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The Impact of the Pandemic on the Innovation Performance of European Countries

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Abstract: *In the last few years, the COVID-19 pandemic has changed our lives and the operation of the whole economy. The technological possibilities in the era of Industry 4.0 were already given, but the spread of digital solutions accelerated due to the pandemic, which was the catalyst of technological progress. The adaptation of new technologies was faster, and the length of the digital transition has been shortened. The impact of the pandemic prevails in both technological leader and follower countries, and because of this, the technological gap between developed and developing countries may decrease. The technological follower countries can converge to leaders mainly in digital infrastructure which is the essential condition of the new technological era but some constraints remain that prevent them from taking advantage of technological progress. This technological revolution requires promoting the use, adoption, and adaptation of new technologies in all countries regardless of the level of technological development. This research aims to analyse the changes in European countries' innovation performance in the last years when the COVID-19 pandemic prevailed with data from European Innovation Scoreboard. Using simple and multivariate statistical methods, the similarities and differences in technological progress in times of pandemic can be highlighted between the technological leader and follower countries in the European Union.*

1. INTRODUCTION

In the last few years, the COVID-19 pandemic dominated the world economy with severe economic and social consequences. Technological progress may offer solutions to many of the challenges due to the crisis. The widespread adaptation of new technologies accelerated, and the length of the digital transition has shortened during the time of the pandemic. The new technological wave, the Fourth Industrial Revolution based on digitalization generates skill-biased technological changes, in which developed countries have a competitive advantage. The adaption of new technologies requires adequate digital infrastructure and a well-skilled labour force not only in the technological leader but also in technological follower countries. As Schwab and Zahidi (2020) pointed out, the combined health and economic shocks due to the COVID pandemic have accelerated the effects of the Fourth Industrial Revolution on trade, skills, digitization, competition, and employment. Analysing the first tendencies during the time of the pandemic, one of the key findings of the Global Competitiveness Report 2020 was that, the COVID-19 crisis has accelerated digitalization in advanced economies and made catching up more difficult for countries or regions that were lagging before the crisis despite the significant expansions of ICT access and use. Renu (2021) also emphasized the advantages the of COVID-19 pandemic crisis in technological leader countries that can develop new technologies to react to new challenges in economics. In contrast, it is assumed that the pandemic crisis enforced technological adaptation to the changed economic environment in all countries regardless of the level of technological development which can lead to slow convergence between the technological leader and follower countries in the long run because the digital infrastructural conditions have already given to further development.

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This study uses the European Innovation Scoreboard to analyse the changes in European countries' innovation performance in the last years when the COVID-19 pandemic prevailed. The different fields of innovation will be compared in innovation performance groups created by the Summary Innovation Index with various statistical methods to highlight the similarities and differences in technological progress in times of pandemic. Two hypotheses are formulated related to our analysis.

Hypothesis One: Comparing the overall innovation performance of the European Union member states, we assume that there is a moderate rearrangement in innovation ranking because of an improvement in the field of innovation in less innovative countries enforced by the pandemic.

Hypothesis Two: The convergence of less innovative countries can be observed mainly in the physical infrastructure and financing because in these fields the improvement is realised more rapidly, in contrast, human conditions and innovative behaviour are difficult to change.

2. DATABASE AND METHODOLOGY

The current 27 member states of the European Union were involved in the analysis which are classified into innovation performance groups based on the Summary Innovation Index (SII) calculated from the European Innovation Scoreboard. Based on SII, countries are classified into four innovation performance groups: innovation leaders, strong innovators, moderate innovators, and emerging innovators. According to EIS (2022), EU 27 countries can be grouped as follows (the order fits for innovation performance):

- *Innovation leaders (5)*: Sweden, Finland, Denmark, Netherlands, Belgium,
- *Strong Innovators (6)*: Ireland, Luxembourg, Austria, Germany, Cyprus, France
- *Moderate Innovators (9)*: Estonia, Slovenia, Czechia, Italy, Spain, Portugal, Malta, Lithuania, Greece
- *Emerging Innovators (7)*: Hungary, Croatia, Slovakia, Poland, Latvia, Bulgaria, Romania

Firstly, we examine how the overall innovation performance of the European countries changed during the pandemic crisis, then we analyse changes in different fields of innovation in detail. Using parametric and non-parametric tests, the innovation performance in different fields is compared to highlight the significant differences between EU member states grouped by innovation performance. Firstly, the normal distribution of variables is tested using the Kolmogorov-Smirnov test. If a variable has a normal distribution, ANOVA is used to compare means of innovation performance groups, in contrast, in the lack of normal distribution, the Kruskal-Wallis test can be run. Another prerequisite of the ANOVA is homoscedasticity which is tested by Levene's test. If equal variances are not assumed, Welch's test is used to compare means instead of the classical F test. Using these methods, we got a comprehensive picture of significant differences between innovation performance groups.

