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DEVELOPMENT OF MANAGEMENT MECHANISMS FOR ENTERPRISE INNOVATION AND INVESTMENT ACTIVITY IN THE CONTEXT OF A TECHNOLOGICAL SOVEREIGNTY STRATEGY

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Abstract. *Technological sovereignty has become a strategic objective for economies seeking to reduce dependence on external sources of technology, yet the mechanisms that link innovation and investment policy to measurable outcomes remain unevenly understood. This study examines how five Asian economies: China, Japan, South Korea, India and Singapore – manage innovation and investment activity between 2021 and 2024, and how effectively they convert research spending into high-technology exports. Data were drawn from open international sources, including the World Bank, WIPO and UNESCO. Compound annual growth rates were computed for nine indicators, an index of technological sovereignty was constructed from normalised measures of R&D intensity, patent applications and high-technology exports, and a coefficient of innovation-investment return was calculated for each country. The results show that China leads the index at 0.817 but returns a negative coefficient of -1.59 , indicating that exports fell while research spending rose. South Korea combines high R&D intensity with moderate positive returns. Singapore achieves the highest coefficient of 17.62 on a small research base. India records the fastest growth in exports and patents from a low starting point, while Japan maintains research intensity as its economy contracts. The study concludes that technological sovereignty depends less on the volume of investment than on institutional arrangements that connect research funding, industrial policy and commercial output, and that these arrangements are transferable in principle but conditional in practice.*

Keywords: *technological sovereignty, innovation management, investment mechanisms, high-technology exports, research and development, Asian economies, industrial policy.*

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Introduction

Technological sovereignty has become a central objective of economic policy across Asia. China, Japan, South Korea, India and Singapore rank among the world's largest investors in research and development and account for a significant share of global patent activity and high-technology exports. Each has adopted national programmes linking innovation funding, industrial policy and investment regulation to the goal of reducing dependence on foreign technology. Their experience offers material for other countries building or reforming mechanisms of innovation and investment management.

This study examines how these mechanisms operate and how effectively they convert research spending into commercial and technological outcomes. The purpose is to analyse the approaches of the five economies, identify what they share, and assess what can be transferred to other national contexts.

Three tasks follow. The first is to examine the experience of China, Japan, South Korea, India and Singapore between 2021 and 2024. The second is to identify the mechanisms common to the economies that perform best on the indicators used here. The third is to determine which mechanisms can be applied elsewhere and under what conditions.

The object of the study is innovation and investment activity at the national level in the five Asian economies. The subject is the set of management mechanisms through which this activity is organised, funded and directed toward technological sovereignty.

Literature Review

Theoretical foundations: innovation, investment and the mechanisms of strategic choice

The literature on innovation and investment management has long moved beyond the question of whether firms should innovate. The pressing question now concerns the internal mechanisms through which external pressures, strategic intentions and resource commitments are translated into innovation outcomes. This section reviews fifteen recent studies that collectively map the field along four interrelated lines: the strategic mediation of external pressures into innovation; the role of managerial cognition and governance in shaping investment decisions; the mechanisms linking investment to sustainable development; and the regional and institutional contexts – particularly Asian economies in which these mechanisms operate. Together, these studies frame the analytical space for the present research on innovation-investment management mechanisms under technological sovereignty strategies.

External pressures, strategy and innovation outcomes

A first strand of research examines how firms convert external pressures into innovation. Manresa-Marhuenda et al. (2025) address a gap that runs through much of the eco-innovation literature: while external pressures from regulators, stakeholders, technology, markets and rivals are widely recognised as drivers of eco-innovation, the internal mechanisms that transform these pressures into actual innovation remain under-examined. Using structural equation modelling on data from 102 Spanish footwear companies, they demonstrate that a proactive environmental strategy functions as the mediating internal mechanism. This finding matters because it establishes strategy not as a passive response to external pressure but as the active organisational filter through which pressure becomes innovation. The implication for the present study is direct: mechanisms of innovation-investment management cannot be reduced to the allocation of funds, since they involve the strategic interpretation of external signals.

Wei (2025) advances this argument from the opposite direction, examining what happens when strategic interpretation fails. Drawing on time-oriented theory and panel data from publicly listed Chinese firms on the Shanghai and Shenzhen exchanges between 2010 and 2023, the study shows that managerial myopia substantially hinders digital innovation. The mechanism runs through deviant strategy: myopic managers deviate from strategies that would benefit long-term growth, most visibly by reducing research and development investment. Two moderating findings complicate the picture. Intense market competition mitigates the negative effect of managerial myopia, whereas government subsidies may exacerbate it. Economic policy uncertainty, meanwhile, alleviates the constraint that myopia imposes on digital innovation. For a study concerned with management mechanisms under technological sovereignty strategies, this is a cautionary result: public financial support does not automatically translate into innovation if the internal governance mechanism is biased toward short-term outcomes.

Rahmiyanti et al. (2025) offer a processual account of the same translation problem in a different setting. Studying Indonesian MSMEs through a multiple-case design with abductive logic, they find that management accounting practices do not affect entrepreneurial performance directly. Instead, accounting information first creates visibility into the state of the business, is then interpreted as opportunity or problem, shapes innovation strategy, passes through experimentation, and only then informs decisions to scale or discontinue. The authors conceptualise this as an accounting-to-innovation translation mechanism and introduce the notion of hybrid management accounting practices that blend formal and informal routines. The study is important for the present

review because it shows that the mechanism linking information to innovation is a dynamic process rather than a statistical relationship a distinction that is often lost in quantitative work.

Managerial cognition, leadership and the governance of green innovation

A second strand focuses on the actors who operate these mechanisms. Khan, Khan and Mehmood (2025), surveying 306 employees in Chinese software firms, examine how digital leadership shapes the internal green organisational climate and, through it, employees' green innovative behaviours. Strategic agility strengthens these effects, suggesting that firms with greater agility are better positioned to convert leadership initiatives into tangible sustainable innovation. The study's contribution lies in specifying the organisational climate as the mediating mechanism rather than treating leadership as a direct cause.

