ISSN: 1576-0162

Technological Capabilities and Patterns of Income Convergence in Europe: A Cluster Analysis

Capacidades tecnológicas y patrones de convergencia en ingresos en Europa. Un análisis de clúster

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Recibido: diciembre 2017; aceptado: julio 2018

Abstract

This paper analyses the patterns of convergence across the European Union countries in terms of both economic growth and technological conditions during the period 1995-2013. We apply the methodology of Phillips-Sul (2007) to study convergence in real income per capita and countries' technological capabilities. We consider separately eight technological indicators as proxies for a country's innovative ability and absorptive capacity. The results support the club convergence hypothesis for income and some technology-related indicators and offer an approximation to the role that technological capabilities could play in the income convergence process.

Keywords: Convergence Clubs; Technology Clubs; European Union; Log T Test.

Resumen

Este trabajo analiza los patrones de convergencia entre países de la Unión Europea en términos de crecimiento económico y condiciones tecnológicas durante el periodo 1995-2013. Para estudiar la convergencia en renta real per cápita y en capacidades tecnológicas se emplea la metodología de Phillips-Sul (2007). En este estudio se consideran, de forma separada, ocho indicadores tecnológicos como variables aproximadas de la habilidad de innovación de los países y su capacidad de absorción. Los resultados apoyan la hipótesis de clubs de convergencia para la renta y para algunos de los indicadores relacionados con capacidad tecnológica y ofrecen una aproximación al papel que las capacidades tecnológicas podrían desempeñar en el proceso de convergencia en renta.

Palabras clave: Clubs de convergencia; Clubs tecnológicos, Unión Europea; Log t test.

Clasificación JEL: C33, O33, O47.

1. Introduction

Heterogeneity in terms of living standards and growth rates across countries in the European Union (EU) has risen notably, especially after the last rounds of enlargements (Cuaresma *et al.*, 2013). The convergence–divergence debate has been capturing the attention of researchers and policymakers in the past several decades and remains a crucial question to answer for reducing inequalities within the European territory. This issue is especially relevant for European policy since strengthening economic, social, and territorial cohesion is one of the main objectives of the European Union.

A precondition for convergence among economies is economic growth, so convergence processes have been analysed within growth theories framework. The neoclassical growth models (Solow, 1956; Swan, 1956) predict that relatively poorer economies will grow faster than relatively richer ones, tending to converge toward a single long-run steady state. In contrast, endogenous growth models (Romer, 1986; Lucas, 1988) describe a situation of non-convergence between poor and rich economies where initial differences could grow in time without limit (Durlauf, 1996). Modern growth theories have suggested that the distribution of per capita income in regions may point out a tendency for a steady distribution to cluster around a small number of poles of attraction. This also leads to the club convergence hypothesis by allowing multiple stable steady states (Durlauf and Johnson, 1995). Countries that are equal in their structural characteristics and have different initial income per capita may belong to different clubs (Durlauf, 1996). This tendency can be explained by several factors: capital market imperfections, imperfectly competitive market structures, and spillovers due to human and capital accumulation (Galor, 1996). An alternative view is provided by Schumpeterian endogenous growth models, setting up the role of technological change as a cause of the emergence of convergence clubs (Castellacci, 2008).

A wide and diverse amount of literature both theoretical (Schumpeter, 1934; Solow, 1956; Romer, 1986) and empirical (Coe and Helpman, 1995; Aghion and Howitt, 1998; Hasan and Tucci, 2010) has recognized the role of technological change as a main driver of economic growth. Technological progress is driven not only by a country's internal efforts in R&D but also by its capacity to absorb advanced technologies from outside sources (Abramovitz, 1986).

The recent empirical research related to technology gap approach suggests that difference in innovation and the international diffusion of advanced technologies as potential causes of convergence clubs and polarization in income levels (Howitt, 2000; Howitt and Mayer-Foulkes, 2005; Stokke, 2008). Some recent empirical works suggest that differences in technological capabilities (Castellacci and Archibugi, 2008) or relatedly, the innovative ability and absorptive capacity of countries, lead to the existence of technology clubs in the world economy that affect their growth dynamics (Castellacci, 2008; 2011; Stöllinger, 2013).

Focus on the European Union, the club convergence hypothesis has been tested by several studies that have found convergence club behaviour across countries for the per capita income variable (Apergis *et al*., 2010; Fritsche and Kuzin, 2011; Monfort *et al*., 2013; Borsi and Metiu, 2015).

At the same time, the empirical evidence suggests a great disparity among the technological capabilities of EU member states (Archibugi and Coco, 2004; Archibugi and Filippetti, 2011). Regarding with this idea, some authors (for instance, Apergis *et al*., 2010) point out that the technological conditions of different European countries are highly responsible for growth and convergence processes within clubs of convergence.

Bearing in mind these previous remarks, the aim of this paper is to explore the patterns of convergence in terms of income per capita and technological capabilities across European countries during the period 1995-2013. Mostly, it examines whether European countries follow a convergence club pattern rather than a full convergence pattern in terms of both per capita income and technological capabilities. In addition, it provides an approximate guide on the possible link between both convergence processes. More specifically, we are interested in answering the following research questions:

- Have European countries converged toward the same per capita income steady state or have convergence clubs arisen in the European Union?
- Has there been a process of overall convergence in technological capabilities in the European Union or have technology clubs emerged?
- Are there signals of a possible association between both processes?

To test these research questions, we use a nonlinear factor model developed by Phillips and Sul (2007), which admits technological heterogeneity across countries (Apergis *et al*., 2010). We follow two steps in our empirical analysis. First, the methodology is applied to identify groups of EU nations that represent per capita income club convergence. Second, we use it to test the existence of technology clubs in EU countries. For this purpose, we employ a set of eight indicators that directly measure various relevant aspects of countries' technological capabilities (proxied by innovative ability and absorptive capacity). The existence of technology clubs is analysed by considering separately each indicator that proxy technological capabilities of the countries.