3. EMPIRICAL RESULTS

Firstly, the overall innovation performance of European countries was compared between 2019 and 2022, so before and after the COVID-19 pandemic. In 2019, the classification of the innovation performance groups was different, but we classified countries in the same way to compare their innovation performance. In 2019, the worst-performing group was called modest innovators, it included only two countries, Bulgaria and Romania whose SII was below 50% of the

EU average. Based on the new classification innovation leaders are all countries with a relative performance in 2022 above 125% of the EU average, strong innovators' relative performance is between 100% and 125% of the EU average, moderate innovators' relative performance is between 70% and 100% of the EU average while emerging innovators are all countries with a relative performance in 2022 below 70% of the EU average in 2022 (EIS 2022). *Figure 1* shows the changes in the innovation performance of the European Union member states using the innovation ranking based on the Summary Innovation Index.

Group (2019)	Innovation performance ranking in 2019		Group (2022)	Innovation performance ranking in 2022		*The direction of change in position*	*Percentage change (%) from 2019 to 2022*
INNOVATION LEADERS	Sweden	0,700	INNOVATION LEADERS	Sweden	0,735		5,056
INNOVATION LEADERS	**Netherlands**	**0,693**	INNOVATION LEADERS	**Finland**	**0,735**	↑	9,308
INNOVATION LEADERS	Denmark	0,683	INNOVATION LEADERS	Denmark	0,731		6,964
INNOVATION LEADERS	**Finland**	**0,672**	INNOVATION LEADERS	**Netherlands**	**0,701**	↓	1,217
STRONG INNOVATORS	**Luxembourg**	**0,656**	INNOVATION LEADERS	**Belgium**	**0,698**	↑	11,280
STRONG INNOVATORS	**Austria**	**0,632**	STRONG INNOVATORS	**Ireland**	**0,645**	↑	4,020
STRONG INNOVATORS	**Belgium**	**0,627**	STRONG INNOVATORS	**Luxembourg**	**0,643**	↓	-1,971
STRONG INNOVATORS	**Ireland**	**0,620**	STRONG INNOVATORS	**Austria**	**0,641**	↓	1,431
STRONG INNOVATORS	Germany	0,608	STRONG INNOVATORS	Germany	0,637		4,800
STRONG INNOVATORS	**France**	**0,578**	STRONG INNOVATORS	**Cyprus**	**0,579**	↑	39,592
STRONG INNOVATORS	**Estonia**	**0,488**	STRONG INNOVATORS	**France**	**0,571**	↓	-1,085
MODERATE INNOVATORS	**Malta**	**0,487**	MODERATE INNOVATORS	**Estonia**	**0,542**	↓	10,969
MODERATE INNOVATORS	**Portugal**	**0,479**	MODERATE INNOVATORS	**Slovenia**	**0,507**	↑	9,952
MODERATE INNOVATORS	**Spain**	**0,471**	MODERATE INNOVATORS	**Czechia**	**0,502**	↑	17,165
MODERATE INNOVATORS	**Slovenia**	**0,461**	MODERATE INNOVATORS	**Italy**	**0,497**	↑	10,725
MODERATE INNOVATORS	**Italy**	**0,448**	MODERATE INNOVATORS	**Spain**	**0,481**	↓	2,134
MODERATE INNOVATORS	**Czechia**	**0,428**	MODERATE INNOVATORS	**Portugal**	**0,465**	↓	-2,976
MODERATE INNOVATORS	**Cyprus**	**0,415**	MODERATE INNOVATORS	**Malta**	**0,459**	↓	-5,729
MODERATE INNOVATORS	Lithuania	0,414	MODERATE INNOVATORS	Lithuania	0,454		9,438
MODERATE INNOVATORS	Greece	0,368	MODERATE INNOVATORS	Greece	0,435		18,111
EMERGING INNOVATORS	Hungary	0,340	EMERGING INNOVATORS	Hungary	0,378		11,292
EMERGING INNOVATORS	**Slovakia**	**0,333**	EMERGING INNOVATORS	**Croatia**	**0,360**	↑	17,659
EMERGING INNOVATORS	**Croatia**	**0,306**	EMERGING INNOVATORS	**Slovakia**	**0,349**	↓	4,659
EMERGING INNOVATORS	Poland	0,294	EMERGING INNOVATORS	Poland	0,328		11,630
EMERGING INNOVATORS	Latvia	0,267	EMERGING INNOVATORS	Latvia	0,275		2,946
EMERGING INNOVATORS	Bulgaria	0,239	EMERGING INNOVATORS	Bulgaria	0,245		2,369
EMERGING INNOVATORS	Romania	0,166	EMERGING INNOVATORS	Romania	0,177		6,642