Chang and Wang (2025) examine the Vietnamese manufacturing sector against the backdrop of the global trade war and the associated shift of supply chains toward Southeast Asia. Their empirical analysis shows that green innovation positively affects corporate sustainability performance and green purchasing; green buying behaviour mediates between innovation and performance; and counterintuitively excessive environmental management readiness negatively moderates the relationship between green buying behaviour and sustainability. The finding that too much management readiness can hinder sustainability efforts is a useful corrective to the assumption that more institutional capacity is always better. It also resonates with Wei's (2025) result on government subsidies, pointing to a broader pattern in which well-intentioned support mechanisms can produce adverse effects when they are not aligned with firms' actual innovation capacity.

Khan et al. (2025) approach green technological innovation from the labour market side, using primary data from 384 respondents in developing economies. They find that green technology adoption contributes to job creation and economic growth, with renewable energy, electric vehicles and waste management showing the strongest employment potential. Green manufacturing, by contrast, faces barriers related to automation and capital intensity. The study identifies skill shortages and training costs as persistent obstacles, and places government incentive policies at the centre of industrial transformation. Its alignment with Schumpeterian innovation theory connects this empirical work to a longer tradition in which innovation is understood as a process of creative destruction requiring institutional support.

Investment, digital transformation and post-investment mechanisms

A third strand addresses investment directly. Yang (2024) uses panel regression on A-share listed companies in Shanghai and Shenzhen from 2012 to 2022 to test whether digital transformation affects corporate innovation investment. The answer is affirmative, and the effect operates through three channels: increasing human capital, reducing surplus management, and lowering cash holdings. The study is significant because it identifies concrete mediating variables rather than asserting a general relationship between digitalisation and innovation.

Shen (2025) reviews the literature on post-investment management in venture capital, examining monitoring, strategic support, resource provision and exit planning as mechanisms for fostering startups' sustainable development. The findings are nuanced: post-investment management raises survival rates and accelerates revenue growth, but excessive intervention correlates with reduced research and development investment. Governance quality is positively linked to long-term performance.

Regional and institutional contexts: Asia as a laboratory

A fourth strand situates these mechanisms in specific regional and institutional settings. Xu (2023a) analyses the impact of financial market volatility on Chinese investment in Southeast Asia, examining how volatility affects portfolio value and investor behaviour, and reviewing the strategies investors use to cope with uncertainty. The paper's contribution is largely synthesising rather than empirical, but it usefully maps the factors: political, economic and technological, that shape investment decisions in the region. Xu (2023b) complements this with an analysis of technology transfer and intellectual property protection in Chinese investment in Southeast Asia, identifying cultural differences, legal environments and uncertain intellectual property protection as

challenges, while noting that technology transfer opens access to new markets and accelerates innovation cycles.

Sun and Wang (2025) apply a PESTEL framework to compare investment environments for Chinese auto parts enterprises in Mexico and Southeast Asia. Their conclusion is that the two regions suit different strategic profiles: Mexico, with its proximity to North American markets and free trade agreement networks, favours high-value-added and technology-intensive enterprises, while Southeast Asian nations appeal through lower labour costs, policy flexibility and market diversification. The authors propose differentiated strategies – supply chain coordination and smart manufacturing in Mexico, localised operations and environmental responsibility in Southeast Asia.

Yan, Hong and Hu (2025) examine knowledge management practices across four cross-sector cases in developed Asia, identifying four socio-technical mechanisms behind successful implementation: codifying tacit knowledge into explicit routines; enabling collaboration through digital platforms; embedding knowledge management into audits and regulatory standards; and reinforcing adoption through leadership and culture. The study extends socio-technical maturity models based on governance, and its emphasis on audit-ready design and phased investment is relevant to firms in less mature institutional contexts.

Sultana et al. (2025) analyse private sector engagement in e-learning in Bangladesh through a mixed-methods study of 780 stakeholders. They identify six critical success factors and report that infrastructure partnerships with balanced public-private investment sharing achieved 75% success rates, while content development collaborations improved learning outcomes by 35%. The study extends stakeholder value theory by showing how complementary value creation can be optimised across multiple stakeholder groups. Li and Yue (2025) address a different dimension of human capital, analysing the mechanisms for training professionals for China's disabled sports industry. While the sectoral focus is distant from industrial innovation, the study's diagnosis imperfect training systems, insufficient teaching staff, unclear career paths mirrors the skill shortage findings reported by Khan et al. (2025) and underscores that human capital mechanisms are a cross-cutting concern.

Synthesis and positioning of the present study

Three observations emerge from this body of work. First, the literature consistently finds that external pressures and financial inputs do not translate directly into innovation outcomes. Mediating mechanisms – environmental strategy (Manresa-Marhuenda et al., 2025), organisational climate (Khan, Khan and Mehmood, 2025), accounting-to-innovation translation (Rahmiyanti et al., 2025), post-investment governance (Shen, 2025) – determine whether resources become innovation. Second, several studies report that excessive or misaligned intervention produces negative effects: government subsidies can worsen managerial myopia (Wei, 2025), excessive environmental management readiness can hinder sustainability (Chang and Wang, 2025), and excessive post-investment intervention can reduce R&D investment (Shen, 2025). Third, the Asian context is prominent but unevenly covered. China dominates the empirical literature on managerial cognition and digital transformation; Southeast Asia appears mainly through investment environment comparisons and supply chain analyses; Japan, Korea and Singapore – central to any discussion of technological sovereignty are largely absent from this sample.

The present study addresses these gaps. It takes the mediating mechanisms identified in the literature as its point of departure but shifts the analytical focus from firm-level cognition to the national mechanisms of innovation-investment management. By examining China, Japan, South Korea, India and Singapore over the period 2021-2024, it extends the empirical base beyond the Chinese cases that dominate current research and tests whether the mechanisms described in the literature operate similarly across economies at different levels of technological development. The concept of technological sovereignty provides the strategic frame: if the literature shows that firms convert pressure into innovation through internal mechanisms, the question for national economies is whether comparable mechanisms exist at the level of innovation and investment policy, and how effectively they function.

Methods

The study compares national mechanisms of innovation and investment management across five Asian economies: China, Japan, South Korea, India and Singapore. The comparison covers the period from 2021 to 2024. A four-year window was chosen for two reasons. First, it captures the post-pandemic restructuring of innovation and investment flows, when supply chain reconfiguration and technological sovereignty policies moved to the centre of economic strategy in the region. Second, longer series are complicated by methodological breaks in national statistics, particularly in patent counting and in the treatment of research and development expenditure after 2020.

