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Research Article

Analogue Between Nanotechnology Intellectual Property Rights and Research & Development Investments in the Asian Continent

Aman Verma^{1*}, Amrit Warshini², Pawan Kumar Gupta³, Agantika Gupta⁴, Vishnu D. Rajput⁵, Tatiana Minkina⁵, Julius R. Orimoloye⁶

¹Department of Agriculture, Integral Institute of Agricultural Science and Technology (IIAST), Integral University, Lucknow, Uttar Pradesh, India

²Department of Agriculture, Sage University, Indore, Madhya Pradesh, India

³Department of Agricultural Extension Education, Chandra Sekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India

⁴Department of Agricultural Extension Education, Sardar Vallabh Bhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India

⁵Academy of Biology and Biotechnology, Southern Federal University, Rostov-on-Don, 344090, Russia

⁶University of Ibadan, Ibadan, Oyo State, Nigeria

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ABSTRACT

This comprehensive meta-analytic study explores the relationship between nanotechnology patenting trends and research and development (R&D) expenditures, focusing on the dynamic Asian markets. Employing a mixed-method approach, the research integrates rigorous quantitative data analysis using SPSS Statistics and Microsoft Excel and a thorough review of existing literature. The study addresses three key questions: 1) The nanotechnology patenting trends evolution across different Asian countries, 2) Correlation between R&D expenditure and the number of patents granted and Variance among countries, 3) Patterns emerge in the ratio of nanotechnology patents to nanoscience research articles, and the share of nanotechnology patents influences overall patent activity in Asian countries. The findings reveal a robust positive correlation between higher R&D expenditure and increased patent application numbers across major patent offices, such as the EPO, Germany, and USPTO. However, the data also highlights substantial disparities in the emphasis and strategic prioritisation of nanotechnology across the region, as evidenced by the ratio of nanotechnology patents to nano-articles and the share of nanotechnology patent applications to total patent applications. Importantly, the reliability of the data was assessed using Cronbach's alpha, which yielded a high-reliability score of 0.734, ensuring the integrity and consistency of the findings. Furthermore, regression analysis was employed to explore the influence of R&D expenditure on nanotechnology patent activity. The study provides valuable insights into the complex interplay between R&D investments, patent outputs, and the strategic positioning of nanotechnology within the broader technological landscape. These findings can inform policymakers and industry stakeholders in fostering innovation, intellectual property generation, and technological progress, particularly in the rapidly evolving field of nanotechnology.

1. Introduction

Nanotechnology is a critical driver of innovation, with transformative potential across sectors such as medicine, materials science, electronics, and energy [1]. As this field

advances, understanding the landscape of patenting activity and research and development (R&D) investments becomes essential to gauge technological progress, pinpoint innovation hotspots, and assess commercial potential [2]. This study aims to offer a comprehensive analysis of nanotechnology patenting trends and

* Corresponding author.

Email: aman.mainext@gmail.com

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R&D expenditures, focusing particularly on dynamic Asian markets [3]. Countries like China and South Korea rapidly increased their patent filings, surpassing established technological frontrunners such as the United States and Europe, indicating a significant shift in the global nanotechnology landscape [4].

Recent data from the World Intellectual Property Organization (WIPO) underscore the strategic investments that Asian countries make in nanotechnology, positioning them at the forefront of this field's evolution [5]. Despite these advancements, there is a critical need to delve deeper into the nuances of patenting trends, explore the correlation between R&D spending and patent outputs, and understand how these dynamics differ across regional landscapes [6].

This study addresses these gaps through three research questions: 1) How have nanotechnology patenting trends evolved across different countries, especially in Asia? 2) What is the correlation between R&D expenditure and the number of patents granted, and how does this relationship vary by country? 3) What patterns emerge in the ratio of nanotechnology patents to nanoscience research articles, and how does the share of nanotechnology patents influence overall patent activity in Asian countries?

Employing a mixed-methods approach, this research integrates quantitative data analysis with a review of extant literature. Patent data from major offices such as the EPO, USPTO, and DPMA will be analyzed using advanced statistical methods, including correlation analysis, regression modelling, and trend analysis [7,8]. Additionally, this study will explore the conversion rate of nanoscience research into patents and the broader significance of nanotechnology within the technological landscape [9,10].

Moreover, the study will discuss nanotechnology developments' broader socio-economic and environmental impacts, acknowledging that the benefits and challenges extend beyond patent filings and R&D spending. By providing insights into these dimensions, the study aims to offer a holistic view of the nanotechnology innovation ecosystem, particularly highlighting the strategic roles of Asian nations.

The expected findings will enhance understanding of the nexus between R&D investments and patent outputs and will help inform strategic decision-making for policymakers and industry stakeholders. By identifying key areas for collaboration and potential challenges, this research intends to foster an environment conducive to innovative and commercial activities in nanotechnology, ensuring sustainable development and technological advancement. This comprehensive approach aims to contribute to academic discourse and practical policy-making and industrial strategies in the rapidly evolving field of nanotechnology [11].

2. Materials and Methods

The research methodology employed a quantitative approach to analyse the relationship between nanotechnology patents and research and development (R&D) expenditure in Asian countries from 2000 to 2023. Data was collected from authoritative sources, including patent offices, government publications, and industry reports, focusing on key indicators such as nanotechnology patents granted and published patent applications in major patent offices (EPO, DPMA, and USPTO), the ratio of nanotechnology patents to nano-articles, the share of nanotechnology patent applications and patents to total patent applications and patents, and R&D expenditure as a percentage of GDP. The statistical analysis was conducted using IBM SPSS Statistics. SPSS was utilised for correlation analysis, which measures the strength and direction of the linear relationship between two variables using the Pearson correlation coefficient formula:

$$r = \frac{\sum X_i Y_i - \frac{(\sum X_i)(\sum Y_i)}{n}}{\sqrt{\left(\sum X_i^2 - \frac{(\sum X_i)^2}{n}\right) \left(\sum Y_i^2 - \frac{(\sum Y_i)^2}{n}\right)}}$$

where, r – correlation coefficient, X, Y – Two variables for which the test is applied, n – Number of observations.

Regression analysis was employed to investigate the influence of R&D expenditure on nanotechnology patent activity, using the linear regression model: $Y = a + bx$, where Y is the dependent variable (nanotechnology patents), X is the independent variable (R&D expenditure), a is the y -intercept, and b is the slope coefficient. Reliability analysis was performed using Cronbach's alpha formula: $\alpha = (N \cdot \bar{r}) / [1 + (N - 1) \cdot \bar{r}]$, where N is the number of items, and $\bar{r}$ is the average inter-item correlation, to assess the internal consistency and reliability of the data and calculation of averages using the arithmetic mean formula: $\sum X_i / N$, where X_i represents the individual data points, and N is the total number of data points and graphical representation through line graphs and bar chart.

