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Club Convergence in R&D Expenditure across European Regions

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Abstract: The increasing disparities between European regions constitute a great challenge for sustainable development and require identification of the factors responsible for this process. Given the substantive role of R&D in shaping innovativeness and economic development, understanding its dynamics and spatial patterns can provide new insights into regional growth prospects. Although prior studies have investigated the patterns of innovation convergence, apparently none has attempted to test the convergence club hypothesis in R&D expenditure in the European regional scope. Therefore, the present study aims to fill this gap. The paper aims at examining the convergence path of R&D expenditure across European regions and at identifying the factors conditioning club membership. Data were retrieved from Eurostat's regional database and Regional Innovation Scoreboard datasets over 2008–2018. Employing a nonlinear time-varying factor model, we reveal that R&D expenditure in the examined regions follows the pattern of club convergence. The results of our research allow to identify five convergence clubs characterised by distinct disparities in the R&D expenditures. We also demonstrate that the emergence of the identified convergence clubs might be attributable to the initial differences in human capital, external knowledge embedded in patents and technological structures across regions as measured by employment in medium-high and high-tech manufacturing and knowledge-intensive services. These results provide policy implications in terms of the formulation and implementation of more tailored innovation policies, based on smart development and specialisation strategies. The presence of business R&D convergence clubs requires shifting EU policy actions towards a more sustainable model promoting both the advantages of the strongest regions and the development opportunities in less-developed ones.

Keywords: R&D expenditure; club convergence; innovation; human capital; KIS; patents; European regions

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1. Introduction

The enlargement of the EU to the Central and Eastern countries has extended the disparities between regions and constitutes a great challenge for sustainable development. It is observed that EU-wide convergence actually conceals growing economic divergence across old member regions and within new members [1]. These considerable and growing disparities could undoubtedly have a negative impact on the sustainability of regional economic development in the future.

Both theoretical considerations and empirical evidence indicate that research and development (R&D) plays a substantive role in shaping innovativeness and economic development [2–6]. The theoretical foundations of the relation between R&D and economic growth lie in the literature on endogenous growth [7–10] as well as on absorptive capacity where R&D plays two roles: it creates new knowledge through innovation and develops the ability to exploit external knowledge [11,12]. The effects of R&D expenditures increase the total factor productivity and therefore have a positive supply side effect on the economic growth potential [13].

Since a large number of empirical studies have demonstrated that existing disparities in economic development across European regions are mostly attributable to differences in productivity [14–18], it could be stated that regional disparities are primarily determined by uneven distribution of R&D. Currently, more-developed regions account for about 85% of R&D expenditure in the EU, transition regions for about 10% and less-developed regions for about 5%. Moreover, the average R&D intensity (i.e., the gross domestic expenditure on R&D as a percentage of GDP) of the top 30 EU regions is more than twice the average intensity of the EU as a whole [19].

The existence of such disparities results from the fact that R&D is a complex activity. It is determined by various factors, regarding human and relational capital, patent rights protection or income growth and also affected by spatial characteristics connected with knowledge spillovers and agglomeration effects [20–22]. Innovation capacity of every region is shaped by multidimensional interactions of local and external research with socio-economic and institutional conditions [23].

The literature on regional convergence tries to explore the factors behind the persistence of disparities in the EU [1]. Very few studies [13,24,25], however, deal with the convergence of innovation-related indicators, and, to our knowledge, none has attempted to test the convergence club hypothesis in R&D expenditure, serving as a proxy for innovation capabilities of European regional economies. Therefore, the present study endeavours to fill this gap.

The aim of the paper is to examine the patterns of convergence in R&D expenditures across European regions and to identify the factors responsible for their emergence. Our main underlying hypothesis is that R&D activities in European regions follow different regimes and consequently regions that have similar innovation potentials and absorptive capacities form technological clubs.

The contribution of the present study to the relevant literature is twofold.

First, employing a nonlinear time-varying factor model, a novel approach developed by Phillips and Sul [26] we demonstrate that R&D intensity (as measured by the relation of business R&D expenditure to GDP) in the examined European regions follows the pattern of club convergence. The analyses allow to identify five convergence clubs characterised by distinct disparities in the R&D intensity.

Second, using an ordered logit model pioneered by McKelvey and Zavoina [27] we reveal the pattern of clubs formation in the sample of European regions. Our results indicate that the existence of the identified convergence clubs might be attributable to the initial differences in human capital, external knowledge embedded in patents and technological structures measured by employment in medium-high and high-tech manufacturing and knowledge-intensive services between regions.

The remainder of the paper is organised as follows. The next section provides the review of relevant literature presenting a theoretical framework and empirical evidence on economic and innovation convergence. The methodological framework of the study and the details of the data selection procedures are presented in Section 3. Section 4 presents the results of the empirical analyses, whereas Section 4 discusses them and demonstrates the suggestions for future research. The paper ends with conclusions summarising its main findings along with policy implications.

2. Literature Review

There is a long tradition among growth economists to focus on convergence, which is generally defined as the tendency for a reduction over time of differences in economic performance (i.e., income, productivity, etc.) across countries or regions. In line with Galor's [28] argumentation, there exists three competing hypotheses in the literature on economic convergence. The first one, called the absolute convergence hypothesis, refers to the situation when countries or regions approach a long-run steady-state independently of their initial conditions. Three measures of absolute convergence are usually employed, i.e., beta convergence, sigma convergence, and gamma convergence. Beta convergence occurs when backward countries or regions grow faster than leaders and therefore catch up on them [29]. In turn, sigma convergence relates to the decline in disparities among countries or regions over time [30] and gamma convergence implies changes in the ranking of countries or regions [31]. The second hypothesis, known as the conditional convergence hypothesis, assumes that steady states differ across countries or regions due to their different structural characteristics and countries or regions converge to their own steady states independently of initial conditions. To study conditional convergence, the conditional beta convergence is often applied [32]. Finally, the third hypothesis, named as the club convergence hypothesis, means that countries or regions with similar structural characteristics converge to their own steady states if their initial conditions are homogenous. The Baumol's [33] approach and the log-*t* test [26] are frequently used to explore this kind of convergence.