Figure 1. Changes in innovation performance between 2019 and 2022

Source: Authors based on EC (2022)

There was a rearrangement in the innovation performance ranking during the time of the pandemic. Sweden preserved the leading role in the EU in the field of innovation, but Finland catches-up and the SII values of these countries were equal in 2022. Belgium's relative innovation performance exceeded 125% of the EU average in 2022 and became an innovation leader. Before the pandemic, there were only four countries that belonged to the innovation leaders group, but after the pandemic, there were five countries whose innovation performance is dominant in the EU. Cyprus realized the most significant improvement in innovation performance during the time of the pandemic, the SII was higher at 39,592% in 2022 than in 2019, and because of this, it became a strong innovator from a moderate one. The SII of Luxembourg and France became lower after the pandemic so they fell behind in the ranking. Despite the around 10% improvement in innovation performance, Estonia became a moderate innovator from a strong one. From 2019 to 2022, the innovation performance of Portugal and Malta became worse, because of this they also fell behind in the ranking. The SII of Lithuania and Greece improved significantly, despite this, there was no change in their ranking between 2019 and 2022. In the emerging innovators' group, Croatia's performance was better significantly, and because of this, it changed places with Slovakia in the ranking. Analysing the changes in innovation performance ranking, we can conclude that the pandemic crisis created possibilities for improving innovation activities. Some less innovative countries took advantage of the enforced technological development while technological leaders preserved their leading role in innovation. Because of this, a moderate rearrangement is shown but there is no significant convergence between technological leader and follower countries.

Figure 2 shows a level and trend analysis related to the Summary Innovation index comparing its actual value and its changes during the time of the pandemic. Cyprus realized an extremely high improvement while Malta suffered a serious decline in innovation performance from 2019 to 2022. Most of the emerging and moderate innovator countries, as well as innovation leaders, improved their performance at a higher level than the EU average while strong innovators' change was below the EU average, and in the case of the two countries, there was a negative tendency. Analysing the trends, we can conclude that the technological gap between technological leader and follower countries remains but a slow convergence can be seen between strong and moderate innovators.