3. Result

3.1 Quantitative Analysis of Nanotechnology Patenting and Research & Development Trends

An analysis of Figure 1, shows a positive correlation between R&D expenditure and patent applications. Countries like Japan (EPO: 134.82, German: 5.0, USPTO: 499.9, R&D: 3.27%), South Korea (EPO: 93.17, German: 3.63, USPTO: 478.45, R&D: 3.67%), and China (EPO: 42.08, German: 0.72, USPTO: 291.72, R&D: 1.78%) demonstrate consistently high levels of patent applications across all three offices, coupled with substantial R&D investments. This suggests a potential causal relationship, where strong R&D efforts translate into more patentable inventions. Countries like Singapore (EPO: 6.82, German: 0.54, USPTO: 34.68, R&D: 2.08%), Saudi Arabia (EPO: 6.13, USPTO: 57.09, R&D: 0.31%), and India (EPO: 8.69, German: 0.36, USPTO: 26.86, R&D: 0.74%) exhibit moderate levels of both patent applications and R&D expenditure. Further investigation into these cases might reveal the influence of other factors alongside R&D, such as specific industry focus or government policies. Finally, several nations, including Uzbekistan, Syria, Indonesia, Yemen, Afghanistan, Armenia, Iraq, Bahrain, and others, exhibit minimum patent applications across all three offices and low R&D expenditure during the same period. This highlights a significant disparity in innovative capacity across different regions [12,13,14].

Figure 2 reveals a significant disparity in nanotechnology patent applications across different patent offices (EPO, German, and USPTO) and research and development (R&D) expenditure among Asian countries from 2000 to 2023. Leading nations in nanotechnology patent applications include Japan (EPO: 245.39, German: 18.81, USPTO: 58.96, R&D: 3.27%), South Korea (EPO: 177.52, German: 18.63, USPTO: 127.94, R&D: 3.67%), China (EPO: 103.26, German: 3.63, USPTO: 92.81, R&D: 1.78%), and Taiwan (EPO: 23.69, German: 7.0, USPTO: 34.7), while countries like Singapore, Saudi Arabia, and India exhibit moderate levels. Several nations, including the UAE, Uzbekistan, Syria, Thailand, Iran, Indonesia, Malaysia, Qatar, North Korea, Iraq, Vietnam, Yemen, Philippines, Afghanistan, Armenia, Kuwait, Oman, Pakistan, Lebanon, Bahrain, Jordan, Bangladesh, and Azerbaijan, demonstrate low nanotechnology patent applications and R&D expenditure. A positive correlation is observed between higher R&D expenditure and increased nanotechnology patent application numbers across the EPO, German, and USPTO patent offices [15,16,17,18].

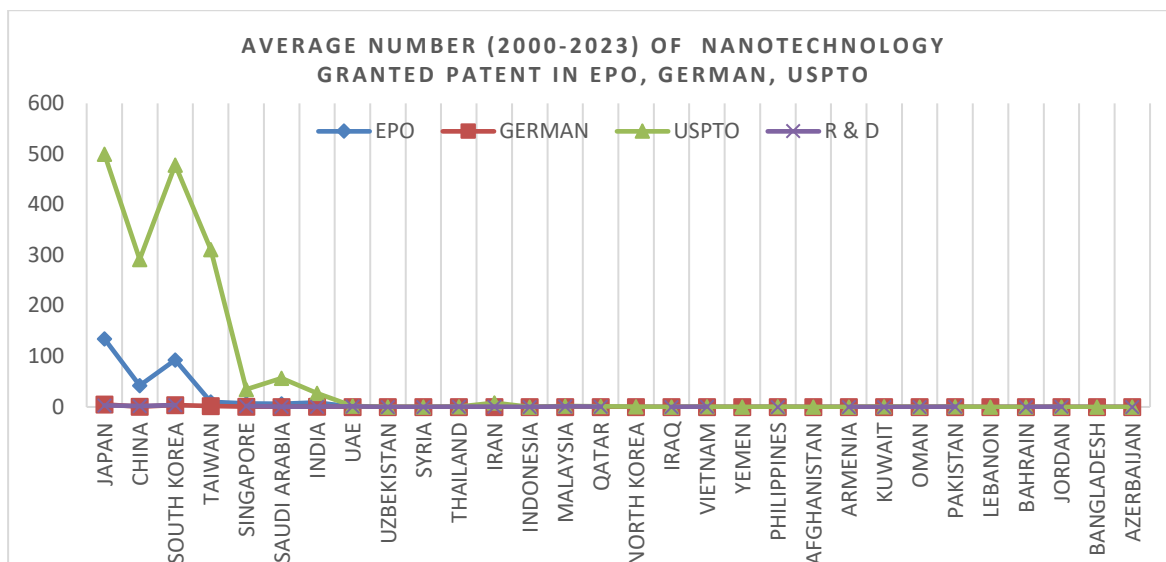


Figure 1. Average Number (2000-2023) Of Nanotechnology Granted Patent in EPO, GERMAN, USPTO