The design is a comparative, indicator-based analysis. It does not attempt to estimate causal effects. The objective is descriptive and evaluative: to establish how the five economies differ in the intensity, composition and effectiveness of their innovation-investment activity, and to draw conclusions about the mechanisms that produce these differences.

Data sources

Data were drawn from open international databases. Macroeconomic indicators: gross domestic product, foreign direct investment inflows, research and development expenditure as a share of GDP, and high-technology exports come from the World Bank Open Data platform. Patent statistics, measured as resident applications, come from the World Intellectual Property Organization IP Statistics Data Center. The Global Innovation Index scores are taken from the annual reports published by WIPO. Researcher density, expressed as researchers per million inhabitants, comes from the UNESCO Institute for Statistics. National statistical offices: the National Bureau of Statistics of China, Statistics Bureau of Japan, KOSTAT of South Korea, the Ministry of Statistics and Programme Implementation of India, and SingStat of Singapore were used to verify figures and to fill gaps where international databases lagged.

Data were drawn from the World Bank (2024b, 2024c, 2024d, 2024e), WIPO (2024a, 2024b) and the UNESCO Institute for Statistics (2024). Foreign direct investment figures were cross-checked against UNCTADstat (UNCTAD, 2024). National statistical offices the National Bureau of Statistics of China (2024), Statistics Bureau of Japan (2024), Statistics Korea (2024) and Singapore Department of Statistics (2024) were used to verify figures and fill gaps.

Two limitations of the data must be stated at the outset. Research and development expenditure in absolute terms is not directly reported for all five countries in a consistent series. It was therefore computed as the product of GDP and the research and development intensity ratio. This introduces a dependency between the two variables, and the resulting figures should be read as estimates rather than as independently measured values. Patent counts also differ in scope: China reports a very large volume of resident applications, but the share of applications that proceed to grant is lower than in Japan or South Korea. The patent indicator is therefore used as a measure of inventive activity, not of patent quality.

Indicators and calculations

Nine indicators were used. They are listed in Table 1 with their units and sources. Table 1 reports compound annual growth rates computed from World Bank (2024a-e), WIPO (2024b) and UNESCO (2024) data.

Table 1. Indicators, units and sources

Indicator	Unit	Source
GDP	billion USD	World Bank
R&D expenditure	% of GDP	World Bank, UNESCO
R&D expenditure	billion USD	computed
FDI inflows	billion USD	World Bank
High-tech exports	% of exports	World Bank
High-tech exports	billion USD	World Bank
Resident patent applications	units	WIPO
Global Innovation Index	score 0–100	WIPO
Researchers	per million inhabitants	UNESCO

Source: author's calculations based on World Bank (2024a-e), WIPO (2024b) and UNESCO (2024) data.

Three calculations were performed on this base.

The first is the compound annual growth rate, computed for each indicator and each country over the three growth periods between 2021 and 2024:

$$CAGR = \left(\frac{X_{2024}}{X_{2021}} \right)^{1/3} - 1 \quad (1)$$

CAGR - Compound Annual Growth Rate – the average annual growth rate over the period;

X_{2024} - value of the indicator in the final year (2024);

X_{2021} - value of the indicator in the initial year (2021);

$1/3$ - exponent equal to one divided by the number of growth periods (2021 → 2024 = 3 periods);

–1- subtraction of the base unit to convert the ratio into a growth rate.

This measure is used to compare the direction and speed of change across economies of very different absolute size. It is reported in percentage terms. CAGR shows how fast an indicator grew each year on average between 2021 and 2024, assuming steady growth. A value of +0.05 means 5% average annual growth; a negative value means average annual decline.

The second is an index of technological sovereignty, constructed for this study. The index combines three normalised components: research and development intensity, resident patent applications, and high-technology exports in value terms. Each component was normalised to the interval from zero to one using the min-max method across the five countries:

$$x_{norm} = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (2)$$

x_{norm} - normalised value of the indicator, scaled to the range from 0 to 1;

x - raw value of the indicator for a given country;

x_{min} - minimum raw value of the indicator across all five countries;

x_{max} - maximum raw value of the indicator across all five countries.

The index is the arithmetic mean of the three normalised components:

$$ITS = \frac{(R \& D_{norm} + Patents_{norm} + Exports_{norm})}{3} \quad (3)$$

ITS - Index of Technological Sovereignty – a composite measure from 0 to 1;

$R \& D_{norm}$ - normalised value of research and development intensity (% of GDP);

$Patents_{norm}$ - normalised value of resident patent applications;

$Exports_{norm}$ - normalised value of high-technology exports (billion USD);

3 - number of components, giving equal weight to each.

The choice of equal weights is deliberate and is acknowledged as a simplification. It reflects the absence of a theoretical basis for assigning differential importance to the three dimensions in the context of technological sovereignty, where research capacity, inventive output and the ability to commercialise technology abroad are treated as complementary rather than substitutable. The index was computed for each year from 2021 to 2024, which allows both cross-country comparison and the observation of change over time. Higher values indicate greater technological sovereignty as defined here. The index is a relative measure: it ranks the five countries against each other and does not carry absolute meaning.

The third is a coefficient of innovation-investment return, which relates the change in high-technology exports to the change in research and development expenditure over the period:

$$K = \frac{\Delta Exports}{\Delta R \& D} \quad (4)$$

K -Coefficient of innovation-investment return;

$\Delta Exports$ - change in high-technology exports (billion USD) between 2021 and 2024;

$\Delta R \& D$ - change in research and development expenditure (billion USD) between 2021 and 2024.

Both numerator and denominator are measured in billions of US dollars between 2021 and 2024. The coefficient indicates how many additional dollars of high-technology exports are associated with each additional dollar of research and development expenditure. Negative values arise when exports fall while expenditure rises, or when both fall at different rates. The coefficient is a descriptive ratio and not an estimated marginal return; it does not control for exchange rate movements, price effects or changes in the composition of exports.

Procedure

Calculations were performed in a structured spreadsheet with separate sheets for source data, intermediate calculations, index construction and ranking. Formulas were checked against source figures for each country and year. Where a source value was missing, the cell was left empty and the affected calculation was marked rather than interpolated. The 2025 values present in the original data file were excluded from all calculations, since they duplicate 2024 values in several series and appear to be projections rather than observations.

