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Universal Convergence in OECD R&D Researcher Capacity: Persistence, Selective Catch-Up, and Multiple Trajectories (2015–2024)

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ABSTRACT

This study examines the convergence, persistence, catch up dynamics, and heterogeneous trajectories of R&D researcher capacity across OECD and selected partner economies during 2015–2023. Using an integrated analytical framework combining σ convergence, absolute β convergence, the Phillips Sul log-t test, Markov transition analysis, trajectory clustering, compound annual growth rate (CAGR) analysis, and a growth level typology, the study investigates whether national researcher stocks move toward a common long run equilibrium or instead follow differentiated development paths. The results decisively reject universal convergence: cross country dispersion did not decline systematically, the β-convergence coefficient was statistically insignificant (β = +0.000599, p = 0.867), and the Phillips Sul test rejected overall convergence (t = -22.002). Markov transition analysis revealed strong structural persistence, with probabilities of remaining in the same capacity state ranging from 74.4% to 94.1%. Nevertheless, the study identified selective catch up: Poland, Türkiye, Hungary, Slovenia, and Croatia showed rapid researcher capacity growth and formed a statistically distinct trajectory cluster. The growth level typology classified countries into four regimes: strategic leaders, mature leaders, catch up economies, and persistent laggards. The study concludes that R&D researcher capacity constitutes a multi regime system characterized by simultaneous persistence, selective catch up, and multiple trajectories rather than a single convergence process. These findings carry significant implications for differentiated science, technology, and innovation policy design.

Keywords: R&D Researcher Capacity, Convergence, OECD, Phillips Sul Test, Markov Transition Analysis, Selective Catch-Up, Trajectory Clustering, Structural Persistence, Growth level typology

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1. Introduction and Conceptual Background

Convergence is a useful analytical concept for examining whether countries or regions with initially different levels of development move toward more similar levels over time. In this context, convergence can be understood broadly as a process in which forces encourage countries, institutions, or social groups to move toward a common objective [1]. In economic and innovation research, convergence is commonly associated with the process through which less-developed economies approach the performance of more developed economies by adopting new technologies and production processes [2, 3].

2. Background

Convergence can be assessed using both aggregate and disaggregated indicators. Conventional macroeconomic measures include total GDP, GDP per capita, and the Human Development Index (HDI). However, these indicators can be complemented by specialized measures that capture the structural dimensions of development, including industry and technology indices, infrastructure indicators such as transportation and communication networks, government and private sector R&D expenditure, and competitiveness indicators such as global market shares in key industries [4] . Such measures provide a more detailed basis for examining whether differences in research and innovation capacity are narrowing across countries.

R&D investment is particularly important because expenditure on research and development is closely connected with innovation, organizational competitiveness, and the ability of firms and governments to support technological development. R&D investment is a key factor shaping company management and competitiveness and can also reflect the extent of state support for R&D activities [5, 6]. From an economic perspective, access to financial resources is a major determinant of innovative activity, particularly among small and medium-sized enterprises [7-11].

2.1 Computational and Network Perspectives

In computer science, the concept of market based control emerged as a framework for understanding decentralized resource allocation (Clearwater, 1996). Multi agent systems embedded in market type structures are characterized by decentralization or distributed operation, interacting agents, and mechanisms for allocating resources. Complex resource allocation and load balancing in computerized systems can therefore be conceptualized through market-based control [12]. From this perspective, a market based control system represents a distributed multi-agent system in which agents possess distinct knowledge, preferences, abilities, and rational behaviours that can be represented computationally. Simulation can consequently be used to examine the behaviour of such distributed systems.

2.2 Evidence on Selective Convergence and Catch-Up

The empirical literature indicates that convergence in research capacity does not necessarily occur uniformly across countries. Javed, S [13] examined whether less developed countries were catching up with developed countries using the log t convergence technique (LCT) and the dynamic spatial ordered probit (DSOP) model. The results indicated no overall convergence in AI research capacity. Nevertheless, club-clustering analysis identified convergence within four of five country groups for AI research output and within three of four groups for AI patent grants. These findings suggest that convergence may be selective, with countries forming distinct convergence clubs rather than following a single global trajectory.

This distinction is important for analysing OECD R&D researcher capacity between 2015 and 2023. Rather than assuming a universal movement toward a common level of capacity, convergence should be examined as a combination of persistence, selective catch up, and potentially divergent trajectories. Countries may therefore differ in how quickly and to what extent their research systems approach higher performing peers. Multiple trajectories align with the broader understanding that convergence can occur whenever forces encourage actors or social groups toward a common aim, while pathways to that aim may remain heterogeneous.

2.3 Economic Foundations of R&D Researcher Capacity

The economic foundations of convergence are especially relevant when considering researcher capacity. The percentage of GDP allocated to R&D can be an important, and potentially decisive, factor in the introduction of new solutions, services, and products and in the development of effective organizational management. Innovation is resource intensive: bringing a new product into consumers' awareness requires extensive analysis and preparation and therefore carries substantial costs [14] (Rutkowski, 2021). Consequently, differences in R&D expenditure can contribute to persistent differences in national research capacity, even when countries face similar technological opportunities.

At the macroeconomic level, convergence in innovation capacity can therefore be linked to broader processes of economic convergence. Countries that successfully increase their technological capabilities, research investment, and production capacity may reduce gaps with more advanced economies. Conversely, persistent differences in financial resources and infrastructure may reinforce existing disparities. R&D investment thus extends beyond producing scientific knowledge; it also shapes organisations' and national systems' capacity to develop, adopt, and commercialise innovation.

2.4 Research Capacity, Development Constraints, and Unequal Trajectories

Global health and development programmes, including the Sustainable Development Goals (SDGs), establish indicators and targets that can be used to develop road maps, budgets, and mechanisms for mobilizing resources through coordinated partnerships. Such approaches can also be applied to strengthening health research capacity [15]. Building, enhancing, and sustaining health research capacity in medicine, biosciences, public health, global health, and allied disciplines is critical for preparing the next generation of researchers and clinicians and for supporting the discovery and refinement of health solutions.

The target of allocating approximately 2% of GDP to R&D as part of building a knowledge economy illustrates the scale of the challenge many low and middle income countries (LMICs) face. Many LMICs struggle to reach such investment levels because resources must also address infrastructure and broader developmental deficits. In addition, available funds may be prioritized for health service delivery before resources reach health research. Research, development, and innovation (RDI) encompasses research to generate knowledge, policy development, and the creation of new products or services, as well as innovation that moves these outputs toward practical application. Health RDI consequently plays an important role in addressing health challenges by generating new knowledge, advancing research, and developing products and services through innovation.

However, health RDI capacity can be constrained by insufficient numbers of practitioners, leaders, and mentors; limited capacity to conduct RDI; inadequate infrastructure and support; insufficient funding and investment; fragmented or underdeveloped RDI systems; misalignment between RDI activities and national needs and priorities; funder led agendas; incompatible collaborations; and ineffective or unequal partnerships [16-20]. These constraints demonstrate that convergence in researcher capacity depends on more than expenditure alone. Institutional infrastructure, human resources, collaboration structures, and alignment between research activity and national priorities can all influence whether countries can sustain catch up.

2.5 Implications for the Analysis of OECD R&D Researcher Capacity, 2015–2023

Taken together, the literature supports an analytical framework that examines OECD R&D researcher capacity through both persistent differences and the possibility of selective catch up. Aggregate economic indicators can establish the broader development context, while R&D expenditure, technological indicators, infrastructure, and competitiveness measures provide more specific evidence about the foundations of research capacity. Computational and network approaches further provide a means of examining decentralized interactions and resource allocation.

Evidence from AI research capacity is particularly relevant because it shows that convergence may occur within groups of countries even when there is no evidence of overall convergence [21]. Accordingly, the OECD context should not be interpreted solely through an assumption of universal convergence. Instead, countries may display persistent leadership, gradual catch up, or distinct trajectories depending on their investment levels, institutional capabilities, infrastructure, and collaborative environments. This perspective provides a stronger conceptual basis for investigating whether researcher capacity across OECD countries moved toward a common equilibrium during 2015–2023 or instead followed multiple convergence paths.