In the theoretical debate on economic convergence, technical progress plays a key role in explaining the convergence or divergence of per capita income levels across countries or regions. In line with neo-classical growth models, notably the Solow [34] model, technical knowledge has public good properties and consequently can be accessed by any economy. The central hypothesis of the Solow model is that diminishing returns to capital lead to a convergence of economies to their steady state equilibrium, implying that richer economies grow slower than poorer ones. In this situation, the growth of output per worker results solely from the rate of technological progress, which is treated as a global exogenous good, available to all countries. It should be noted that the public good properties of technological knowledge allow for convergence in a case where technology levels vary across countries, since less technologically advanced economies can adapt new technologies and reduce a technological gap created by technological leaders [35,36]. The optimistic prediction on the converging effect of technological diffusion has been questioned to some extent by early endogenous growth models [8,37,38]. These models show that technical progress is endogenously driven by R&D and human capital and its trajectory depends on fundamentals/structural characteristics of countries or regions [39]. As suggested by Romer [7] in his endogenous growth two sector model, the impact of country specific factors, e.g., R&D policy, on long-run technology growth is reinforced by non-diminishing returns to knowledge in the knowledge creation sector.

To explain different technological trajectories for groups of countries, Howitt [40] proposed the multi-country model of growth through creative destruction. This model is consistent with a Schumpeterian growth theory based on three main assumptions. Firstly, long-run growth is driven by technological innovations. Secondly, innovations are the results of entrepreneurial search processes motivated by the expectations of monopoly rents. Thirdly, new innovations crowd out old innovations. In the Howitt model, technology transfer is beneficial for countries investing in new technology, whereas countries without investment in R&D cannot adapt and modify external technology. As a result, there appears a specific form of club convergence with two clubs. The former includes countries that draw inventions from each other and approach a common development trajectory. The latter relates to countries that experience technological stagnation. Unfortunately, the model presented above does not pay attention to different strategies for technology creation and catching-up processes. To mitigate this problem, Howitt and Mayer-Foulkes [41] introduced a new model that assumes there are two strategies for technological investments. The first one is mostly related to basic and applied research. This strategy requires a high level of human capital, in particular creativity skills. As regards the second strategy, it refers to experimental development and is more likely to draw on knowledge gained from research and practical experience. In the case of experimental development it depends on absorptive capacity, which is a function of innovation-effective skills. Considering the erosion of absorptive capacity, the country without sufficient skills may be stuck in stagnation. In summary, the existence of different technology clubs results from different strategies for technological investments and dynamics of absorptive capacity.

A few empirical papers deal with the convergence of innovation related indicators (e.g., patents, R&D expenditure, European Innovation Scoreboard indicators and Regional

Innovation Scoreboard indicators) among European countries and regions. Table 1 presents the results of selected studies on innovation convergence processes. It could be noticed that from a chronological point of view, the initial studies of innovation convergence focused on absolute convergence using sigma and beta convergence models. Increasing disparities in regional innovation performance have resulted in the shift of research interest towards the concept of club convergence. These studies employed a novel approach for identifying the stochastic properties of convergence and setting different convergence clubs, introduced by Phillips and Sul [26].

Table 1. Empirical studies on innovation convergence.

Author(s)	Units (Period)	Convergence Approach (Model)	Main Findings
Mulas-Granados and Sanz (2008) [42]	177 EU regions (1990–2002)	Absolute convergence (sigma convergence)	Both R&D expenditure and patents converged among regions.
Archibugi and Filippetti (2011) [43]	27 EU countries (2004–2008)	Absolute convergence (beta convergence)	Convergence occurred in the seven European Innovation Scoreboard dimensions apart from the “Innovators” dimension. “Finance and Support” and “Throughputs” dimensions showed the fastest rates of convergence.
Kijek and Matras-Bolibok (2018) [44]	220 European regions (2009–2017)	Absolute convergence (sigma and gamma convergence)	Sigma divergence took place in the Regional Innovation Index—RII and there was the lack of gamma convergence of RII among regions.
Barrios et al. (2019) [25]	180 European regions (2002–2012)	Club convergence (the log *t*-test)	The results support the club convergence in patenting activity.
Blanco et al. (2020) [45]	28 EU countries	Absolute convergence (sigma convergence) and club convergence (the log-*t* test)	The results show both absolute convergence and club convergence in regional R&D expenditures.

Although the above empirical evidence on innovation convergence produces mixed results, we hypothesize that R&D activities in European regions follow different regimes and consequently regions that have similar innovation potentials and absorptive capacities form technological clubs. The existence of technological clubs has been found in European regional space by Verspagen [46] and Capello and Lenzi [47]. On the other hand, it should be noted that the existence of club convergence does not mean an unambiguous rejection of absolute convergence, as under the presence of absolute convergence there may be clubs of countries or regions with different rates of convergence (local convergence). For example, Durlauf and Johnson [48] argue that their results revealing the compatibility of cross-country growth patterns with multiple steady states cannot be interpreted as a formal rejection of a single steady state model. They found the rates of convergence within the groups to be higher than that in the whole sample. Moreover, Barrios et al. [25] show that the relative transition paths of identified clubs have a tendency to unite, suggesting a possible tendency toward absolute convergence in the long-run.

In the case of the club convergence hypothesis, the important issue is to find factors conditioning club membership. As mentioned previously, endogenous growth theory identifies heterogeneity of human capital endowments as a main factor explaining the existence of multiple steady state equilibria in technology development. As stated by Azariadis and Drazen [49], there exists threshold externalities in the accumulation of human capital and a critical mass of human capital is required for gaining these externalities. In other words, initial conditions in relation to human capital accumulation may affect the paths of regional technology development. In line with Redding’s [50] theoretical argumentations, human capital and R&D investments are strategically complementary. The empirical analysis provided by Charlot et al. [51] confirms the existence of high complementarity between R&D

and human capital in the sample of 169 EU regions. Moreover, Moreno et al. [52] found that R&D expenditures in one region affect innovation activities of other regions. This finding suggests that external knowledge outside a region's boundaries in the form R&D and/or patents may be an important knowledge source for R&D. It is worth noting that knowledge production processes are becoming more and more interregional, as can be seen from the growing number of cross-regional collaborations in scientific publications [20].

In addition, one particularly important structural characteristic of an economy, from the point of view of R&D activities, is the employment in knowledge intensive sectors—KIS, i.e., high-tech manufacturing and knowledge-intensive services. Kijek and Matras-Bolibok [53] suggest that regional industrial and service structures affect a long run innovativeness. What is important is that the share of high-tech manufacturing and knowledge-intensive services in the economy reveals a tendency to be rigid, since its change requires sufficient tangible and intangible infrastructure. This leads to a possible innovation lock-in situation, especially in the short term.

