Indian Journal of Economics and Finance (IJEF)
ISSN: 2582-9378 (Online), Volume-5 Issue-2, November 2025

Does Biotechnology Innovation Drive Economic Growth? Panel Evidence from Developed Economies, 2018-2023

Navya Patel

Abstract: ***In today's world, the biotechnology field is not just a scientific development but also a pivotal economic contributor across healthcare, agriculture, and many other industries. This study explores the crucial relationship between the biotechnology innovations and the economic growth indicators of 11 nations for the years 2018 to 2023. A secondary dataset comprising 11 countries over 6 years was gathered and used to conduct correlation and regression analyses. These analyses help evaluate how innovation indicators affect an economy's growth. The findings reveal a strong global biotechnological innovation infrastructure dominated by the United States, while Switzerland shows extraordinary innovation efficiency during the selected period. The correlation test shows a strong positive relationship among various innovation parameters, including Research and Development Spending and nations' GDP shares, as well as biotechnology patent registrations. However, the regression results for both Fixed and Random effects fail to establish an impactful relationship between innovation and economic parameters. The findings suggest that policymakers should consider longer-term data when evaluating R&D investments and develop dedicated frameworks for measuring innovation impacts beyond traditional GDP metrics. The study enriches the innovation economics literature by verifying the complex, non-linear relationship between biotechnology innovation inputs and economic growth outcomes.***

Keywords: Biotechnology Innovation, Economic Growth, R&D Investment, Panel Regression, Innovation Policy.

Nomenclature:
R&D: Research and Development

I. INTRODUCTION

Biotechnology innovation is a notable contributor to any nation's economic growth, a growing economic indicator of the 21st century. It is expected that the global biotechnology market will grow to 3.88 trillion dollars by 2030. This assumption shows a compound annual growth rate of more than 7% in many growing nations [1].

The economic impact of biotechnologies is said to extend well beyond the size of the market; it is also seen as affecting a nation's research and development (R&D) expenditures. Biotechnology patents have grown by over 15 per cent every year since 2010. This increased expenditure is mainly seen in many developed economies. In such a setting, biotechnology R&D accounts for a considerably larger share of total innovation spending.

Citizens of various nations are becoming increasingly aware of the economic benefits from the growth of biotechnology firms and innovations. This thought has led many countries to frame policies regarding innovations and biotechnology. These plans include developing research and development facilities and training technical and skilled personnel in the biotechnology domain. Many studies have highlighted various benefits resulting from biotechnology innovation – increased GDP, more job opportunities, and a difficult-to-imitate international market [2]. There are also related spillovers that boost productivity across various sectors in the economy [3]. However, these benefits differ by nation: some countries have advanced facilities, while others use proven models that deliver maximum benefits with limited resources.

Biotechnology innovation is a field of scientific and technical expertise, and the resulting products or services ideally help resolve healthcare, agricultural, and manufacturing challenges. Thus, these innovations are not just laboratory work, as was the case in 1980. Today, this field brings together academic research, business growth, venture funding, and regulatory guidelines; i.e., it starts with researching an innovation, developing it, and bringing it to market [4]. The innovation growth of developing nations showed an increasing trend, which emphasises the specified planned innovations [5]. To support innovation, even investors and venture capitalists, along with a strong information and technology infrastructure, are now imperative [6]. The innovation rules for the coming generations are drafted with societal issues in mind while also promoting economic growth [7]. However, a strong entrepreneurial presence is said to mitigate the risks associated with innovation adoption [8]. Also, for any nation, an accessible infrastructure for innovation, with enhanced networking and knowledge sharing is a boon for the biotechnology domain [9].

A nation that develops biotechnology innovations in a planned, strategic way can yield significant benefits for its economic development and for its innovation-support infrastructure. A strong innovation setup yields robust economies by giving a strong push to knowledge creation. A country with strong innovation policies has stronger exports, more foreign investment in research, and better social issue resolution.

Manuscript received on 30 September 2025 | First Revised Manuscript received on 11 October 2025 | Second Revised Manuscript received on 29 October 2025 | Manuscript Accepted on 15 November 2025 | Manuscript published on 30 November 2025.
*Correspondence Author(s)
Navya Patel*, Navrachana International School Vadodara, Vadodara (Gujarat), India. Email ID: navya05108@gmail.com, ORCID ID: 0009-0000-1887-0547

The national authorities must better understand how R&D expenditure, research intensity, patent generations and industry growth relate to economic performance. Many venture capitalists, startup creators, and investors would benefit from this and may have the opportunity to examine this complex interaction in both a critical and profitable way. This may lead to better policies that promote the optimal utilisation of resources.

There is a varied academic literature on biotechnology innovations – some examine trends in R&D expenditure, others assess the effectiveness of patents, and others focus on individual achievements. But there are very few studies that examine how these biotechnology growth indicators are linked to nations' economic indicators. Many existing studies also limit themselves to a single variable in biotechnology, i.e., they do not analyse the full associations between innovation expenditure and economic development at the national level.

This study aims to test the connection between economic development and biotechnology innovation for developed economies. It tests whether variables such as R&D expenditure, patent productivity, sectoral growth, and innovation intensity affect GDP growth over time.

More specifically, the research considers the following research questions:

RQ1: What are the relationships between biotechnology innovation inputs (R&D expenditure, research intensity, number of biotechnology *firms) and innovation outputs (patent productivity) across developed economies?*

RQ2: To what extent do biotechnology innovation factors significantly predict GDP growth over time, and what is the nature of these relationships?

This study first presents a detailed literature review discussing the biotechnology field, its developments, and its economic implications. Then, a brief methodology section explains the research methods of this study. The following findings section gives a detailed analysis of innovation and economic growth indicators. The discussion section thereafter discusses the analysis, linking it to the literature review. Finally, the conclusion section comprises key findings, limitations, practical implications, and directions for future research.

II. LITERATURE REVIEW

A. Innovation and Economic Growth

Biotechnology innovations have drastically changed developed nations by replacing conventional industrial methods with sophisticated knowledge-based, competitive frameworks. Biotechnology is no longer just a state-controlled model; it is now a modern, private-sector-led domain that is advancing through innovation policies guided by global competitions and national self-sufficiency concerns [10]. This new shift is a fundamental change in innovation frameworks, in which regulatory authorities connect the private and public sectors through modes of partnership, franchising, and other mechanisms.

The biotechnology domain has very high, uncertain capital requirements, similar to those of other highly technical fields. Like other technical industries, it faces rapid technological advances and uncertain demand in the global market [11]. In itself, the innovation process is hazardous and lengthy. Thus, the policy framework must support long-term innovation development while accounting for its uncertain nature, given the significant investment required.