Overall, the literature indicates that convergence in R&D researcher capacity is a multidimensional process shaped by economic resources, technological development, infrastructure, institutional capacity, and collaborative arrangements. Financial investment remains a fundamental enabling condition, but persistent constraints in human resources, infrastructure, governance, partnerships, and research system alignment can limit countries' ability to translate investment into sustained capacity. The analysis of OECD countries over 2015–2023 can therefore contribute to the literature by distinguishing between universal convergence, selective catch up, and persistent or divergent trajectories rather than treating convergence as a single uniform process.

2.6 Research Gap

Although the literature has widely examined convergence in economic development, innovation performance, technological capability, and research capacity, it provides limited evidence on whether national R&D researcher capacity converges toward a common long run level. Conventional convergence studies frequently focus on aggregate economic indicators such as GDP per capita, productivity, or broad innovation measures. While these indicators are useful for assessing general development, they do not directly capture the human-resource dimension of national research and innovation systems. R&D researchers constitute a critical component of scientific and technological capacity because they are directly involved in generating new knowledge, developing technologies, and supporting innovation.

A second gap concerns the assumption of uniform convergence. Previous evidence indicates that countries do not necessarily follow a single convergence path. For example, research on AI research capacity has reported no overall convergence while identifying convergence within specific country groups [21]. This suggests that countries may form distinct convergence clubs or follow heterogeneous trajectories rather than gradually approaching a single equilibrium. Nevertheless, this perspective has not been sufficiently developed for the broader analysis of R&D researcher capacity across countries.

A third gap relates to the limited integration of complementary σ convergence techniques. A single convergence test can only partially represent a complex longitudinal process. β convergence evaluates whether cross country dispersion decreases, whereas σ-convergence examines whether initially lower capacity countries grow faster than initially higher capacity countries. Neither approach alone can adequately identify persistence, structural mobility, heterogeneous trajectories, or convergence clubs. The present study addresses this limitation by integrating σ-convergence, absolute β-convergence, Phillips Sul convergence testing, Markov transition analysis, trajectory clustering, CAGR-based growth analysis, and a growth level typology.

A fourth gap concerns the distinction between capacity level and capacity growth. Ranking countries according to the absolute number of researchers may obscure important differences in development dynamics. A country with a relatively small researcher base may be expanding rapidly, whereas a country with a large researcher base may show limited growth because its research system has reached a more mature stage. Consequently, an assessment based solely on researcher counts cannot distinguish strategic leaders, mature research systems, emerging catch up countries, and persistent laggards. The present study addresses this gap by combining researcher capacity levels with longitudinal growth rates.

A fifth gap concerns persistence. Existing convergence interpretations may implicitly assume that countries move relatively freely across development levels. However, the present analysis indicates substantial state dependence in researcher capacity. The Markov transition results show high probabilities of remaining in the same capacity state, particularly among high performing countries. This indicates that researcher capacity may be characterized by structural persistence rather than continuous mobility.

Finally, incomplete longitudinal coverage creates a methodological and empirical gap. The OECD dataset contains uneven country coverage across years, with only five countries available for 2024. Therefore, 2015–

2023 provides a more appropriate analytical window for cross country convergence analysis. A systematic analysis using a balanced panel within this period can provide a more robust assessment of long term researcher capacity trajectories.

Accordingly, this study addresses the central gap: the lack of an integrated longitudinal framework that can distinguish universal convergence, selective catch up, persistence, convergence clubs, and differentiated growth regimes in national R&D researcher capacity. Rather than asking only whether countries converge, this study investigates how countries move, whether they remain trapped in particular capacity states, which countries demonstrate catch up dynamics, and whether multiple development trajectories coexist.

2.7 Research Problem

Despite increasing international emphasis on research and innovation capacity, substantial differences remain in the size and development of national R&D researcher populations. R&D investment, infrastructure, human resources, institutional capabilities, and collaborative arrangements can influence countries' ability to build and sustain research capacity. However, it remains unclear whether countries with initially lower researcher capacity systematically catch up with countries possessing larger research systems.

The central research problem is therefore whether differences in R&D researcher capacity across the observed OECD and partner economies are narrowing over time or whether countries remain characterized by persistent and differentiated trajectories.

More specifically, three possibilities require empirical distinction. First, countries may exhibit universal convergence, whereby initially different researcher capacity levels progressively move toward a common long run equilibrium. Second, countries may demonstrate selective convergence or catch up, whereby only particular countries or groups improve their relative position. Third, countries may exhibit persistent divergence or multiple trajectories, whereby high capacity countries remain high performers while lower capacity countries remain trapped in relatively low capacity states.

The preliminary analysis provides evidence against the first possibility. Cross country dispersion did not decline systematically, absolute β-convergence was statistically unsupported, and the Phillips Sul test strongly rejected overall convergence. The research problem therefore shifts from simply testing whether convergence exists to identifying the structure, persistence, and heterogeneity of national researcher capacity trajectories.

2.8 Research Statement

This study investigates whether R&D researcher capacity across OECD and selected partner economies followed a common convergence path during 2015–2023. It examines whether cross country differences decreased over time, whether initially lower capacity countries grew systematically faster, whether countries formed statistically or empirically identifiable trajectory groups, and whether researcher capacity states exhibited substantial persistence.

The study proceeds from the proposition that national research capacity is unlikely to evolve according to a single homogeneous trajectory. Instead, differences in economic resources, institutional capabilities, research infrastructure, human capital, and research system organization may generate persistent disparities and selective catch up. The analysis therefore conceptualizes convergence as a multidimensional process that may involve simultaneous persistence, catch up, and differentiated trajectories.

The study's central statement is:

R&D researcher capacity across countries is not necessarily characterized by universal convergence; rather, countries may exhibit persistent capacity states, selective catch up, and multiple development trajectories.

2.9 Research Questions

The study addresses the following research questions:

RQ1. Has cross-country dispersion in R&D researcher capacity decreased during 2015–2023?

RQ2. Do countries with initially lower levels of R&D researcher capacity grow faster than countries with initially higher levels of capacity?

RQ3. Is there evidence of a common long-run convergence path in R&D researcher capacity?

RQ4. Do countries form distinct convergence or trajectory clubs based on their researcher capacity dynamics?

RQ5. How persistent are countries' positions across different researcher capacity states?

RQ6. Which countries demonstrate the strongest catch up dynamics, and which countries exhibit persistent high or low performance?

RQ7. Can countries be differentiated into meaningful strategic groups by researcher capacity level and growth rate?

2.10 Research Objectives

General Objective

The primary objective of this study is to examine the convergence, persistence, catch up dynamics, and heterogeneous trajectories of R&D researcher capacity across OECD and selected partner economies from 2015 to 2023.

Specific Objectives

1. To measure annual cross country dispersion in R&D researcher capacity using s-convergence indicators.

2. To test whether initially lower researcher capacity countries experienced systematically higher subsequent growth using absolute b-convergence.

3. To examine whether countries share a common long run trajectory using the Phillips Sul convergence framework.

4. To identify potential convergence clubs and differentiated trajectory groups.

5. To assess the persistence and mobility of countries across researcher capacity states using Markov transition analysis.

6. To identify countries exhibiting rapid researcher capacity growth and potential catch up dynamics.

7. To classify countries according to their combined researcher capacity level and growth performance.

8. To develop an integrated interpretation of universal convergence, selective catch up, persistence, and differentiated national trajectories.

9. To provide an empirical basis for understanding the heterogeneous development of national research human capital.

2.11 Conceptual Framework

The study conceptualizes national R&D researcher capacity as a longitudinal system characterized by four interconnected dimensions:

Initial capacity → Growth dynamics → State persistence → Long-run trajectory

Initial researcher capacity sets each country's starting position. Growth dynamics capture whether countries expand their researcher populations and whether lower capacity countries grow faster than higher capacity countries. State persistence examines whether countries remain within the same relative capacity category over time. Long run trajectory analysis determines whether countries move toward a common equilibrium or instead follow distinct paths.

The framework consequently distinguishes four possible outcomes:

1. Universal convergence: countries progressively approach a common researcher capacity level.

2. Selective catch up: a subset of lower capacity countries experiences substantially faster growth.

3. Persistence: countries remain within their existing relative capacity states.

4. Multiple trajectories: countries follow distinct development paths or trajectory clubs.

This conceptualization is consistent with the empirical evidence in the dataset, which identifies differentiated national trajectories, selective catch-up, and strong performance persistence rather than a single common equilibrium.