3. Data and Methods

Our sample consists of 219 European regions. The regional coverage of this study is consistent with the Regional Innovation Scoreboard—RIS methodology, which allows for a comparative assessment of innovation performance across European regions at NUTS 1 and NUTS 2 levels. Depending on the differences in regional data availability, the sample covers 47 NUTS 1 regions and 172 NUTS 2 regions (Appendix A), including Austria (3 NUTS 1 regions), Belgium (3 NUTS 1 regions), Bulgaria (6 NUTS 2 regions), Croatia (1 NUTS 2 region), Czech Republic (8 NUTS 2 regions), Denmark (5 NUTS 2 region), France (14 NUTS 1 regions), Finland (1 NUTS 1 region, 4 NUTS 2 regions), Germany (9 NUTS 1 regions, 29 NUTS 2 regions), Greece (1 NUTS 1 region, 12 NUTS 2 regions) Hungary (8 NUTS 2 regions), Italy (21 NUTS 2 regions), Ireland (3 NUTS 2 regions), Lithuania (2 NUTS 2 regions), Netherlands (12 NUTS 2 regions), Poland (17 NUTS 2 regions), Portugal (2 NUTS 1 regions, 5 NUTS 2 regions), Romania (8 NUTS 2 regions), Spain (2 NUTS 1 regions, 17 NUTS 2 regions), Slovenia (2 NUTS 2 regions), Slovakia (4 NUTS 2 regions), Sweden (8 NUTS 2 regions), and the United Kingdom (12 NUTS 1 regions).

Regional data for R&D expenditures in the business sector per GDP over 2008–2018 were extracted from Eurostat's regional database [54]. Along with the literature review section devoted to the possible determinants of regional innovation activity [20,49–53] we identified a set of explanatory variables related to initial conditions and structural characteristics that may affect the club membership. The first group of variables pertains to initial conditions that create the internal and external knowledge base for regional R&D activities. It includes: human capital (HC)—as measured by the share of the population aged 25–64 enrolled in education or training aimed at improving knowledge, skills and competences; scientific knowledge (SK)—as measured by the number of scientific publications with at least one co-author based abroad per thousand population; external R&D (ERD)—as measured by the spatial lag of R&D with a contiguity spatial weighting matrix of first-order neighbours; and external patent intensity (EP)—as measured by the spatial lag of patent intensity (patent applications per billion regional GDP) with a contiguity spatial weighting matrix of first-order neighbours. Additional variables related to the second group of factors affecting the club memberships is employment in medium-high and high-tech manufacturing and knowledge-intensive services as a percentage of total employment (KIS). All variables relate to the first years of the period of analysis (HC-2009, SK-2008, ERD-2008, KIS-2008, EP-2011). Data were retrieved from the Regional Innovation Scoreboard datasets [55]. Due to data availability at the regional level the number of observations in the ordered logistic regression was 202.

To study the convergence patterns in R&D intensity across European regions, a non-linear time-varying factor model introduced by Phillips and Sul [26] was employed. Their log-t test is a semi-parametric clustering method, which is robust to potential violations of standard econometric assumptions, for example, assumptions concerning trend stationarity or stochastic non-stationarity of the variables. The log-t test allows for the identification of convergence in the situation, where other methods, including stationarity tests, fail.

The log-t test is based on the time-varying factor representation of the convergence variable:

$$X_{it} = \delta_{it}\mu_t \quad (1)$$

where μ_t is the common factor and δ_{it} is the time varying idiosyncratic distance from the common factor. In our research, X_{it} relates to R&D intensity, proxied by R&D expenditure in the business sector as a percentage of GDP. The time varying element δ_{it} is modelled in a semi-parametric form as:

$$\delta_{it} = \delta_i + \sigma_i \xi_{it} L(t)^{-1} t^{-\alpha} \quad (2)$$

where δ_i is the time-invariant part of δ_{it}, σ_i is the idiosyncratic scale parameter, ξ_{it} is iid (0, 1) across i and weakly dependent over t, and $L(t)$ is a slowly varying function for which $L(t) \to \infty$ as $t \to \infty$.

Relative loading coefficient:

$$h_{it} = \frac{X_{it}}{N^{-1}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{N^{-1}\sum_{i=1}^{N} \delta_{it}} \quad (3)$$

measures the relationship of the loading coefficient δ_{it} to the panel average at time t. As the cross sectional mean of h_{it} is unity, its variance is given by:

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

The convergence exists if $H_t \to \infty$ as $t \to \infty$.

Concerning the methodology of Phillips and Sul [26], the null hypothesis of the convergence test is formulated as follows:

$$H_0 : \ \delta_i = \delta \text{ and } \alpha \geq 0 \text{ against } H_1 : \ \delta_i \neq \delta \text{ for all } i \text{ or } \alpha < 0 \quad (5)$$

The testing algorithm covers the following steps:

1. Calculation of cross-sectional variance ratios H_1/H_t (t = 1, 2, . . . , T).
2. Estimation of the following regression:

$$\log\left(\frac{H_1}{H_t}\right) - 2\mathrm{logL}(t) = a + b\log t + u_t, \text{ for } t = [rT], \ [rT]+1, \ \ldots, \ T \quad (6)$$

   where $r \in (0, 1)$. Considering the results of their simulations, Phillips and Sul [26] suggest the use of $r \in [0.2, 0.3]$. In the case of a small T, r = 0.2 is preferred, and if T is large, r = 0.3 is a better decision.
3. Application of autocorrelation and a heteroskedasticity robust one-sided t test to verify the null hypothesis H_0 applying $\hat{b} = 2\hat{\alpha}$ and a HAC standard error. At a standard significance level (0.05), the null hypothesis is rejected if $t_{\hat{b}} < -1.65$.

Rejection of the null hypothesis implies that there is a lack of convergence in the group of all panel units. It does not mean, however, that it remains unproven that there is convergence in the subgroups of units (i.e., club convergence). Phillips and Sul [26] suggest a specific procedure for testing club convergence. The algorithm consists of four steps. First, the units are set in descending order with respect to the last period. Next, a main group is formed by adding countries one after another to a group of the two highest-R&D regions at the start and performing the log-t test until the $t_{\hat{b}}$ for this group is larger than 1.65. Then, the log-t test is performed again for this group and all the other units (one after another) from the sample to determine if they converge. If they do not converge, the first three steps are performed for all the other units. In the case that no clubs are revealed, this implies that those units diverge.