This paper, empirical in nature, makes three main contributions to the existing literature. First, it brings new evidence regarding the process-of per-capita income convergence of EU countries using a novel methodological approach that allows the identification of convergence clubs endogenously. Second, it allows us to approximate the patterns of convergence in technological capabilities for the EU by analysing separately each of the dimensions of innovation, on which there has been little empirical evidence. Regarding the latter, although the methodology developed by Phillips and Sul (2007) has been previously applied in the empirical literature to analyse income convergence, this paper imposes a novel application of this methodology to technology-related indicator data. Third, it offers an approximation to the role that technology-related indicators have been able to play in income convergence clubs.

The rest of the paper is structured as follows: Section 2 outlines the methodology applied for the analysis of economic and technology club convergence. Section 3 describes the data. Section 4 and Section 5 provide the identification of income convergence clubs and technology clubs, respectively. Finally, conclusions are drawn in Section 6.

2. Methodology

In the following paragraphs the empirical methodology used for club convergence identification is described. According to Galor (1996), three different concepts of convergence may be considered. The absolute convergence hypothesis considers that the variables converge to a common steady state equilibrium regardless of initial conditions. The conditional convergence hypothesis presumes convergence to a common steady state independently of initial levels, but only among countries that share common structural characteristics (demography, policy, geography…). Finally, the club convergence hypothesis describes a situation in which groups of countries with similar initial conditions and structural characteristics converge to a common steady state equilibrium. In the case of club convergence, multiple steady states can exist (Durlauf and Johnson, 1995; Galor, 1996; Islam, 2003).

There are diverse estimation methods that can be applied for testing the club convergence hypothesis. The club-convergence hypothesis was first tested using the β-convergence method (Durlauf and Johnson, 1995), but this approach has its limitations because it requires identifying priorities factors that can explain the existence of multiple equilibria and preselecting groups of countries according to these criteria.

In order to avoid making such arbitrary choices, more recent methods have been developed to endogenize the groups of countries. Phillips and Sul (2007) have developed a methodology related to the so-called σ-convergence, and it has been used in recent empirical works on country and region club convergence[1], thus avoiding the weaknesses of other estimation techniques (Bartkowska and Riedl, 2012; Monfort *et al.*, 2013). This methodology allows us to distinguish between global convergence, divergence, or club convergence

[1] The methodology developed by Phillips and Sul (2007) can be applied to other variables in addition to output (see for instance, Apergis *et al.*, 2012; Apergis and Cooray, 2014).

across different countries. This approach has clear advantages over alternative methods. First, while other methodologies group economies a priori without using any specific methodology, which limits the results, the log *t* test does it endogenously, grouping by unspecified factors that determine the formation of clubs of convergence. Second, this methodology is based on the cross-sectional distribution of per capita income, sigma convergence rather than beta convergence, modelling the structure of the panel data as a nonlinear relationship in which the coefficients can vary along time, showing that the asymptotic properties are well defined. The test is a regression process as well as a grouping process that does not depend on possible assumptions about the stationary trend of the variables examined (Monfort *et al*., 2013). In addition, with this methodology it is possible to estimate the speed of the convergence parameter, which allows us to empirically distinguish the relative convergence.

We apply the methodology developed by Phillips and Sul (2007) to technological indicators and per capita income to identify groups of EU countries that represent technology clubs and income convergence clubs respectively.

2.1. Log t test description

Phillips and Sul (2007) propose a nonlinear time-varying factor model for testing the convergence hypothesis and the identification of convergence clubs. From a traditional approach, the variable under study, y_{it}, is usually explained by two components:

$$log y_{it} \approx \beta_i \mu_t, \tag{1}$$

where β_i is the component containing the structural characteristics of each country, while u_t represents the common trend in growth. Phillips-Sul´s (2007) contribution is to add variation over time so that the logarithm of the variable will be explained with a new decomposition:

$$log y_{it} \approx \beta_{it} \mu_t \tag{2}$$

where β_{it} is a time-varying idiosyncratic element that captures the deviation of country i from the common path defined by μ_t. Thus, Phillips and Sul (2007, 2009) introduce a cross-sectional analysis as well as an analysis of heterogeneous time series in the parameters of a neoclassical growth model in order to take into account the heterogeneity of the transition temporary variable analysed.

This idea leads to the following procedure:

Let $\{Y_{it}\}$ be a panel data of the variable under study, where t = 1, 2,..., T are the values of time, and i = 1, 2, ..., N the countries. Then the following steps are performed:

First, for each time t, the mean value is calculated, and each individual value is compared with the obtained average value

$$h_{it}=\frac{Y_{it}}{\frac{\sum_{i=1}^{N} Y_{it}}{N}} \tag{3}$$

Second, for each time t, the variance of the values h_{it} is calculated using the following formula:

$$H_t=\frac{\sum_{i=1}^{N}(h_{it}-1)^2}{N} \tag{4}$$

The reason for comparing each value with 1 is that if there was convergence, all these values should converge to 1 (transition curves).

Finally, the absolute convergence hypothesis is based on the fact *that* H_t tends to zero. To study it, if we consider the following model to fit the data:

$$log\left(\frac{H_1}{H_t}\right) -2log(log\, t) = a+\beta\, log\, t + u_t, \qquad t=[rT],\ [rT]+1,\dots,T \tag{5}$$

if $\beta<0$, the absolute convergence hypothesis is rejected. Based on Monte Carlo simulations, Phillips and Sul (2007) suggest using $r=0.3$ for sample sizes below T=50.