3. Materials and Methods

3.1 Research Design

The study uses a quantitative longitudinal comparative research design to examine how R&D researcher capacity evolves across countries. The analysis covers the period 2015–2023 and combines descriptive, econometric, convergence, stochastic transition, and clustering approaches.

A longitudinal design is appropriate because convergence is inherently a dynamic phenomenon. Cross-sectional comparisons at a single point in time cannot determine whether differences between countries are narrowing, widening, or persisting. The 2015–2023 period therefore provides a consistent temporal framework for evaluating changes in researcher capacity.

The methodological strategy consists of five complementary stages:

1. Descriptive assessment of researcher capacity levels and dispersion.

2. Testing of σ- and absolute β-convergence.

3. Testing of common long-run convergence using the Phillips Sul framework.

4. Analysis of state persistence and mobility using Markov transition probabilities.

5. Identification of trajectory clusters and growth level country typologies.

3.2 Data Source and Dataset

The study uses the OECD Research and Development Statistics database, specifically the dataset titled "Research and Development (R&D) personnel by sector of performance and formal qualification." The OECD Directorate for Science, Technology and Innovation provides the data, compiled according to the definitions established in the Frascati Manual.

The dataset measures human resources engaged in research and experimental development across countries and distinguishes R&D personnel according to occupation, sector of performance, formal qualification, and measurement unit.

For the present study, the analysis focuses specifically on Researchers (RSE). Researchers are defined as professionals engaged in conceiving or creating new knowledge, products, processes, methods, and systems.

3.3 Variable Definition

The principal dependent variable is the number of R&D researchers, measured as headcount.
The dataset parameters aggregate:

- occupation: Researchers (RSE);
- sector of performance: Total Sectors;
- formal qualification: Total Qualification Levels;
- sex: Total;
- unit of measurement: Persons/Head Count;
- frequency: Annual.

The use of headcount is particularly relevant because the study seeks to examine the absolute stock of scientific human capital rather than the volume of labor time devoted to R&D.

3.4 Study Period and Country Coverage

The initial dataset extends from 2015 onward. However, country coverage is uneven across years. In particular, only five countries are represented in 2024. Because convergence analysis requires sufficient cross sectional and longitudinal coverage, we excluded 2024 from the principal convergence analysis.

Accordingly, we selected 2015–2023 as the principal study period. For balanced longitudinal analyses, the dataset contains 20 countries with complete observations over the entire period.

This approach reduces the risk of interpreting incomplete 2024 coverage as evidence of cross-country convergence or divergence.

3.5 Analytical Procedures

3.5.1 Descriptive Analysis

First, annual descriptive statistics were calculated to establish the overall structure of researcher capacity. These include:

- number of reporting countries;
- mean researcher count;
- median researcher count;
- standard deviation;
- coefficient of variation;

- logarithmic standard deviation;

- Gini coefficient.

These statistics provide an initial assessment of the scale and distribution of researcher capacity and indicate whether cross country inequality declines or persists over time.

3.5.2 σ-Convergence

σ-convergence assesses whether dispersion across countries decreases over time. The study uses the log-standard deviation and Gini coefficient as complementary measures of cross country dispersion.

The interpretation is straightforward: a sustained reduction in dispersion would provide evidence consistent with β-convergence, whereas persistent or increasing dispersion would indicate the absence of convergence.

The analysis shows that the log-standard deviation and Gini coefficient fluctuated considerably between 2015 and 2023 without a sustained downward trend.

3.5.3 Absolute b-Convergence

Absolute b-convergence tests whether countries with initially lower researcher capacity grow faster than countries with initially higher capacity.

The study estimates the relationship between the initial logarithmic researcher level and subsequent average annual growth using countries observed in both 2015 and 2023.

The estimated coefficient was:

- $\beta = 0.000599$;

- $R^2 = 0.0014$;

- $p = 0.867$;

- 95% CI ≈ -0.00633 to 0.00753.

The coefficient was statistically indistinguishable from zero, indicating that initially smaller researcher systems did not systematically grow faster than larger systems.

3.5.4 Compound Annual Growth Rate

To identify country specific growth dynamics, we calculated CAGR over 2015–2023.

The CAGR provides a standardized measure of average annual researcher capacity growth and allows countries with different starting levels to be compared.

The highest growth countries included Poland, Türkiye, Hungary, Slovenia, Croatia, Portugal, Greece, Estonia, Belgium, and Korea.

The authors then combined CAGR with researcher-capacity levels to distinguish rapid growth countries from mature or low growth systems.

3.5.5 Phillips–Sul Convergence Test

The Phillips–Sul log-t test examined whether countries move toward a common long-run path. This method is particularly appropriate for heterogeneous panels because it allows countries to exhibit different transitional dynamics rather than imposing a homogeneous adjustment process.

For the 20 countries with complete observations, the estimated log-t slope was -1.247, corresponding to $\sigma = -0.623$, with a t-statistic of -22.002. Because the statistic is well below the 5% critical value of -1.65, we rejected the null hypothesis of overall convergence.

The Phillips–Sul procedure was also used to investigate convergence clubs. The analysis identified a dominant trajectory group of 16 countries and Latvia as a singleton. These results are interpreted as evidence of trajectory similarity rather than definitive long run equilibrium convergence because of the relatively short time dimension.

3.5.6 Markov Transition Analysis

Markov transition analysis was used to examine the persistence and mobility of researcher capacity positions. Countries were classified annually into four relative capacity states based on cross sectional quartiles:

1. Low;

2. Lower-middle;

3. Upper-middle;

4. High.

The transition matrix estimates the probability that a country remains in or moves between these states from one year to the next.

The results demonstrate strong state persistence. The probability of remaining in the same state was 86.5% for the Low group, 74.4% for Lower middle, 75.8% for Upper-middle, and 94.1% for the High group.

This analysis provides evidence that countries' positions in the researcher capacity distribution are not highly fluid and that high performing countries, in particular, exhibit strong persistence.

3.5.7 Trajectory Clustering

Trajectory clustering was conducted after normalizing each country's researcher series to 2015 = 100. This procedure emphasizes the shape and relative growth trajectory rather than absolute researcher counts.

The silhouette analysis indicated that a two cluster solution provided the strongest separation, with a silhouette score of 0.553 compared with 0.304 for three clusters.

The two clusters were:

- Cluster 1: broad/main trajectory group comprising 15 countries;

- Cluster 2: rapid-growth/catch-up trajectory comprising Croatia, Hungary, Poland, Slovenia, and Türkiye.

This approach complements conventional convergence tests by identifying countries that follow similar temporal growth patterns.

3.5.8 Growth–Level Typology

We constructed a four quadrant typology using the 2023 researcher-capacity level and the 2015–2023 CAGR.

Sample medians were used as thresholds.

The resulting categories were:

High level–High growth: strategic leaders.

High level–Low growth: mature leaders.

Low level–High growth: catch-up economies.

Low level–Low growth: persistent or vulnerable laggards.

The resulting classification identified seven high level/high growth countries, three high level/low growth countries, three low level/high growth countries, and seven low level/low growth countries.

This typology offers a more informative interpretation than a simple country ranking because it considers both the scale and dynamism of national researcher capacity.

3.6 Integrated Analytical Framework

The methodological approaches were not treated as independent tests. Instead, they were integrated to provide a multidimensional assessment of convergence.

The analytical logic was:

Descriptive statistics → σ-convergence → β-convergence → Phillips–Sul test → Markov transitions → trajectory clustering → growth level typology → integrated interpretation

The first two stages establish whether dispersion is declining and whether lower capacity countries systematically grow faster. The Phillips–Sul analysis then evaluates common long run trajectories and potential clubs. Markov analysis examines persistence and mobility, while clustering identifies empirically similar growth paths. Finally, the growth level typology translates the longitudinal findings into strategically interpretable country groups.

This integrated approach is necessary because no single indicator can distinguish universal convergence from selective catch up, persistence, and multiple trajectories.

3.7 Hypotheses

Based on the conceptual framework, the following hypotheses can be formulated:

H1: Cross-country dispersion in R&D researcher capacity decreases systematically over time.

H2: Countries with initially lower R&D researcher capacity experience significantly faster subsequent growth than countries with initially higher capacity.

H3: OECD and selected partner economies converge toward a common long-run researcher-capacity trajectory.

H4: Countries exhibit significant mobility between researcher-capacity states over time.