To reveal the pattern of clubs formation in the sample of European regions, an ordered logit model pioneered by McKelvey and Zavoina [27] was employed. This model takes the following form:

$$y_i^* = X_i\beta + \varepsilon_i \quad (7)$$

where y_i^* is a latent variable indicating the membership in a certain club, X_i contains the explanatory variables relating to factors that affect the club membership, $i = 1 \ldots 202$ denotes the regions, β is a vector of the structural coefficients, and ε_i is the error term.

Finally, the study suffers from a few methodological limitations. First of all, due to data availability the research period did not allow for addressing the consequences of the COVID-19 pandemic for R&D convergence. Secondly, we focused solely on R&D expenditures of the business enterprise sector without taking account of government and higher education sectors. Thirdly, the set of club membership determinants was dominated by initial conditions minimising the impact of structural characteristics.

4. Results

4.1. Convergence Clubs Identification

After applying the log-*t* test to R&D expenditure in the business sector as a percentage of GDP across European regions, we rejected the hypothesis of overall convergence at the 5% significance level. Next, we performed the clustering and merging algorithms proposed by Phillips and Sul [56]. As a consequence, we identified five clubs (Table 2, Appendix B).

Table 2. Summary results for the log-*t* test.

Club	No. of Regions	$\hat{b}$	SE	t
1	61	−0.2944	0.3162	−0.9310
2	46	−0.3010	0.3579	−0.8410
3	69	−0.1249	0.3142	−0.3975
4	35	−0.0239	0.2094	−0.1142
5	8	−0,2800	0.3672	−0.7625

Club 1 consisted of the regions that spend the least on R&D (0.15% of GDP on average). The regions that converge in this club belong mostly to Eastern countries (Poland–11 regions, Romania—8 regions) and Southern countries (Greece—12 regions, Spain—9 regions, Italy—5 regions, and Portugal—4 regions). Club 2, with an average of R&D intensity equal to 0.47% of GDP, is spatially heterogeneous and contains regions from two-thirds of the sample countries. Although German regions are more numerous than regions from any other country in this club, Germany has a large percentage of its territory in clubs with higher R&D intensity. What is more, German regions consistently constituted the most numerous groups in these clubs. As regards club 3, it was the most inclusive one and apart from German regions, this club was dominated by regions from Northern Italy, France, Czech Republic, and the United Kingdom. The most innovative clubs, i.e., club 4 and club 5, were the least numerous and their core groups were formed by regions from Germany, Netherlands, France, and Sweden. The spatial distribution of clubs is presented at Figure 1.

Figure 2 visualizes the change in R&D intensity (in log) of the regions in particular clubs in 2008–2018. It can be observed that there appeared to be catch-up processes, which were particularly the case for club 2 and club 3, where regions with low R&D intensities in 2008 showed higher growth rates, proxied by the distances between the marked points and the 45 dashed line, than regions with higher R&D intensities. Conversely, it is worth emphasising that there were also downturn processes of R&D intensity in some regions. This was particularly visible in the regions with high R&D intensity in 2008 within club 1, club 2, club 3 and club 4. Interestingly, the two-dimensional distribution of the points marking regions belonging to particular clubs had a horizontal pattern for all clubs apart from club 1. The colour bands at Figure 2 may indirectly indicate convergence tendencies of different regimes for particular clubs. In the case of club 1 the situation may be more complex. Notwithstanding the fact that the distribution of the points for club 1 was less horizontally clustered than in the case of other clubs, there also seems to be a slight trend to the steady state. Finally, Figure 2 shows the within-club convergence, since R&D dispersion within each club was constantly higher in 2008 than in 2018.

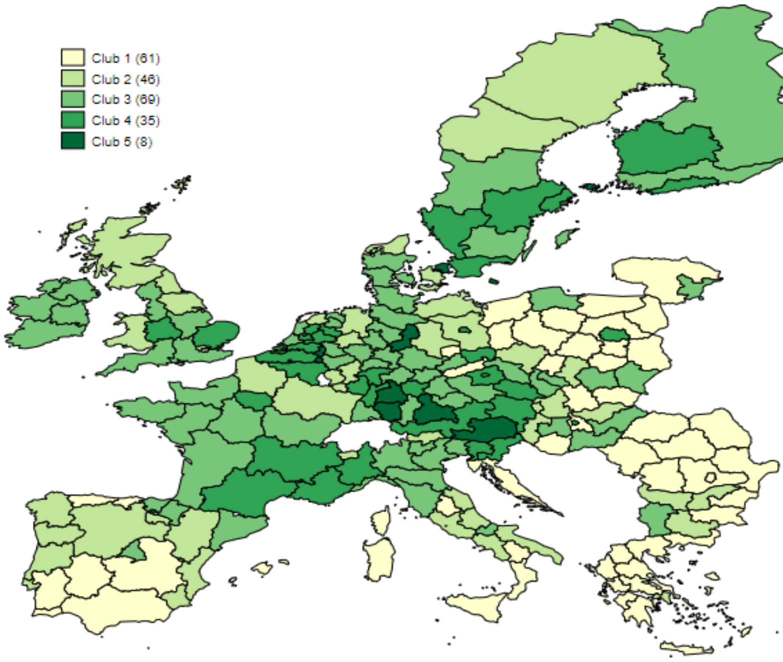

Figure 1. Spatial distribution of convergence clubs.