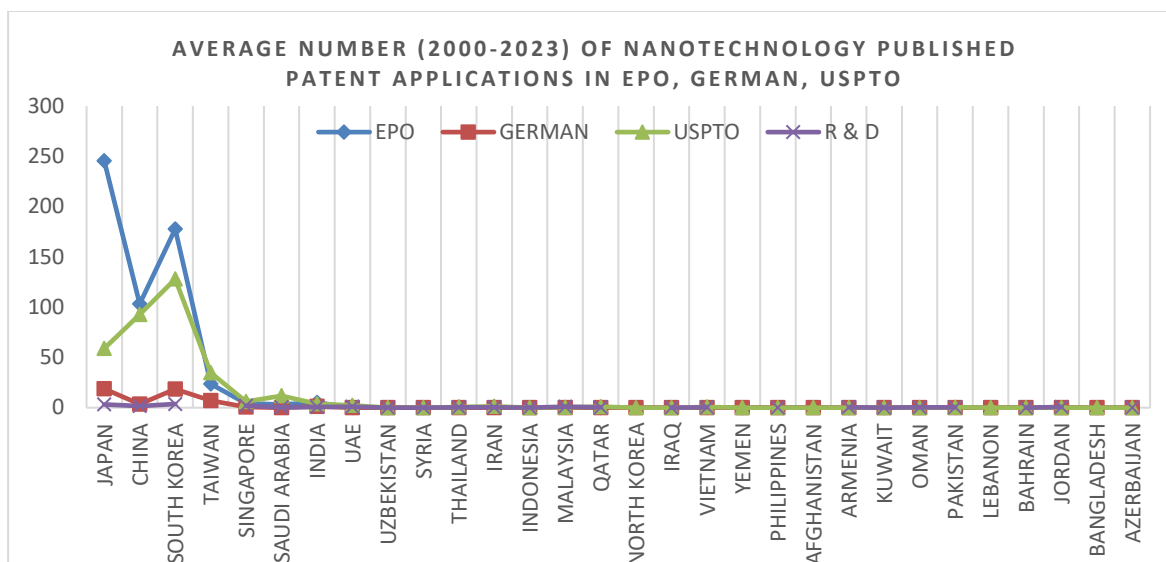


Figure 2. Average Number (2000-2023) Of Nanotechnology Published Patent Application in EPO, GERMAN, USPTO

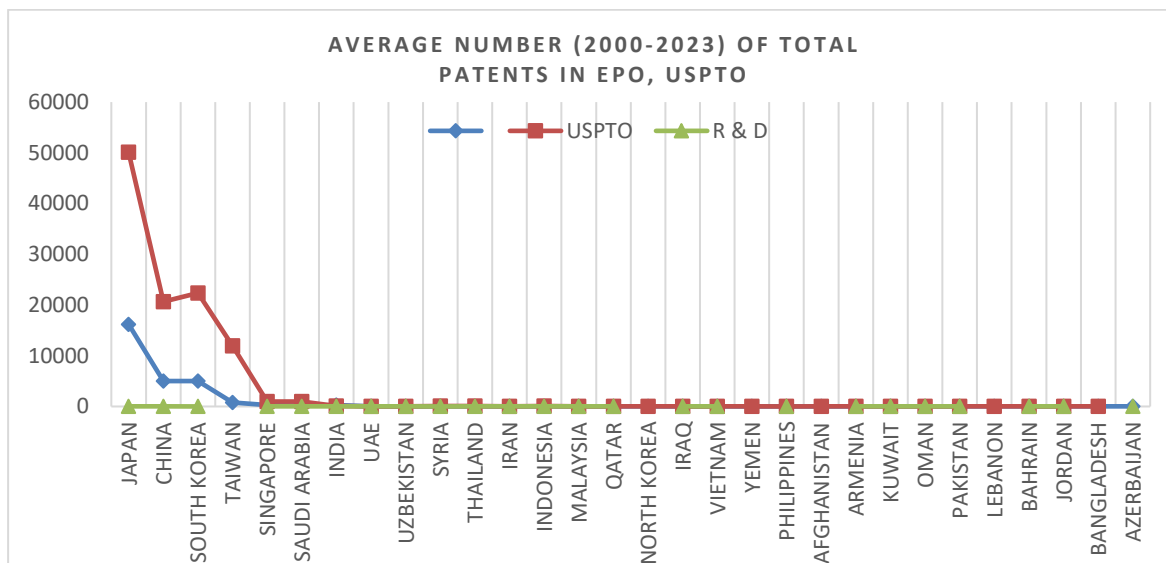


Figure 3. Average Number (2000 - 2023) of Total Patents in EPO and USPTO

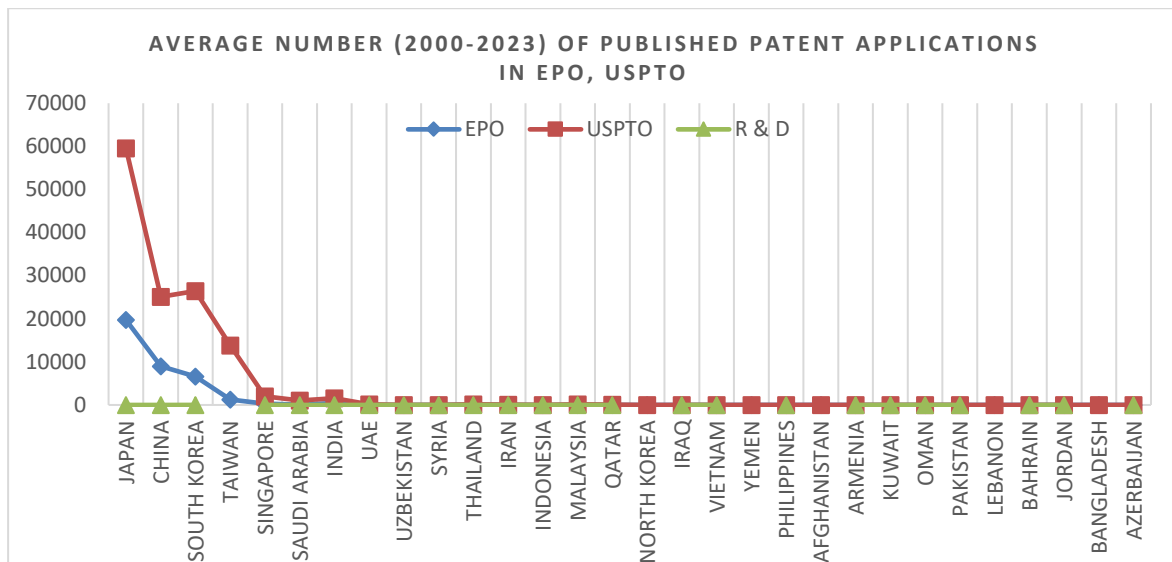


Figure 4. Average Number (2000-2023) of Published Patent Application in EPO and USPTO

Figure 3 reveals that the total patents granted at the European Patent Office (EPO) and the United States Patent and Trademark Office (USPTO), along with Research & Development (R&D) expenditure as a percentage of GDP, reveals significant disparities among countries from 2000 to 2023. Nations like Japan (EPO: 16197, USPTO: 50092.33, R&D: 3.27%), South Korea (EPO: 4986.7, USPTO: 22384.44, R&D: 3.67%), and China (EPO: 5005.11, USPTO: 20659.44, R&D: 1.78%) exhibit substantially higher numbers of total patents granted at both patent offices, coupled with significant R&D expenditure. Countries such as Singapore (EPO: 302.11, USPTO: 942.88, R&D: 2.08%), Saudi Arabia (EPO: 140.67, USPTO: 1002.44, R&D: 0.31%), and Malaysia (EPO: 26.11, USPTO: 26.22, R&D: 1.01%) demonstrate moderate levels of total patents and R&D expenditure. However, several nations, including the UAE, Uzbekistan, Syria, Thailand, Iran, Indonesia, Qatar, North Korea, Iraq, Vietnam, Yemen, Philippines, Afghanistan, Armenia, Kuwait, Oman, Pakistan, Lebanon, Bahrain, Jordan, Bangladesh, and Azerbaijan, exhibit relatively low numbers of total patents across both offices and low R&D expenditure during the same period [12,19].