The ranking of countries was produced in two steps. First, each country was ranked on the technological sovereignty index for 2024. Second, an aggregate score was computed as the mean of four normalised indicators: the technological sovereignty index, the compound annual growth rate of research and development intensity, the coefficient of innovation-investment return, and the Global Innovation Index score. This aggregate is reported as a summary ordering and not as a composite measure with independent validity.

Limitations

Four limitations should be noted. The sample is small, with five countries and four years, which precludes statistical inference and limits the analysis to description and comparison. The technological sovereignty index rests on equal weights and on three components only; alternative specifications would produce different rankings, and the index should be read as one possible operationalisation among several. The coefficient of innovation-investment return captures a contemporaneous association and cannot support claims about causality or about the lag structure between spending and export outcomes. Finally, the five economies differ substantially in size, industrial structure and institutional history, and cross-country comparison of ratios should not be read as comparison of like units.

These limitations shape the interpretation of results. The findings are presented as patterns within the selected group of countries and period, not as general laws. Their value lies in the comparison itself: the five economies represent distinct models of state involvement in innovation and investment, and the differences between them are informative precisely because they are not adjusted away.

Results

The five economies in the sample differ by more than an order of magnitude in absolute size. China's GDP in 2024 was 18,730 billion USD, while Singapore's was 570 billion USD – a ratio of roughly 33 to 1. This disparity shapes the interpretation of every indicator that follows. Absolute values describe the scale of each economy; growth rates and normalised indices describe its dynamics and relative position. Both are reported, and both are needed.

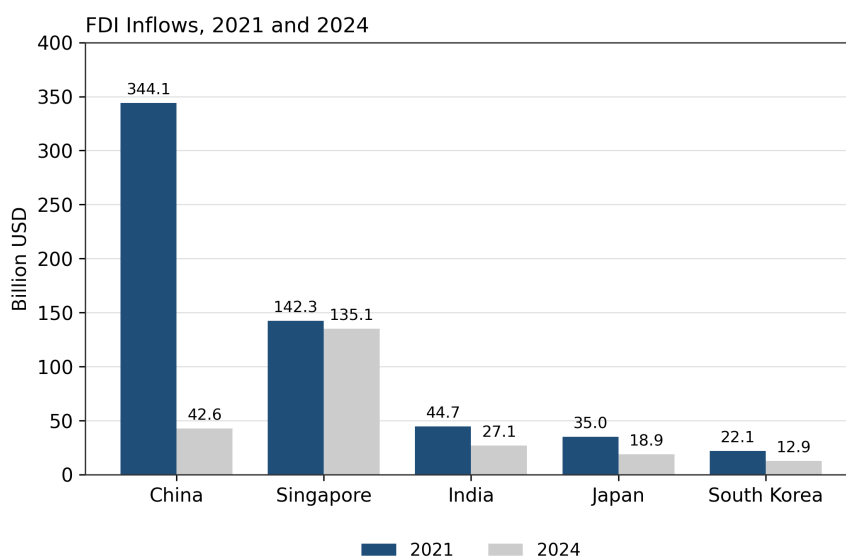
Table 1 presents the compound annual growth rates for all nine indicators over the three growth periods between 2021 and 2024. Three patterns stand out. First, India recorded the highest growth on four of the nine indicators – high-tech exports by value (+25.42%), high-tech exports as a share of total exports (+22.07%), patent applications (+21.50%) and the Global Innovation Index (+2.28%).

Table 1. Compound annual growth rate by indicator, 2021-2024, %

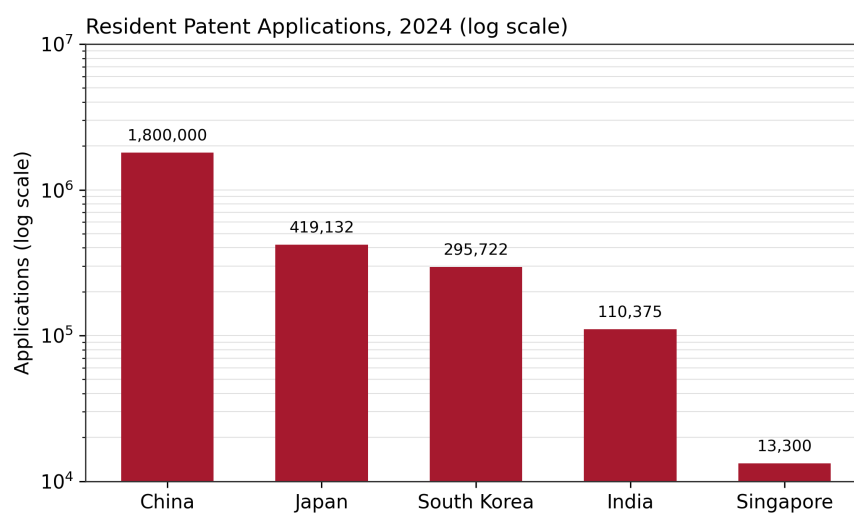
Indicator	China	Japan	South Korea	India	Singapore
GDP	+0.96	-7.09	-1.03	+5.84	+9.03
R&D expenditure (% of GDP)	+2.73	+1.71	+2.41	0.00	-2.29
FDI inflows	-50.16	-18.64	-16.47	-15.34	-1.72
High-tech exports (% of exports)	-4.55	-0.84	+0.23	+22.07	+2.63
High-tech exports (billion USD)	-2.92	-4.26	+1.96	+25.42	+5.15
Resident patent applications	+4.30	+0.51	+3.40	+21.50	-1.70
Global Innovation Index	+0.73	+0.49	+0.80	+2.28	+1.11
Researchers per million	+8.92	+0.91	+2.22	+2.50	+1.85
Government share of R&D funding	-3.13	0.00	-4.32	-7.08	-4.55

Source: author's calculations based on World Bank (2024a–e), WIPO (2024a, 2024b) and UNESCO Institute for Statistics (2024).

Second, foreign direct investment declined across all five economies, with China's contraction of 50.16% per year the steepest. Third, Japan's GDP fell by 7.09% annually, the largest decline in the group, and its R&D expenditure contracted in absolute terms even as intensity rose slightly (Fig. 1).

**Fig. 1. FDI Inflows, 2021 and 2024**

Source: World Bank (2024a).