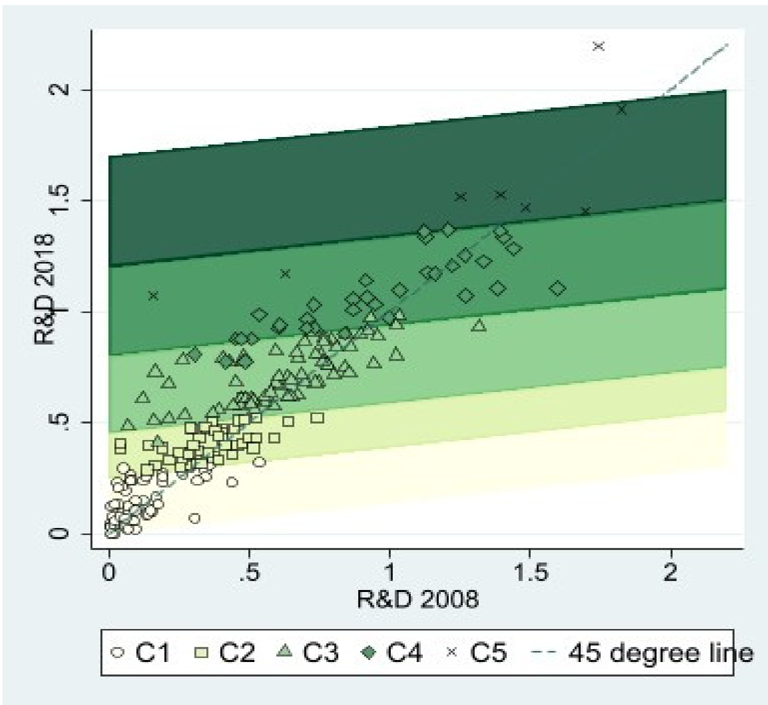

Figure 2. Change of regional R&D intensities in 2008–2018.

4.2. Determinants of Club Membership

In the next step of the analysis we tried to explain the club formation in European regions. The results of the ordered logit estimation are presented in Table 3. In line with our expectations, the initial conditions related to human capital and external knowledge embedded in patents affected club membership. The positive sign on HC suggests that regions with a higher initial endowment of human capital experience had a higher probability of belonging to a high-R&D club than regions with a low initial endowment of human capital. The same holds true for the external knowledge embedded in patents. As regards scientific knowledge (SK) and external knowledge (ERD) their impacts on the club formation were insignificant ($p > 0.1$). In the case of SK its insignificance may suggest that the impact of interregional scientific networking on club formation is indirect and sensitive to the type of research cooperation [20]. The insignificance of ERD, in turn, may suggest that knowledge spillover may mainly come from codified knowledge embedded in patents. Finally, we found that differences in technological structure across regions measured by employment in medium-high and high-tech manufacturing and knowledge-intensive services played a significant role in explaining the club formation. The inter-regional inequality in business R&D intensity undoubtedly resulted from the existence of differences in structural characteristics between regional economies. Regional disparities might also be associated with structural change related to the new wave of technological revolution that is biased towards more creative skills, and thus contributed to the concentration of the most advanced industries and services in the richest European regions [16].

Table 3. Ordered logit model results.

Variable	Coef.	Std. Err.	z	P > |z|
HC	0.142	0.029	4.84	0.000
SK	0.319	0.373	0.86	0.392
KIS	0.353	0.049	7.26	0.000
ERD	−0.664	0.428	−1.55	0.121
EP	0.222	0.117	1.90	0.058
Pseudo R2 = 0.2883, LR chi2(5) = 169.87				

Since there is a lack of interpretation of the coefficients in the ordered logit model, we provide information on the marginal effects, calculated as a mean of marginal effects at each value of explanatory variables, in Table 4. These effects give a direct and easily interpreted answer to the question of how changes in covariates affect the change in the probability of outcomes (club membership).

Considering the significance and magnitude of partial derivatives with respect to human capital and external patent intensity, it may be observed that both variables were significant at conventional levels, but, curiously, the positive marginal effects of small changes in these variables were higher for club 4 than for the most innovative club (club 5). It may indirectly suggest the existence of diminishing returns to knowledge accumulation and knowledge spillovers. A similar situation exists in the case of structural characteristics of the region's economy. The regional knowledge specialisation has the expected positive but decreasing impact on the probability of belonging to medium- and high-innovative clubs (club 3, club 4, club 5) and a negative effect on the probability of belonging to the least innovative clubs (club 1 and club 2). As such, our results suggest that a region's degree of specialisation in knowledge intensive sectors has some limitations and should be tailored to the region's endogenous potential in science and technology.

Table 4. Marginal effects on probabilities.

Variable	dy/dx	Std. Err.	z	P > z
Club 1				
HC	−0.014	0.003	−5.37	0.000
SK	−0.032	0.0379	−0.85	0.397
KIS	−0.035	0.004	−9.65	0.000
ERD	0.067	0.043	1.53	0.125
EP	−0.022	0.012	−1.86	0.062
Club 2				
HC	−0.005	0.001	−4.39	0.000
SK	−0.012	0.0138	−0.87	0.385
KIS	−0.013	0.003	−4.95	0.000
ERD	0.025	0.016	1.57	0.116
EP	−0.008	0.004	−1.98	0.048
Club 3				
HC	0.005	0.001	3.75	0.000
SK	0.012	0.0143	0.81	0.420
KIS	0.013	0.003	3.77	0.000
ERD	−0.024	0.017	−1.41	0.159
EP	0.008	0.005	1.69	0.092
Club 4				
HC	0.011	0.002	4.33	0.000
SK	0.025	0.0291	0.86	0.388
KIS	0.028	0.004	6.31	0.000
ERD	−0.052	0.034	−1.54	0.123
EP	0.017	0.009	1.88	0.060
Club 5				
HC	0.003	0.001	3.01	0.003
SK	0.001	0.001	0.85	0.398
KIS	0.008	0.002	3.41	0.001
ERD	−0.015	0.010	−1.48	0.139
EP	0.005	0.003	1.77	0.077

5. Discussion

The results of our research allow to reject the hypothesis of overall convergence and identify the club convergence in business R&D expenditure across the European regions over the period 2008–2018. We hypothesise and demonstrate that business R&D activities in European regions follow different regimes and, consequently, regions with similar innovation and absorption capacities form clubs.

Our results confirm the conclusions of prior studies indicating that although technological progress and innovation diffusion create important macroeconomic benefits at the country level, simultaneously they render regional convergence even more challenging [1,57] as the concentration of knowledge intensive sectors gradually escalates at the regional level. Therefore, even though the cross-country disparities may decrease, the within-country divergence remains constant or increases. Given the above, our findings contribute to the better understanding of the underlying conditions shaping those processes.

Given the fact that in theory knowledge spillovers and labour mobility should trigger an overall convergence, the identified club convergence suggests the presence of significant barriers mitigating the positive impact of those factors. This notion is consistent with the conclusions of Iammarino et al. [58] who identify these barriers in terms of skill structures and formal and informal institutions.