Figure 4 reveals significant disparities in published patent applications at the European Patent Office (EPO) and the United States Patent and Trademark Office (USPTO), as well as Research

& Development (R&D) expenditure as a percentage of GDP among countries from 2000 to 2023. Nations like Japan (EPO: 19738.5, USPTO: 59577.22, R&D: 3.27%), China (EPO: 8957.37, USPTO: 25124.77, R&D: 1.78%), and South Korea (EPO: 6637.37, USPTO: 26421.55, R&D: 3.67%) exhibit substantially higher numbers of published patent applications at both patent offices, coupled with significant R&D expenditure. Countries such as Singapore (EPO: 298, USPTO: 1963.88, R&D: 2.08%), Saudi Arabia (EPO: 102.62, USPTO: 1026.67, R&D: 0.31%), and India (EPO: 416.12, USPTO: 1569.78, R&D: 0.74%) demonstrate moderate levels of published patent applications and R&D expenditure. However, several nations, including Uzbekistan, Syria, Yemen, Afghanistan, Armenia, Iraq, Bahrain, and others, exhibit minimum numbers of published patent applications across both offices and relatively low R&D expenditure during the same period [13,14].

Figure 5 reveals that the ratio of nanotechnology patents to nano-articles (patents per 100 articles) reveals substantial variations across countries from 2000 to 2023. Nations like Taiwan (29.32), Japan (23.43), South Korea (21.06), and North Korea (6.5) exhibit significantly higher ratios, indicating a greater emphasis on patenting nanotechnology innovations compared to research output.



Figure 5. Ratio of Nanotechnology Patents to Nano articles (The map was generated in Microsoft Excel, powered by Bing, ©GeoNames, Microsoft, Navinfo, Open Places, Open Street Map TomTom, Zenrin. We are neutral with regard to jurisdictional claims in this map).

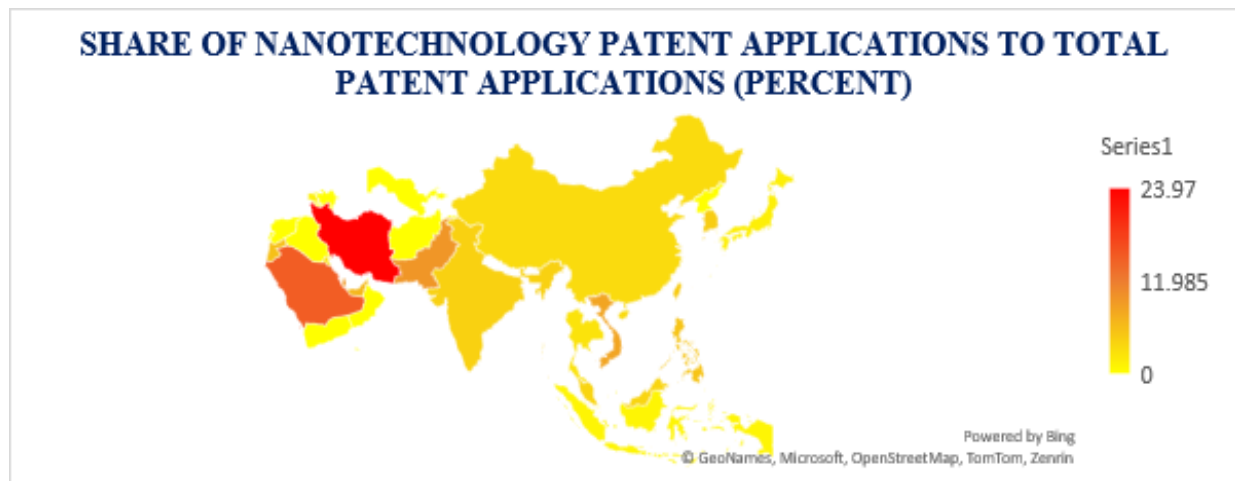


Figure 6. Share of Nanotechnology patent applications to the total patent application (Percent). (The map was generated in Microsoft Excel, powered by Bing, ©GeoNames, Microsoft, Navinfo, Open Places, Open Street Map TomTom, Zenrin. We are neutral with regard to jurisdictional claims in this map).

Countries such as Singapore (5.95), Saudi Arabia (7.56), and Indonesia (4.89) demonstrate moderate ratios, while nations like China (1.88), India (1.44), UAE (1.94), Thailand (1.5), Iran (0.58), Malaysia (3.53), Qatar (0.96), Vietnam (0.85), Yemen (3.26), Philippines (3.61), Kuwait (1.86), Oman (0.08), Pakistan (0.31), Lebanon (0.46), Jordan (0.97), Bangladesh (0.11), and Azerbaijan (1.28) have relatively lower ratios. Several countries, including Syria, Iraq, Afghanistan, Bahrain, and Armenia (0.16), have a minimum ratio, suggesting negligible or no nanotechnology patent activities during the same period [18,20,21].

Figure 6 shows the share of nanotechnology patent applications to total patent applications (in percentage), revealing significant variations across countries from 2000 to 2023. Iran (23.97%), Saudi Arabia (15.05%), Bangladesh (15.62%), and Qatar (9.5%) exhibit substantially higher shares, indicating a greater emphasis on nanotechnology patent activities relative to their overall patent applications. Countries such as Vietnam (8.31%), UAE (6.58%), Taiwan (4.76%), South Korea (4.6%), Singapore (4.27%), India (4.19%), and Malaysia (3.89%) demonstrate moderate shares, ranging from around 4% to 8%. In contrast, nations like Japan (1.49%), Thailand (2.6%), Armenia (1.25%), and Kuwait (2.83%) have

relatively minimum shares, while several countries, including China (3.34%), Uzbekistan, Syria, North Korea, Iraq, Yemen, Afghanistan, Oman, Pakistan, Lebanon, Bahrain, and Azerbaijan, have a minimum share, suggesting no nanotechnology patent applications during the period [15,21].