A nation with a commendable research infrastructure and strong innovation outcomes serves as an example to developing countries by sharing its experience, available expertise, and actual implementation [12]. Empirical evidence shows that complex scientific knowledge in other developed nations may both hinder and support breakthrough innovations, whereas technological knowledge from similar countries has a positive effect. This means that biotechnology innovations in developed countries need to strike a proper balance between strong local research and global partnerships [12].

B. National Systems of Innovation and Institutional Arrangements

Complex institutional agendas that organise different actors and flows of knowledge are vital in advanced economies for shaping biotechnology innovation competencies. The National Systems of Innovation framework highlights that biotechnology innovation is the product of the accumulation of scientific knowledge in research institutions and firms (stock) and its dispersal between them (flow) [13]. Developed economies will have more advanced and mature forms of such systems than developing economies.

The advanced economies have built an experienced biotechnology innovation infrastructure, supported by world-class research universities, adequately funded government research institutes, and advanced private-sector research capacities. Institutional building methodically, rather than ad hoc policy actions, clarifies the evolution of biotechnology innovation in the developed economies. The United States, Switzerland, Germany, and Sweden have developed strategic national biotechnology plans that combine research support, regulation, technology transfer, and human development [14]. These steps acknowledge that cooperative organisation among research institutions, public and private firms, and foreign associates is key to active biotechnology innovation [15].

A developed nation uses various methods, such as national innovation councils, sectoral innovation institutions, and public-private partnerships, to inspire and develop biotechnological innovations [16]. These mechanisms are highly effective in balancing the need for knowledge sharing with the market demand for these innovations.

C. R&D Investment Patterns and Scale Effects

R&D spending is one of the significant advantages that a developed nation has over a developing one. R&D expenditure itself is proof of strong regulatory policies and better planning. Developed economies have a robust biotechnology innovation infrastructure that yields long-term benefits [17]. Their innovation strength results from the quantity and quality of resources they invest in. These countries have been observed to spend more on R&D to build better research facilities and support long-term projects.

Economic scale and innovative potential have been empirically documented, and larger economies can fund risky, long-term research projects that would be far-fetched for smaller economies [18]. Scale effects, though, play out with competence contemplations in complicated ways. A few of the less developed, high-R&D-intensity-as-a-percentage-of-GDP economies show that institutional efficiency and strategic attentiveness can overcome limited size to some extent. This attainment indicates that success in innovation in developed economies is not based solely on available resources but also on the extent to which they are efficiently utilised [19]. Advanced economies have become increasingly invested in biotechnology as a strategically important field, and R&D expenditure has risen sharply as a share of total innovation spending.

D. Knowledge Networks and Global Collaboration

Biotechnology innovation in developed economies is progressively dependent on international collaboration and global knowledge-sharing networks. The complex, resource-intensive nature of modern biotechnologies requires global cooperation, with developed nations serving as a central hub for a knowledge network [20]. These central hubs not only compete but also collaborate to lead in technological advancement while laying the groundwork for research and resources to be shared with the global scientific community. Collaboration in biotechnology advancement is essential, as only then can countries capitalise on their research partnerships and networks worldwide to drive better inventions and innovations [21].

E. Patent Productivity and Innovative Outputs

Various biotechnology datasets demonstrate that, in innovation leadership, a significant share is held by a few nations, with the United States as the dominant player, along with a handful of others that have core biotechnology innovations at the centre of their development [21]. Although patent registration data shows a considerable difference in the impact of such innovations, i.e., some nations have more patent registrations than research spending. This demonstrates the nation's strength in converting academic research into application-driven outcomes through profitable partnerships and collaborations. Such nations are an example of how effective research infrastructure management and strong knowledge sharing within innovation collaborations benefit the nation [22]. It is noteworthy that the rising trend in patent filings indicates that nations are competing to outperform one another, particularly in the biotechnology field. Thus, a nation's innovation infrastructure, regulatory authorities, and innovation policies are essential to the global innovation hierarchy.

F. Policy Frameworks and Economic Impact

It has been observed that rapid innovation development often takes into account risks and ethical issues [23]. Over the past few years, policies have become more concrete, including research funding, tax measures and subsidies, technological transfer programmes, and human skills management. Developed nations apply crucial risk-management approaches to ensure a safe and favourable environment for innovation [24]. Such developments benefit not just the specific industry but leverage various other strengths of nations, such as better job opportunities, more foreign investments and thus rapid development. For a developed economy, a firm regulatory policy therefore helps provide a competitive advantage. But now and then, it has been proven that biotechnology innovation development requires long-term planning and effective policy implementation [25].

III. RESEARCH METHODOLOGY

This study aims to investigate the relationship between the biotechnological innovation indicators and the economic indicators. Initially, a correlation test is conducted to examine the relationship between the two, followed by a panel regression model with economic growth as the dependent variable and the biotechnological innovation indicators as independent variables. The regression models test in detail whether these innovation factors have a strong influence on economic growth. The Hausman test supports the panel regression model. For the same purpose, the dataset has been selected for the years 2018 – 2023, which neutralises the pre-pandemic, pandemic (COVID), and post-pandemic damage and recovery.

A. Sampling Framework

The research uses a balanced panel dataset of 11 countries observed over 6 years, yielding 66 total observations (N = 66). The countries were chosen for their relatively high levels of R&D expenditure compared to international peers, as well as for their economic importance and contributions to biotechnology research. This selection ensures coverage of both top research investors and major contributors to global GDP. Table 1 shows the independent and dependent variables.

Table I: Variables and Rationale

Variable Type	Variable	Rationale
Dependent	GDP Growth (%)	Primary indicator of economic performance
Independent	Number of biotechnology firms	Measure of sectoral scale
	R&D expenditure	Absolute financial investment in research
	R&D intensity (% of GDP)	Measure of research prioritisation
	Biotechnology patents (annual counts)	Proxy for innovation outputs
	Economies' share of global GDP (%)	Proportion of the global biotechnology market attributed to different economies

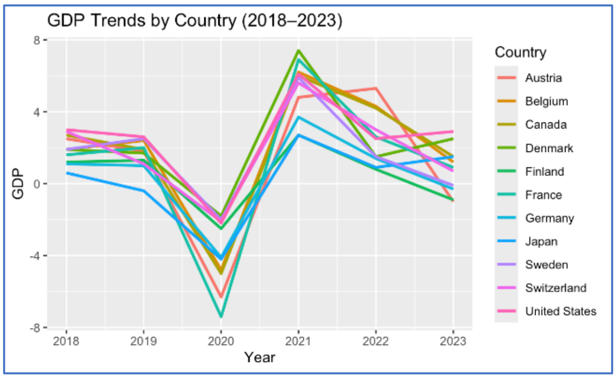
B. Data Collection

Secondary data was gathered from global statistical sources, national reports, and biotechnology/innovation patent databases. Years were averaged and harmonised over the eleven countries to make them comparable.