The revealed club convergence at the regional level indicates that innovation processes in the business sector in different clubs take place with different speeds, as proxied by the level of R&D expenditure. The regions that converge within the club with the highest level of business R&D intensity belong, at the same time, to the most developed European regions, which clearly indicates that interregional divergence is inevitably going to increase. This can induce the petrification of the existing structure of regions reflecting their level of innovativeness. In consequence, given the positive returns to scientific knowledge in regional innovation patterns [59], it can also lead to the deepening of the divergence in productivity and economic development.

It could be also underlined, in line with the conclusions of Škrinjarić [60] and Constatin et al. [61], that the uneven distribution of business R&D intensity across European regions could undoubtedly have a negative impact on the sustainability of regional economic development in the future. The presence of club convergence seems to call for a proper policy response, especially in the face of the challenges related to the implementation of the key sustainable development goals, such as the *European Green Deal* [62]. Therefore, there is a need for joint innovative effort and stronger inclusion of the laggard regions in these actions; however, it is barely presumable, that the above goals could be achieved without substantial public support.

Among the five clubs distinguished in the study, the regions that converge within the club with the lowest level of business R&D intensity (as measured by the relation of business R&D expenditure to GDP) include mostly Eastern (Poland and Romania) and Southern (Greece, Spain, Italy, and Portugal) European countries, whereas the clubs with the highest level of R&D intensity are mainly formed by the regions belonging to Germany, Netherlands, France, and Sweden. Our results are in line with Barrios et al. [25] who examined the innovation activity (as measured by the patenting activity, i.e., the number of patents per million inhabitants) convergence process across European regions over the period 2002–2012 and identified seven innovation clubs with different levels of innovation potential and growth dynamics. According to their results, the groups of the high and intermediate innovation clubs are mainly composed of regions belonging to the Nordic countries, France, Germany, Belgium, Austria, UK, and Ireland, whereas the less innovative clubs were mainly formed by the regions belonging to Eastern European countries, Portugal and southern regions of Spain and Italy. Our findings are also similar to Bednář and Halásková [24] who examined 178 Western European NUTS 2 regions over the years 2007–2012. They found local variation of convergence and divergence and general spatial regime divergence in innovation performance and R&D intensity (as measured by intramural R&D expenditure as a percentage of GDP). Our findings are also in line with the results of the study on spatial distribution of innovation provided by Moreno et al. [63] who examined regional patenting in Europe over the period 1978–2001, demonstrating that innovation activity is concentrated in regions of Northern and Central Europe, while modest or even no technological activity is performed in most Southern European regions. Our results can also be compared to Blanco et al. [45] who examined the convergence of the total R&D expenditure in the EU28 for 2004–2015 and identified two distinct clubs of 15 and 13 EU countries, showing that in the first one the main driver of R&D convergence was the business enterprise sector, whereas in the second one this role was played by government expenditures.

The revealed inter-regional inequality in business R&D intensity undoubtedly results from the existence of differences in the structural characteristics between regional economies. We demonstrate that the existence of the identified convergence clubs might be attributable to the initial differences between regions in terms of human capital, external knowledge embedded in patents, technological structures measured by employment in medium-high and high-tech manufacturing, and knowledge-intensive services.

Our findings regarding the factors responsible for the distinction of regional clubs in R&D expenditure could be also compared with the study by Alexiadis [64] who revealed income club convergence across European regions and demonstrated that spatial interaction, technology creation and adoption, accompanied by spatial agglomeration effects, play a role in determining the pattern of regional growth. However, in contrast to our results, his findings suggest that diversity in economic activity is more significant than regional specialisation in regional growth and convergence.

We provide support to the argument that regions with a higher initial endowment of human capital experience have a higher probability of belonging to a high-R&D club than regions with a low initial endowment of human capital. These results justify the need for further development of EU cohesion policy oriented towards fostering investment in human capital in less-developed regions. Providing incentives for the reorientation of industry-mix in less-developed regions towards more technologically advanced structures would naturally increase the demand for highly skilled labour.

The revealed significance of structural characteristics (as measured by employment in medium-high and high-tech manufacturing and knowledge-intensive services as a percentage of total employment (KIS)) for club formation in business R&D expenditure is in line with the results of Kijek and Matras-Bolibok [53], who examined 248 European regions at the NUTS 2 level over the period 2014–2016 and argued that regional industrial and service structures affect long-term innovativeness.

Unexpectedly, we found that the impact of external knowledge (as measured by the spatial lag of R&D with a contiguity spatial weighting matrix of first-order neighbours) on the club formation is insignificant. It remains in contrast with studies by Rodríguez-Pose and Crescenzi [23] or de Dominicis et al. [65], who found that given the spatial characteristics of innovation, the less developed regions have a greater potential to innovate when being surrounded by innovative, central regions. The revealed insignificance of external R&D may suggest that knowledge spillovers may mainly come from codified knowledge embedded in patents. As the gap between European regions is increasing and which appear to be led by the centripetal forces of agglomeration, the EU policy actions should therefore allocate more resources to enhance knowledge spillovers from the richest regions to the less developed, and to promoting integration and complementarity between regions with different development levels [16].

As regards scientific knowledge, as measured by the number of scientific publications with at least one co-author based abroad (per thousand of population) we found the impact on the club formation of business R&D intensity insignificant. This can be interpreted in line with the results of Varga et al. [20] who demonstrated that interregional scientific networking (as measured by Framework Programme (FP) participation) is an important determinant of R&D productivity only in the case of science-driven (Pasteur-type) research.

With regional convergence being one of the most important goals, the EU still fosters a policy aiming at increasing expenditure on R&D; however, the obtained results indicate, in line with [66], that the less developed regions require not only the redirecting of financial efforts towards R&D, but also to improving the environmental factors and the institutional components that foster innovation. The argument for this is the regional innovation paradox connected with the higher need of lagging regions to invest in innovation, and their relatively lower capacity to absorb investments in comparison to more advanced ones [67]; however, as suggested by Gómez-Tello et al. [16], while structural changes spread unevenly and favour the most advanced regions, the poorest regions continue to shift factors towards more productive activities, increasing the probability of achieving convergence in the future.

The revealed club convergence in the field of business R&D intensity calls for more tailored innovation policies, based on smart development and specialisation strategies. These strategies should recognise more fully both the specificity of individual economies, and the existing path dependencies in their innovation performance. Given the above, our findings are largely in line with Tödtling and Trippl [68] who provide strong arguments against the 'ideal' innovation policy model demonstrating the significant disparities in innovation activities conducted in central, peripheral, and old industrial areas. Moreover the presence of business R&D convergence clubs requires shifting EU policy actions towards a more sustainable model promoting both the advantages of the strongest regions and the development opportunities in less-developed ones, following the approach proposed by Iammarino et al. [58], labelled as the ”place-sensitive distributed development policy”.