Figure 7 shows the share of nanotechnology patents to total patents (in percentage), which exhibits substantial variations across countries from 2000 to 2023. Iran (30.25%), North Korea (11.31%), Pakistan (11.98%), and Vietnam (9.07%) demonstrate significantly higher shares, indicating a greater emphasis on nanotechnology patents relative to their overall patent portfolios. Countries such as Saudi Arabia (14.77%), Qatar (8.93%), Oman (7.4%), and India (5.47%) exhibit moderate shares, ranging from around 5% to 15%. In contrast, nations like Japan (1.41%), South Korea (3.9%), Taiwan (4.22%), Singapore (3.42%), UAE (4.92%), Thailand (1.31%), Malaysia (3.57%), Philippines (5.29%), Kuwait (4.88%), Lebanon (0.55%), and Jordan (3.45%) have relatively minimum shares, while several countries, including China (3.1%), Uzbekistan, Syria, Indonesia, Iraq, Yemen, Afghanistan, Armenia, Bahrain, Bangladesh, and Azerbaijan, have a low share, suggesting no nanotechnology patents during the period [18,20,21].

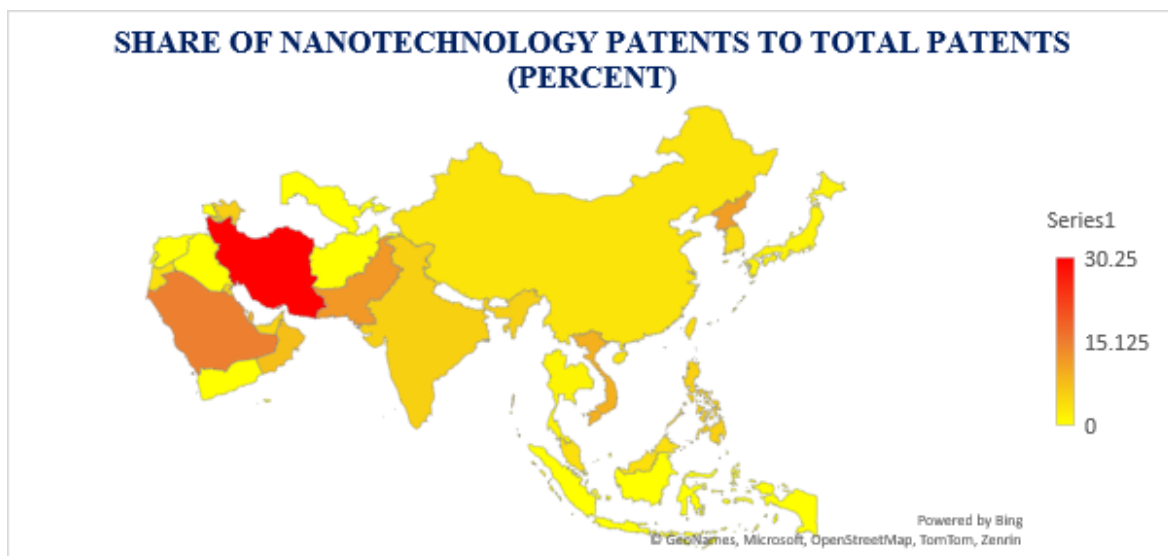


Figure 7. Share of Nanotechnology patents to total patents (per cent). (The map was generated in Microsoft Excel, powered by Bing, ©GeoNames, Microsoft, Navinfo, Open Places, Open Street Map TomTom, Zenrin. We are neutral with regard to jurisdictional claims in this map).

3.2 Empirical Investigation of the Relationship Between Research and Development Efforts and Nanotechnology Patenting Activities

3.2.1 Correlation Analysis: Examining the Degree of Concordance Between Nanotechnology Patent Filings and R&D Expenditure

A close analysis of Table 1 revealed that- EPO nanotechnology patents have a strong positive correlation (0.868) with the dependent variable, Research and Development expenditure. This indicates that as the number of EPO nanotechnology patents increases, the R&D expenditure also tends to increase. The EPO is known for its rigorous examination process and high-quality standards, which incentivise researchers

and companies to protect their nanotechnology-related innovations through the EPO patent system. The prevalence of nanotechnology patents at the EPO reflects the vibrant R&D activities in this field, particularly in Europe. GERMAN nanotechnology patents also have a strong positive correlation (0.817) with research and development expenditure, suggesting a similar relationship with EPO patents. Germany is a global leader in advanced manufacturing and engineering, focusing strongly on research and development in emerging technologies, including nanotechnology. [22]. The correlation indicates that German companies and research institutions actively engage in nanotechnology R&D and seek patent protection for their innovations through the German Patent Office [23].

Table 1. Correlation Analysis of Nanotechnology Patents and Research & Development

S. No.	Independent Variables	Value r
1.	Nanotechnology patents in EPO Office	0.868**
2.	Nanotechnology patents in the German Patent Office	0.817**
3.	Nanotechnology patents in the USPTO Office	0.793**
4.	Nanotechnology published patent applications in EPO Office, which is not granted	0.862**
5.	Nanotechnology published patent applications in the German Office, which is not granted	0.833**
6.	Nanotechnology published patent applications in the USPTO Office, which were not granted.	0.799**
7.	Total patents in EPO Office	0.768**
8.	Total patents in the USPTO Office	0.785**
9.	Published patent applications in EPO Office	0.768**
10.	Published patent applications in the USPTO Office	0.785**
11.	Ratio Of Nanotechnology Patents to Nanoparticles	0.545**
12.	Share Of Nanotechnology Patent Applications to Total Patent Application (Percent)	0.001
13.	Share Of Nanotechnology Patent to Total Patent (Percent)	-0.062

** - Significant at 0.01 per cent level

A close analysis of Table 1 revealed that EPO nanotechnology patents have a strong positive correlation (0.868) with the dependent variable, Research and Development expenditure. This indicates that as the number of EPO nanotechnology patents increases, the R&D expenditure also tends to increase. The EPO is known for its rigorous examination process and high-quality standards, which incentivise researchers and companies to protect their nanotechnology-related innovations through the EPO patent system. The prevalence of nanotechnology patents at the EPO reflects the vibrant R&D activities in this field, particularly in Europe. GERMAN nanotechnology patents also have a strong positive correlation (0.817) with research and development expenditure, suggesting a similar relationship with EPO patents. Germany is a global leader in advanced manufacturing and engineering, focusing strongly on research and development in emerging technologies, including nanotechnology. [22]. The correlation indicates that German companies and research institutions actively engage in nanotechnology R&D and seek patent protection for their innovations through the German Patent Office [23].