IV. ANALYSIS

A. Frequency Analysis of Variables

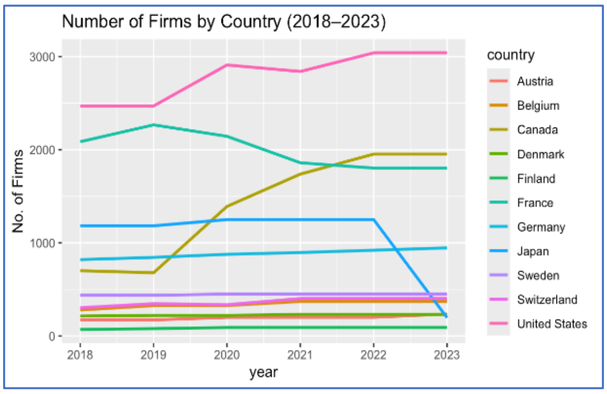
i. GDP Growth Trends by Country



[Fig.1: GDP Trends by Country]

GDP trends from 2018 to 2023 across 11 major economies reveal significant fluctuations, primarily driven by the global COVID-19 pandemic. From 2018 through 2019, these countries experienced relatively steady, moderate GDP growth, driven by stable economic conditions. Nevertheless, 2020 saw extraordinary GDP declines across the world, as some economies, such as France and Japan, suffered near- or below-7 % declines, reflecting sharp disruptions triggered by pandemic lockdowns and supply chain disruptions.2021 saw a strong economic recovery across all economies, with growth rates ranging from 4% to 8%. Denmark and the United States experienced a rapid recovery, especially demonstrating effective policy responses and the revival of their economies. Following this increase, GDP growth slowed in 2022 and 2023, with numerous countries, such as Austria and Germany, recording negative growth, indicating external challenges from inflation, energy crises, and geopolitical uncertainties that are influencing the sustainability of the recovery. The V-shaped economic cycle seems to result from the pre-, ongoing, and post-pandemic phases, highlighting economic disturbances across various countries.

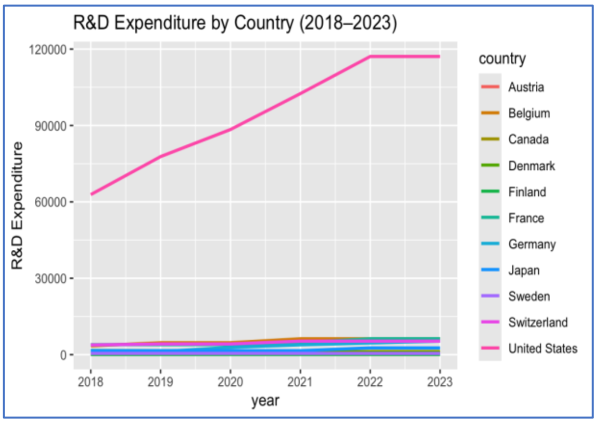
ii. Number of Biotech Firms by Countries



[Fig. 2: Number of Biotech Firms by Countries]

In the above graph, it can be observed that the number of biotechnology firms in the United States grew from 2500 to 3000 from 2018 to 2023, while in Canada, the number rose from 700 to 2000 by 2023. France, which began with around 2100 firms, experienced a steady decline to 1800 firms after 2021. Germany, on the other hand, shows steady growth of 900 firms in 2023. Japan shows a substantial decrease, i.e., from 1300 firms in 2022 to 300 firms. Smaller economies remained stable with fewer than 500 firms.

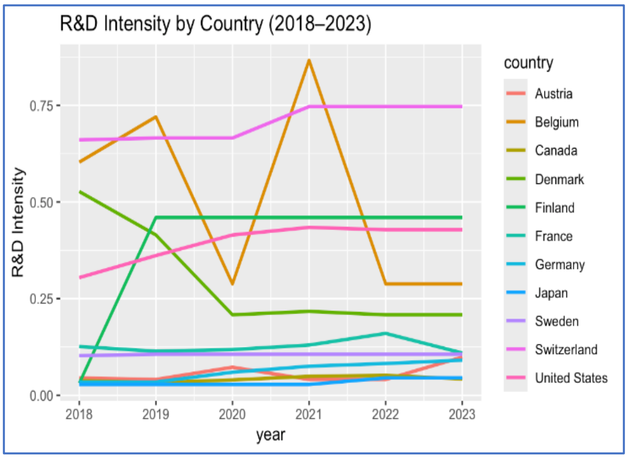
iii. R&D Expenditure by Country



[Fig.3: R&D Expenditure by Country]

This graph shows that research and development spending paints an inconsistent picture: the United States doubled its expenditure from about 62,000 in 2018 to almost 1,20,000 in 2023, demonstrating its undivided attention on innovation and development. In total contrast, other nations have research spending less than 10,000 dollars, with modest increases over the years. Even if some nations show a gradual rise in spending on a high-level summary, the increases are nominal values only.

iv.R&D Intensity by Country



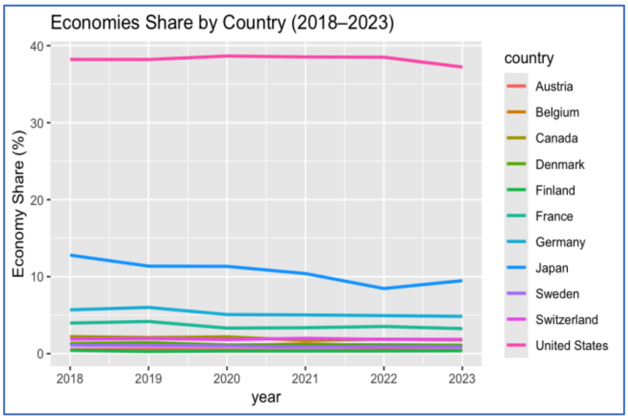
[Fig.4: R&D Intensity by Country]

Research intensity shows varied trends across nations during the selected period. While Belgium shows the most volatile rates — rising and declining, then rising again — Switzerland has only seen a rising trend. Sweden maintained a strong, steady performance between 0.70% and 0.75%. The United States recorded steady growth from about 0.40% to 0.50%, while Finland experienced significant growth, jumping from 0.10% in 2018 to 0.55% in 2019 and sustaining it through 2023. In contrast, Denmark's R&D intensity declined from 0.60% to 0.20%, and Germany, France, Japan, Austria, and Canada remained relatively low and stable, all under 0.20%.