The next step is to measure, with a suitable statistic, the degree of reliability of the value obtained for β.

If the global convergence hypothesis is rejected, then it goes on to identify possible convergence clubs. To this end, an iterative algorithm developed by Phillips and Sul (2007) is applied; the results of this algorithm have a significance level of 5%. The iterative procedure to identify convergence clubs is summarized in four steps:

Step 1 (sort the data panel cross-section): When $T\rightarrow\infty$, the convergence, even inside each club, is most evident in the latest observations of the series. For this reason, the first step is to order the panel data from highest to lowest based on the observations of the last period.

Step 2 (formation of convergence clubs): Select k in the panel countries to form each club. This begins to form groups of countries from the highest value of each variable in the last period, so that the groups will be formed by a number of countries $2<k<N$, in such a way that the core group size is chosen on the basis that maximizes t_k according to the criterion (level of significance 5%).

$$k^*=arg\, max_k\{t_k\} \text{ subject to } min\{t_k\}>-1.65 \tag{6}$$

This is done for the first two countries, and if it does not meet the criterion, it is done with the second and third, and continued until a couple of countries meet the criterion; if this does not happen, we can conclude that there are no clubs of convergence in the data panel.

Step 3 (sift data to form clubs): If in the previous step two countries meet the established criterion, the process will continue, adding countries in the order they appear in the data panel, which is already sorted, while the data continue to meet the criterion. When the data no longer meet the criterion it has found the first club.

Step 4 (repeat and stop rule): Countries not selected in the first club form a complement group. With them we run the log *t* regression again and, if it converges, then these countries form a second club. If not, we repeat steps 1 to 3 in order to find successive clubs. These countries show divergent behaviour if no core group can be found.

Likewise, Phillips and Sul (2007) propose modelling the transitional elements β_{it} by building a relative measure of such coefficients:

$$h_{it}=\frac{Y_{it}}{\frac{\sum_{i=1}^{N} Y_{it}}{N}}=\frac{\beta_{it}}{\frac{\sum_{i=1}^{N}\beta_{it}}{N}} \quad (7)$$

This measures the weighted coefficients β_{it} in relation to the panel data so that the variable h_{it} is called the relative transition path, and traces an individual path for each country *i* relative to the average panel data. Thus, h_{it} measures the trajectory of each country *i* from the starting position relative to the path of common growth. When there is a common behaviour in the path of growth between countries, $h_{it}=h_t$, it could find a convergence club between that group and, in the same way, could trace the path of common growth of the club on the panel data.

Studying convergence in a panel data set has several appealing features. Since the model traces an individual path for each country *i* relative to the average panel of data, we can distinguish empirically different degrees of convergence; the regression coefficient β provides a scaled estimator of the speed of convergence parameter.

3. DATA AND SOURCES

This paper analyses convergence clubs in terms of both per capita income and technological capabilities between European Union countries (EU-25) during the period 1995-2013. The data for the empirical analysis were obtained from different databases with the aim of completing an adequate number of indicators for the countries examined. Countries included in the analysis are Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom. The databases consulted were Eurostat, UNESCO, and the World Bank.

For testing convergence in per capita income, we use GDP at constant 1995 prices using purchasing power parities divided by total domestic employment (both variables come from Eurostat).

To analyse the existence of technology clubs we use a set of eight indicators related to two key aspects of countries' technological capabilities: innovative ability-the extent to which a country is able to produce new advanced knowledge (Castellacci, 2011) and the capacity for absorbing external knowledge, so-called absorptive capacity (Cohen and Levinthal, 1989). The patterns of convergence in technological capabilities for the EU-25 studied here were analysed by attending to each indicator separately. This will allow us to shed light on the level of convergence reached by countries for each single dimension of countries' technological capabilities.

The innovative ability comprises both the creation of technological and scientific knowledge (measured by the number of patents and scientific articles published per million people) and R&D effort accomplished by countries (measured by R&D expenditure per GDP)[2]. The absorptive capacity incorporates the level of human capital (measured by the school life expectancy and the share of tertiary education and tertiary science and engineering (S&E) enrolment) and the level of technological infrastructure (measured by the telephone and Internet penetration) existing in the countries. The details regarding the technological capabilities indicators used in the analysis are as follows[3]:

- Patents per million people: Patents is a proxy measure for innovative capabilities. The total European patent applications refers to requests for protection of an invention sent either directly to the European Patent Office (EPO) or filed under the Patent Cooperation Treaty and designating the EPO (Euro-PCT), regardless of whether they are granted or not. The data show the total number of patent applications per million people (Eurostat).
- Articles per million people: This variable captures scientific production in a country. To construct this variable, we divide the number of articles and scientific publications (World Bank) by the country's population (Eurostat).
- R&D expenditure per GDP: Total intramural R&D expenditure by all sectors, private and public, as a percentage of GDP (Eurostat). This is an indicator of generation of new knowledge and innovation. This indicator is weighted by GDP to support the comparison between countries.
- Telephone penetration: This refers to the sum of the number of mobile and fixed phone lines per 100 inhabitants (World Bank). Telephony is a basic infrastructure requirement for business performance.
- Internet penetration: This refers to the number of Internet users per 100 inhabitants (World Bank). The Internet has become an indispensable tool for the development of both public and private business.
- Electricity consumption: This variable counts the number of kilowatts of electricity consumed per hour per capita (World Bank). This is a proxy measure for the use of equipment and plants since they use electric power.
- School Life Expectancy: It refers to the number of years a person of school entrance age can expect to spend within the specified level of education (UNESCO). It is a proxy for basic human capital.

[2] In innovation literature patents are considered as an innovation output while R&D expenditure is treated as an innovation input.

[3] We chose the indicators following previous studies on technology clubs for measuring technology capabilities of countries (see for instance, Castellacci, 2008; 2011; Castellacci and Archibugi, 2008).