The methodological limitations presented in detail in the Data and Methods section of the paper, provide some possible avenues for future studies on regional club convergence in R&D performance. The first of them could concern the extension of the research period, thus addressing the impact of the COVID-19 pandemic on the R&D convergence process. Moreover, extending the analyses to all institutional R&D sectors, i.e., business, government and higher education, could contribute to more comprehensive conclusions regarding development paths and determinants of R&D performance in the European regional scope. Another possible direction of future research is taking into account the different structural characteristics affecting R&D transition paths.

6. Conclusions

R&D expenditures are important contributors to long-term growth, as shown in the endogenous growth models. That is precisely why increasing R&D, particularly in less developed regions, is one of the main priorities in the EU regional development and cohesion policies. The official statistics show that R&D activities in the European regions are not evenly performed. The pattern of R&D expenditures distribution suggests the existence of technological clubs in the European regional space. In this context, the club convergence hypothesis takes on particular importance as regards regional R&D. From the theoretical perspective the existence of club convergence of innovation-input activities may result from different R&D strategies and regional dynamics of absorptive capacity.

In this paper we employed the log-*t* test to endogenously find potential convergence clubs. The results of the log-*t* test allowed us to reject the hypothesis of overall convergence in innovation input activities in the European regions. After applying the clustering and merging algorithms, we identified five regional clubs with different R&D transition paths. These clubs may be ordered from the least innovative club (club 1) to the most innovative club (club 5). The high input innovation clubs (club 4 and club 5) are mainly formed by regions belonging to Germany, Netherlands, France, and Sweden. In turn, the low input innovation club consists of regions belonging mostly to Eastern (Poland and Romania) and Southern (Greece, Spain, Italy, and Portugal) European countries.

As regards the medium input innovation clubs (club 2 and club 3), these clubs are spatially heterogeneous and cover regions from three quarters of the sample countries. Finally, we found that the club membership depends on a region’s initial conditions (human capital and inter-regional patent knowledge flows) and structural characteristics (employment in medium-high and high-tech manufacturing and knowledge-intensive services).

Our results provide some useful implications for policymakers, which are interested in boosting economic growth by R&D expenditure and consequently reduce the gap between less developed regions and more developed regions. Since human capital appeared to positively affect the probability of belonging to the medium and high-innovative clubs, the regional lifelong learning policies should focus on creativity, entrepreneurship, and innovation. Moreover, there is a need to create institutional mechanisms supporting inter-regional collaboration networks formed by inventors. Last but not least, regions’ authorities can enhance R&D incentives placing pressure on supporting knowledge-intensive sectors in manufacturing and/or services. It should be noted that policymakers should apply a set of innovation enhancing instruments that is tailored to the initial and structural conditions of particular regions.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Country	Number of Regions at NUTS Level		Regions (NUTS Code)
	1	2	
Belgium	3		Région de Bruxelles-Capitale/Brussels Hoofdstedelijk Gewest (BE1) *, Vlaams Gewest (BE2), Région wallonne (BE3)
Bulgaria		6	Severozapaden (BG31), Severen tsentralen (BG32), Severoiztochen (BG33), Yugoiztochen (BG34), Yugozapaden (BG41), Yuzhen tsentralen (BG42)
Czechia		8	Praha (CZ01), Střední Čechy (CZ02), Jihozápad (CZ03), Severozápad (CZ04), Severovýchod (CZ05), Jihovýchod (CZ06), Střední Morava (CZ07), Moravskoslezsko (CZ08)
Denmark		5	Hovedstaden (DK01), Sjælland (DK02), Syddanmark (DK03), Midtjylland (DK04), Nordjylland (DK05)
Germany	9	29	Stuttgart (DE11), Karlsruhe (DE12), Freiburg (DE13), Tübingen (DE14), Oberbayern (DE21), Niederbayern (DE22), Oberpfalz (DE23), Oberfranken (DE24), Mittelfranken (DE25), Unterfranken (DE26), Schwaben (DE27), Berlin (DE3) *, Brandenburg (DE4) *, Bremen (DE5) *, Hamburg (DE6) *, Darmstadt (DE71), Gießen (DE72), Kassel (DE73), Mecklenburg-Vorpommern (DE8) *, Braunschweig (DE91), Hannover (DE92), Lüneburg (DE93), Weser-Ems (DE94), Düsseldorf (DEA1), Köln (DEA2), Münster (DEA3), Detmold (DEA4), Arnsberg (DEA5), Koblenz (DEB1), Trier (DEB2), Rheinhessen-Pfalz (DEB3), Saarland (DEC) *, Dresden (DED2), Chemnitz (DED4), Leipzig (DED5), Sachsen-Anhalt (DEE) *, Schleswig-Holstein (DEF) *, Thüringen (DEG) *
Ireland		3	Northern and Western (IE04), Southern (IE05), Eastern and Midland (IE06)
Greece	1	12	Attiki (EL3) *, Voreio Aigaio (EL41), Notio Aigaio (EL42), Kriti (EL43), Anatoliki Makedonia, Thraki (EL51), Kentriki Makedonia (EL52), Dytiki Makedonia (EL53), Ipeiros (EL54), Thessalia (EL61), Ionia Nisia (EL62), Dytiki Ellada (EL63), Sterea Ellada (EL64), Peloponnisos (EL65)
Spain	2	17	Galicia (ES11), Principado de Asturias (ES12), Cantabria (ES13), País Vasco (ES21), Comunidad Foral de Navarra (ES22), La Rioja (ES23), Aragón (ES24), Comunidad de Madrid (ES3) *, Castilla y León (ES41), Castilla-la Mancha (ES42), Extremadura (ES43), Cataluña (ES51), Comunitat Valenciana (ES52), Illes Balears (ES53), Andalucía (ES61), Región de Murcia (ES62), Ciudad de Ceuta (ES63), Ciudad de Melilla (ES64), Canarias (ES7) *
France	14		Île de France (FR1) *, Centre - Val de Loire (FRB) *, Bourgogne-Franche-Comté (FRC), Normandie (FRD), Hauts-de-France (FRE), Grand Est (FRF), Pays de la Loire (FRG) *, Bretagne (FRH) *, Nouvelle-Aquitaine (FRI), Occitanie (FRJ), Auvergne - Rhône-Alpes (FRK), Provence-Alpes-Côte d'Azur (FRL) *, Corse (FRM) *, RUP FR—Régions ultrapériphériques françaises (FRY)
Croatia		1	Jadranska Hrvatska (HR03)
Italy		21	Piemonte (ITC1), Valle d'Aosta/Vallée d'Aoste (ITC2), Liguria (ITC3), Lombardia (ITC4), Provincia Autonoma Bolzano/Bozen (ITH1), Provincia Autonoma Trento (ITH2), Veneto (ITH3), Friuli-Venezia Giulia (ITH4), Emilia-Romagna (ITH5), Toscana (ITI1), Umbria (ITI2), Marche (ITI3), Lazio (ITI4), Abruzzo (ITF1), Molise (ITF2), Campania (ITF3), Puglia (ITF4), Basilicata (ITF5), Calabria (ITF6), Sicilia (ITG1), Sardegna (ITG2)
Lithuania		2	Sostinės regionas (LT01), Vidurio ir vakarų Lietuvos regionas (LT02)
Hungary		8	Budapest (HU11), Pest (HU12), Közép-Dunántúl (HU21), Nyugat-Dunántúl (HU22), Dél-Dunántúl (HU23), Észak-Magyarország (HU31), Észak-Alföld (HU32), Dél-Alföld (HU33)
Netherlands		12	Groningen (NL11), Friesland (NL12), Drenthe (NL13), Overijssel (NL21), Gelderland (NL22), Flevoland (NL23), Utrecht (NL31), Noord-Holland (NL32), Zuid-Holland (NL33), Zeeland (NL34), Noord-Brabant (NL41), Limburg (NL42)
Austria	3		Ostösterreich (AT1), Südösterreich (AT2), Westösterreich (AT3)