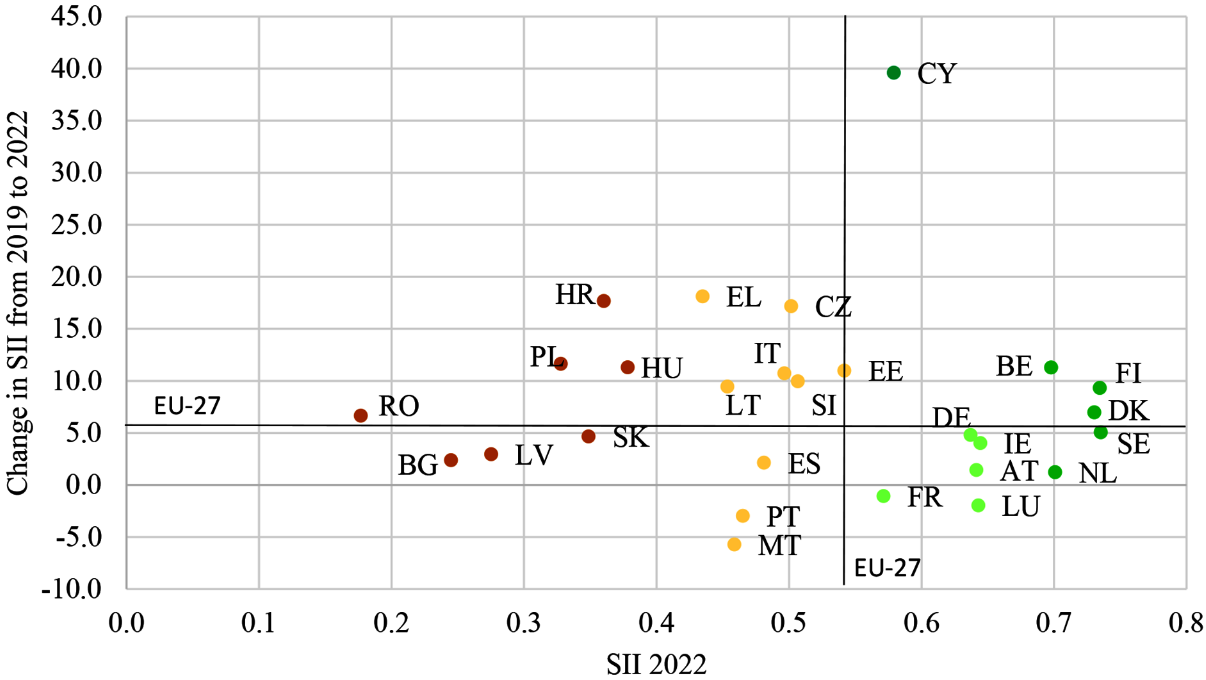


Figure 2. The value of the Summary Innovation Index in 2022
and its change from 2019 to 2022

Source: Authors based on EC (2022)

In the next step of the analysis, the innovation performance of European countries by groups is compared in detail with multivariate statistical methods using the 32 indicators from EIS. Based on the Kolmogorov-Smirnov test, there is no normal distribution (P value < 0.05) in the case of seven variables, namely international scientific co-publications per million population, direct government funding, and government tax support for business R&D, R&D expenditure in the business sector, public-private co-publications, PCT patent applications, trademark applications, and air emissions by fine particulates in Industry (see the results of the Kolmogorov-Smirnov test in Appendix 1). In these cases, the Kruskal-Wallis test can be run to compare the means of innovation performance groups. As *Table 1* shows, there is no significant difference between innovation performance groups in the case of direct government funding and government tax support for business R&D and air emissions by fine particulates in Industry based on the Kruskal-Wallis test.

Table 1. The results of the Kruskal-Wallis test

Variable	Chi-square test statistic	Sig.
International scientific co-publications per million population	20,329	0.000
Direct government funding and government tax support for business R&D	*4,977*	*0.173*
R&D expenditure in the business sector	12,320	0.006
Public-private co-publications	17,821	0.000
PCT patent applications	16,122	0.001
Trademark applications	7,798	0.050
Air emissions by fine particulates in industry	*6,581*	*0.087*

Source: Authors based on EC (2022)

In the case when the variables have a normal distribution, ANOVA can be run if there is homoscedasticity of variables. Based on the Levene test, there is no homoscedasticity in the case of ICT specialists and employment in knowledge-intensive activities. In these cases, Welch's test can be run instead of the F test to compare means between innovation performance groups. As *Table 2* shows, based on ANOVA we can conclude that there is no significant difference between innovation performance groups in these variables: non-R&D innovation expenditures, job-to-job mobility of Human Resources in Science & Technology, medium and high-tech product exports, sales of new or improved products ('product innovations'), and resource productivity. At a 10% significant level, the significant difference is shown in the case of design applications per billion GDP and the development of environment-related technologies.

Analysing the means plots related to ANOVA some interesting tendencies are seen. The general consequence is that innovation leaders realize the highest value of the most indicators but there are some exceptions. Percentage population aged 25-34 having completed tertiary education, the job-to-job mobility of Human Resources in Science & Technology, the medium and high technology product export and resource productivity are higher in strong innovators than in innovation leaders. In the case of employment impacts, the values of innovation leaders and strong innovators are quite similar. The most interesting thing is that non-R&D innovation expenditures are the highest in moderate innovators. The broadband penetration is higher in moderate innovators than in strong innovators. The innovation leaders and moderate innovators realize quite the same value, while strong innovators lag. We can conclude that there are some fields of innovation where technological followers are not far behind significantly.