Retrieval Number:100.1/ijef.B263805021125
DOI:10.54105/ijef.B2638.05021125
Journal Website: www.ijef.latticescipub.com

Published By:
Lattice Science Publication (LSP)

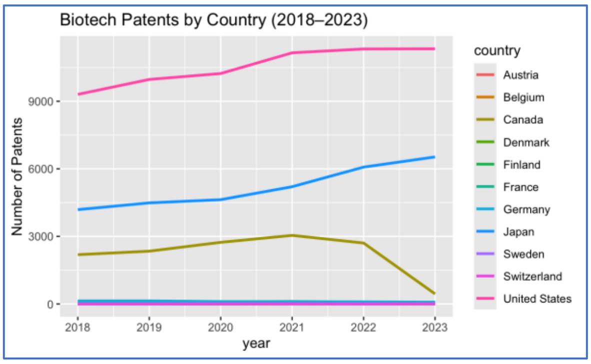
v. Economic Share by Country



[Fig.5: Economies Share by Country]

This graph shows each nation's share of collective GDP from 2018 to 2023, accounting for differences in economic scale. The United States controls the entire period with a 38-39% share of the total, but shows a solid decline to around 37% in 2023, indicating a gradual loss of comparative economic significance. Japan stands second at a much smaller scale, falling continuously from close to 12.5% in 2018 to approximately 8% in 2022, before rising to 9.5% in 2023. This trend follows structural issues such as ageing, deflationary pressures, and softer growth compared to associates. Germany holds third place, steadily delivering 4-5% growth with slight variation, highlighting its status as Europe's anchor economy and its stability amid global volatility. Developed nations take up lower levels, 0.5-3% each. France leads this group at around 3%, and Switzerland, although it has world leadership in R&D intensity, delivers only 1-1.5% because of its smaller geographic and population scale.

vi. Biotechnology Patents by Country



[Fig.6: Biotech Patents by Country]

Biotechnology patenting activity during the period 2018-2023 shows dominance by the United States. The United States has consistently ranked first in patenting activity, rising from roughly 9,000 in 2018 to almost 10,500 in 2023, accounting for around 60-70% of biotechnology patents in developed countries. Japan follows in second place, although well below the United States, beginning at about 4,000 patents in 2018 and increasing steadily to approximately 6,500 in 2023. This steady but reasonable growth reflects ongoing biotechnology focus, best explained by healthcare needs of an ageing population and the recognised pharmaceutical presence. Canada shows a disparate trend, starting with around 2,200 patents in 2018, increasing slowly to almost 3,000 by 2021, and then plummeting quickly to less than 500 by 2023. The sudden shift may be linked to funding adjustments, patent reclassification, evolving business strategies, or talent movement toward stronger biotechnology hubs. Other nations, such as Germany, France, Switzerland, Sweden, Denmark, and Finland, produced fewer than 500 biotechnology patents annually, suggesting that, despite their strong economies and R&D capacity, their innovation priorities lie elsewhere.

B. Descriptive Statistics

Table II: Descriptive Statistics of All Variables

Variable	GDP	No of Firms	R&D Expenditure	R&D Intensity	Economies Share	Biotech Patents
N	66	66	66	66	66	66
Mean	1.39	889.73	10667.15	0.25	5.98	1656.82
SD	3.05	859.99	27406.25	0.24	10.68	3260.34
Median	1.65	443.50	1558.00	0.12	1.84	14.50
Min	-7.40	70.00	72.15	0.03	0.28	1.00
Max	7.40	3040.00	117108.00	0.87	38.66	11330.00
Skew	-0.63	1.09	2.99	0.94	2.45	1.93
Kurtosis	0.55	-0.05	7.54	-0.40	4.59	2.48

In the above table of descriptive statistics, GDP growth shows good results, with a mean of 1.39 and a median of 1.65. However, the wide range from -7.40 to 7.40% indicates that while some nations experienced strong growth, others faced major downfall. The negative skewness (-0.63) shows that a few downturn periods had a substantial impact on the overall distribution. Firm numbers reveal a structural difference: a high mean (889.73) but a lower median (443.5), indicating that a few nations have a large pool of biotechnology firms. The positive skewness (1.09) confirms this imbalance, showing the dominance of outliers with large firm counts. R&D spending shows the most significant disparity in distribution. The mean expenditure (10,667) is much higher than the median (1,558), and the high positive skewness (2.99) and kurtosis (7.54) confirm a substantial contribution by a handful of firms, while many are outliers. R&D intensity, measured as R&D expenditure relative to GDP, shows a balanced trend, with a mean of 0.25%, a median of 0.12%, and low kurtosis (-0.40), reflecting a relatively equitable distribution of research effort despite significant absolute gaps. Economic share patterns further confirm concentration, with an average of 5.98%, a much smaller median of 1.84%, and a maximum of 38.66%, indicating dominance by a few economies, as indicated by the high skewness values. Biotechnology patents mirror the inequality in R&D spending, with a mean of 1,657 patents but a very low median of

Retrieval Number:100.1/ijef.B263805021125
DOI:10.54105/ijef.B2638.05021125
Journal Website: www.ijef.latticescipub.com

Published By:
Lattice Science Publication (LSP)

14.5. High skewness (1.93) and kurtosis (2.48) highlight that most innovation is concentrated among a few advanced economies. Overall, these results confirm that a small group of leading economies drive economic growth, R&D investment, and technological innovation, while others operate at much lower levels.

C. Correlation

The correlation analysis provides essential insights into the relationships among economic indicators, research obligations, and innovation outputs across the sampled economies.

Table III: Correlation Analysis of All Variables

	GDP	No of Firms	R&D Expenditure	R&D Intensity	Economies Share	Biotech Patents
GDP	1	0.047	0.126	0.151	0.071	0.074
No of Firms	0.047	1	0.719	-0.141	0.765	0.725
R&D Expenditure	0.126	0.719	1	0.233	0.937	0.856
R&D Intensity	0.151	-0.141	0.233	1	0.094	0.000
Economies Share	0.071	0.765	0.937	0.094	1	0.938
Biotech Patents	0.074	0.725	0.856	0.000	0.938	1

The correlation analysis highlights strong relationships between economic scale, research spending, and innovation output. A significant finding is the strong positive link between R&D spending and global GDP share (r = 0.937), showing that larger economies invest more in research due to greater resources. R&D spending also strongly correlates with biotechnology patents (r = 0.856), suggesting that higher investments translate directly into innovation. Likewise, R&D intensity correlates even more strongly with patent output (r = 0.938), underscoring that economies that prioritise research achieve superior innovation performance. Economies with higher GDP allocations to R&D activity are found to yield higher innovation outcomes despite relatively small overall economic size. This strengthens the value of a policy focus on R&D intensity and commitment rather than size. Conversely, connections between firm numbers and other factors are weak. Correlation between R&D spending (r = 0.233) and GDP share (r = 0.094) by firm numbers suggests that increased firm numbers do not necessarily imply greater innovation potential. GDP growth rates also lack correlation with R&D or patenting activity, implying short-run macroeconomic performance is not necessarily commensurate with long-run innovation capacity commitments.