Logarithmic scale used because the range spans two orders of magnitude.

Fig. .2. Resident Patent Applications, 2024

Source: WIPO (2024b).

Note: Logarithmic scale used because the range spans two orders of magnitude.

The contrast between China and India is instructive. China's patent applications grew at 4.30% annually from an already enormous base of 1,586,000 in 2021, while India's grew at 21.50% from a base of 61,573. The growth rates favour India; the absolute figures favour China by a factor of sixteen in 2024. The distribution is highly skewed, as Figure 2 shows.

Research and development expenditure in absolute terms

Since R&D intensity is reported as a share of GDP, absolute expenditure was computed as the product of GDP and intensity. Table 2 reports the results.

Table 2. R&D expenditure, billion USD, 2021-2024

Country	2021	2022	2023	2024	Change
China	433.16	456.17	471.37	483.23	+50.07
Japan	171.02	151.30	150.67	144.14	-26.88
South Korea	89.24	87.30	90.90	92.87	+3.63
India	20.61	21.13	22.75	24.44	+3.83
Singapore	8.54	9.23	9.23	10.32	+1.78

Source: author's calculations based on World Bank (2024b, 2024e).

$$R \& D_{(billion\ USD)} = GDP_{(billion\ USD)} \times R \& D_{(\%GDP)} \quad (5)$$

$R \& D_{(billion\ USD)}$ - Research and development expenditure expressed in billions of US dollars;

$GDP_{(billion\ USD)}$ - Gross Domestic Product in billions of US dollars;

$R \& D_{(\%of\ GDP)}$ - Research and development expenditure as a percentage of GDP.

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i \quad (6)$$

$\bar{x}$ - arithmetic mean (average) of the values;

n - number of observations;

i - index of summation;

x_i - i -th value in the series.

China's R&D spending exceeds the combined total of the other four economies. Japan is the only country in the group whose absolute R&D expenditure fell by 26.88 billion USD, or roughly 16% of its 2021 level. This decline occurred while Japan's R&D intensity rose from 3.27% to 3.44% of GDP, which means the fall in absolute spending reflects the contraction of the economy itself rather than a reduction in research effort as a share of output.

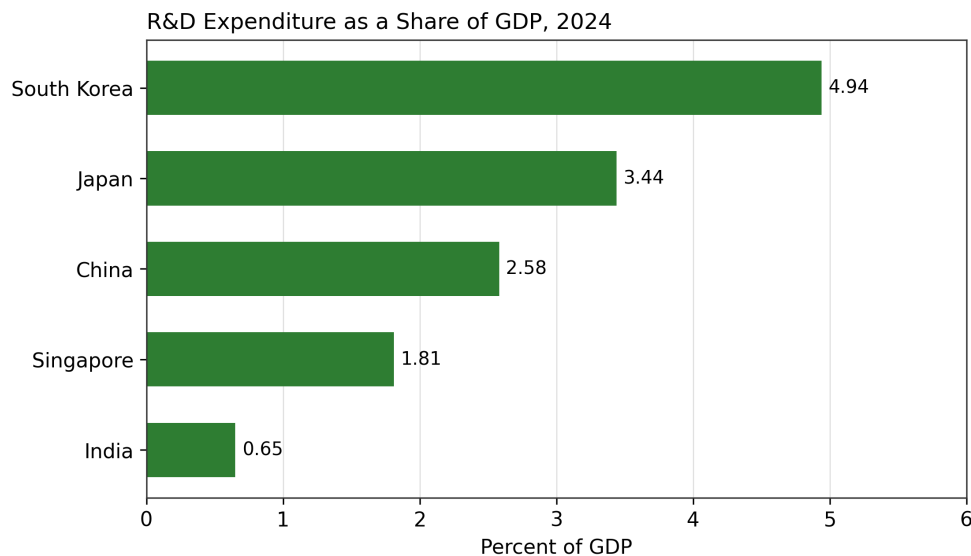


Fig. 3. R&D Expenditure as a Share of GDP, 2024

Source: World Bank (2024e).

South Korea's R&D intensity of 4.94% in 2024 is the highest in the group and among the highest in the world. The ranking by intensity is presented in Fig. 3. In absolute terms, however, its 92.87 billion USD is less than a fifth of China's. The comparison illustrates why both measures are necessary: intensity captures commitment relative to economic capacity, while absolute spending captures the scale of the research system.

Coefficient of innovation-investment return

Table 3 relates the change in high-technology exports to the change in R&D expenditure over the period.

Table 3. Coefficient of innovation-investment return (K), 2021-2024

Country	Δ Exports, billion USD	Δ R&D, billion USD	K
China	-79.63	+50.07	-1.59
Japan	-14.25	-26.88	+0.53
South Korea	+12.21	+3.63	+3.36
India	+26.69	+3.83	+6.97
Singapore	+31.37	+1.78	+17.62

Source: author's calculations based on World Bank (2024b, 2024c, 2024e).

The coefficient separates the five economies into two groups. Singapore and India converted additional R&D spending into export growth at rates of 17.62 and 6.97 respectively. South Korea shows a moderate positive return of 3.36. China and Japan show weak or negative returns: China's high-technology exports fell by 79.63 billion USD while R&D spending rose by 50.07 billion USD, producing a coefficient of -1.59. Japan's coefficient of +0.53 is arithmetically positive but reflects the fact that both exports and R&D expenditure declined, with exports falling more slowly than spending (Fig. 4).