H5: Countries can be grouped into statistically or empirically distinguishable researcher capacity trajectories.

H6: Countries with high researcher-capacity levels and high growth rates constitute a distinct strategic-performance group.

The empirical results reject H1, H2, and H3. The evidence for H4 is instead characterized by strong persistence and limited mobility, while H5 and H6 receive empirical support through trajectory clustering and the growth–level typology. The Markov analysis demonstrates particularly strong persistence among high capacity countries.

3.8 Research Contributions

The study makes several contributions to the literature.

First, it shifts the analysis of convergence from broad economic indicators toward researcher capacity as a core component of national scientific and technological human capital.

Second, it demonstrates that the absence of universal convergence does not imply an absence of positive development. Several countries exhibit substantial researcher-capacity growth and relative catch up even though overall convergence is not detected.

Third, the study integrates multiple analytical perspectives to distinguish dispersion, growth, long run trajectories, state persistence, clustering, and strategic performance.

Fourth, identifying a rapid-growth/catch up trajectory comprising Croatia, Hungary, Poland, Slovenia, and Türkiye provides evidence that convergence processes may be selective rather than universal.

Fifth, the growth level framework provides a policy relevant classification of countries into strategic leaders, mature leaders, catch up economies, and persistent laggards.

Finally, the study contributes to the conceptualization of convergence as a multi regime process rather than a single linear movement toward equilibrium.

3.9 Methodological Limitations

Several limitations should be acknowledged.

First, the analysis is based primarily on researcher headcounts. Headcount measures the number of individuals but does not directly capture differences in research productivity, researcher quality, working time, disciplinary composition, or scientific impact.

Second, country coverage is uneven across years. Restricting the main analysis to 2015–2023 and using balanced observations for longitudinal procedures reduces the effect of missing observations but also limits the number of countries included in some analyses.

Third, conditional β-convergence could not be estimated using the present dataset alone because it lacks the required explanatory variables. Variables such as GDP per capita, population, R&D expenditure, GERD intensity, human capital, patent activity, and scientific publication output would be required to control for structural differences between countries.

Fourth, the relatively short nine-year period limits the interpretation of convergence clubs as definitive long-run equilibria. The Phillips–Sul club results should therefore be interpreted primarily as evidence of trajectory similarity.

Fifth, the study identifies statistical associations and trajectory patterns rather than establishing causal relationships. In particular, the analysis cannot determine whether R&D expenditure, human capital, infrastructure, government policy, or institutional arrangements directly caused the observed researcher capacity trajectories.

3.10 Future Research Directions

Future research should extend the present framework by integrating additional structural and socioeconomic variables. In particular, GDP per capita, population size, R&D expenditure, GERD as a percentage of GDP, researchers per 1,000 employed persons, higher education attainment, government R&D expenditure, patent activity, and scientific publication output could be incorporated into conditional convergence models.

A panel data framework could subsequently be used to estimate conditional β-convergence using fixed effects or random effects models. Dynamic panel estimators could further account for temporal dependence in researcher capacity.

Future research could also investigate whether countries belonging to different trajectory clubs differ systematically in their R&D investment structures, higher education systems, research infrastructure, international collaboration, and policy environments. Such an extension would move the analysis from identifying where convergence and divergence occur toward explaining why different trajectories emerge.

3.11 Expected Policy Relevance

The findings have important implications for science, technology, and innovation policy. The absence of universal convergence indicates that policies based on a single catch up model may be inappropriate. Countries characterized by low researcher capacity and low growth may require policies focused on fundamental capacity building, including research infrastructure, human resource development, institutional strengthening, and sustained investment.

Catch up countries may benefit from policies designed to consolidate rapid growth and prevent the loss of newly accumulated research capacity. Mature high capacity countries may instead require policies emphasizing research quality, productivity, international collaboration, and the renewal of the researcher workforce.

The four regime framework therefore supports differentiated policy strategies rather than a uniform convergence policy. The empirical evidence suggests that researcher capacity development is better understood as a system in which some countries rapidly close gaps, some maintain mature capacity, and others remain structurally persistent at lower levels.

3.12 Transition to the Results Section

The methodological framework establishes the basis for evaluating whether national R&D researcher capacity follows a universal convergence process or multiple differentiated trajectories. The subsequent Results section therefore reports the empirical evidence sequentially, beginning with cross country dispersion and absolute convergence, followed by long run convergence testing, convergence club identification, state transition analysis, trajectory clustering, and growth level classification. This sequence moves from the broad question of whether convergence exists to the more substantive question of how countries differ in their researcher-capacity development paths.

4. Analysis

Country convergence/divergence analysis

Key results

4.1 σ-convergence: No sustained convergence

Cross-country dispersion fluctuated substantially rather than declining continuously.

4.1 σ-Convergence

We examined cross-country dispersion in the stock of R&D researchers (headcounts) using the log-standard deviation and the Gini coefficient over 2015–2023. Both measures fluctuated without a sustained downward trend. The log-standard deviation rose from 1.229 in 2015 (29 countries) to 1.355 in 2023 (25 countries). The Gini coefficient ranged from approximately 0.590 to 0.635. These results indicate no σ-convergence: countries have not progressively approached a common level of researcher capacity.

Year	Countries	Log-SD	Gini
2015	29	1.229	0.619
2016	24	1.354	0.635
2017	29	1.238	0.606
2018	24	1.352	0.624
2019	28	1.226	0.590
2020	22	1.316	0.622
2021	26	1.249	0.609
2022	22	1.349	0.631
2023	25	1.355	0.607

Table 1. σ-convergence

4.2 Absolute σ-convergence: Not supported

Using countries with observations in both 2015 and 2023 (n = 23), the estimated relationship between initial researcher level and subsequent average annual growth was:

- =β +0.000599
- R^2 = 0.0014
- p = 0.867
- 95% CI ≈ - 0.00633 to +0.00753

The coefficient is very close to zero and statistically insignificant.

We tested absolute β -convergence on the balanced sample of 23 countries observed in both 2015 and 2023. The estimated relationship between the initial (log) level of researchers and subsequent average annual growth yielded a coefficient of β = +0.000599 (R^2 = 0.0014, p = 0.867; 95 % confidence interval approximately -0.00633 to +0.00753). The coefficient is statistically indistinguishable from zero. Countries that began the period with smaller researcher stocks did not systematically grow faster than those with larger stocks. The absence of absolute σ-convergence is consistent with the lack of ó-convergence and implies that no general catch-up mechanism operated across the sample.

4.3 Catch-up dynamics

The fastest-growing countries over 2015–2023 were:

Country	CAGR	Rank change
Poland	8.34%	+1
Türkiye	7.93%	+2
Hungary	7.20%	+2
Slovenia	5.68%	0
Croatia	5.50%	0
Portugal	5.01%	+1
Greece	4.95%	0
Estonia	4.69%	+1
Belgium	4.43%	+2
Korea	3.64%	0

Table 2. Country CAGR

Although overall convergence is unsupported, individual countries exhibited heterogeneous growth. The highest compound annual growth rates (CAGR) between 2015 and 2023 were recorded by Poland (8.34 %), Türkiye (7.93 %), Hungary (7.20 %), Slovenia (5.68 %), Croatia (5.50 %), Portugal (5.01 %), Greece (4.95 %), Estonia (4.69 %), Belgium (4.43 %) and Korea (3.64 %). Several of these economies also improved their relative ranking. Selective catch-up therefore occurred, yet it was insufficiently widespread to generate detectable absolute β - or σ-convergence.

4.4. Leader–laggard dynamics

The strongest catch-up performance was concentrated among Poland, Türkiye and Hungary, with each achieving both relatively high growth and positive rank movement.

In contrast, several countries experienced slower researcher growth, including:

- Slovak Republic — 0.58% CAGR
- Japan — 1.08%
- Latvia — 1.22%
- Lithuania — 1.31%
- Romania — 1.70%
- Chinese Taipei — 2.22%
- Argentina — 2.26%

The rank analysis therefore indicates mobility at the margins rather than wholesale restructuring of the country hierarchy.

The strongest simultaneous gains in growth and rank were concentrated among Poland, Türkiye and Hungary. In contrast, a group of economies recorded markedly slower expansion: the Slovak Republic (0.58%), Japan (1.08 %), Latvia (1.22 %), Lithuania (1.31%), Romania (1.70%), Chinese Taipei (2.22%) and Argentina (2.26%). Rank mobility remained largely confined to the margins of the distribution; the overall hierarchy of researcher capacity displayed only limited restructuring.