D. Fixed-Effect Regression

A Fixed Effects panel regression was conducted to measure the impact of innovation-related variables on GDP growth of selected nations. The model was assessed on a balanced panel dataset comprising 11 economies observed over 6 years, yielding 66 total observations—the Fixed Effects estimator controls for unobserved heterogeneity across countries, which may bias joint specification results.

Table IV: Fixed Effects Panel Regression

Variable	Coefficient	Std. Error	t-Statistic	p-Value
No. of Firms	-0.000367	0.002099	-0.175	0.862
R&D Expenditure	-1.87E-06	9.11E-05	-0.021	0.984
R&D Intensity	3.8449	4.3078	0.893	0.376
Economies' Share	-0.1095	0.9903	-0.111	0.912
Biotech Patents	0.000666	0.001392	0.479	0.634

Statistic	Value
Total Sum of Squares (TSS)	569.93
Residual Sum of Squares (RSS)	552.68
R-squared	0.030
Adjusted R-squared	-0.261
F-statistic (df = 5, 50)	0.312
Overall Model p-value	0.903

Fixed Effects model reports poor explanatory power, with R-squared 0.030 indicating 3% of variation in within-country GDP growth explained by included variables. The negative adjusted R-squared (-0.261) highlights the specification's weakness, and the F-statistic of 0.312 (p = 0.903) indicates that the explanatory variables are not jointly significant. No predictors were statistically significant. R&D intensity had the largest positive coefficient (β = 3.84), but it was not significant (p = 0.376). Biotechnology patents showed a tiny positive coefficient (β = 0.0007) but were not significant (p = 0.634). Other predictors showed tiny or negative coefficients with little explanatory power. These results indicate that the tested indicators of innovation and economic structure do not notably affect GDP growth in the 2018-2023 period in the Fixed Effects specification. Possible reasons include delayed R&D and the need for longer horizons for biotechnology innovation, as well as overlooked macro factors such as institutional quality and human capital.

E. Random Effects Regression

Random-Effects regression examined whether firm-level and macroeconomic factors meaningfully predict GDP growth. Unlike Fixed Effects, Random Effects assumes that the unobserved country-specific effects are uncorrelated with the predictors, enabling an approximation that exploits both within-country and between-country variation.

Table V: Random Effects Regression

Variable	Estimate	Std. Error	t/z-value	p-value
Intercept	1.034	0.894	1.157	0.247
Number of Firms	0.000	0.001	0.162	0.872
R&D Expenditure	0.000	0.000	0.968	0.333
R&D Intensity	1.459	1.957	0.746	0.456
Economies Share	-0.152	0.161	-0.941	0.347
Biotech Patent	0.000	0.000	0.558	0.577

Model Statistic	Value
Total Sum of Squares (TSS)	605.64
Residual Sum of Squares (RSS)	577.78
R-squared	0.046
Adjusted R-squared	-0.033
Chi-square (df = 5)	2.89
p-value (Chi-square)	0.716

The Random Effects model has very low explanatory power, with an R-squared of

Retrieval Number:100.1/ijef.B263805021125
DOI:10.54105/ijef.B2638.05021125
Journal Website: www.ijef.latticescipub.com

Published By:
Lattice Science Publication (LSP)

0.046, indicating that predictors explain only 4.6% of the variation in the dependent variable. More than 95% of the variance in the outcome is unexplained, implying that the included variables fail to capture the main drivers of growth. The negative adjusted R-squared (-0.033) indicates the model performs worse than the mean-only benchmark.

Looking at the coefficients, none of the predictors—number of companies, R&D spending, R&D intensity, shares of global GDP in economies, or biotech patents—reaches statistical significance, as indicated by p-values well above the standard 0.05 cut-off. This shows a lack of proof of an interesting linear relationship between these variables and the dependent variable in the Random Effects model. Notably, the lack of significance across all variables indicates that the given specification fails to adequately explain both between-country and within-country variation. The chi-square test of overall model fit ($\chi^2 = 2.89$, df = 5, p = 0.716) confirms this conclusion, indicating that as a whole, the predictors do not explain the dependent variable any better than chance. The model is therefore statistically insignificant as a whole.

These results could occur for several reasons: the underlying relationships may be nonlinear or weak, important explanatory variables may be omitted, or unobserved heterogeneity may override effects estimated from the chosen predictors. Also, limited time horizons and high volatility may hinder the model's ability to extract structural effects. Subsequent models may thus require covariates beyond those included here, lag testing, investigation of interaction terms, or the use of alternative estimation methods to enhance explanatory power.

F. Hausman Test

To determine which condition was more appropriate, a Hausman test was used to compare the FE and RE estimates.

Table VI: Summary of the Hausman Test

Test Statistic	df	p-value	Decision
$\chi^2 = 1.0573$	5	0.9578	Accept H_0 → Random Effects appropriate

The test yielded a chi-square statistic of 1.0573 with 5 degrees of freedom (p = 0.958). A significant p-value indicates failure to reject the null hypothesis, thereby vindicating Random Effects as the more efficient specification. Results show no systematic correlation between unobserved country effects and regressors; the RE estimator can therefore be employed without bias.

But this does not assert that the RE model claims that the poor explanatory power is a specification failure; rather, it reflects structural limitations: limited time coverage, possible omitted variables, or lagged effects between R&D investments and observable macroeconomic outcomes. Within-country or cross-country variation in firm numbers, R&D inputs, or biotechnology outputs does not significantly explain GDP growth for this sample and time period. This implies that the interaction between development and innovation can only be realised with a longer time horizon, by incorporating additional institutional dimensions and structural controls, or through dynamic modelling methods to capture the dynamics in full.