USPTO nanotechnology patents have a relatively strong positive correlation (0.793) with Research and development expenditure, though slightly lower than the correlations with EPO and GERMAN patents. The active pursuit of nanotechnology patents in the United States is closely linked to substantial investments in R&D, as companies and researchers seek to protect their intellectual property and commercialize their nanotechnology-related innovations [24].

The higher levels of R&D spending are associated with higher volumes of nanotechnology patent applications, even for those that

do not ultimately result in granted patents. EPO nanotechnology patent applications (not granted) have a strong positive correlation (0.862) with the dependent variable, Research and Development expenditure. This indicates that as the number of EPO nanotechnology patent applications increases, the R&D expenditure also tends to increase. GERMAN nanotechnology patent applications (not granted) also have a strong positive correlation (0.833) with research and development expenditure, suggesting a similar relationship with EPO patent applications [25]. USPTO nanotechnology patent applications (not granted) have a relatively strong positive correlation (0.799) with Research and development, though slightly lower than the correlations with EPO and GERMAN patent applications. These positive correlations indicate that the number of nanotechnology patent applications can indicate the level of innovation and technological development in this field [26]. Even if the patents are not yet granted, the application process suggests that companies and researchers actively engage in R&D activities, which would typically lead to higher R&D expenditures. The strong positive correlations indicate that the number of nanotechnology patent applications, especially in the EPO and German patent systems, can be a reliable predictor of R&D expenditure in this field. The positive correlations between nanotechnology patent applications and R&D expenditure indicate that the level of patenting activity in this field is closely linked to the level of research and development investment. There is a positive correlation between both independent variables (total granted patents in EPO and USPTO offices) and the dependent variable (research and development expenditures). This means that there is a positive association between the number of granted patent applications and the amount of money spent on research and

development [27].

Patents often represent the product of successful R&D efforts. Companies and research institutions may invest heavily in R&D to develop new technologies and inventions, ultimately seeking patent protection for their creations. Higher R&D expenditure can lead to a greater number of patentable inventions. The correlation between published patent applications in the EPO Office and R&D activities is 0.768, which is statistically significant at the 0.01 level. This indicates a strong positive relationship between the number of published patent applications in the EPO and the level of R&D investments [28]. The correlation between published patent applications in the USPTO Office and R&D activities is 0.785, which is also statistically significant at the 0.01 level. This suggests a strong positive relationship between the number of published patent applications in the USPTO and the level of R&D investments. The strong positive correlation between published patent applications and R&D activities in both the EPO and USPTO offices can be attributed to the fact that R&D investments are a crucial driver of innovation and technological development. Increased R&D efforts often lead to the generation of new ideas and inventions, which are then translated into patent applications. The similarities in the correlation coefficients for the EPO and USPTO offices suggest that the relationship between patent applications and R&D is relatively consistent across different patent jurisdictions. This indicates that R&D investments are a significant factor in shaping the innovation landscape globally [29,30].

The value of 0.545, which is statistically significant at the 0.01 level. This indicates a strong positive correlation between the ratio of nanotechnology patents to nanoarticles and research and development activities. The positive correlation suggests that as the ratio of nanotechnology patents to nanoarticles increases, the research and development efforts in this field also tend to increase. This implies that the development and protection of intellectual property through patents are closely linked to the ongoing research and innovation in nanotechnology. The Value r of 0.001, which is statistically significant at the 0.01 level. This indicates a strong positive correlation between the share of nanotechnology patent applications and research and development expenditure. The positive correlation suggests that as the share of nanotechnology

patent applications increases relative to total patent applications, the research and development efforts in this field also tend to increase. This implies that the patenting of nanotechnology inventions is closely linked to the ongoing research and innovation activities in this domain [31,32].

The correlation analysis between the "Share of Nanotechnology Patent to Total Patent (Percent)" and research and development. The correlation coefficient (r) is -0.062, which is statistically significant at the 0.05 per cent level [33].

The negative correlation coefficient indicates an inverse relationship between the share of nanotechnology patents and research and development expenditure. This suggests that as the share of nanotechnology patents relative to total patents increases, the investment in research and development tends to decrease. The primary purpose of this analysis is to understand the relationship between the relative importance of nanotechnology patents and the investment in R&D activities. Exploring this correlation can reveal insights into the dynamics between patent-driven innovation and the allocation of resources for technological exploration in the nanotechnology domain [34,35].

3.2.2 Regression Analysis: Econometric Modeling of the Influence of R&D Investments on Nanotechnology Patent Generation

Table 2. provides the linear regression coefficients and the standard errors, t-values, and significance levels for the different models. These statistical measures help to understand the strength and significance of the relationship between the independent variables (nanotechnology patents) and the dependent variable (R&D expenditure).

The coefficient for EPO is 0.033, which indicates that a one-unit increase in EPO nanotechnology patents is associated with a 0.033 increase in R&D expenditure, holding other variables constant. The standardised Beta coefficient for EPO is 1.058, suggesting a relatively strong positive relationship between EPO patents and R&D expenditure. The number of nanotechnology patent applications, particularly in the EPO and USPTO, significantly predicts R&D expenditure in this field.

Table 2. Regression Analysis of Nanotechnology Patents and Research & Development

S.N.	Independent Variables	Dependent Variables	B	S.E.	Beta	t	Sig.
1.	Nanotechnology patents in EPO Office	Research and Development expenditure	0.033	0.011	1.058	3.017	0.006
2.	Nanotechnology patents in German Patent Office		-0.243	0.341	-0.298	-0.712	0.483
3.	Nanotechnology patents in USPTO Office		0.001	0.002	0.105	0.364	0.719
4.	Nanotechnology published patents application Bin EPO Office which is not granted		0.010	0.005	0.605	1.909	0.002
5.	Nanotechnology published patents application in German Office which is not granted		0.11	0.059	0.055	0.178	0.860
6.	Nanotechnology published patents application in USPTO Office which is not granted.		0.008	0.006	0.244	1.349	0.189
7.	Total patents in EPO Office		-4.005	0.000	-0.174	-0.252	0.803
8.	Total patents in the USPTO Office		7.110	0.000	0.956	1.388	0.176
9.	Published patent applications in EPO Office.		0.072	0.043	2.418	1.682	0.10
10.	Published patent applications in the USPTO Office		-0.034	0.017	-5.366	-2.017	0.05
11.	Ratio of Nanotechnology Patents to Nanoarticles		0.018	0.034	0.148	0.520	0.60
12.	Share Of Nanotechnology Patent Applications to Total Patent Application (Percent)		0.017	0.015	0.112	1.143	0.267
13.	Share of Nanotechnology Patent to Total Patent (Percent)		0.000	0.013	-0.001	-0.010	0.99