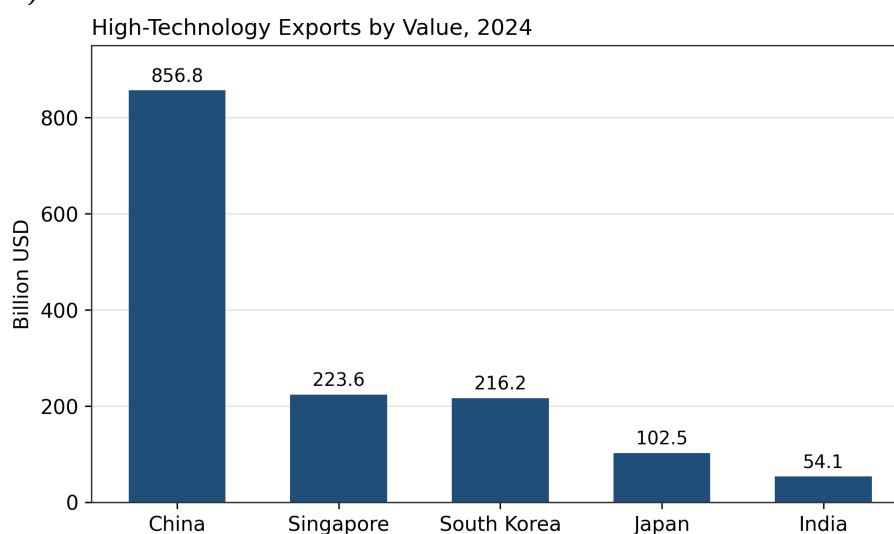


Fig. 4. High-Technology Exports by Value, 2024

Source: World Bank (2024c).

Singapore's coefficient of 17.62 should be read with care. Its high-technology exports in 2021 were 192.22 billion USD, a figure inflated by re-exports and by the presence of large electronics and pharmaceutical manufacturing operations owned by foreign multinationals. A coefficient this high reflects the structure of Singapore's trade and not necessarily the productivity of its domestic research system. The same caution applies, in reverse, to China: a substantial share of its high-technology exports consists of assembled goods whose research content is generated elsewhere, which weakens the link between national R&D spending and export value.

Normalised indicators and the index of technological sovereignty

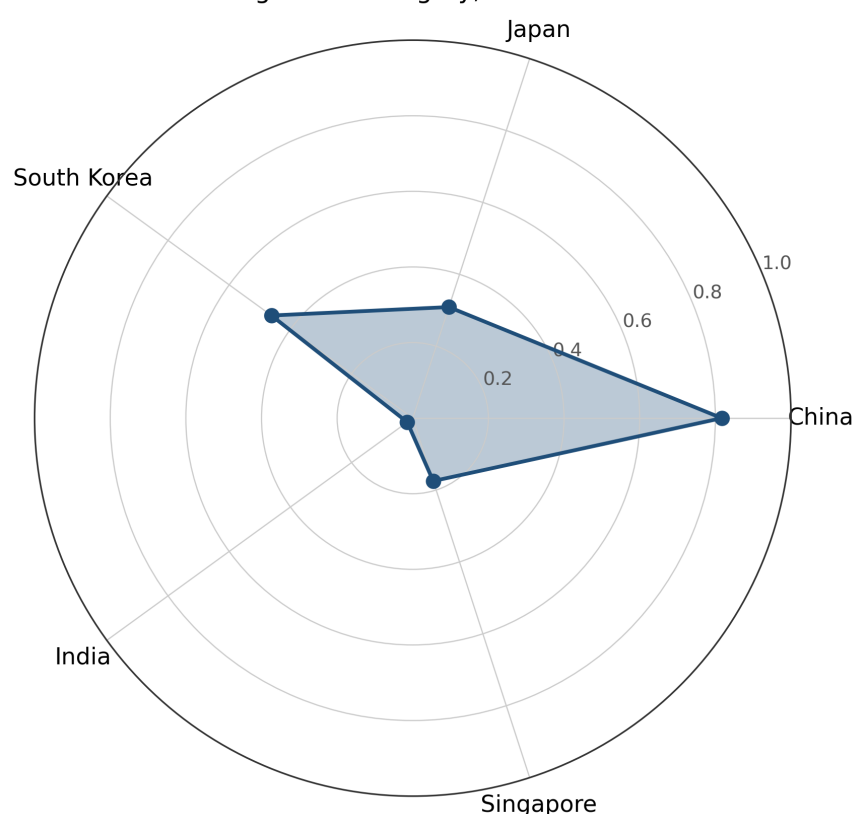
Table 4 reports the normalised values for the three components of the index in 2024. Normalisation was performed across the five countries using the min-max method, so the lowest value in each column is 0 and the highest is 1.

Table 4. Normalised components of the index of technological sovereignty, 2024

Country	R&D intensity	Patent applications	High-tech exports	ITS
China	0.450	1.000	1.000	0.817
Japan	0.651	0.227	0.049	0.309
South Korea	1.000	0.158	0.229	0.462
India	0.000	0.054	0.000	0.018
Singapore	0.269	0.000	0.256	0.175

Source: author's calculations based on World Bank (2024c, 2024e) and WIPO (2024b).

China leads on two of the three components and receives the highest index value of 0.817. South Korea leads on R&D intensity but ranks third overall at 0.462, because its patent and export volumes are small relative to China's. Japan ranks second on R&D intensity at 0.651 but fourth overall at 0.309, held back by weak export performance. India ranks last on two components and receives an index value of 0.018. The dynamics are presented in Fig. 5.

Index of Technological Sovereignty, 2024**Fig. 5. Index of Technological Sovereignty, 2024, Radar Chart**

Source: author's calculations based on World Bank (2024c, 2024e) and WIPO (2024b).

The index rewards scale. China's dominance in patent counts and export value reflects the size of its economy and its industrial base as much as the effectiveness of its innovation mechanisms. This is a property of the indicator, not a finding about policy. A country with a smaller economy cannot score highly on the patent component regardless of the quality of its institutions. The index should therefore be read alongside the coefficient of return and the growth rates, which capture dimensions that the index obscures.

Table 5. Index of technological sovereignty, 2021-2024

Country	2021	2022	2023	2024	Change
China	0.780	0.795	0.810	0.817	+0.037
Japan	0.305	0.301	0.308	0.309	+0.004
South Korea	0.448	0.452	0.457	0.462	+0.014
India	0.008	0.011	0.015	0.018	+0.010
Singapore	0.167	0.170	0.172	0.175	+0.008

Source: author's calculations based on World Bank (2024c, 2024e) and WIPO (2024b).

All five economies improved their index values over the period, but the absolute changes are small. China's gain of 0.037 is the largest; Japan's gain of 0.004 is the smallest. The ranking did not change between 2021 and 2024. This stability suggests that the structural determinants of technological sovereignty, as measured here, change slowly and are not easily altered within a four-year window (Fig. 6).