Poland		17	Małopolskie (PL21), Śląskie (PL22), Wielkopolskie (PL41), Zachodniopomorskie (PL42), Lubuskie (PL43), Dolnośląskie (PL51), Opolskie (PL52), Kujawsko-Pomorskie (PL61), Warmińsko-Mazurskie (PL62), Pomorskie (PL63), Łódzkie (PL71), Świętokrzyskie (PL72), Lubelskie (PL81), Podkarpackie (PL82), Podlaskie (PL84), Warszawski stoleczny (PL91), Mazowiecki regionalny (PL92)
Portugal	2	5	Norte (PT11), Algarve (PT15), Centro (PT16), Lisboa (PT17), Alentejo (PT18), Região Autónoma dos Açores (PT2) *, Região Autónoma da Madeira (PT3) *
Romania		8	Nord-Vest (RO11), Centru (RO12), Nord-Est (RO21), Sud-Est (RO22), Sud-Muntenia (RO31), Bucuresti-Ilfov (RO32), Sud-Vest Oltenia (RO41), Vest (RO42)
Slovenia		2	Vzhodna Slovenija (SI03), Zahodna Slovenija (SI04)
Slovakia		4	Bratislavský kraj (SK01), Západné Slovensko (SK02), Stredné Slovensko (SK03), Východné Slovensko (SK04)
Finland	1	4	Helsinki-Uusimaa (FI1B), Etelä-Suomi (FI1C), Länsi-Suomi (FI19), Pohjois-ja Itä-Suomi (FI1D), Åland (FI2) *
Sweden		8	Stockholm (SE11), Östra Mellansverige (SE12), Småland med öarna (SE21), Sydsverige (SE22), Västsverige (SE23), Norra Mellansverige (SE31), Mellersta Norrland (SE32), Övre Norrland (SE33)
United Kingdom	12		North East (UKC), North West (UKD), Yorkshire and The Humber (UKE), East Midlands (UKF), West Midlands (UKG), East of England (UKH), London (UKI), South East (UKJ), South West (UKK), Wales (UKL), Scotland (UKM), Northern Ireland (UKN) *

* NUTS 1 and NUTS 2 levels are identical.

Appendix B

Club 1	BG33, BG34, CZ04, DED5, EL52, EL42, EL43, EL62, EL64, EL61, EL63, EL54, EL53, EL65, EL51, EL41, ES61, ES63, ES42, ES12, ES64, ES43, ES13, ES53, ES7, FRY, FRM, HR03, HU23, HU12, ITF6, ITF5, ITG1, ITG2, ITI2, LT02, PL52, PL72, PL92, PL62, PL41, PL43, PL81, PL84, PL42, PL61, PL71, PT3, PT2, PT15, PT18, RO12, RO42, RO21, RO31, RO11, RO41, RO22, RO32, SK04, SK03
Club 2	BG32, BG31, BG42, DEB2, DEB1, DE94, DE4, DEE, DEC, DE8, DEA3, DK02, DK05, EL3, ES41, ES23, ES24, ES11, ES62, ES52, FRF, FRE, HU31, HU22, ITI3, ITC2, ITF4, ITH1, ITF3, ITF1, ITI4, NL12, PL51, PL22, PT11, PT17, PT16, SE33, SE32, SK02, SK01, UKL, UKI, UKM, UKC, UKE
Club 3	BE1, BG41, CZ01, CZ05, CZ03, CZ08, CZ07, DE6, DE5, DEA4, DED4, DE92, DEA5, DE26, DE13, DE73, DEG, DE23, DE24, DEA1, DE72, DEF, DEA2, DE93, DE27, DE22, DK04, DK03, ES3, ES51, ES21, ES22, FI1D, FI1C, FRC, FRD, FRG, FRH, FRI, FRB, HU32, HU21, HU33, IE06, IE05, IE04, ITF2, ITH4, ITI1, ITH2, ITH5, ITC3, ITH3, ITC4, LT01, NL13, NL33, NL11, NL32, PL82, PL63, PL21, SE21, SE31, UKD, UKK, UKF, UKJ, UKN
Club 4	AT1, AT3, BE2, L BE3, CZ02, CZ06, DE12, DE25, DE3, DE71, DEB3, DED2, FI19, FI1B, FR1, FRJ, FRK, FRL, HU11, ITC1, NL21, NL22, NL23, NL31, NL34, NL41, PL91, SE11, SE12, SE22, SE23, SI03, SI04, UKG, UKH
Club 5	AT2, DE11, DE14, DE21, DE91, DK01, FI2, NL42

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