- Tertiary science and engineering (S&E) enrolment. This is the share of graduates in science and engineering compared with the total number of graduates in all fields (UNESCO). This variable is related to the formation of advanced workforce in science and technology able to create and manage advanced technological knowledge.

4. INCOME CONVERGENCE CLUBS

In this section, we explore the patterns of convergence in per capita income across UE countries. Phillips and Sul (2007) log *t* test was applied to per capita income to test the relevance of the club convergence hypothesis for explaining the convergence process at the national level. When the log *t* test was applied to per capita income across 25 European countries, the overall convergence hypothesis was rejected at the 5% significance level (Table 1) and therefore the study of the formation of convergence clubs can proceed.

TABLE 1. OVERALL INCOME CONVERGENCE TEST RESULT

Variable	t Statistic	Coefficient
Per capita income	-10.4937	-0.2874

For evaluating the existence of convergence clubs, we applied a clustering mechanism test procedure in which we identified four clubs and one diverging country, Ireland, which followed its own growth path. Table 2 reports the results for per capita income convergence clubs[4]. As shown in Table 2 and Figure 1, there is a notorious group of European countries that converge in the same group, while the rest of the countries do not go through the same path of growth, forming other less numerous convergence clubs. Specifically, relatively high-income level Western European countries (Austria, Belgium, Finland and Sweden) plus Lithuania form the first club. Club 2 is the most numerous of the four clubs; a conglomerate of 12 countries integrated mainly by the old state members plus five Eastern countries (Czech Republic, Latvia, Poland, Slovakia and Slovenia). The geographical proximity between countries of this club can be observed in Figure 1. Clubs 3 is, mainly formed by Eastern Europe (Croatia and Estonia) countries plus Greece. Finally, three South East countries (Hungary, Romania and Bulgaria) plus Portugal form Club 4.

[4] As previously mentioned, empirical research focused on EU countries support the club convergence hypothesis for income per capita (Borsi and Metiu, 2015; Monfort *et al*., 2013; Fritsche and Kuzin, 2011; Apergis *et al*., 2010).

This club formation points out that some Eastern European countries have experienced a catch-up process with Western countries[5], while some of the southern periphery Western countries have followed a growth process more similar to some Eastern countries[6].

Examining the empirical results in detail, we can see that Clubs 2 and 3 experience a greater degree of convergence within clubs: the estimated speeds of convergence are 0.1024 (=0.2048) and 0.2072 (=0.4144), respectively. It is also easy to see that the corresponding t statistics clearly meet the criterion of being greater than -1.65, reaching in both clubs the highest values, so we can say they are the most cohesive clubs for per capita income.

On the other hand, Clubs 1 and 4, which are located in the upper and lower extremes in terms of per capita income, also present convergence, but with statistical parameters showing that they have been growing at a slower rate of convergence: convergence speeds of 0.0494 ($\beta = 0.0988$) and 0.0025 ($\beta = 0.0051$), respectively. In this case, the values of *t* statistics show that clubs 1 and 4 are the least cohesive clubs.

Table 2. Per capita income club convergence

	Countries	t Statistic	Coefficient
1st club	Austria, Belgium, Finland, Lithuania, Sweden	0.9333	0.0988
2nd club	Czech Republic, Denmark, France, Germany, Italy, Latvia, Netherlands, Poland, Slovakia, Slovenia, Spain, United Kingdom	2.5746	0.2048
3rd club	Croatia, Estonia, Greece	2.7570	0.4144
4th club	Bulgaria, Hungary, Portugal, Romania	0.1831	0.0051
Non-converging	Ireland		

[5] As Monfort *et al.*, (2013) point out structural reforms undertaken in countries with different initial income per capita could contribute to increase the pace of growth of the economy and the convergence with rich countries.

[6] These results are in line with those obtained in similar studies (see for instance Borsi and Metiu, 2015).

FIGURE 1. PER CAPITA INCOME CLUB CONVERGENCE

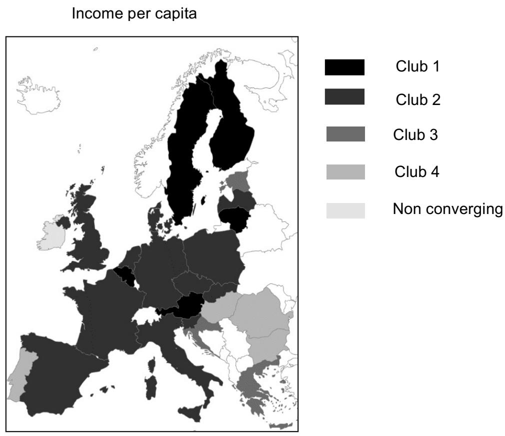
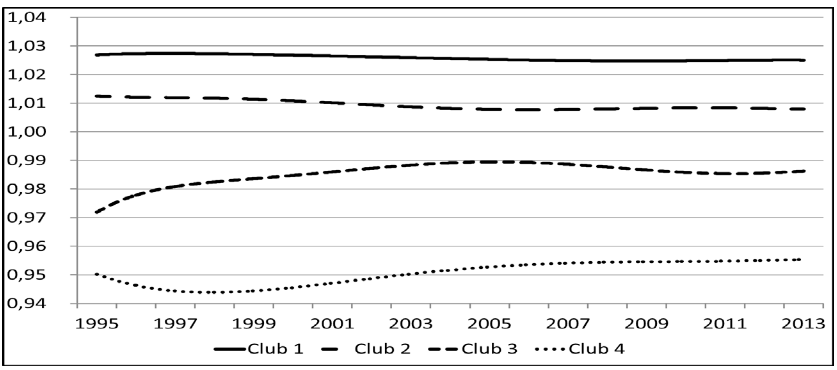


FIGURE 2. RELATIVE TRANSITION PATHS OF PER CAPITA INCOME CLUBS



The relative transition paths of the four clubs displayed in Figure 2 show the tendencies across groups. Under the assumption of convergence for the full panel of countries, the relative transition path should tend to unity - that is, all should converge to the same level of per capita income. However, assuming club convergence, the relative transition paths of the different clubs tend to different values. In this case, it seems that the second club is around average; the first is above average and the third and fourth are below average. Club 3 is approaching Club 2, and Club 2 seems to maintain an equivalent distance with Club 1 throughout the period. Club 4, which is clearly below average, seems to show a slightly upward trend.