Table 2. The results of ANOVA

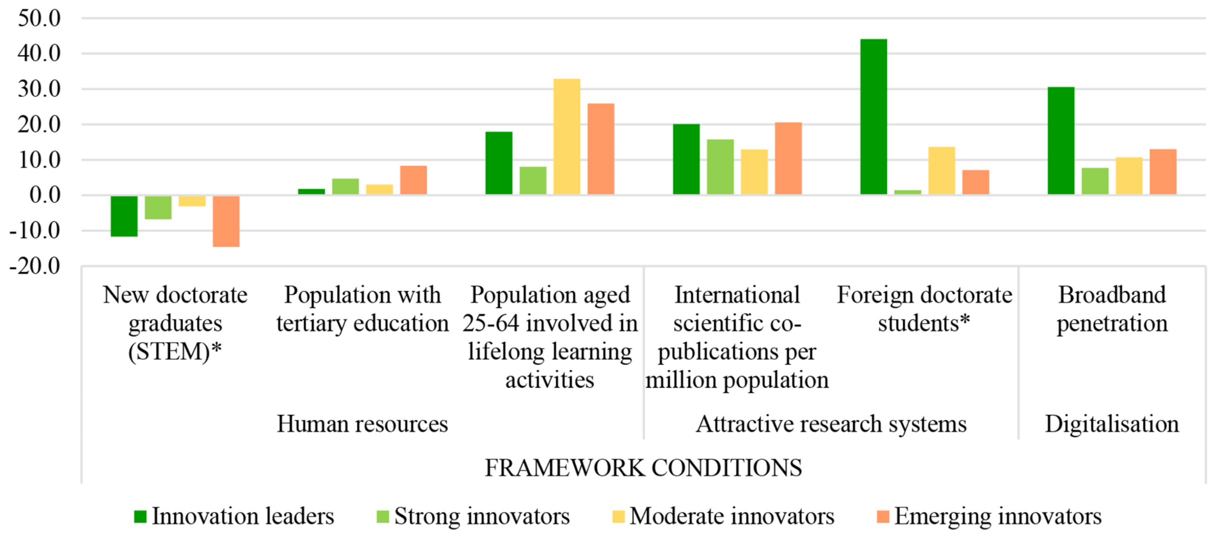
Variable	**F test**	**Sig.**
New doctorate graduates (STEM) per 1000 population aged 25-34	11,172	,000
Population with tertiary education (% share)	4,056	,019
Population aged 25-64 involved in lifelong learning activities (%-shares)	13,641	,000
Top 10% most cited publications (% share)	25,650	,000
Foreign doctorate students (% share)	9,149	,000
Broadband penetration (% share)	5,124	,007
Individuals who have above basic overall digital skills (% share)	6,384	,003
R&D expenditures public sector (% of GDP)	6,983	,002
Venture capital expenditures (% of GDP)	9,784	,000
Non-R&D innovation expenditures (% of turnover)	*,647*	*,593*
Innovation expenditure per person employed	9,343	,000
Enterprises providing training to develop or upgrade the ICT skills of their personnel (% share)	8,900	,000
SMEs with product innovations (% share)	5,633	,005
SMEs with business process innovations (% share)	10,420	,000
Innovative SMEs collaborating with others (% share)	9,523	,000
Job-to-job mobility of Human Resources in Science & Technology (% share)	*1,990*	*,144*
Design applications per billion GDP (in PPS)	*2,547*	*,081*
Employment in innovative enterprises (% share)	9,606	,000
Medium and high-tech product exports (% share)	*,314*	*,815*
Knowledge-intensive services exports (% share)	10,418	,000
Sales of new or improved products ('product innovations') (% of turnover)	*2,017*	*,140*
Resource productivity (measured as domestic material consumption (DMC) about GDP)	*2,068*	*,132*
Development of environment-related technologies	*2,530*	*,082*
Variable	**Welch's test**	**Sig.**
Employed ICT specialists	14,637	,000
Employment in knowledge-intensive activities	14,186	,000

Source: Authors based on EC (2022)

Finally, we analyse the changes in each variable differentiated by innovation performance groups to highlight whether innovation followers converge to innovation leaders during the time of the pandemic. The impact of the COVID-19 pandemic cannot be measured in some cases because the latest data is from 2019. In the digitalisation pillar, the variables are available for 2020 and 2021, in the case of individuals who have above basic overall digital skills there is only data for 2021. In other cases, the most recent year for which data are available is 2020 so we can analyse the change from 2019 to 2020 (marked with *).

Figure 3 shows the changes in framework conditions including human resources, the attractive research system, and digitalization. There is a decrease in new doctorate students in STEM in all groups; the reduction is highest in emerging innovators (-14.58%) followed by innovation leaders (-11.67%). There is good improvement in the tertiary educated population and participation in lifelong-learning activities in the worst-performing innovation group. We can conclude that in the field of human resources, there is a moderate convergence. In attractive research systems and digitalisation, the innovation leaders' performance improves significantly mainly in the number of foreign doctorate students and broadband penetration so surprisingly a divergence is observed between technological leaders and followers.