V. DISCUSSION

A. Innovation Concentration and Economic Dominance

The analysis suggests an intensely focused world innovation system, dominated by the US across many fields of biotechnology and R&D. This is consistent with recent research on national innovative capacity as a function of generic innovation infrastructure and cluster-specific environments [26]. The U.S., with 60-70% of biotech patents and almost doubling R&D expenditures between 2018 and 2023, exhibits what new scholars refer to as "innovation capacity"—the ability of a country to generate a stream of commercially relevant innovations [17]. Switzerland's consistent ranking in R&D intensity, with rates over 0.75% throughout the research period, reflects what recent literature has termed "innovation efficiency" - the ability to convert inputs into innovative outputs efficiently [18]. This trend is corroborated by the literature on small, innovation-attracted economies that compensate for the lack of scale with focused effort and high-value specialisation [27]. The ubiquity of innovation assets with a few dominant players is an echo of what recent research on innovation systems identifies as path-dependent institutional contexts, policy regimes, and historical investments that create self-reinforcing strengths [23].

B. The R&D Investment-Growth Paradox

The most striking outcome of this analysis is likely to be the absence of strong relationships between R&D spending and GDP growth, despite high correlations between innovation inputs and outputs [26]. The same paradox aligns with the broader literature on the "productivity paradox" in the context of innovation studies [28]. There may be theoretical and empirical reasons consistent with the prevailing literature. In the first place, such a lag in time between R&D expenditure and economic return may explain such results. New longitudinal studies show that lagged effects of R&D expenditure on measurable productivity typically take 5-15 years, especially in biotechnology, where the incubation period is more extended [25]. The 2018-2023 span of such an analysis might be too short to capture lagged effects, as argued by contemporary growth economists [29]. Secondly, R&D spillover advantages are not always accounted for in national GDP statistics. Contemporary studies on innovation have shown that knowledge spillovers tend to be multinational, and thus R&D spending in a particular country can contribute to global rather than domestic economic advancement [3]. This is especially true for biotechnology, where knowledge is highly mobile and international collaborative research is prevalent [21]. Third, the quantity-versus-quality aspect of R&D expenditure can be most crucial. Recent literature on organisational learning stresses that R&D expenditure must cross a threshold to establish "absorptive capacity" - the capacity to identify, absorb, and utilise new knowledge [30]. The relative lack of cutting-edge research across a handful of leading nations implies that subthreshold expenditure will yield decreasing returns.

C. Sectoral Specialisation and National Innovation Strategies

There is a significant disconnect between biotechnology innovations in developed and underdeveloped economies. Developed economies have the advantage of stronger national innovation policies and sector-specific patterns. Countries pursue various biotechnology strategies, ranging from broad-based approaches to niche strategies, reflecting variations in institutional capacity, resource endowments, and historical innovation trajectories that shape competitiveness. The evidence indicates that no universal model guarantees success. The United States benefits from large-scale capabilities and integrated biotechnology systems, whereas smaller economies such as Switzerland and Sweden prosper through strategic focus and high research intensity. These models demonstrate what innovation systems literature identifies as multiple pathways to competitiveness, shaped by national contexts and institutional frameworks [15].

International collaboration remains a key factor in biotechnology advancement regardless of economic size or strategy. The growing interconnectedness of biotechnology research enables countries to tap into global knowledge networks and engage in advanced scientific work beyond domestic limits [20]. Empirical findings show that nations with highly internationalised research networks achieve superior innovation outcomes compared to those with less global connectivity [21].

D. Scale Effects versus Innovation Efficiency

The correlation analysis provides strong evidence of an interaction between economic scale and innovation performance. The extremely high correlation between economies' GDP percentages and R&D expenditure ($r = 0.937$) reinforces the importance of scale effects on innovation, as predicted by endogenous growth theory [14]. However, the equally high correlation between biotech patents and R&D intensity ($r = 0.938$) suggests that innovation efficiency can be as crucial as overall scale.

This finding aligns with recent research on the relationship between firm size and innovation at the national scale [31]. Economies with smaller innovation intensity, such as Sweden and Switzerland, show that high R&D intensity and focused strategies can yield substantial innovation outcomes despite smaller overall size. This supports modern theories of national competitive advantage, which argue that specialised clusters can attain global competitiveness through concentrated excellence [17]. Weak correlations between firm quantity and innovation outcomes contradict traditional assumptions in entrepreneurial economics. The results imply that firm quality and innovative capacity matter more than the number of firms, consistent with recent frameworks that distinguish between creative and imitative entrepreneurship [32].

E. Policy Implications and Innovation System Design

The results have significant implications for the design of innovation policy. Failure by Fixed Effects and Random Effects models to identify meaningful relationships between innovation inputs and growth over short horizons suggests that policymakers should consider longer-term perspectives when evaluating R&D investments [33].

The concentration of innovation capacity among a small group of leaders is also a concern for international innovation governance and knowledge spillovers. Recent research purports that knowledge has characteristics of a public good, which could imply possible market failures in innovation investment [34]. The trend of observed facts may necessitate an international collective policy to induce knowledge spillovers and avoid excessive concentration of innovation assets. For small developed economies, the Swedish and Swiss experiences offer authentic models of innovation competitiveness through an emphasis on excellence and high R&D intensity. These align with established claims about the significance of knowledge creation and absorption for the learning economy at scale [19].

VI. CONCLUSION

This study examined the relationship between biotechnology innovation and economic growth in eleven high-income economies between 2018 and 2023, answering simple questions about how innovation inputs translate into measurable financial outcomes. The picture portrays a highly clustered global biotechnology innovation system, with the United States having an overwhelming presence across various dimensions [21]. The focus aligns with theoretical explanations of national innovative capacity, which posit that institutional support and cluster-related environments create reinforcing benefits [17].

Switzerland stands out as a leader in innovation efficiency, maintaining R&D intensity above 0.75% of GDP throughout the study period. This supports the evidence that small, innovation-driven economies can overcome their limited scale by focusing on strategic specialisation and high-value research [27]. The Swiss case illustrates that relative economic size is not the sole determinant of innovation performance, as the high correlation ($r = 0.938$) between R&D intensity and biotech patent outputs demonstrates.

Most strikingly, there is no correlation between R&D spending and GDP growth, despite strong correlations between innovation inputs and outputs. Neither the Fixed Effects nor the Random Effects panel regression models found a statistically significant correlation between economic growth and innovation variables. This paradox aligns with the broader "productivity paradox" literature [26, 28], which posits that the returns to investment in innovation are realised over more than six years, the period of our study. Correlation analysis revealed strong structural relations within the innovation ecosystem. R&D expenditure and world GDP share of the economies had the strongest positive correlation, confirming scale effects in innovation in accordance with endogenous growth theory [14]. However, if as strong a relation between R&D intensity and biotechnology patents as between either and world GDP share, then the efficiency of innovation could be as beneficial as absolute magnitude [19].

The findings address the central research questions by demonstrating that while there is high potential for innovation outcomes to be predicted by innovation inputs, short-run economic growth remains elusive.