5. Technological capabilities across European countries: patterns of convergence

The lack of overall convergence in per capita income in UE countries and the formation of convergence clubs over the period 1995-2013 drive to analyse the possible factors responsible for this finding. Following technology-gap approach, the differences in technological capabilities across European countries may be related with this behaviour[7].

Thus, in this section, first we focus on technological conditions of countries belong to each income club and estimate the technology gap across income clubs and, secondly, we focus on the patterns of convergence in technological capabilities across UE countries. Likely, technological indicators that converged in clubs have played a more salient role in explaining convergence clubs for income than those with overall convergence pattern.

Table 3 presents the technological capabilities for the four income clubs at the beginning (1995) and the end of the analysed period (2013). It also displays the technology-gap between Club 1 and Club 2, between Club 2 and Club 3 and between Club 3 and Club 4[8]. The results reveal for all indicators the existence of technological differences between the richest group and the middle-income group and between it and the groups of poor countries. At the beginning of the period the technology gap between the richest countries and the middle-income countries was greater for Internet penetration, patents per capita and electricity consumption indicators. At the end of the period the greater gap was in patents per capita. The results also indicate that the largest technology gap was between middle-income countries and poor countries, especially with respect innovative ability indicators. For instance, at the beginning of the period middle-income countries produced on average 19 patents per capita for each patent produced by poor countries, expended approximately the double of R&D as percentage of GDP and published more than the double of articles per capita than poor countries. Note that the technology gap is greater for per capita patents than for the rest of indicators. At the end of the period the differences still exist but they have diminished.

[7] Being aware that in addition to countries' technological capabilities could exist other factors that could explain the club formation, such as the initial and structural conditions of the different economies (Bartkowska and Riedl, 2012). This paper offers only a first approximation to the role of that technological capabilities could play to explain the formation of income clubs, but a deep analysis of the explanatory factors of this behaviour is beyond the scope of this study.

[8] Technology-gap between clubs has been obtained by dividing the value of the indicator for the highest club by the value of the indicator for the club that follows it in a similar way to other studies (see for instance, Castellacci, 2008; 2011).

Table 3. Technological capabilities across European countries

	Club 1		Club 2		Club 3		Club 4	
TECHNOLOGICAL CAPABILITIES*								
Indicators/Year	1995	2013	1995	2013	1995	2013	1995	2013
Patents per capita	95.83	186.02	49.41	101.26	2.59	7.32	2.38	13.88
R&D expenditure	2.14	3.10	1.69	2.25	0.96	1.40	0.85	1.28
Articles per capita	568.76	1507.19	394.94	1286.95	157.56	1045.36	99.81	826.96
Telephone penetration	57.67	183.67	51.55	170.65	49.35	176.39	49.54	159.23
Internet penetration	4.43	83.51	1.91	78.11	1.35	68.67	0.75	61.50
Electricity consumption	9065.84	9904.70	5001.11	5745.98	3414.69	5149.31	2824.05	3689.96
School life expectancy	15.28	17.87	14.14	17.00	12.43	16.23	12.73	15.76
Tertiary S&T enrolment	26.12	24.14	22.16	22.42	22.21	22.95	19.68	23.14
TECHNOLOGY GAP			Club 1 vs. Club 2		Club 2 vs. Club 3		Club 3 vs. Club 4	
Indicators/Year			1995	2013	1995	2013	1995	2013
Patents per capita			1.94	1.84	19.05	13.84	1.09	0.53
R&D expenditure			1.26	1.38	1.76	1.61	1.13	1.10
Articles per capita			1.44	1.17	2.51	1.23	1.58	1.26
Telephone penetration			1.12	1.08	1.04	0.97	1.00	1.11
Internet penetration			2.32	1.07	1.42	1.14	1.80	1.12
Electricity consumption			1.81	1.72	1.46	1.12	1.21	1.40
School life expectancy			1.08	1.05	1.14	1.05	0.98	1.03
Tertiary S&T enrolment			1.18	1.08	1.00	0.98	1.13	0.99

* Technological capabilities have been calculated as the average value for the UE-25 for each indicator.

In order to analyse the process of convergence in technological capabilities across European countries, we applied a convergence test to each technology-related indicator. This analysis strategy will allow us, first, to know the convergence process of each indicator during the analysed period and, second, to identify those indicators that when converging in clubs, may be associated to a greater extent with income convergence clubs identified in Section 4.

Table 4 presents the results of overall convergence test for all indicators; articles per million people, telephone penetration, Internet penetration and school life expectancy show full convergence in the analysed period.

The results of applying the log *t* test are discussed in the following paragraphs separately for every indicator.

Table 4. Overall convergence test results for technology-related indicators

Variables	t Statistic	Coefficient
Innovation Ability Indicators		
Patents per million people	-66.9757	-0.6701
R&D expenditure per GDP	-4.7139	-0.4318
Articles per million people	1.3933	0.1106
Absorptive Capacity Indicators		
Technological Infrastructure Indicators		
Telephone penetration	1.6728	0.5225
Internet penetration	11.4677	1.7135
Electricity consumption	-11.3466	-0.4541
Human Capital Indicators		
School Life Expectancy	0.7552	0.2232
Tertiary S &E enrolment*	-2.7571	-0.4816

*Panel data from 1999 was used. Greece was excluded due to lack of data.

