological intensity has fallen as a result of technological capital stock increasing below the GVA growth. However, the intra-industry effect is higher in the USA, as it accounts for 69% of the total effect, compared to 38.8% in the EU. The static-industry effect (output composition) accounts for 50.9% of the fall in technological intensity in the U.S. and 79.2% in the EU. Its negative sign indicates that change in specialization has been orientated to less technologically advanced sectors. The relative importance of the dynamic industry effect is similar in the two areas.

The analysis conducted separately for the sub-periods 1980-1995 and 1995-2003 shows considerable differences, especially in the case of the EU. That is, in the U.S. the fall in technological intensity is of a relatively similar magnitude in both sub-periods (falling to an average of 2.25% in 1980-95 and 2.35% in 1995-2003), whereas in the EU there is a complete change in technological intensity: in the first sub-period it is reduced to an average annual rate of 2.1%, while it increases 0.4% per annum in the period 1995-2003.

In the case of the U.S., the intra-industry effect accounts for 88% of the fall in technological intensity over the period 1980-1995 and explains only 15.5% from 1995. By contrast, the static-industry effect is much more significant in the sub-period 1995-2003, as it explains 76% compared to 16.3% in the first sub-period.

This result indicates that the recent fall in the technological intensity of the USA is due mainly to a change in productive specialization, diminishing the relative importance of the sectors which initially had higher technological intensity.

In the case of the EU, there is a significant temporary change since 1995: the technological intensity ratio slightly increases (0.04%) compared to the fall in the USA (-2.35%). This increase is caused by a greater investment effort in R&D, which means that the intra-industry effect is of high importance. By contrast, the static-industry effect is negative, indicating the increasing relative importance of industries based on a lower technological intensity ratio.

4.2. Explaining the inequalities among the EU countries: country vs. industry effect

To analyze whether there are more differences in technological capital intensity between industries or between countries, a Theil inequality index is calculated for the ratio (K/Y). Its evolution shows an initial decrease until 1986, and an increase until 1993. There then follows a subsequent fall until the end of 2000 and an upturn in the recent years examined until reaching the most significant inequalities in 2003. If we take the "country" variable as reference (table 5), the main part of the inequality is within, explaining around 90% of the total inequality. This result indicates that eliminating differences between countries would not eliminate the major percentage of inequality in technological capital intensity, which is internal.

The decomposition of the within-industry and between-industry inequality by means of the Theil index (table 6) indicates that most of the inequalities are explained by the between component. In addition, the evolution over time (see figure 2) shows an increasing importance of this component, demonstrating once again that specialization plays a key role when explaining the origin of the inequalities in technological capital intensity among European countries.

5. Conclusions

This study presents an analysis of the differences between the U.S. and EU-11 in the R&D capital stock in the private sector at industry level for the period 1980-2003. Although there is a wide range of studies examining the role of R&D at firm or country level, sector analysis is relatively unexploited.

The EU-KLEMS data used suggest that although at the beginning of the period the U.S. economy had a higher technological intensity in the private sector than the EU-11 (approximated by the ratio of R & D capital stock with respect to GVA), since the early 90s the technology gap has been closing. This result has also been shown in other studies when only the manufacturing sector or the private sector of the economy is considered.

The U.S. economy has been more intensive in innovation effort in all years and sectors except for the following: Chemicals and chemical products; Machinery, nec; and Electricity, gas and water supply, in which the EU-11 stands out. Both at the beginning and end of the period, the sectors that are more intensive in knowledge are Electrical and optical equipment; Transport equipment; and Chemical and chemical products, with Europe only standing out in the latter sector. However, the EU-11 has been able to reduce the gap with the U.S. over time in the areas where this country is more intensive in R&D (Electrical and optical equipment; and Transport equipment). At the same time, it also manages to maintain a distance with the USA in those sectors in which the EU-11 has become more intensive in knowledge (Chemicals and chemical products; Machinery, nec; and Electricity, gas and water supply), contributing in particular to the convergence in (K/Y) between the two economic areas.