This study demonstrates the strong positive relationship between nanotechnology patents and research and development activities across major patent offices. The findings suggest that the active pursuit of nanotechnology patents, particularly at the EPO, German Patent Office, and USPTO, is closely linked to the substantial investments in R&D in this rapidly evolving field. Nanotechnology patent applications not yet granted in the EPO office have a positive and statistically significant relationship with Research and Development expenditure [36]. The unstandardised coefficient (B) is 0.010, indicating that a one-unit increase in EPO nanotechnology patent applications is associated with a 0.010 increase in R&D expenditure, holding other variables constant. Nanotechnology patent applications that still need to be granted in the GERMAN office also have a positive and statistically significant relationship with Research and development expenditure. The unstandardised coefficient (B) is 0.011, suggesting that a one-unit increase in German nanotechnology patent applications is associated with a 0.011 increase in R&D expenditure [37]. Nanotechnology patent applications that are yet to be granted in the USPTO office have a positive but relatively smaller relationship with research and development expenditure, with an unstandardised coefficient (B) of 0.008. The more patent applications are filed, the more it indicates that companies and researchers are actively engaged in developing new nanotechnology-based technologies and products. This increased investment in R&D, as reflected by the patent application process, is then likely to be accompanied by higher R&D expenditures [38].

The stronger relationships observed for EPO and German patent applications compared to USPTO applications suggest that the European and German innovation ecosystems may be more closely tied to R&D spending in the nanotechnology sector. The B value of -4.005 indicates that for every unit increase in R&D expenditure, there is a decrease of 4.005 in the total number of patents granted by the EPO office. This suggests that higher R&D expenditure is associated with fewer patents being granted by the EPO. The negative B value signifies an inverse relationship between R&D expenditure and the number of ungranted patents in the EPO office [39]. This means that increased R&D efforts do not necessarily lead to more granted patents but rather fewer granted patents. The statistical significance of this relationship is indicated by the t-value of -0.252, which is below the commonly used threshold of significance (typically $p < 0.05$), suggesting a statistically significant relationship. The B value in the USPTO Office is 7.110, which indicates that for every unit increase in R&D expenditure, there is an increase of 7.110 in the total number of patents granted by the USPTO office. This suggests that higher R&D expenditure is associated with more patents being granted by the USPTO. The positive B value signifies a direct relationship between R&D expenditure and the number of ungranted patents in the USPTO office. This means that increased R&D efforts lead to more granted patents rather than fewer. The statistical significance of this relationship is indicated by the t-value of 1.388, which is also below the commonly used threshold of significance (typically $p < 0.05$), suggesting a statistically significant relationship [40,41].

The regression analysis indicated that R&D expenditures significantly predict ungranted patents, even when considering both the EPO and USPTO offices. The negative B value for the EPO office suggests that higher R&D spending is associated with fewer granted patents. In contrast, the positive B value for the USPTO office suggests that higher R&D spending is associated with a higher number of granted patents. For the independent variable, "Published patents application in EPO Office," the coefficient (B) is 0.072, with a standard error of 0.043, a beta value of 2.418, a t-statistic of 1.682, and a significance level of 0.109. This suggests a positive relationship between published patents at the EPO and research and development, but the relationship is not statistically significant at the conventional 0.05 level. For the second independent variable, "Published patents application in USPTO Office," the coefficient (B) is -0.034, with a standard error of 0.017, a beta value of -5.366, a t-statistic of -2.017, and a significance level

of 0.058. This indicates a negative relationship between published patents at the USPTO and expenditure, and the relationship is statistically significant at the 0.05 level [42].

The regression analysis shows a positive and statistically significant coefficient (B = 0.018) for the independent variable, "Ratio of Nanotechnology Patents to Nanoarticles." This indicates that as the ratio of nanotechnology patents to nanoarticles increases, the research and development expenditure also tends to increase. The standard error (S.E.) of 0.034 and the t-statistic of 0.520 suggest that the estimated relationship between the independent and dependent variables is robust and statistically significant at the 0.60 level. These findings indicate that the patenting activity in nanotechnology is closely linked to the ongoing research and development efforts in this field [43].

The regression analysis shows a positive and statistically significant coefficient (B = 0.017) for the independent variable, "Share of Nanotechnology Patent Applications to Total Patent Application (Percent)." This indicates that as the share of nanotechnology patent applications increases relative to total patent applications, the research and development expenditure also tends to increase. The standard error (S.E.) of 0.015 and the t-statistic of 1.143 suggest that the estimated relationship between the independent and dependent variables is robust and statistically significant at the 0.267 level. This patenting activity in nanotechnology is closely linked to the ongoing research and development efforts in this field. The increased focus on protecting intellectual property through nanotechnology patents drives investment in further exploration and innovation as companies and researchers seek to capitalise on their technological advancements. The linear regression analysis where the dependent variable is "Research and Development" (expenditure) and the independent variable is "Share of Nanotechnology Patent to Total Patent (Percent)". The coefficient (B) for the independent variable is 0.013, and the p-value (Sig) is 0.99. A coefficient of 0.013 suggests that for every one-unit increase in the share of nanotechnology patents, there is a corresponding increase of 0.013 units in research and development expenditure [44]. However, it's important to consider the p-value. A p-value of 0.99 is greater than the standard significance level of 0.05. This means that we cannot reject the null hypothesis: there is no statistically significant relationship between the share of nanotechnology patents and research and development expenditure. In other words, the observed association between the two variables could be due to chance.

3.2.3 Establishing Robust Data Reliability: A Cronbach's Alpha Assessment of Nanotechnology Patenting and R&D Investments

The reliability of the data was assessed using Cronbach's alpha. Cronbach's alpha is a measure of internal consistency, which determines how closely related a set of items (14 items in this study) are as a group. The Cronbach's alpha calculated for the independent and dependent variables in this study was 0.734, which indicates a high level of internal consistency and reliability. The reliability analysis was conducted to ensure the consistency and stability of the data used in the statistical analyses, such as the correlation and regression analyses. A Cronbach's alpha value of 0.734 suggests that the measures used in this study, including the nanotechnology patent data, R&D expenditure, and other variables, are reliable and can be confidently used to conclude the relationships between these factors. The high reliability of the data strengthens the validity of the findings and allows for more robust interpretations of the relationships observed in the study. It suggests that the patterns and trends identified in the analysis are not due to random or inconsistent factors but rather reflect the true underlying relationships between nanotechnology patenting, R&D investments, and other relevant variables in the Asian context [45,46].