5.1. Innovation ability indicators convergence

5.1.1. *Patents per capita club convergence*

Table 4 presents the results of overall convergence test for patents per capita. It can be observed that the null hypothesis of convergence is rejected at 5% of significance level. When the log *t* test was applied to patents per capita indicator, four convergence clubs and two divergent countries, Spain and Latvia, were identified. Table 5 displays the results for patents per million people convergence club classification. The results show that Clubs 1 and 2 are formed only by Western European countries geographically close; the first club contains the Nordic countries Denmark, Finland and Sweden plus Austria and Germany, while the second club comprises Belgium, Netherlands and France. Further, Clubs 1 and 2 have a greater degree of convergence within clubs, in such a way that the estimated speed of convergence is 0.2500 ($\beta = 0.5001$) and 0.0815 ($\beta = 0.1630$), respectively.

Club 3 includes mainly Eastern countries (Czech Republic, Estonia, Hungary, Poland, Slovakia and Slovenia) but also three Western European countries

(Italy, Ireland and United Kingdom). Finally, Club 4 incorporates both Southern periphery Western countries (Greece and Portugal) and Eastern countries (Bulgaria, Croatia, Lithuania and Romania). Club 3 also converges but with a slower speed than Clubs 1 and 2; the β in club 4 is negative (β = -0.1243) but not significantly different from zero suggesting that this is the weakest convergence club for patents per capita.

The map shows that the group of more technologically advanced countries is in the center, while Club 2 and Club 3 are on both sides; Club 4 is on the periphery (Figure 7 a).

In brief, the results suggest a clear distinction between Western and Eastern countries for this indicator. Most of the Western countries belong to the two most technologically advanced clubs. Surprisingly, Ireland, Italy and United Kingdom converge with a group formed mainly by Eastern countries.

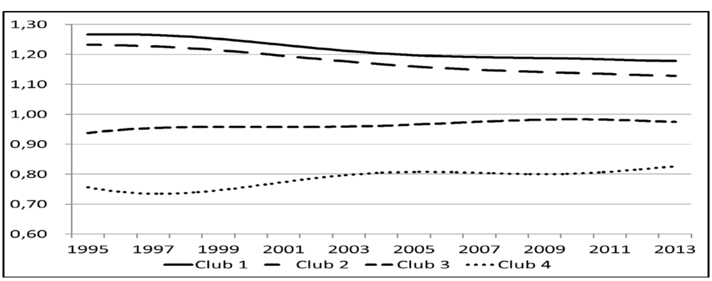
Within Eastern countries there seem to be two groups. In the first group (Club 3) four countries (Czech Republic, Poland, Slovakia and Slovenia) are those that have experienced greater success in the per capita income catching-up (belonging to Club 2 of income convergence). The second one is a group of Eastern countries that together with the Eurozone's southern periphery countries (Greece and Portugal) are the most technologically lagged.

The relative transition paths of Clubs 1 and 2 appear distinctively above the average, while those of Clubs 3 and 4 are clearly below the average, anyway all transition path seem to be approaching the average very slowly (Figure 3).

Table 5. Patents per million people club convergence

	Countries	*t* Statistic	β Coefficient
1st club	Austria, Denmark, Finland, Germany, Sweden	4.1056	0.5001
2nd club	Belgium, France, Netherlands	1.0044	0.1630
3rd club	Czech Republic, Estonia, Hungary, Ireland, Italy, Poland Slovakia, Slovenia, United Kingdom	1.2658	0.0647
4th club	Bulgaria,Croatia, Greece, Lithuania, Portugal, Romania	-0.8808	-0.1243
Non-converging	Latvia, Spain		

Figure 3. Relative transition paths of patents per capita clubs



5.1.2. *R&D* convergence clubs

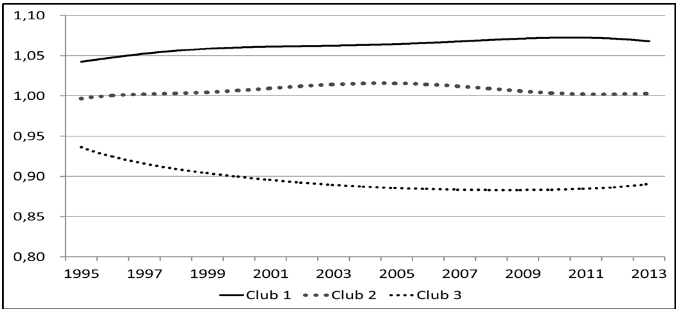
For R&D expenditure per GDP indicator, the null hypothesis of convergence is rejected at 5% significance level (Table 4), therefore the log *t* test was applied for identify clubs. Table 6 reports the results of the log *t* test for this indicator. The results show three convergence clubs and one divergent country, France. As can be noted, countries of Western and Eastern Europe form all clubs (see Figure 7b). The first club is the largest with 11 countries; mostly Western countries belong to the club although also three Eastern countries (Czech Republic, Estonia and Slovenia) integrate it. Club 1 has the highest speed of convergence 0.2201 ($\beta = 0.4403$) and is the most cohesive club. Clubs 2 and 3 both have 7 members, but while in Club 2 Eastern countries are a minority (Hungary and Lithuania) Club 3 contains mainly Eastern countries (all except Greece). Further, while Club 2 has a speed of convergence 0.0144 ($\beta = 0.0367$) with a positive value, this is not the case with Club 3, which has the weakest cohesion of the three clubs ($\beta = -0.1196$).