In light of these data, the paper quantifies the extent to which the greater investment in R&D capital stock (country effect) or sectoral composition (specialization effect) explains the technological gap between the EU and U.S., existing in many of the years of the sample. Using the shift-share methodology, results show that at the beginning of the period there is a considerable technological gap in favor of the U.S., mainly explained by the country effect or greater accumulation of technological capital in most of the productive sectors considered. However, since 1995 there has been a strong convergence between the two economies regarding the accumulation of technological capital, mainly due to change in productive specialization. Thus, if we focus on the specialization effect, we find that it plays an important role in the significant fall in the weight represented by sectors with low intensive technology in the economy in the EU 11, as well as a greater drop in the weight represented by some medium intensive technology sectors in the U.S. It is therefore not the increased specialization of the U.S. in technology intensive sectors that determines its greater competitiveness in technology, but its greater technological effort throughout its productive structure.

The second shift-share carried out focuses on analyzing how change in specialization has contributed to the growth of technological capital stock (as a Percentage of GVA) in the U.S. and EU-11 economies. Results show that for the entire 1980-2003 period, there is a drop in the technological capital stock / GVA ratio as a consequence of technological capital stock growing below GVA growth which, in addition, is more intense in the U.S. than in the EU. In both cases the variation in the composition of output contributes positively to explaining this fall, with a greater relative importance in the EU than in the U.S.. Furthermore, the shift-share analysis conducted separately for the sub-periods 1980-1995 and 1995-2003 demonstrates significant differences, especially in the case of the EU. While in U.S. the decline in the technological capital stock/GVA ratio is of a similar magnitude in both sub-periods, the behavior of the ratio completely changes in the EU, falling in the first sub-period but increasing in the second. The latest drop in the U.S. technological capital stock/GVA ratio is due mainly to a change in productive specialization, diminishing the relative importance of the sectors which initially had higher ratios. As mentioned earlier, in the case of the EU there is a significant temporal change. That is, since 1995 the technological capital stock/GVA ratio has increased slightly in comparison to a fall in the case of the U.S. because of greater efforts to invest in R&D and an increase in the relative importance of those sectors that started from a lower ratio.

It is widely agreed that the volume of R&D capital stock needs to be increased if the most technologically advanced economies are to be reached. However, innovation policy must be accompanied by a strategy defining the key sectors in which to channel investment in R&D and public aid. The European goal of turning this economic area into the largest economy dedicated to innovation cannot be undertaken by merely increasing expenditure on R&D. What is needed is a sectoral strategy as it has been shown that reducing inequalities between countries requires changes in the composition of each industrial country.

The results clearly point to a reduction in the technological gap between the U.S.-EU. However, numerous studies have shown that there remain differences in productivity between the two areas and thus we can conclude that, although the technological capital stock in relation to the GVA in the private sector of the economy has been favourable for convergence in productivity, this effect is not sufficient to offset the possible divergent effect of other factors such as human capital, ICT, public infrastructures, etc.

Finally, we have carried out an analysis on the inequalities between EU-member country through the Theil index.The evolution of this index does not show a stable behavior over time, although there are more significant inequalities in the last year than in previous years. The decomposition of the Theil index using both the country variable and the industry variable as reference illustrates the significance of productive specialization when explaining the origin of inequalities.This result implies that to reduce inequalities in the technological intensity between countries within the EU, it is also essential to increase the investment effort in the R&D of lagging countries, thus eliminating the huge differences in the productive structure of their economies. ,Consequently even if all countries made the same investment effort, major differences between countries would persist because of their differences in specialization.

References

Audretsch, D. and Feldman, M. (1996) “R&D spillovers and the geography of innovation and production”. *American Economic Review,* 86: 641-652.