The agglomeration of biotechnology innovation worldwide, with few leading

Published By:
Lattice Science Publication (LSP)

firms investing in the majority of research expenditures and receiving most of the patents, reflects what recent studies identify as "national systems of innovation," in which institutional settings construct competitive advantage [23].

A. Limitations

This research recognises methodological and scope limitations that may affect the generalizability of the results. The six-year period (2018-2023) may be too short to capture the long-term impacts of R&D investment on economic growth, especially given that the literature proposes lags between R&D investment and quantifiable productivity improvements of 5-15 years [25, 29]. Including the COVID-19 years may have distorted typical innovation–growth relationships, as the pandemic created exceptional conditions that likely disrupted underlying trends. Focusing on country-level data could also obscure significant differences within regions, sectors, or firm types. Using biotechnology patents as the sole indicator of innovation captures only part of the economic and knowledge spillover effects. Additionally, the study's sample—limited to 11 high-R&D-spending developed economies—introduces selection bias and limits applicability to emerging nations with different innovation dynamics. Given biotechnology's rapid pace of technological and policy change, some findings may soon become irrelevant as new developments unfold.

B. Practical Implications

The findings make significant contributions to innovation policy and strategic planning for biotechnology. Policymakers should adopt long-term perspectives on R&D investments, as biotechnology revenues take time to materialise and may not be reflected in short-term GDP growth indicators. The absence of critical short-run relationships in regression analyses suggests that the traditional economic measurement system may be ineffective for assessing innovation outcomes. For smaller economies, the Swiss and Swedish models demonstrate sustainable competitiveness through focused excellence and high R&D intensity rather than large-scale competition. Countries with limited resources should prioritise developing "absorptive capacity" [30] and pursue targeted specialisation in biotechnology niches where they can achieve global impact.

The heavy concentration of innovation capacity among major economies raises concerns about global knowledge inequality. Since knowledge acts as a public good [34], international policy cooperation may be needed to encourage broader knowledge diffusion and prevent excessive concentration of innovation power. Economies with fewer resources should therefore strengthen institutional frameworks that enable integration into global knowledge networks instead of trying to build complete domestic innovation systems.

C. Scope for Future Research

Further research is needed to better understand the economic impacts of biotechnology innovation. Long-term studies spanning 10–15 years would help capture the delayed effects of R&D investment on economic growth, addressing the time lag identified in this analysis. More detailed investigations focusing on specific clusters, technologies, and firms could uncover insights hidden by national-level data. Future research should also consider factors such as institutional quality, human capital, and innovation infrastructure to better explain how R&D translates into economic gains.

The study underscores the complex and indirect relationship between biotechnology innovation and economic growth. While R&D inputs and innovation outputs are closely linked, their influence on measurable economic outcomes operates through non-linear and long-term mechanisms. The lack of short-run correlations between R&D spending and GDP growth should guide policymakers toward more nuanced strategies that account for the prolonged and globally distributed nature of innovation rewards. Understanding these complexities is crucial for designing effective innovation policies and institutional frameworks.

DECLARATION STATEMENT

I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:**
  The authorship of this article is contributed solely.

REFERENCES

1. Grand View Research, "Biotechnology Market Size, Share & Trend Analysis By Technology," 2025. [Online]. Available: https://www.grandviewresearch.com/industryanalysis/biotechnology-market
2. I. Hemmatian, T. A., Ponzio, A. M., and Joshi, A. M., "Exploring the role of R&D collaborations and non-patent IP policies in government technology transfer performance: Evidence from U.S. federal agencies (1999-2016)," *PLoS ONE*, vol. 17, no. 5, p. e0268828, 2022. DOI: https://doi.org/10.1371/journal.pone.0268828
3. D. B. Audretsch and M. Belitski, "The role of R&D and knowledge spillovers in innovation and productivity," *European Economic Review*, vol. 123, p. 103391, 2020. DOI: https://doi.org/10.1016/j.euroecorev.2020.103391
4. R. N. Weerasinghe, A. K. W. Jayawardane, and Q. Huang, "Critical inquiry on National Innovation System: Does NIS fit with developing countries?" *Sustainable Technology and Entrepreneurship*, vol. 3, no. 1, p. 100052, 2024. DOI: https://doi.org/10.1016/j.stae.2023.100052
5. S. Ndicu, D. Ngui, and L. Barasa, "Technological catch-up, innovation, and productivity analysis of national innovation systems in developing countries in Africa 2010-2018," *Journal of the Knowledge Economy*, vol. 15, pp. 7941-7967, 2024.