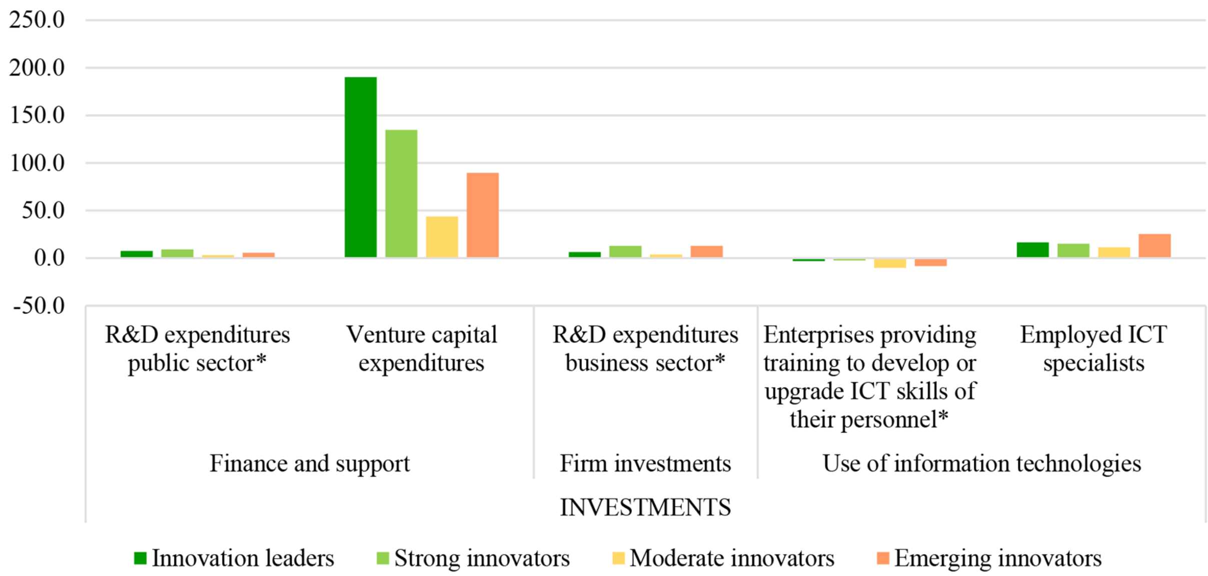
Figure 4 shows the changes in investments including finance and support, firm investments, and the use of ICT. There is no significant change at the time of the pandemic in R&D expenditures in the public and business sectors and the number of enterprises providing training to develop or upgrade the ICT skills of their personnel. The venture capital expenditures increased significantly in each group mainly in technological leader countries and surprisingly in the worst-performing group. The number of employed ICT specialists increased the most in emerging innovators (25.34%). We can conclude that there is no convergence in the field of investments between technological leaders and followers.



Note: the change in the top 10% of most cited publications and individuals who have above-basic overall digital skills cannot be measured because of the data availability.

Figure 3. Changes in framework conditions differentiated by innovation performance groups during the time of the pandemic

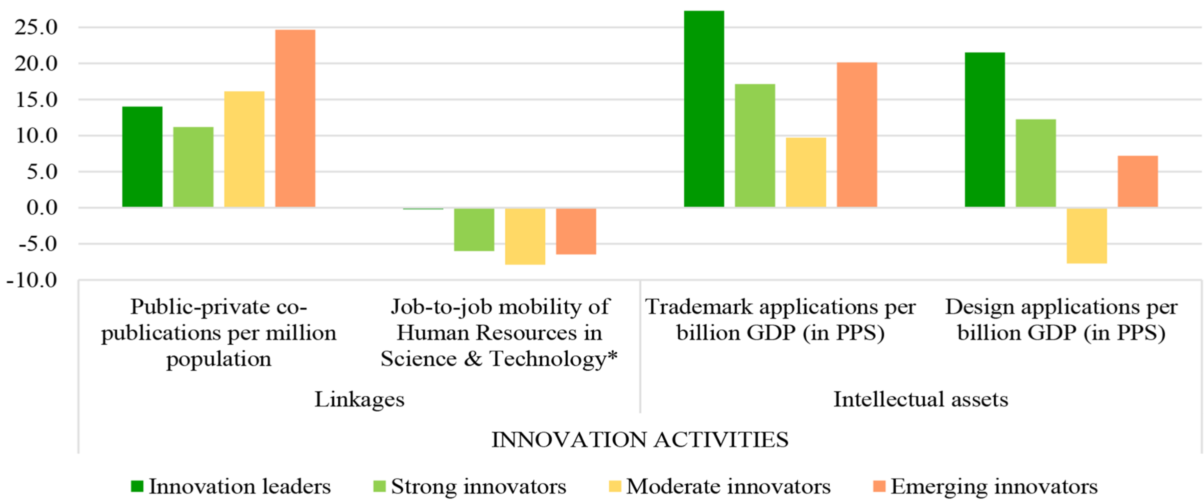
Source: Authors based on EC (2022)