Bottazzi, L. and Peri, G. (2003) “Innovation and spillovers in regions: evidence from European patent data”. *European Economic Review,* 47: 687-710.

Ciupeaga, C. and Moncada-Paternó-Castelló, P. (2006) "Industrial R&D Investment: A comparative analysis of the top EU and non EU companies Based on the EU 2004 R&D Scoreboard", *Revista de Economía Mundial*, 15: 89-120

Dosi, G.P., Llerena,P. and M. Silos Labini (2005) “Evaluating and comparing the innovation performance of the United States and the European Union” *Trend Chart Policy Workshop 2005*

Evangelista,R. and Mastrostefano,V. (2006) “Firma size, sectors and countries as sources of varitey of innovation”, *Economis of Innovation and New Technology,* 15: 247-270

Erken, H. and van Es, F. (2007) “Disentangling the R&D shortfall of the EU via-á-vis the US”, Jena Economic Reserch Papers, 2007-107.

Fagerberg, J. and Verspagen, B. (2009) “Innovation studies. The emerging structure of a new scientific field”, *Research Policy*, 28: 218-233.

Gumbau-Albert, M. (1997) "Análisis microeconómico de los determinantes de la innovación: aplicación a las empresas industriales españolas", *Revista Española de Economía*, 14: 41-66

Gumbau-Albert,M. and Maudos,J. (2009) "Patents, technological inputs and spillovers among regions”, *Applied Economics*, 41(12): 1473-1486

Helmers, C., Schulte, C. and Strauss, H. (2009) “Business R&D expenditure and capital in Europe” *EIB Papers, vol.14, No.1,* pp 36-61.

Iorwerth, A. (2005) “Canada’s low business R&D intensity: the role of industry composition” *Working Paper 2005-03, Department of Finance.*

Lindmark, S., Turlea, G. and Ulbrich, M. (2010) "Business R&D in the ICT sector: examining tue European ICR-R&D deficit", Science and Public Policy.

Malerba, F. and Orseningo, L. (1997) "Technological regimes and sectoral patterns of innovative activities" *Industrial and Corporate Change,* 6: 83-117

Malerba, F., Mancusi, L. and Montobbio, F. (1997) "Innovation, international R&D spillovers and the sectoral heterogeneity of knowledge flows", *Working Paper* 204, *CESPRI*

Mancusi, L. (2003) "Geographical Concentration And The Dynamics Of Countries' Specialization In Technologies," *Economics of Innovation and New Technology*, 12(3), 269-291.

Maudos. J., Pastor, J.M. and L. Serrano (2008) "Explaining the US-EU productivity growth gap: structural change vs. intra sectoral effect", *Economic Letters*, vol. 100(2), pp. 311-313.

Pol, E. Carroll, P. and Robertson, P. (2002) "A new typology for economic sectors with a view to policy implications" *Economics of Innovation and New Technology,* 11: 1, 61-76.

van Ark, Bart, Mary O'Mahoney, and Marcel P. Timmer (2008). "The Productivity Gap between Europe and the United States: Trends and Causes." *Journal of Economic Perspectives*, 22(1): 25–44.

Van Reenen, J. (1997) "Why has Britain had slow R&D growth?" *Research Policy*, 26:493-507.

Table 1. Capital stock in R&D/GVA (%)