As shown in Figure 4, the relative transition paths show that, while Club 2 has a trend similar to the average of the panel, Clubs 1 and 3 are clearly above and below average, respectively. Moreover, the three clubs have a slight tendency to separate between them.

Table 6. R&D expenditure per gdp club convergence

	Countries	t Statistic	Coefficient
1st club	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, Germany, Ireland, Portugal, Slovenia, Sweden	1.9546	0.4403
2nd club	Hungary, Italy, Lithuania, Netherlands, Spain, United Kingdom	0.6904	0.0367
3rd club	Bulgaria, Croatia, Greece, Latvia, Poland, Romania, Slovakia	-0.9106	-0.1196
Non-converging	France		

Figure 4. Relative transition paths of r&d expenditure per gdp clubs



5.1.3. *Scientific articles convergence*

For articles per million people indicator the null hypothesis of convergence is not rejected at 5% of significance level (Table 4). Scientific articles are one of the most valued research results in the academic world. In recent decades, the EU has been committed to promoting scientific collaboration among researchers from various universities and research centers as well as between university and industry. Further, the development of the new information and communication technologies (ICTs) has facilitated this scientific collaboration in a global world. Our results indicate that during the analysed period European countries have converged on this indicator.

5.2. Absorptive capacity indicators convergence

5.2.1. *Technological infrastructure indicators convergence*

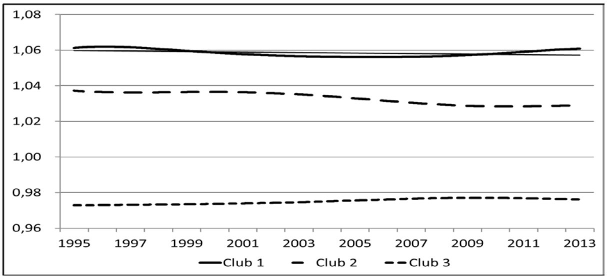
As shown in Table 4 the null hypothesis of convergence is not rejected for new technological infrastructure indicators (telephone penetration and Internet penetration). The accessibility to the new information and communication technologies is a fundamental element for the economic development of the countries. The results indicate that in the period analysed, European countries have reduced their differences in relation to new technological infrastructures following a process of convergence between them.

With respect to old technological infrastructures the Electricity consumption is a proxy measure for the employment of plants and equipment in the countries, which use electric power. Since we reject the null hypothesis of convergence at 5% significance level with the log *t* test for the full sample (Table 4), the empirical results hold up three convergence clubs and one divergent country (Table 7 and Figure 7 c). Western and Eastern countries compose all clubs. The first club contains three countries while Clubs 2 and 3 contain six and sixteen countries respectively, while Finland forms an independent diverging club. Speeds of convergence point out as follows: 0.0340 ($\beta = 0.0681$) for Club 1; 0.0250 ($\beta = 0.0500$) for Club 2 and 0.0383 ($\beta = 0.0757$) for Club 3. The relative transition paths (Figure 5) indicate that Clubs 1 and 2 are above average while Club 3 is clearly below average, and it seems clear that trends remain constant throughout the period.

Table 7. Electricity consumption clubs convergence

	Countries	*t* Statistic	β Coefficient
1st club	Austria, Estonia, Sweden	0.8601	0.0681
2nd club	Belgium, Czech Republic, France, Germany, Netherlands, Slovenia,	0.5679	0.0500
3rd club	Bulgaria, Croatia, Denmark, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Spain, United Kingdom	0.7214	0.0757
Non-converging	Finland		

Figure 5. Relative transition paths of electricity consumption clubs



5.2.2. *Human capital indicators convergence*

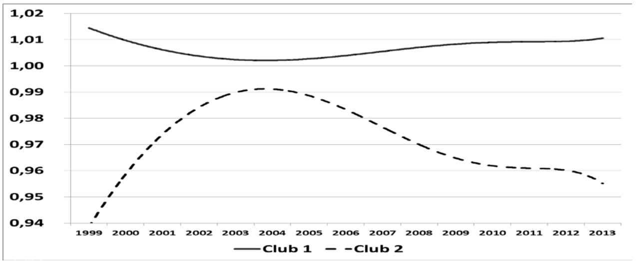
Human capital plays an important role for the economic growth of countries, but it is needed a threshold level of human capital to be able, not only to generate new knowledge, but also to imitate advanced technologies developed abroad. The results of overall convergence test suggest a convergence process for basic human capital (School life expectancy indicator) but not for scientific and engineering tertiary population resources across European countries (Table 4).

The indicator Science and Engineering enrolment shows the share of graduates in science and engineering compared with the total number of graduates in each country. These graduates are more related with changes and innovations in technology. Table 8 reports the result for this indicator. Since it has been rejected the null hypothesis of full convergence at the 5% significance level, the empirical findings identify two different convergence clubs and three divergent countries, Germany, Netherlands and Belgium. Seventeen of the twenty-five countries belong to the Club 1 with a high speed of convergence ($\beta = 0.4515$). Four countries form Club 2 converging at a slower speed of convergence ($\beta = 0.3519$) than Club1. Therefore, it is produced a high convergence between EU members in relation to human capital resources. Figure 7 d charts these two convergence clubs. Figure 6 presents the relative transition paths for both clubs showing an increasing separation between them since 2004.