DOI: https://doi.org/10.1007/s13132-023-01327-4
6. R. P. Pradhan, M. B. Arvin, M. Nair, S. E. Bennett, and J. H. Hall, "Sustainable economic growth in the European Union: The role of ICT, venture capital, and innovation," *Review of Financial Economics*, vol. 38, no. 1, pp. 34-62, 2020. DOI: https://doi.org/10.1002/rfe.1064
7. S. Kuhlmann and A. Rip, "Next-generation innovation policy and Grand Challenges," *Science and Public Policy*, vol. 45, no. 4, pp. 448-454, 2018. DOI: https://doi.org/10.1093/scipol/scy011
8. M. Mazzucato, *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*. New York: PublicAffairs, 2015. https://www.hachettebookgroup.com/
9. H. W. Chesbrough, "The future of open innovation: The future of open innovation is more extensive, more collaborative, and more engaged with a wider variety of participants," *Research-Technology Management*, vol. 60, no. 1, pp. 35-38, 2017. DOI: https://doi.org/10.1080/08956308.2017.1255054
10. J. M. Ahn, T. Minshall, and L. Mortara, "Understanding the human side of openness: The fit between open innovation modes and CEO characteristics," *R&D Management*, vol. 47, no. 5, pp. 727-740, 2017. DOI: https://doi.org/10.1111/radm.12264
11. A. Saeed, S. S. Mukarram, and Y. Belghitar, "Read between the lines: Board gender diversity, family ownership, and risk-taking in Indian high-tech firms," *International Review of Financial Analysis*, vol. 62, pp. 186-204, 2019. DOI: https://doi.org/10.1016/j.irfa.2019.01.006
12. A. Colombelli, J. Krafft, and F. Quatraro, "Properties of knowledge base and firm survival: Evidence from a sample of French manufacturing firms," *Technological Forecasting and Social Change*, vol. 80, no. 8, pp. 1469-1483, 2015. DOI: https://doi.org/10.1016/j.techfore.2013.03.003
13. C. Chaminade, B. Å. Lundvall, and S. Haneef, *Advanced Introduction to National Innovation Systems*. Cheltenham: Edward Elgar Publishing, 2018. DOI: https://doi.org/10.4337/9781784711108
14. P. M. Romer, "Mathiness in the theory of economic growth," *American Economic Review*, vol. 105, no. 5, pp. 89-93, 2015. DOI: https://doi.org/10.1257/aer.p20151066
15. C. Edquist, "Towards a holistic innovation policy: Can the Swedish National Innovation Council (NIC) be a role model?" *Research Policy*, vol. 48, no. 4, pp. 869-879, 2019. DOI: https://doi.org/10.1016/j.respol.2018.10.008
16. A. Watkins, T. Papaioannou, J. Mugwagwa, and D. Kale, "National innovation systems and the intermediary role of industry associations in building institutional capacities for innovation in developing countries: A critical review of the literature," *Research Policy*, vol. 44, no. 8, pp. 1407-1418, 2015. DOI: https://doi.org/10.1016/j.respol.2015.05.004
17. F. Castellacci and J. M. Natera, "Innovation, absorptive capacity and growth heterogeneity: Development paths in Latin America 1970-2010," *Structural Change and Economic Dynamics*, vol. 37, pp. 27-42, 2016. DOI: https://doi.org/10.1016/j.strueco.2015.11.002
18. C. Edquist and J. M. Zabala-Iturriagagoitia, "Pre-commercial procurement: A demand or supply policy instrument in relation to innovation?" *R&D Management*, vol. 45, no. 2, pp. 147-160, 2015. DOI: https://doi.org/10.1111/radm.12052
19. M. B. Jensen, B. Johnson, E. Lorenz, and B. Å. Lundvall, "Forms of knowledge and modes of innovation," in *The Learning Economy and the Economics of Hope*, London: Anthem Press, 2016, pp. 155-180. DOI: https://doi.org/10.7135/UPO9781843318903.009
20. C. G. E. Pepe, M. V. A. Fonseca, and C. F. Silva Marques, "International collaboration towards innovation management: A network perspective and the Global Innovation Index," *Journal of Innovation and Entrepreneurship*, vol. 13, p. 32, 2024. DOI: https://doi.org/10.1186/s13731-024-00384-6
21. C. Beaudry and A. Schiffauerova, "Impacts of collaboration and network indicators on patent quality: The case of Canadian nanotechnology innovation," *European Management Journal*, vol. 35, no. 3, pp. 362-373, 2017. DOI: https://doi.org/10.1016/j.emj.2016.06.006
22. M. Corsino, R. Gabriele, and A. Giunta, "Are geographic and organisational proximities complementary in fostering innovation? The case of an Italian industrial district," *Regional Studies*, vol. 53, no. 7, pp. 1029-1041, 2019. DOI: https://doi.org/10.1080/00343404.2018.1505507
23. N. Sharif, "From innovation policy to science and technology policy," in *Atlas of Islamic World Science and Innovation*, Trieste: TWAS, 2015, pp. 8-11. https://www.twas.org/
24. P. Arque-Castells, "How venture capitalists spur invention in Spain: Evidence from patent trajectories," *Research Policy*, vol. 51, no. 1, p. 104395, 2022. DOI: https://doi.org/10.1016/j.respol.2021.104395
25. N. Bloom, J. Van Reenen, and H. Williams, "A toolkit of policies to promote innovation," *Journal of Economic Perspectives*, vol. 33, no. 3, pp. 163-184, 2019. DOI: https://doi.org/10.1257/jep.33.3.163
26. X. Cirera and W. F. Maloney, *The Innovation Paradox: Developing-Country Capabilities and the Unrealised Promise of Technological Catch-Up*. Washington, DC: World Bank Publications, 2017. DOI: https://doi.org/10.1596/978-1-4648-1160-9
27. D. Wuepper and M. Patry, "The world development report 2008: Implications for technology transfer," *The Journal of Technology Transfer*, vol. 42, no. 1, pp. 150-167, 2017. DOI: https://doi.org/10.1007/s10961-016-9530-9
28. A. Fosfuri and T. Rønde, "Absorptive capacity in a more (or less) absorptive environment: A meta-analysis of contextual effects on firm innovation," *Journal of Product Innovation Management*, vol. 41, no. 5, pp. 742-768, 2023. DOI: https://doi.org/10.1111/jpim.12758
29. C. I. Jones and J. C. Williams, "Paul Romer: Ideas, nonrivalry, and endogenous growth," *Scandinavian Journal of Economics*, vol. 122, no. 3, pp. 859-883, 2020. DOI: https://doi.org/10.1111/sjoe.12370
30. E. Martínez-Ros and F. Orfila-Sintes, "Absorptive capacity and innovation: The mediating role of organisational learning," *PLOS ONE*, vol. 17, no. 1, p. e0262860, 2022. DOI: https://doi.org/10.1371/journal.pone.0262860
31. N. Ahmed, "How creative destruction functions in corporate entrepreneurial process: An empirical investigation of Schumpeterian concept in engineering firm settings in Pakistan," *Journal of Innovation and Entrepreneurship*, vol. 11, no. 1, p. 16, 2022. DOI: https://doi.org/10.1186/s13731-022-00199-3
32. M. Henrekson, D. Johansson, and J. Karlsson, "To be or not to be: The entrepreneur in neo-Schumpeterian growth theory," *Journal of Management Studies*, vol. 61, no. 1, pp. 271-302, 2024. DOI: https://doi.org/10.1177/10422587221141679
33. R. R. Nelson, "Behaviour and cognition of economic actors in evolutionary economics," *Journal of Evolutionary Economics*, vol. 26, no. 4, pp. 737-751, 2016. DOI: https://doi.org/10.1007/s00191-015-0431-7
34. K. J. Arrow, "Kenneth Arrow, uncertainty and the welfare economics of medical care," *Journal of Health Politics, Policy and Law*, vol. 42, no. 5, pp. 821-824, 2017. DOI: https://doi.org/10.1215/03616878-3940456

AUTHOR'S PROFILE

Navya Patel is a Grade 12 student at Navrachana International School, Vadodara, currently enrolled in the International Baccalaureate Diploma Programme. She has developed a strong interest in English Language and Literature, where she enjoys analysing how writers use language to explore identity, emotion, and social structures. Navya is also drawn to business and economics, fascinated by how ideas, people, and systems interact in the real world. She approaches her work with curiosity and reflection, aiming to connect academic learning with everyday observations. Beyond academics, Navya enjoys reading, writing, solving puzzles, and engaging in meaningful discussions about a wide range of topics. She hopes to pursue higher studies in business or finance, combining analytical thinking with creativity to understand better how societies and economy's function.