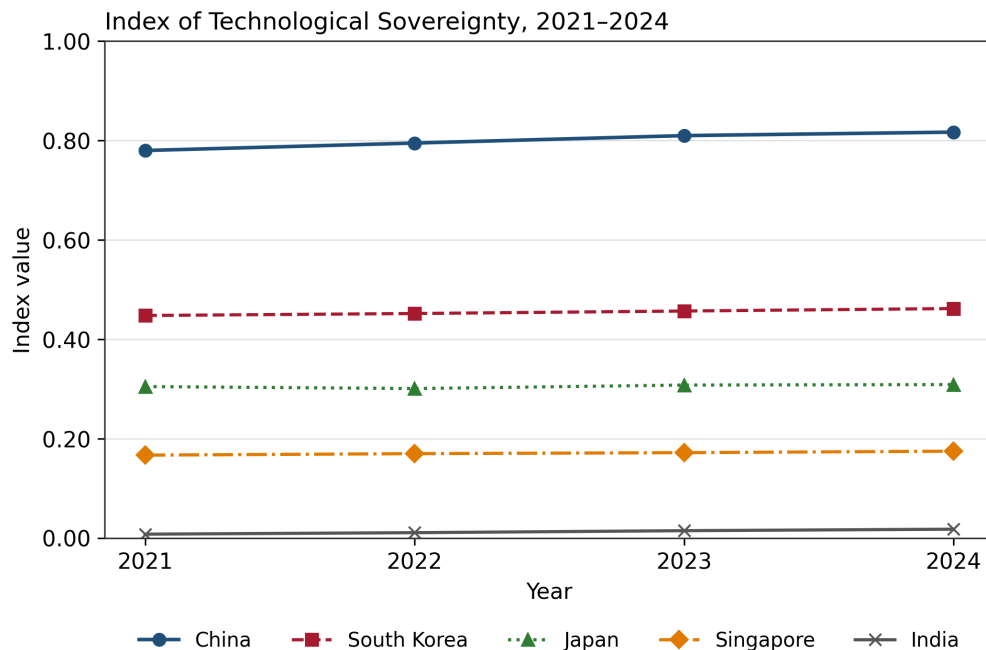


Fig. 5. Index of Technological Sovereignty, 2021-2024

Source: author's calculations based on World Bank (2024c, 2024e) and WIPO (2024b).

Aggregate ranking

Table 6 combines four normalised indicators into a summary score: the index of technological sovereignty, the growth rate of R&D intensity, the coefficient of innovation-investment return and the Global Innovation Index.

Table 6. Aggregate ranking, 2024

Rank	Country	ITS	CAGR R&D	K	GII	Aggregate score
1	China	0.817	+2.73	-1.59	56.0	0.489
2	South Korea	0.462	+2.41	+3.36	59.1	0.451
3	Singapore	0.175	-2.29	+17.62	58.5	0.421
4	Japan	0.309	+1.71	+0.53	54.5	0.301
5	India	0.018	0.00	+6.97	38.3	0.215

Source: author's calculations based on World Bank (2024a–e), WIPO (2024a, 2024b) and UNESCO Institute for Statistics (2024).

The aggregate score narrows the gap between the five economies considerably. China leads on the index but has the weakest coefficient of return; Singapore has the strongest coefficient but negative R&D growth; India has the fastest export and patent growth but the lowest index value. No single economy performs well on all four dimensions, and the ranking depends on which dimensions are weighted most heavily. This is the central empirical finding of the study: the five economies represent distinct configurations of innovation and investment mechanisms rather than points on a single scale of success.

The results describe five distinct configurations rather than a single ranking. China combines the highest index value with the weakest coefficient of return, a pattern consistent with a system that produces large volumes of inventive output and exports while facing diminishing returns on additional research spending. South Korea combines high R&D intensity with moderate returns and stable index growth. Singapore achieves the highest coefficient of return on a small R&D base, a result shaped by its role in regional supply chains. India shows the fastest growth on export and

patent indicators from a low base. Japan shows contraction on almost every dimension except R&D intensity, which rose slightly while absolute spending and GDP fell.

Discussion

Similarities and differences in approaches

The five economies examined in this study share a common recognition that innovation and investment are strategic resources rather than neutral market outcomes. All five have adopted national programmes linking research funding, industrial policy and export promotion. All five increased their index of technological sovereignty between 2021 and 2024, though the gains were modest. And all five experienced a decline in foreign direct investment inflows over the same period, a pattern that reflects global capital reallocation rather than any single national policy failure.

Beyond this common ground, the approaches diverge sharply.

China combines state-directed industrial policy with an enormous domestic market. Its index value of 0.817 in 2024 rests on dominance in two components: patent applications (1,800,000) and high-technology exports (856.76 billion USD). Yet its coefficient of innovation-investment return is negative (−1.59), meaning that high-technology exports fell by 79.63 billion USD while R&D spending rose by 50.07 billion USD. This combination rising inputs, falling outputs, dominant scale points to a system that has entered a phase of diminishing marginal returns. The mechanisms that produced rapid growth in the 2010s appear less effective in the mid-2020s.

South Korea presents the most balanced profile. Its R&D intensity of 4.94% is the highest in the group and among the highest in the world. Its coefficient of return is positive (+3.36), its index rose steadily, and its Global Innovation Index score of 59.1 is the highest among the five. South Korea's approach is built on large industrial conglomerates operating within a coordinated national framework, with sustained public and private investment in research and development. The result is a system that converts spending into exports at a moderate but reliable rate.

Japan occupies a different position. Its R&D intensity rose slightly (from 3.27% to 3.44%), but its GDP fell by 7.09% annually and its absolute R&D expenditure declined by 26.88 billion USD. Its coefficient of return of +0.53 is arithmetically positive only because both exports and R&D fell, with exports declining more slowly. Japan's case illustrates a structural constraint: when the economy contracts, even a stable innovation policy loses absolute capacity. The mechanisms are intact, but the resource base is shrinking.

Singapore achieves the highest coefficient of innovation-investment return in the group (+17.62) on the smallest R&D base. Its index value of 0.175 is low in absolute terms, but its Global Innovation Index score of 58.5 is second only to South Korea's. Singapore's model depends on integration into global supply chains, attraction of foreign multinationals and targeted public investment in strategic sectors. The high coefficient reflects the structure of its trade: high-technology exports include substantial re-exports and goods produced by foreign-owned firms – and should not be read as evidence that its domestic research system is 17 times more productive than China's.