Note: the change in direct government funding and government tax support for business R&D, non-R&D innovation expenditures, and innovation expenditure per person employed cannot be measured because of the data availability.

Figure 4. Changes in investments differentiated by innovation performance groups during the time of the pandemic

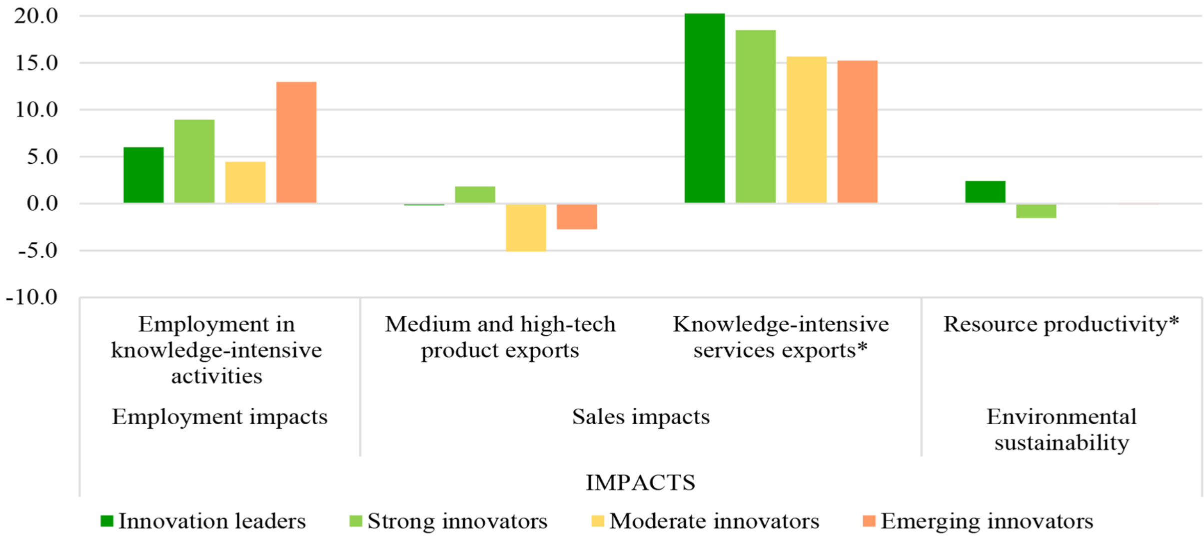
Source: Authors based on EC (2022)



Note: the change in variables related to innovators and innovative SMEs collaborating with others, PCT applications cannot be measured because of the data availability.

Figure 5. Changes in innovation activities differentiated by innovation performance groups during the time of the pandemic

Source: Authors based on EC (2022)



Note: the change in employment in innovative enterprises, sales of new-to-market and new-to-enterprise innovations, air emissions by fine particulates, and development of environment-related technologies cannot be measured because of the data availability.

Figure 6. Changes in impacts differentiated by innovation performance groups during the time of the pandemic

Source: Authors based on EC (2022)

Figure 5 shows the changes in innovation activities including innovators, linkages, and intellectual assets. There is a strong decrease in job-to-job mobility of HRST in all performance groups except for the innovation leaders. The public-private co-publications increase the most in emerging innovators and there are also more trademark applications in this group. In innovation activities the moderate innovators' performance is poor, and the number of design applications decreases while there is a significant improvement in other groups. We can conclude that in the field of innovation activities, there is an improvement in the performance of emerging innovators but there is no convergence between innovation leaders and followers.