Table 8. Tertiary science and engineering enrolment clubs convergence

	Countries	t Statistic	β Coefficient
1st club	Austria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Hungary, Ireland, Lithuania, Latvia, Portugal, Romania, Slovenia, Spain, United Kingdom, Sweden	1.1943	0.4515
2nd club	Bulgaria, Poland, Italy, Slovakia	1.4711	0.3519
Non-converging	Belgium, Germany, Netherlands		

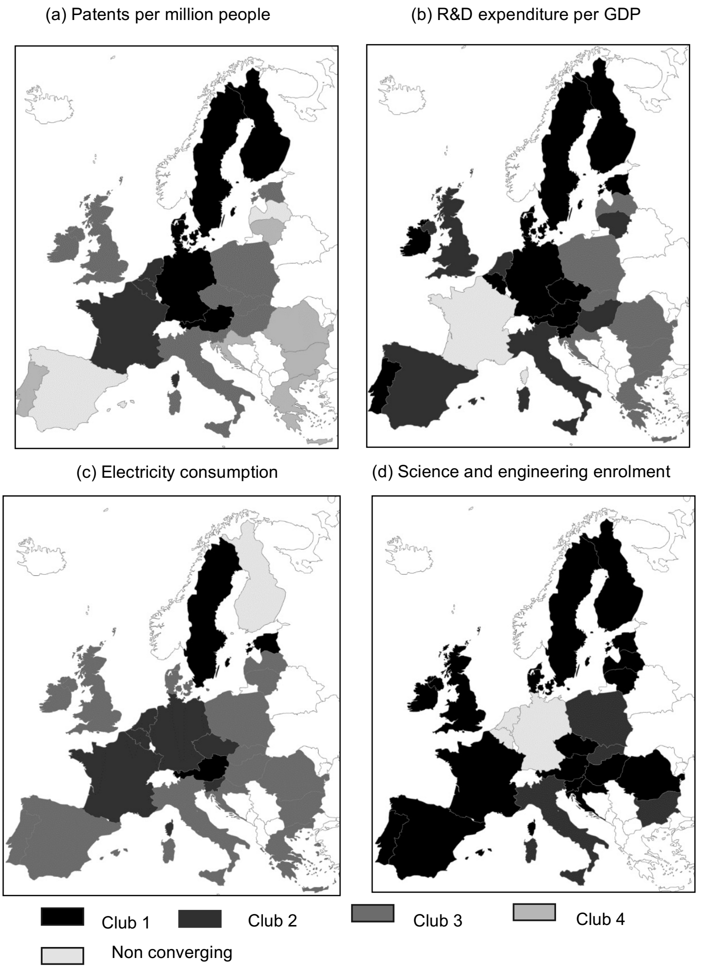
Figure 6. Relative transition paths of tertiary s&e enrolment clubs



In short, the above results indicate that for technological indicators related to the capacity of countries to create new technological knowledge (measured by per capita patents or R&D effort) the hypothesis of convergence clubs is fulfilled; while for the creation of scientific knowledge there has been a process of absolute convergence among European countries in the analysed period. For absorption capacity indicators that refer to the new technological infrastructures, there has been a convergence between countries, while for the old technological infrastructures they have converged into clubs. There has also been a process of convergence in basic human capital, whereas when considering human capital specialized in science and technology, there are two clubs, although most of the countries are in the same club.

These results allow us to suppose, firstly, that those indicators that present convergence in clubs can play a more important role in explaining the convergence in clubs for income than those that present overall convergence. And secondly, within the former the creation of new technological knowledge seems to have a prominent role, being the indicators for which there is a greater technological gap between rich and poor countries. Nevertheless, to determine the factors that explain the formation of income clubs identified above a deep analysis that is beyond the scope of this study would be needed.

Figure 7. Club membership for indicators of technological capabilities



6. Conclusions

There are both theoretical and empirical arguments supporting the club convergence hypothesis. Different approaches within growth theories offer different explanations for that economic convergence behavior. Technology gap models suggest difference in innovation and the international diffusion of new technologies as possible causes of convergence clubs.

Several papers have analysed real convergence in EU countries, pointing to the existence of club convergence behavior in per capita income across European countries. On the other hand, there is evidence of heterogeneity in technological capabilities of EU members being able to influence real club convergence processes observed between European countries.

In this context, this paper analysed the degree of economic convergence in the EU-25 countries from 1995 to 2013 using a novel methodology developed by Phillips and Sul (2007). In addition, we applied this methodology to test convergence patterns in technological capabilities in Europe by means of eight technology-related indicators. The results support the club convergence hypothesis for income and some technology-related indicators, and offer an approximation to the role that technological capabilities have been able to play in the income convergence process.

Regarding income variable, the results suggest the existence of four clubs with different speeds of convergence; specifically, the rate of convergence of clubs located in the upper and lower extremes in terms of per capita income have been slower than the corresponding for clubs located in the middle. Notice that the second club is the largest with twelve countries; this implies that almost half of the European countries have followed the same path of economic growth with some Eastern European countries experiencing a catching-up process.

There results show that there exist differences in technological capabilities between income clubs for all technological indicators. The largest technology gap is between middle-income countries and poor countries, particularly with respect innovative abilities mainly for patents per capita.

Although each technology-related indicator is an incomplete measure of the countries' technological capabilities, their separate analysis has allowed us to know their convergence process as well as to highlight those indicators whose convergence in clubs can be associated to a greater extent with income convergence clubs. In this sense, the results suggest a process of convergence across European countries mainly in terms of new technological infrastructure indicators (ICTs), basic human capital and creation of scientific knowledge. It indicates that poor countries have grown at a faster rate than rich countries catching-up for these indicators.

On the other hand, the old technology infrastructures, specialized human capital, internal R&D effort and the creation of new technological knowledge show a club convergence pattern. This leads to guess that absorptive capacity but mainly innovation ability of EU countries may be determinant factors of the income convergence clubs found in this paper.

Bearing in mind that in addition to technological capabilities there are other factors that may explain income convergence clubs and that initial and structural conditions matter, an in-depth study about determinants of the divergent behaviour in per capita income of the European countries would be needed for implementing effective economic policy measures to reduce inequalities between European countries.

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