4.5 Convergence clubs

Using countries with complete 2015–2023 trajectories and clustering their normalized researcher trajectories, three broad convergence clubs emerged:

Club 1 — Lower-level / catch-up trajectory- Croatia Hungary, Poland, Slovenia, Türkiye

Club 2 — Middle-level trajectory-Bulgaria, Estonia, Italy, Korea, Portugal, South Africa, Spain

Club 3 — Higher-level / mature trajectory- Argentina, Chinese Taipei, Japan, Latvia, Lithuania, Romania, Singapore, Slovak Republic

These should be interpreted as empirical trajectory clubs, not as definitive economic classifications. The clustering suggests that countries may follow different development paths rather than converging toward a single common equilibrium.

4.5.1 Persistent high performers

Based on repeated annual percentile positions, the strongest persistent performers were Japan, Korea, Spain, Türkiye and Italy. These countries remained in the upper part of the cross-country distribution during most/ all of the available 2015–2023 observations.

4.5.2 Persistent low performers

The persistent lower performing group was: Estonia, Latvia, Croatia, Slovenia and Lithuania. They remained predominantly in the lower quartile of the available cross country distribution. This provides evidence of performance persistence, further supporting the conclusion that no strong universal convergence process exists.

Trajectory clustering of countries with complete 2015–2023 series produced three empirical clubs. Club 1 (lower level/catch up trajectory) comprises Croatia, Hungary, Poland, Slovenia and Türkiye. Club 2 (middle-level trajectory) includes Bulgaria, Estonia, Italy, Korea, Portugal, South Africa and Spain. Club 3 (higher-level/mature trajectory) consists of Argentina, Chinese Taipei, Japan, Latvia, Lithuania, Romania, Singapore and the Slovak Republic. These groupings reflect observed trajectory similarity rather than formal economic classification.

Persistent high performers, identified by repeated upper percentile positions, were Japan, Korea, Spain, Türkiye and Italy. Persistent low performers were Estonia, Latvia, Croatia, Slovenia and Lithuania. The existence of stable high and low performing groups further corroborates the absence of a strong universal convergence process.

4.6 Conditional β -convergence

Not estimated from the current dataset

Conditional β -convergence requires additional explanatory variables that can account for structural differences between countries, such as:

- GDP per capita
- Population
- R&D expenditure
- GERD as % of GDP
- Researchers per 1,000 employed persons
- Higher-education attainment
- Government R&D expenditure
- Human capital
- Patent activity
- Scientific publication output

Conditional l β -convergence could not be estimated from the present dataset alone. Such an analysis requires the incorporation of additional structural covariates (for example GDP per capita, population, R&D expenditure intensity, human capital indicators and patent or publication output). Once these variables are merged, panel fixed effects or random effects models, conditional l β -convergence regressions and dynamic panel estimators become feasible.

4.7 Country Convergence-Divergence Analysis

Year	Countries	Mean Researchers	Median Researchers	SD	CV	Log-SD	Gini
2015	29	118775.6689	5218	185638.5162	1.562933872	1.228608691	0.619044737
2016	24	134191.6611	54479.06725	204241.711	1.522014926	1.354218466	0.635176799
2017	29	128261.6881	61616	190358.1688	1.484138963	1.23764464	0.605861581
2018	24	144033.5852	57299.5	210515.4807	1.461572178	1.35161409	0.623512875
2019	28	140470.9095	64054	197999.7591	1.4095428	1.225806208	0.590188807
2020	22	148238.0827	62266.66736	220958.6088	1.490565749	1.315700776	0.621762504
2021	26	143060.9787	70931	213017.5635	1.488998366	1.249411094	0.609399515
2022	22	158932.8108	5821.5	236169.5146	1.485970792	1.348635051	0.630583706
2023	25	153846.8425	89396	220408.5924	1.432649438	1.35483958	0.607456858

Table 3. Country Convergence-Divergence

We used 2015–2023 as the principal analytical period because 2024 has incomplete country coverage. For the balanced longitudinal analyses, 20 countries have complete observations across 2015–2023.

4.7 Descriptive Statistics of Cross-Country Dispersion

The table of annual cross sectional moments (number of countries, mean, median, standard deviation, coefficient of variation, log standard deviation and Gini coefficient) confirms the patterns reported in Section 4.1. Mean researcher stocks rose over the period, yet measures of relative dispersion remained elevated and non-monotonic. The principal analytical window is restricted to 2015–2023 because 2024 coverage is incomplete; twenty countries supply complete trajectories for balanced longitudinal analysis.

Taken together, Sections 4.1–4.7 demonstrate that R&D researcher capacity across the observed economies is characterised by differentiated national trajectories, strong performance persistence and selective rather than systematic catch up. No evidence supports the existence of a single common long run equilibrium path.

4.8 Phillips–Sul convergence test

The Phillips–Sul log-t test gives:

Statistic	Result
Countries	20
Years	2015–2023
Log-t slope	-1.247
σ = slope/2	-0.623
SE	0.057
t-statistic	-22.002
5% critical value	-1.65
Decision	Reject convergence

This section applies the Phillips–Sul (PS) log-t test and related techniques to assess whether the 20 countries with complete 2015–2023 data on R&D researcher headcounts are converging toward a common long-run path.

The overall PS log-t test yields a slope of -1.247 (σ = -0.623), with a t-statistic of -22.002. This is far below the 5% critical value of -1.65, leading to a clear rejection of the null hypothesis of overall convergence. The result is consistent with the earlier findings of no sustained ó-convergence and no absolute â-convergence: the OECD researcher landscape does not exhibit a single common convergence process.

Club clustering under the Phillips–Sul procedure identifies one dominant group of 16 countries (Argentina, Bulgaria, Chinese Taipei, Croatia, Estonia, Hungary, Italy, Lithuania, Poland, Portugal, Romania, Singapore, Slovak Republic, Slovenia, South Africa, and Spain) that share a common trajectory (club log-t = -21.993). Latvia forms a singleton and does not join any statistically supported club. These results indicate trajectory similarity rather than true long-run equilibrium convergence, especially given the panel's short time dimension.

Markov transition analysis classifies countries annually into four quartile-based states (Low, Lower-middle, Upper-middle, High). The transition matrix shows very strong persistence:

• Probability of remaining Low: 86.5%

• Lower-middle: 74.4%

• Upper-middle: 75.8%

• High: 94.1%

Mobility between states is limited. The implied long-run stationary distribution is roughly balanced across the four states (Low ≈ 26%, Lower-middle ≈ 25%, Upper-middle ≈ 19%, High ≈ 30%), confirming that the system does not collapse into a single common level of researcher capacity.

Trajectory clustering (after normalizing each country's series to 2015 = 100) selects a two-cluster solution as optimal (silhouette = 0.553). Cluster 1 (15 countries) follows a broad/main trajectory; Cluster 2 (Croatia, Hungary, Poland, Slovenia, Türkiye) follows a distinctly rapid-growth/catch up trajectory.

4.8.1 Phillips–Sul convergence clubs

The club procedure identified a dominant trajectory group:

Club 1: Common trajectory group

16 countries

Argentina, Bulgaria, Chinese Taipei, Croatia, Estonia, Hungary, Italy, Lithuania, Poland, Portugal, Romania, Singapore, Slovak Republic, Slovenia, South Africa and Spain.

The club log-t statistic is -21.993.

Club 2: Isolated country

Latvia

Latvia forms a singleton under the implemented club-selection procedure, meaning that it does not form a sufficiently large statistically supported club with the remaining countries under the algorithm.

The Phillips–Sul result does not indicate universal convergence. Rather, the data suggest a dominant common trajectory plus an isolated trajectory. Because the club statistic is based on the balanced sample and the current dataset has a short time dimension, these club results should be treated as evidence of trajectory similarity rather than definitive long run equilibrium convergence.

4.8.2 Markov transition analysis

Countries were classified annually into four researcher capacity states based on the cross-sectional quartiles:

• Low

• Lower-middle

• Upper-middle

• High

The transition probability matrix is:

Current → Next	**Low**	**Lower middle**	**Upper middle**	**High**
Low	0.865	0.135	0.000	0.000
Lower middle	0.140	0.744	0.116	0.000
Upper middle	0.000	0.152	0.758	0.091
High	0.000	0.000	0.059	0.941

There is very strong state persistence.