	1,980		1,990		1,995		2,003		Growth 1980-03		Percentage difference
	USA	EU	USA	EU	USA	EU	USA	EU	USA	EU	USA-EU 2003
MARKET ECONOMY	28.5	22.3	22.5	16.9	20.3	16.3	16.8	16.8	-40.9	-24.7	0.0
Electrical and optical equipment	242.4	150.4	175.0	130.0	145.9	135.6	177.8	146.9	-26.7	-2.3	21.0
Post and telecommunications											
Food products, beverages and tobacco	11.4	12.6	10.0	9.5	8.8	9.4	7.8	10.1	-32.2	-19.7	-23.3
Textiles, textile products, leather and footwear	4.0	7.3	4.2	4.5	4.4	4.8	6.1	6.4	51.0	-12.4	-4.2
Manufacturing nec; recycling	23.3	20.5	15.8	12.5	14.6	11.2	12.1	9.6	-48.1	-53.2	25.8
Wood and products of wood and cork	8.5	7.7	5.3	6.0	3.9	5.0	4.3	4.3	-49.7	-44.0	-1.0
Pulp, paper, paper products, printing and publishing	8.1	10.5	5.6	7.2	6.7	6.5	10.3	7.7	27.3	-26.5	33.8
Coke, refined petroleum products and nuclear fuel	66.1	42.1	72.8	54.7	84.6	45.8	33.0	29.3	-50.1	-30.4	12.7
Chemicals and chemical products	99.2	124.9	81.6	101.9	78.9	95.8	74.0	109.3	-25.4	-12.5	-32.3
Rubber and plastics products	48.6	26.2	23.0	18.5	18.9	16.6	18.4	18.3	-62.1	-29.9	0.4
Other non-metallic mineral products	26.4	17.9	26.6	12.4	16.2	11.0	11.3	11.1	-57.4	-38.2	1.8
Basic metals and fabricated metal products	15.2	23.0	13.9	16.3	10.5	13.6	10.9	12.3	-27.9	-46.8	-10.7
Machinery, nec	30.1	50.8	28.8	43.4	30.5	43.9	39.2	45.0	30.1	-11.5	-12.9
Transport equipment	294.5	137.2	228.3	106.1	175.4	112.1	125.5	111.9	-57.4	-18.4	12.2
Mining and quarrying											
Electricity, gas and water supply	1.0	11.5	1.3	8.6	1.4	7.2	0.9	5.4	-12.2	-52.8	-84.2
Construction	0.3	1.5	0.6	1.1	0.6	1.1	0.5	1.0	37.8	-30.7	-56.1
Agriculture, hunting, forestry and fishing											
MARKET SERVICES	1.7	2.4	3.5	2.4	5.5	3.0	5.4	4.7	219.1	94.3	15.0

EU does not include Ireland due to lack of information in energy and constructions sectors
EU-11: Austria, Denmark, Finland, France, Germany, Italy, Holland, Norway, Spain, Sweden and UK

Source: EUKLEMS

Table 2: Percentage distribution of GVA

	1,980		1,990		1,995		2,003		Variation 1980-03 (pp.)		Diference USA-EU
MARKET ECONOMY	USA	EU	USA	EU	USA	EU	USA	EU	USA	EU	2003
Electrical and optical equipment	4.1	4.1	4.2	3.8	4.2	3.4	3.1	2.9	-1.0	-1.2	0.2
Post and telecommunications											
Food products, beverages and tobacco	3.2	4.2	3.0	3.7	2.8	3.6	2.6	3.1	-0.7	-1.1	-0.6
Textiles, textile products, leather and footwear	2.1	2.4	1.4	1.8	1.2	1.5	0.6	1.0	-1.5	-1.4	-0.4
Manufacturing nec; recycling	1.2	1.3	1.0	1.2	1.0	1.2	1.0	1.0	-0.2	-0.3	0.0
Wood and products of wood and cork	0.7	1.0	0.6	0.9	0.6	0.8	0.5	0.7	-0.2	-0.3	-0.2
Pulp, paper, paper products, printing and publishing	3.5	3.2	3.4	3.2	3.2	3.4	2.6	2.7	-0.9	-0.6	-0.1
Coke, refined petroleum products and nuclear fuel	1.1	0.9	0.8	0.4	0.5	0.3	0.6	0.3	-0.5	-0.5	0.3
Chemicals and chemical products	2.9	3.0	3.0	2.9	3.2	3.0	2.8	2.8	-0.1	-0.2	0.0
Rubber and plastics products	1.1	1.3	1.1	1.2	1.2	1.3	1.0	1.2	-0.2	-0.1	-0.2
Other non-metallic mineral products	1.0	1.6	0.7	1.4	0.8	1.3	0.7	1.0	-0.3	-0.6	-0.3
Basic metals and fabricated metal products	5.4	5.2	3.3	4.4	3.2	4.3	2.2	3.5	-3.2	-1.7	-1.3
Machinery, nec	3.7	4.4	2.4	3.8	2.1	3.5	1.6	3.1	-2.1	-1.3	-1.5
Transport equipment	3.4	3.5	3.3	3.3	3.2	3.0	2.9	3.0	-0.6	-0.5	-0.1
Mining and quarrying											
Electricity, gas and water supply	3.3	3.5	3.8	3.6	3.7	3.7	3.1	3.1	-0.2	-0.4	-0.1
Construction	7.4	10.5	6.9	9.4	6.2	8.3	7.3	8.2	-0.2	-2.3	-0.9
Agriculture, hunting, forestry and fishing											
MARKET SERVICES	55.8	49.9	61.2	55.2	63.0	57.6	67.7	62.4	11.9	12.5	5.3