The reliability analysis and the comprehensive quantitative methods employed in this study, such as correlation, regression, and

trend analyses, contribute to the overall rigour and credibility of the research findings. This ensures that the insights generated from this study can be relied upon to inform decision-making, policy development, and strategic planning in nanotechnology innovation and research.

4. Discussion

The comprehensive data analysis reveals significant disparities in patent activities, particularly in nanotechnology, across various Asian countries from 2000 to 2023 [47,48]. Several key findings and implications emerge from the data.

Firstly, a robust positive correlation is observed between higher research and development (R&D) expenditure as a percentage of GDP and increased patent application numbers across major patent offices, such as the European Patent Office (EPO), German Patent Office, and United States Patent and Trademark Office (USPTO) [49,50]. Nations like Japan, South Korea, China, and Taiwan, which allocate substantial resources towards R&D activities, exhibit significantly higher patent application and grant numbers, underscoring the pivotal role of R&D investments in fostering innovation and intellectual property generation [51,52].

The relationship between research and development (R&D) expenditure and patent output is well-established [53]. However, recent studies suggest a more nuanced picture [54]. While R&D spending is undeniably important [55], other factors can significantly influence a nation's patent output [56].

Strategic industry prioritisation, targeted innovation policies, access to skilled human resources, and overall economic strength can all play a crucial role [57]. The success stories of countries like Singapore, Saudi Arabia, and India, with moderate patent activities and R&D expenditure, exemplify how focused efforts and strategic investments can yield significant results [58].

Furthermore, data on the ratio of nanotechnology patents to research publications (patents per 100 articles) and the share of nanotechnology patent applications within a country's total patent applications reveal substantial variations in the strategic prioritisation of nanotechnology [59]. Countries like Taiwan, Japan, South Korea, and Iran exhibit significantly higher ratios and shares, suggesting a more concentrated focus on patenting nanotechnology innovations relative to their research output and overall patent portfolios [60].

These disparities in nanotechnology patent activities could be attributed to factors such as robust innovation ecosystems, strong intellectual property frameworks [61], targeted research programs and specific technological capabilities in this field. Conversely, countries with lower or zero shares may need help in developing nanotechnology innovations or need more strategic focus in this domain [48].

Addressing the observed disparities in patent activities and the strategic prioritisation of nanotechnology across Asia requires a multifaceted approach [62]. This may include continuous efforts to promote R&D investments, foster industry-academia collaborations (16), implement policies encouraging and incentivising innovation across various sectors, and strengthen intellectual property protection mechanisms [63]. Furthermore, regional cooperation, knowledge sharing, and capacity-building initiatives hold significant promise in enabling less technologically advanced nations to benefit from the expertise and experiences of leading Asian patent-generating countries [60]. Such collaborative efforts could contribute to bridging the innovation and intellectual property (IP) creation gaps across the region, fostering a more conducive environment for all [60,63].

5. Summary and Future Prospects

The comprehensive analysis presented in this study unveils significant disparities in nanotechnology patenting activities and strategic prioritisation across various Asian countries. While nations

like Japan, South Korea, and China exhibit robust patenting trends coupled with substantial R&D investments, others need to catch up, indicating untapped potential and challenges in capitalising on the transformative potential of nanotechnology. To bridge these gaps and foster a more inclusive and dynamic nanotechnology innovation ecosystem in the Asian region, several key prospects emerge.

Firstly, promoting regional cooperation and knowledge-sharing initiatives could prove instrumental in enabling less technologically advanced nations to benefit from the expertise and experiences of leading patent-generating countries. Such collaborative efforts could involve joint research programs, capacity-building initiatives, and platforms for knowledge exchange, ultimately contributing to disseminating best practices and harmonising intellectual property (IP) frameworks across the region. Concurrently, strengthening IP protection mechanisms and streamlining patent application processes would create a more conducive environment for researchers, companies, and institutions to safeguard their nanotechnology-related inventions and innovations.

Furthermore, targeted policies and funding programs geared towards nanotechnology research, development, and commercialisation could play a pivotal role in fostering strategic prioritisation and focused efforts in this domain. Initiatives such as dedicated research centres, industry-academia collaborations, tax incentives, and support for technology transfer and entrepreneurship could catalyse the translation of R&D investments into tangible patentable innovations.

Investing in capacity-building and human resource development is also crucial to sustaining long-term growth and competitiveness in nanotechnology. Establishing specialised education and training programs, attracting and retaining top talent, and promoting interdisciplinary research collaborations would build a skilled workforce capable of effectively capitalising on R&D investments and driving nanotechnology advancements.

Finally, continuous monitoring and assessment of patenting trends, R&D investments, and strategic priorities across Asian countries are imperative in this rapidly evolving field. Regular evaluations and benchmarking exercises inform data-driven decision-making, enabling policymakers and stakeholders to proactively adapt their strategies and seize emerging opportunities.

By addressing these prospects, Asian countries could unlock their full potential in nanotechnology innovation, fostering a more robust, collaborative, and inclusive ecosystem that drives technological progress, economic growth, and sustainable development in the region.

6. Conclusion

These findings emphasise the crucial role of R&D investment and strategic policies in driving innovation and patenting activity. While leading Asian nations like Japan and South Korea excel in both R&D and patenting, other countries stand to gain from targeted efforts and regional collaboration. By fostering R&D, industry-academia partnerships, and strong intellectual property frameworks, Asian countries can bridge the innovation gap and create a more dynamic environment for technological progress, particularly in cutting-edge fields like nanotechnology.

Author Contributions

Conceptualisation, A.V.; writing-original draft preparation, A.V., A.W.; writing-review and editing, A.V., P.W., A.G., and A.W; visualisation, A.V. All authors have read and agreed to the published version of the manuscript.

Ethics approval and consent to participate

The authors followed the required ethics in preparing this manuscript. We used secondary data, which doesn't require ethics approval for data collection.

Consent for publication

This study used secondary data and thus, the authors did not collect the data directly of which informed consent to participate is applicable.

Competing interests

The authors declare no competing interests

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