The probability of remaining:

• Low = 86.5%

• Lower-middle = 74.4%

• Upper-middle = 75.8%

• High = 94.1%

The high group is particularly persistent. A country already in the high researcher-capacity group has a 94.1% probability of remaining there from one year to the next.

Likewise, low-performing countries have an 86.5% probability of remaining low.

This provides strong evidence of structural persistence and limited mobility.

The estimated stationary probabilities are:

State	**Long-run probability**
Low	26.0%
Lower middle	25.1%
Upper middle	19.2%
High	29.7%

The system therefore does not naturally collapse into one common researcher capacity state. Instead, the distribution remains divided across multiple performance levels.

4.8.3 Researcher trajectory clustering

We normalized each country's trajectory to:

2015 = 100

and clustered the complete trajectories.

The silhouette comparison selected two trajectory clusters:

Number of clusters	**Silhouette**
2	0.553
3	0.304
4	0.304
5	0.325

The two-cluster solution is therefore substantially better separated.

Cluster 1 — Broad/main trajectory group

15 countries

Argentina, Bulgaria, Chinese Taipei, Estonia, Italy, Japan, Korea, Latvia, Lithuania, Portugal, Romania, Singapore, Slovak Republic, South Africa and Spain.

Cluster 2 — Rapid-growth/catch-up trajectory

5 countries

Croatia, Hungary, Poland, Slovenia and Türkiye

This second group is particularly interesting because these countries have relatively distinctive upward researcher trajectories.

The Phillips–Sul framework, Markov chains, and trajectory clustering together reinforce that researcher stocks are characterized by strong state dependence and differentiated national paths rather than universal catch-up. Selective high-growth trajectories exist, but they are not widespread enough to produce overall convergence. Persistence is especially pronounced at the high end of the distribution.

4.9 Growth–level typology

I classified countries using their 2023 researcher level and 2015–2023 CAGR, with the respective sample medians as the dividing thresholds.

A. High level / High growth — 7 countries

Poland, Türkiye, Hungary, Portugal, Korea, Italy and Spain

These are the strongest overall performers in the combined level-growth framework.

They combine relatively high researcher capacity with above-median growth.

B. High level / Low growth — 3 countries

Argentina, Chinese Taipei and Japan

These countries have relatively high researcher levels but comparatively slower growth.

This is consistent with a mature/stabilized researcher-capacity profile.

C. Low level / High growth — 3 countries

Slovenia, Croatia and Estonia

These countries have comparatively lower researcher levels but relatively strong growth.

They therefore represent the clearest catch-up group.

D. Low level / Low growth — 7 countries

South Africa, Singapore, Bulgaria, Romania, Lithuania, Latvia and Slovak Republic

These countries combine lower researcher capacity with below-median growth and therefore represent the most vulnerable/lagging group under this framework

Countries are classified into four groups using the 2023 researcher level and the 2015–2023 compound annual growth rate (CAGR), with sample medians as thresholds:

• High level / High growth (7 countries): Poland, Türkiye, Hungary, Portugal, Korea, Italy, Spain — the strongest combined performers.

• High level / Low growth (3 countries): Argentina, Chinese Taipei, Japan — mature/stabilized profiles with high capacity but slower expansion.

• Low level / High growth (3 countries): Slovenia, Croatia, Estonia — clearest catch-up group.

• Low level / Low growth (7 countries): South Africa, Singapore, Bulgaria, Romania, Lithuania, Latvia, Slovak Republic — the most vulnerable/lagging group.

This typology moves beyond simple rankings by combining absolute scale with growth dynamics. It identifies strategic leaders, mature leaders, genuine catch-up economies, and persistent laggards, providing a more nuanced policy-relevant map of relative performance.

5. Integrated interpretation

The five analyses produce a remarkably consistent picture.

Finding 1 — No universal convergence
The Phillips–Sul test rejects overall convergence, reinforcing the earlier findings from ó-convergence and absolute â-convergence.

Finding 2 — Strong persistence
The Markov results show that countries tend to remain in their existing researcher-capacity state, particularly high performing countries.

Finding 3 — Catch-up exists but is selective
Poland, Türkiye, Hungary, Croatia, and Slovenia show strong upward trajectories, but this catch-up is not widespread enough to drive overall convergence.

Finding 4 — Different development trajectories exist

Trajectory clustering separates Croatia, Hungary, Poland, Slovenia and Türkiye from the broader group, indicating a distinctive high growth/catch up trajectory.

Finding 5 — Researcher capacity has four identifiable regimes

The growth–level typology identifies:

High level–high growth → strategic leaders

High level–low growth → mature leaders

Low level–high growth → catch-up economies

Low level–low growth → persistent laggards

This provides a much more informative interpretation than ranking countries solely by researcher numbers.

Section 5: Integrated Interpretation

The section synthesizes all preceding analyses into five consistent findings:

1. No universal convergence — confirmed by the Phillips–Sul rejection as well as the absence of σ- and absolute β-convergence.

2. Strong persistence — Markov results show countries tend to remain in their existing capacity state, especially high performers.

3. Selective catch up — Poland, Türkiye, Hungary, Croatia, and Slovenia display strong upward trajectories, but these are insufficient to generate overall convergence.

4. Different development trajectories — clustering separates the rapid-growth group from the broader set of countries.

5. Four identifiable regimes the growth level typology distinguishes strategic leaders, mature leaders, catch-up economies, and persistent laggards.

Overall, sections 4.8, 4.9, and 5 paint a coherent picture of differentiated national trajectories, persistent strong performance, and only selective (not systematic) catch up in R&D researcher capacity across the observed economies. No evidence suggests a single common long run equilibrium path. The landscape is better understood as a multi regime system in which a subset of countries closes gaps while others remain locked in high or low capacity states.

6. Discussion

6.1 Absence of Universal Convergence: Reinterpreting the Convergence Narrative

The central finding of this study is the robust rejection of universal convergence in R&D researcher capacity across OECD and selected partner economies during 2015–2023. Three independent analytical approaches—β -convergence, absolute σ-convergence, and the Phillips–Sul log-t test consistently indicate that countries have not progressively approached a common long-run equilibrium in researcher stocks. The log-standard deviation rose from 1.229 in 2015 to 1.355 in 2023, the Gini coefficient fluctuated between 0.590 and 0.635 without a sustained downward trend, and the β - convergence coefficient was statistically indistinguishable from zero (β = +0.000599, p = 0.867). The Phillips–Sul test produced a t-statistic of -22.002, far below the 5% critical value of -1.65, providing decisive rejection of the null hypothesis of overall convergence.

These findings challenge the implicit assumption in much of the innovation and development literature that economic integration, technology diffusion, and knowledge spillovers will gradually equalize national research capacities. While the classical convergence literature in economics rooted in the Solow growth model and extended by Barro and Sala-i-Martin predicts that poorer economies should grow faster and eventually catch up with richer ones, the present results demonstrate that this mechanism does not operate automatically in the domain of scientific human capital. The absence of β-convergence implies that initially smaller researcher systems did not benefit from a systematic "advantage of backwardness" that would enable them to expand more rapidly than established systems.

This result is consistent with the findings of Javed (2023), who reported no overall convergence in AI research capacity while identifying convergence within specific country subgroups. The parallel between AI research capacity and broader R&D researcher capacity suggests that the absence of universal convergence may be a structural feature of knowledge-intensive human capital rather than an artifact of measurement or sample selection. It also aligns with the broader convergence literature, which has increasingly recognized that convergence is conditional, club-based, or sector-specific rather than universal (Rapacki & Próchniak, 2019; Hammar & Belarbi, 2021).

6.2 Structural Persistence and the Lock-In of Capacity States

Perhaps the most striking empirical result is the degree of state persistence revealed by the Markov transition analysis. The probability of remaining in the same researcher capacity quartile ranged from 74.4% (lower-middle) to 94.1% (high). The high capacity group exhibited near complete persistence, with only a 5.9% probability of downward mobility in any given year. Similarly, the low capacity group displayed an 86.5% probability of remaining in the lowest quartile. The estimated stationary distribution approximately 26% low, 25% lower middle, 19% upper middle, and 30% high confirms that the system does not collapse toward a single equilibrium but instead maintains a structurally stratified distribution over the long run.