Source: EUKLEMS

Table 3: Contribution of productive specialization to the differences in capital stock in R&D/GVA between the US and the EU-11

Relative difference: Percentage w.r.t. EU

	1980	1995	2003
Country effect	30.4	15.7	2.3
Specialization effect	-3.2	5.2	-3.3
Interaction effect	0.2	3.8	1.1
Total	27.3	24.7	0.0

Percentage distribution

	1980	1995	2003
Country effect	111.1	63.8	6273.1
Specialization effect	-11.7	21.0	-9296.3
Interaction effect	0.6	15.2	3123.2
Total	100.0	100.0	100.0

Source: own elaboration

Table 4: Contribution of structural change to the variation of capital stock in R&D/GVA ratio

Decomposition of annual growth rate

	1980-2003		1980-1995		1995-2003	
	USA	EU	USA	EU	USA	EU
Intrasectorial effect	-1.57	-0.48	-1.98	-1.30	-0.36	1.29
Static sectorial effect	-1.16	-0.98	-0.37	-0.98	-1.79	-0.89
Dynamic sectorial effect	0.45	0.22	0.10	0.18	-0.20	0.00
Total	-2.28	-1.24	-2.25	-2.11	-2.35	0.40

Percentage distribution

	1980-2003		1980-1995		1995-2003	
	USA	EU	USA	EU	USA	EU
Intrasectorial effect	68.8	38.8	88.0	61.7	15.5	325.9
Static sectorial effect	50.9	79.2	16.3	46.7	76.0	-225.2
Dynamic sectorial effect	-19.7	-18.0	-4.3	-8.4	8.5	-0.6
Total	100.0	100.0	100.0	100.0	100.0	100.0

Source: own elaboration

Table 5: Decomposition of the Theil index by country

				Percentage over total Theil index	
	Theil Index (total)	Between countries	Within countries	Between countries	Within countries
1980	1.352	0.113	1.239	8.37	91.63
1981	1.339	0.123	1.217	9.15	90.85
1982	1.321	0.127	1.194	9.64	90.36
1983	1.296	0.132	1.164	10.16	89.84
1984	1.285	0.137	1.149	10.64	89.36
1985	1.256	0.139	1.117	11.06	88.94
1986	1.252	0.136	1.116	10.89	89.11
1987	1.288	0.142	1.146	11.03	88.97
1988	1.316	0.149	1.167	11.31	88.69
1989	1.336	0.142	1.194	10.63	89.37
1990	1.362	0.130	1.232	9.52	90.48
1991	1.386	0.127	1.259	9.17	90.83
1992	1.418	0.129	1.289	9.07	90.93
1993	1.434	0.133	1.301	9.25	90.75
1994	1.386	0.130	1.256	9.41	90.59
1995	1.344	0.126	1.218	9.39	90.61
1996	1.353	0.139	1.215	10.26	89.74
1997	1.315	0.147	1.168	11.15	88.85
1998	1.307	0.149	1.158	11.43	88.57
1999	1.326	0.156	1.170	11.74	88.26
2000	1.328	0.161	1.168	12.08	87.92
2001	1.400	0.180	1.220	12.82	87.18
2002	1.424	0.195	1.230	13.67	86.33
2003	1.442	0.203	1.239	14.09	85.91