Figure 6 shows the changes in innovation activities including employment impacts, sales impacts, and environmental sustainability. There is no significant change in resource productivity in less innovative groups while there is an improvement in this field in innovation leaders and a decrease in strong innovators. There is a decrease in medium and high-tech product exports in moderate and emerging innovators while strong innovators' performance becomes better and there is no change in innovation leaders. The knowledge-intensive services export increased significantly in each group, matching their innovation performance. In contrast, employment in knowledge-intensive activities increases the most among emerging innovators. We can conclude that there is a moderate convergence in employment impacts between innovation leaders and followers but in the other field, like sales impact and environmental sustainability, there is a significant improvement in less innovative countries.

4. CONCLUSION

This research aims to analyse the changes in European countries' innovation performance in the last years when the COVID-19 pandemic prevailed with data from European Innovation Scoreboard. We assumed that there is a moderate rearrangement in innovation ranking because of an improvement in the field of innovation in less innovative countries enforced by the pandemic. Sweden preserved the leading role in the EU in the field of innovation, Finland caught up and the SII value of these countries was equal in 2022. Before the pandemic, there were only four countries that belonged to the innovation leaders group, but after the pandemic, there are five countries whose innovation performance is dominant, because Belgium's relative innovation performance exceeded 125% of the EU average in 2022. Some less innovative countries have taken advantage of technological development in the last few years. Cyprus realized the most significant improvement in innovation performance during the time of the pandemic, the SII was higher at 39,592% in 2022 than in 2019, and because of this, it became a strong innovator from a moderate one. Some countries changed places in each group, so there is a rearrangement in ranking due to the pandemic but there is no significant convergence between technological leaders and followers. The other hypothesis is that the convergence of less innovative countries can be observed mainly in the physical infrastructure and financing was not confirmed. Our analysis pointed out that there is a moderate convergence in the field of human resources and employment impacts between innovation performance groups while technological leaders' performance improves significantly in investments and innovation activities.

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Appendix

A1. The results of the Kolmogorov-Smirnov test of variables

Innovation dimension		Variable	Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)
FRAMEWORK CONDITIONS	Human resources	New doctorate graduates (STEM) (% share)	,114	,200
		Population with tertiary education (% share)	,078	,200
		Population aged 25-64 involved in lifelong learning activities (%-shares)	,126	,200
	Attractive research systems	International scientific co-publications per million population	,188	,015
		Top 10% most cited publications (% share)	,133	,200
		Foreign doctorate students (% share)	,109	,200
	Digitalisation	Broadband penetration (% share)	,167	,051
		Individuals who have above basic overall digital skills (% share)	,130	,200
INVESTMENTS	Finance and support	R&D expenditures public sector (% of GDP)	,093	,200
		Venture capital expenditures (% of GDP)	,126	,200
		Direct government funding and government tax support for business R&D	,212	,003
	Firm investments	R&D expenditures business sector (% of GDP)	,179	,027
		Non-R&D innovation expenditures (% of turnover)	,109	,200
		Innovation expenditure per person employed	,132	,200
	Use of information technologies	Enterprises providing training to develop or upgrade the ICT skills of their personnel (% share)	,102	,200
		Employed ICT specialists (% of total employment)	,160	,073
INNOVATION ACTIVITIES	Innovators	SMEs with product innovations (% share)	,108	,200
		SMEs with business process innovations (% share)	,159	,080
	Linkages	Innovative SMEs collaborating with others (% share)	,103	,200
		Public-private co-publications per million population	,223	,001
		Job-to-job mobility of Human Resources in Science & Technology (% share)	,134	,200
	Intellectual assets	PCT patent applications per billion GDP (in PPS)	,225	,001
		Trademark applications per billion GDP (in PPS)	,203	,006
		Design applications per billion GDP (in PPS)	,144	,159
IMPACTS	Employment impacts	Employment in knowledge-intensive activities (% share)	,107	,200
		Employment in innovative enterprises (% share)	,102	,200
	Sales impacts	Medium and high-tech product exports (% share)	,095	,200
		Knowledge-intensive services exports (% share)	,130	,200
		Sales of new or improved products ('product innovations') (% of turnover)	,135	,200
	Environmental sustainability	Resource productivity (measured as domestic material consumption (DMC) in relation to GDP)	,152	,112
		Air emissions by fine particulate matter (PM2.5) in Industry	,187	,017
		Development of environment-related technologies	,130	,200

Source: Authors based on EC (2022)