This persistence has important theoretical implications. It suggests that researcher capacity is characterized by substantial hysteresis and path dependence. Countries that have built large research systems benefit from cumulative advantages: established universities, dense networks of research institutions, mature funding mechanisms, deep pools of doctoral trained personnel, and entrenched collaboration structures. These features create self reinforcing dynamics that lower capacity countries cannot replicate quickly, regardless of marginal increases in R&D expenditure. Conversely, countries trapped in low capacity states face structural constraints including limited higher education infrastructure, brain drain, fragmented research systems, and insufficient critical mass that incremental policy adjustments alone cannot overcome.

The persistence finding also resonates with the development literature on research capacity constraints. As Woodward, Bowsher, Laabes, Franzen, and Bates (2020–2023) documented, health RDI capacity in low and middle income countries is constrained not merely by funding but by insufficient numbers of practitioners and mentors, inadequate infrastructure, fragmented systems, misalignment with national priorities, and ineffective partnerships. Although the present study focuses on OECD economies, analogous structural barriers may operate among the lower-performing countries in the sample, limiting their ability to translate investment into sustained growth in researcher capacity.

6.3 Selective Catch-Up: Growth Without Convergence

The absence of universal convergence does not imply stagnation. A distinctive subset of countries Poland (CAGR 8.34%), Türkiye (7.93%), Hungary (7.20%), Slovenia (5.68%), and Croatia (5.50%) exhibited rapid researcher capacity growth and, in several cases, positive rank mobility. Trajectory clustering confirmed that these five countries follow a statistically distinguishable rapid growth/catch up path (Cluster 2, silhouette = 0.553), separate from the broader main trajectory (Cluster 1). This selective catch up is consistent with the convergence club literature, which predicts that convergence may occur within subgroups of countries sharing similar structural characteristics, policy orientations, or development stages, even when no overall convergence is detectable.

The identification of Poland, Türkiye, and Hungary as the strongest simultaneous performers in both growth and rank improvement is particularly noteworthy. These countries have pursued active science and technology policies, expanded higher-education enrolment, increased GERD intensity, and leveraged EU structural funds (in the case of Poland and Hungary) to build research infrastructure. Their experience suggests that targeted, sustained policy intervention can generate genuine catch up dynamics, but that such dynamics remain country specific rather than system wide.

However, the selective nature of this catch up underscores a critical limitation of convergence as a policy concept. If only a small subset of countries can sustain rapid growth while the majority remain locked in their existing capacity states, then the convergence narrative may overstate the likelihood of broad-based equalization. The present findings suggest that convergence is better understood as a possibility available to countries that meet specific preconditions sufficient institutional capacity, sustained investment, alignment between research and economic priorities, and access to international collaboration networks rather than as an automatic outcome of economic development.

6.4 Multiple Trajectories and the Four-Regime Typology

The growth level typology provides a strategically informative classification that moves beyond simple country rankings. The four identified regimes strategic leaders (high level/high growth), mature leaders (high level/low growth), catch up economies (low level/high growth), and persistent laggards (low level/low growth) capture the heterogeneity of national researcher capacity trajectories in a manner that is directly relevant to policy design.

The strategic leader group (Poland, Türkiye, Hungary, Portugal, Korea, Italy, Spain) combines substantial existing capacity with continued expansion, suggesting that these countries are simultaneously consolidating and extending their research systems. The mature-leader group (Argentina, Chinese Taipei, Japan) shows high capacity but slower growth, consistent with the view that these systems have reached a more advanced stage of development, where marginal expansion becomes harder and policy attention may need to shift from quantity to quality, productivity, and researcher workforce renewal.

The catch up group (Slovenia, Croatia, Estonia) represents countries with smaller absolute researcher stocks but above median growth rates. These countries are in a critical window during which sustained investment and institutional development could enable them to transition toward higher capacity states. However, the Markov analysis warns that upward mobility is not guaranteed: the probability of moving from the lower-middle to the upper-middle quartile is only 11.6% per year, and the probability of moving directly from low to high capacity is effectively zero.

The persistent laggard group (South Africa, Singapore, Bulgaria, Romania, Lithuania, Latvia, Slovak Republic) combines lower researcher capacity with below median growth. This group faces the greatest policy challenge, as the Markov results indicate an 86.5% annual probability of remaining in the low capacity state. Without structural interventions addressing fundamental capacity constraints research infrastructure, doctoral training pipelines, retention of skilled personnel, and alignment of research with national development priorities these countries risk remaining locked in low capacity equilibria.

6.5 Computational and Network Perspectives on Differentiated Trajectories

The findings of this study can also be interpreted through the lens of market based control and multi-agent systems (Clearwater, 1996; Wellman, Ferguson et al., 1996). National research systems can be conceptualized as distributed multi agent environments in which heterogeneous actors universities government laboratories, private sector R&D units, funding agencies, and individual researchers interact under different resource constraints, institutional rules, and incentive structures. In such systems, convergence toward a common equilibrium is not guaranteed; instead, the interaction of decentralized agents with distinct knowledge, preferences, and capabilities can generate multiple stable states, path dependent trajectories, and persistent inequality.

The Phillips–Sul identification of a dominant 16-country trajectory group alongside Latvia as a singleton, and the trajectory clustering separation of the rapid growth group, are consistent with this interpretation. Rather than a single global attractor, the system exhibits multiple basins of attraction corresponding to different capacity regimes. Countries within the same basin may display trajectory similarity, but movement between basins is limited by structural barriers analogous to transaction costs, information asymmetries, and coordination failures in decentralized markets.

6.6 Reconciling Aggregate Growth with Distributional Persistence

An important nuance is that mean researcher stocks rose over 2015–2023 (from approximately 118,776 to 153,847), indicating absolute growth in global researcher capacity. However, this aggregate expansion did not translate into distributional convergence. The coefficient of variation remained elevated (ranging from approximately 1.41 to 1.56), and the Gini coefficient stayed above 0.59 throughout the period. This dissociation between aggregate growth and distributional equalization is a well known phenomenon in development economics: total output can increase while inequality persists or even widens if the gains from growth are distributed unevenly.

In the context of R&D researcher capacity, this pattern suggests that research systems have expanded unevenly across countries. Larger, more established systems have continued to grow in absolute terms, maintaining or extending their lead, while smaller systems have grown more slowly or stagnated. The result is a rising tide that lifts some boats substantially more than others, reinforcing rather than reducing cross-country disparities.

6.7 Methodological Considerations and the Value of Integrated Analysis

A key methodological contribution of this study is integrating multiple complementary convergence techniques. No single test was sufficient to characterize the full structure of researcher capacity dynamics. σ-convergence established that dispersion was not declining; β-convergence confirmed the absence of a systematic catch up mechanism; the Phillips–Sul test rejected a common long run path and identified trajectory clubs; Markov analysis revealed the depth of state persistence; trajectory clustering identified empirically distinct growth paths; and the growth level typology translated these findings into a policy relevant classification.

This integrated approach addresses a significant gap in the existing literature, where convergence studies often rely on one or two indicators and may consequently mischaracterize the underlying dynamics. For example, a study relying solely on β-convergence might conclude that convergence is absent without detecting the selective catch up occurring within a subset of countries. Conversely, a study focusing only on descriptive growth rates might identify catch up dynamics without recognizing the broader absence of convergence. The multi method framework adopted here provides a more complete and internally consistent picture.

6.8 Limitations Revisited

While the integrated framework strengthens the analysis, several limitations remain when interpreting the results. First, the use of headcount as the sole measure of researcher capacity does not capture differences in research quality, productivity, disciplinary composition, working time, or scientific impact. A country with many researchers in low intensity or part time R&D roles may not have the same capacity as a country with fewer but more intensively engaged researchers. Future analyses should complement headcount data with full time equivalent (FTE) measures, publication output, patent activity, and citation based indicators.

Second, the nine year observation window (2015–2023) is relatively short for convergence analysis. Long-run convergence processes may unfold over decades, and the Phillips–Sul club results should therefore be interpreted as evidence of trajectory similarity rather than definitive long run equilibrium convergence. Excluding 2024 because of incomplete country coverage further limits the temporal scope.

Third, the absence of structural covariates precludes estimating conditional β-convergence. Without controlling for GDP per capita, R&D expenditure intensity, human capital, population size, and institutional quality, the analysis cannot determine whether the absence of absolute convergence masks conditional convergence among countries with similar structural characteristics. This remains an important direction for future research.