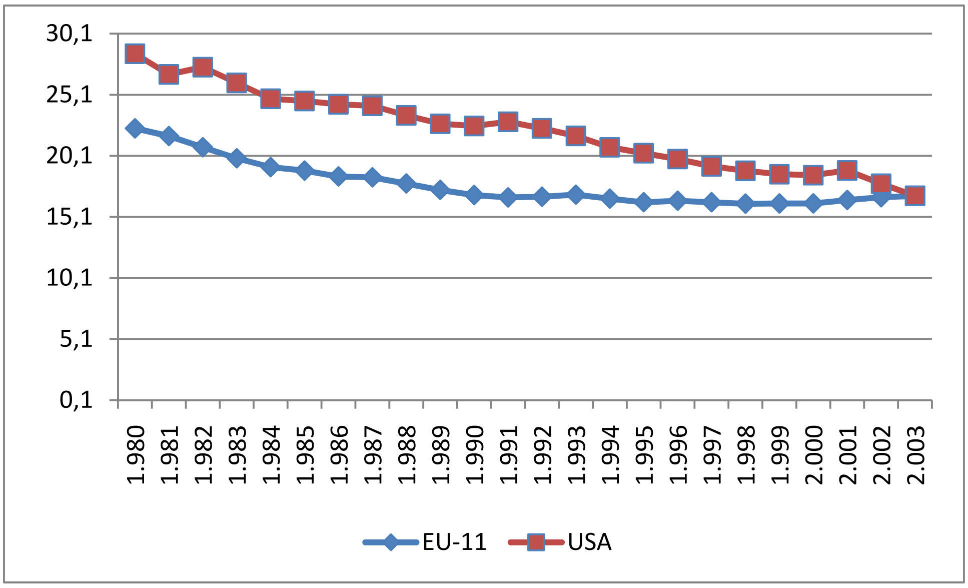
Source: own elaboration

Table 6: Decomposition of the Theil index by industry

			Percentage over total Theil index	
Theil Index (total)	Between countries	Within countries	Between countries	Within countries
1.352	1.022	0.330	75.58	24.42
1.339	1.015	0.325	75.75	24.25
1.321	1.005	0.316	76.06	23.94
1.296	0.991	0.304	76.51	23.49
1.285	0.986	0.299	76.70	23.30
1.256	0.962	0.294	76.55	23.45
1.252	0.967	0.285	77.24	22.76
1.288	1.004	0.284	77.94	22.06
1.309	1.025	0.284	78.33	21.67
1.336	1.053	0.284	78.78	21.22
1.362	1.084	0.277	79.64	20.36
1.386	1.105	0.281	79.73	20.27
1.418	1.135	0.283	80.03	19.97
1.434	1.146	0.288	79.93	20.07
1.386	1.120	0.266	80.81	19.19
1.345	1.097	0.247	81.61	18.39
1.353	1.091	0.263	80.59	19.41
1.315	1.053	0.262	80.06	19.94
1.307	1.048	0.259	80.18	19.82
1.326	1.069	0.257	80.62	19.38
1.328	1.077	0.252	81.06	18.94
1.400	1.142	0.258	81.58	18.42
1.424	1.170	0.254	82.14	17.86
1.442	1.202	0.240	83.37	16.63

Source: own elaboration

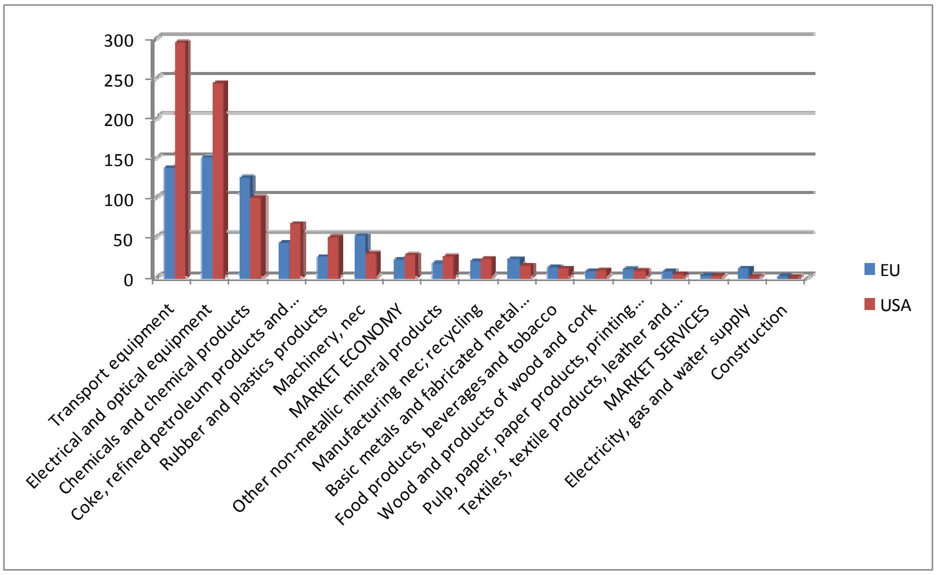
Figure 1: Capital stock in R&D/GVA (private sector)