Fourth, the study identifies statistical associations and trajectory patterns but does not establish causal relationships. The observed catch up dynamics in Poland, Türkiye, Hungary, Slovenia, and Croatia may be driven by specific policy interventions, EU funding cycles, demographic factors, or broader economic conditions that are not directly modeled in the present framework.

7. Conclusion

7.1 Summary of Findings

This study examined the convergence, persistence, catch up dynamics, and heterogeneous trajectories of R&D researcher capacity across OECD and selected partner economies during 2015–2023. Using an integrated analytical framework combining σ-convergence, absolute β -convergence, the Phillips–Sul log-t test, Markov transition analysis, trajectory clustering, compound annual growth rate analysis, and a growth level typology, the study arrives at five principal conclusions.

First, the study decisively rejects universal convergence. Cross-country dispersion in researcher capacity did not decline over the study period. The log-standard deviation and Gini coefficient fluctuated without a sustained downward trend. The absolute β -convergence coefficient was statistically insignificant, and the Phillips–Sul test rejected the null hypothesis of overall convergence with a t-statistic of -22.002. Countries have not progressively approached a common level of researcher capacity.

Second, researcher capacity is characterized by strong structural persistence. The Markov transition analysis revealed high probabilities of remaining in the same capacity state, ranging from 74.4% to 94.1%. The high-capacity group exhibited the strongest persistence (94.1%), indicating that countries with large research systems are very unlikely to experience downward mobility. The low-capacity group also showed substantial persistence (86.5%), suggesting that countries with small researcher stocks face significant barriers to upward movement. The estimated stationary distribution confirms that the system maintains a stratified, multi-level structure rather than collapsing toward a single equilibrium.

Third, catch-up is real but selective. Poland, Türkiye, Hungary, Slovenia, and Croatia demonstrated rapid researcher capacity growth and, in several cases, positive rank mobility. Trajectory clustering confirmed that these countries follow a statistically distinguishable rapid growth path. However, this catch up was not wide spread enough to produce detectable overall convergence. The convergence process, to the extent it exists, is confined to specific country subgroups rather than operating as a system wide phenomenon.

Fourth, countries follow multiple development trajectories rather than a single convergence path. The Phillips–Sul procedure identified a dominant 16-country trajectory group and Latvia as a singleton. Trajectory clustering separated the rapid growth/catch up group from the broader main trajectory. The growth level typology further differentiated countries into strategic leaders, mature leaders, catch up economies, and persistent laggards. Together, these results show that national researcher capacity development is a multi regime process.

Fifth, distinguishing capacity level from capacity growth is analytically essential. Ranking countries solely by the absolute number of researchers obscures important differences in development dynamics. The growth level typology shows that some countries with large researcher stocks are growing slowly (mature leaders), while others with smaller stocks are expanding rapidly (catch up economies). This distinction has direct implications for policy design and resource allocation.

7.2 Theoretical Implications

The findings contribute to the convergence literature in several ways. They extend the analysis of convergence from aggregate economic indicators to the specific domain of scientific human capital, demonstrating that the human resource dimension of national innovation systems does not follow the same convergence dynamics as

GDP per capita or productivity. They challenge the assumption of uniform convergence by providing empirical evidence of persistence, selective catch up, and multiple trajectories within a single analytical framework. They also contribute to the conceptualization of convergence as a multi regime process in which different countries may simultaneously exhibit different dynamics growth, stability, or stagnation depending on their structural characteristics, institutional capabilities, and policy environments.

The results align with the broader theoretical perspective that convergence occurs when forces encourage actors toward a common aim, but pathways to that aim may remain heterogeneous (Kluth, 2023). In the context of R&D researcher capacity, the “common aim” of building robust national research systems is shared across countries, but the trajectories through which countries pursue this aim are shaped by deeply embedded structural factors that resist rapid change.

7.3 Policy Implications

The absence of universal convergence and the presence of multiple capacity regimes carry significant implications for science, technology, and innovation policy.

For persistent laggards (South Africa, Singapore, Bulgaria, Romania, Lithuania, Latvia, Slovak Republic), pol icies focused on fundamental capacity building are essential. These include investment in research infrastructure, expanding doctoral and postdoctoral training pipelines, strengthening university research systems, retaining skilled researchers, and aligning research agendas with national development priorities. Given the 86.5% probability of remaining in the low-capacity state, incremental policy adjustments are unlikely to be sufficient; structural transformations in research governance, funding, and human resource development are required.

For catch up economies (Slovenia, Croatia, Estonia), the priority is to consolidate rapid growth and prevent the loss of newly accumulated research capacity. Policies should focus on sustaining investment levels, integrating newly trained researchers into productive research environments, building international collaboration networks, and transitioning from quantity driven expansion to quality driven development.

For mature leaders (Argentina, Chinese Taipei, Japan), the policy emphasis should shift from expanding researcher numbers to enhancing research quality, productivity, and impact. Workforce renewal, interdisciplinary collaboration, international mobility, and integrating emerging technologies into research practices are likely more relevant than further quantitative expansion.

For strategic leaders (Poland, Türkiye, Hungary, Portugal, Korea, Italy, Spain), the challenge is to maintain growth momentum while ensuring that expansion is sustainable and translates into increased innovation output. Policies should balance continued investment in researcher capacity with efforts to improve research efficiency, strengthen industry academia linkages, and enhance the international visibility and impact of national research systems.

More broadly, the four regime framework supports differentiated policy strategies rather than a uniform convergence policy. International organizations and funding bodies should recognize that a single catch up model is inappropriate for countries at different stages of research capacity development. Tailored interventions that account for each country’s specific capacity level, growth trajectory, institutional context, and structural constraints are more likely to be effective than generic policy templates.

7.4 Future Research Directions

This study suggests several avenues for future research. First, integrating structural covariates GDP per capita, population, R&D expenditure, GERD intensity, researchers per 1,000 employed persons, higher education attainment, patent activity, and scientific publication output would enable estimation of conditional β-convergence and dynamic panel models. This would allow researchers to determine whether the absence of absolute convergence masks conditional convergence among structurally similar countries.

Second, extending the temporal coverage beyond 2023, as more complete data become available, would strengthen the interpretation of convergence clubs and long run trajectories. The nine year window used in this study is sufficient for identifying short to medium term dynamics but limits the ability to distinguish between temporary fluctuations and permanent structural shifts.

Third, incorporating qualitative and institutional analysis examining specific policy interventions, funding mechanisms, higher education reforms, and international collaboration agreements in catch up countries such as Poland, Türkiye, and Hungary would move the analysis from identifying where convergence and divergence occur toward explaining why different trajectories emerge.

Fourth, extending the framework to include FTE-based measures, sectoral disaggregation (business, higher education, government, and private non-profit sectors), and disciplinary composition would provide a more nuanced picture of researcher capacity than headcount alone.

Fifth, cross regional comparisons extending the analysis beyond OECD and partner economies to include African, South Asian, and Latin American country groups would test whether the patterns of persistence, selective catch up, and multiple trajectories observed here are generalizable or specific to the OECD context.

7.5 Final Remarks

This study demonstrates that R&D researcher capacity across OECD and selected partner economies is not characterized by a single, uniform convergence process. Instead, the landscape is best understood as a multi-regime system in which persistent high performers maintain their positions, a small group of dynamic catch-up countries rapidly closes gaps, and a substantial number of countries remain locked in lower capacity states with limited upward mobility. The coexistence of aggregate growth, distributional persistence, and selective catch up underscores the complexity of national research capacity development and the inadequacy of simple convergence narratives.

The central message is that convergence, where it occurs, is neither automatic nor universal. It is the product of sustained investment, institutional development, strategic policy choices, and favorable structural conditions. Recognizing the multiplicity of trajectories and the depth of persistence is essential for designing effective, differentiated policies that support the development of research human capital across countries at different stages of capacity building. The absence of universal convergence is not a counsel of despair; rather, it is an invitation to understand the specific conditions under which catch-up succeeds and to design policies that address the particular constraints facing each country. In doing so, the goal of building robust, inclusive, and sustainable national research systems becomes not a distant equilibrium toward which all countries automatically drift, but an achievable outcome of deliberate, context sensitive, and sustained effort.

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