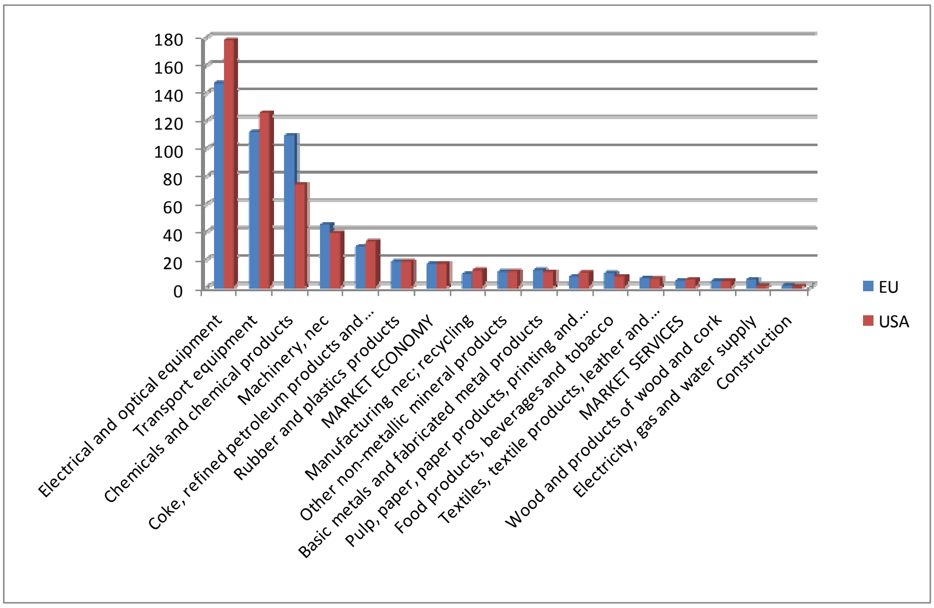
Source: EU-KLEMS

Figure 2: Capital stock in R&D/GVA by industries

a) 1980

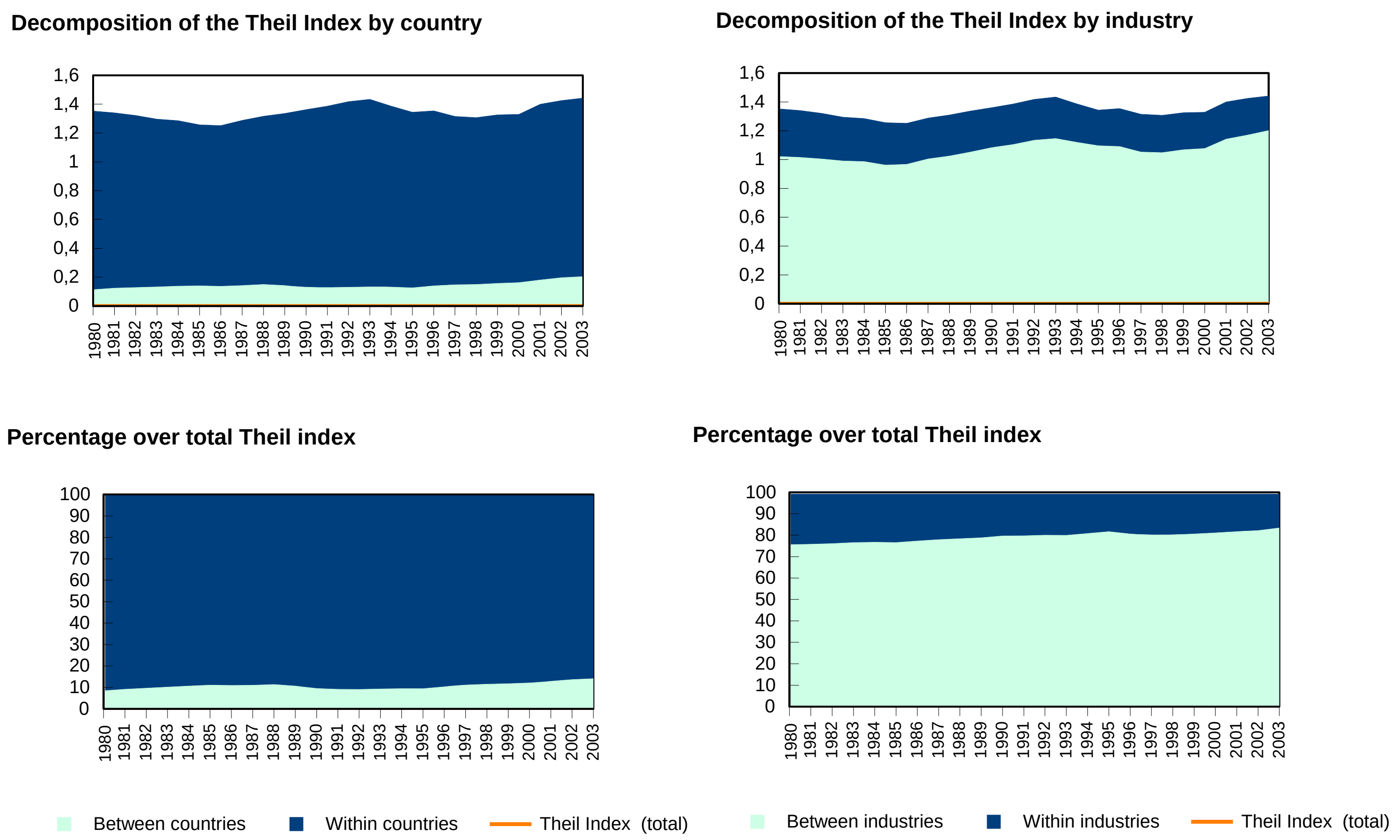


b) 2003



Source: EU-KLEMS

Figure 2: Evolution of inequalities in technological capital intensity among industries of the EU countries. The Theil index



Source: own elaboration