India shows the fastest growth on export and patent indicators, from a low base. Its high-technology exports grew at 25.42% annually, its patent applications at 21.50%, and its Global Innovation Index score at 2.28%. Yet its index of technological sovereignty remains the lowest in the group (0.018), its R&D intensity has not moved from 0.65% of GDP, and its coefficient of return of +6.97 is high only because the R&D base is so small. India's trajectory is that of a late starter with strong momentum and weak foundations.

What successful models have in common

Three features appear in the economies that combine high index values with positive returns: South Korea and, in a different way, Singapore.

1. *Sustained public commitment to research funding.* South Korea's R&D intensity has remained above 4.5% of GDP throughout the period. Singapore's has fluctuated around 1.8-1.9%, but its absolute spending grew every year. In both cases, public funding has been stable rather than

cyclical. The opposite pattern appears in Japan, where R&D spending contracted with the economy, and in China, where rapid increases in spending have not been matched by export growth.

2. *Integration of innovation policy with industrial and trade policy.* South Korea's conglomerates operate within a framework that links research priorities to export markets. Singapore's economic agencies coordinate foreign investment, talent attraction and infrastructure development. In both cases, innovation policy is not a standalone programme but a component of a broader development strategy.

3. *Functioning translation mechanism from research to commercial output.* South Korea's coefficient of +3.36 and Singapore's of +17.62 — however differently they should be interpreted — indicate that research spending in these economies is connected to export performance. The same connection is weak or absent in China and Japan.

The comparison suggests that technological sovereignty is not achieved by maximising any single indicator. China maximises patents and exports but cannot convert additional R&D into additional exports. India maximises growth rates but from a base too small to matter at scale. Japan maintains research intensity while its economy contracts. The successful models are those that keep inputs, outputs and institutional coordination in balance.

Practical significance

Which mechanisms can be applied in other countries

Four mechanisms identified in this study appear transferable, with appropriate adaptation.

a) *Targeted public co-financing of research.* South Korea's model of sustained public commitment to R&D, combined with private sector co-investment, has produced both high intensity and positive returns. For countries with limited fiscal space, the lesson is not to match Korean spending levels but to ensure that public funding is stable, predictable and linked to commercialisation.

b) *Integration of foreign investment with domestic innovation capacity.* Singapore's experience shows that attracting foreign multinationals can build domestic research capacity if the policy framework requires technology transfer, local hiring and joint research. Without these requirements, foreign investment produces exports without building sovereignty.

c) *Sector-specific strategies rather than uniform incentives.* India's rapid growth in high-technology exports has been concentrated in specific sectors – information technology, pharmaceuticals, automotive components. The lesson is that broad-based innovation incentives may be less effective than targeted support for sectors where a country has existing or emerging comparative advantage.

d) *Institutional coordination between research, industry and trade policy.* In all successful cases, innovation policy operates within a broader development framework. Standalone innovation programmes (tax credits, grant schemes, technology parks) produce weaker results when they are not connected to industrial and trade policy.

The role of government and business

The comparison shows that neither pure state direction nor pure market allocation produces technological sovereignty.

Government provides three things that markets do not: long-term commitment beyond commercial time horizons, coordination across sectors and institutions, and risk absorption for early-stage research. South Korea's and Singapore's governments have played all three roles. China's government has played them at a much larger scale, but the negative coefficient of return suggests that scale alone does not guarantee effectiveness. India's government has provided commitment but not yet coordination – its R&D intensity has not moved in four years.

Business provides the commercial discipline that converts research into products and exports. South Korea's conglomerates and Singapore's multinationals play this role. In China, the link between research spending and export performance has weakened, suggesting that business translation mechanisms are not keeping pace with state investment. In Japan, business investment in R&D has contracted with the economy.

The most successful configurations combine state commitment with business execution, and connect the two through institutional mechanisms — joint research programmes, technology transfer requirements, export promotion agencies, sectoral coordination bodies. Neither side alone produces the result.

Limitations

Different levels of development

The five economies differ by more than an order of magnitude in GDP, by a factor of eight in R&D intensity, and by a factor of 135 in patent applications. Comparing them on a single index imposes a common scale on entities that are not commensurable. China's index value of 0.817 and India's of 0.018 are not measurements of the same phenomenon at different levels; they reflect different stages of industrial development, different positions in global supply chains, and different institutional histories.

The index of technological sovereignty constructed for this study is relative: it ranks the five countries against each other and does not carry absolute meaning. A country scoring 0.5 is not "half sovereign" – it is positioned at the midpoint of this particular group. The findings should be read as comparisons within the sample, not as statements about technological sovereignty in general.

Political and cultural factors

The mechanisms examined in this study operate within political systems that differ substantially. China's state-directed model, South Korea's conglomerate-led model, Singapore's agency-driven model, Japan's corporatist model and India's mixed model are products of distinct political histories and institutional cultures. The transferability of mechanisms is therefore conditional: what works in one political context may not work in another.

A further limitation concerns data quality. The R&D expenditure figures in absolute terms were computed as the product of GDP and R&D intensity, not independently reported. Patent counts measure inventive activity but not patent quality or commercial value. High-technology export figures include re-exports and goods produced by foreign-owned firms, which weakens the link between national research spending and export performance. These measurement issues affect all five countries but not equally, and they should be kept in mind when interpreting the coefficients of return.

Further research

The comparative design of this study necessarily sacrifices depth for breadth. Each of the five economies deserves a dedicated study that examines the mechanisms of innovation-investment management in their institutional specificity.

For **China**, the priority is to understand why R&D spending has continued to rise while high-technology exports have fallen. Possible explanations include the shift of export composition toward goods with lower research content, the effect of trade restrictions on technology-intensive exports, and diminishing returns to state-directed research investment. Firm-level data would allow these hypotheses to be tested.

For **India**, the priority is to understand whether the rapid growth in exports and patents can be sustained without an increase in R&D intensity. The current trajectory – strong growth from a small base – may continue or may encounter structural limits. Sectoral analysis would clarify which industries are driving the growth and whether it is broad-based or concentrated.

For **Japan**, the priority is to understand the relationship between economic contraction and innovation capacity. The decline in absolute R&D spending is a consequence of GDP decline, but the mechanisms linking the two (reduced corporate investment, fiscal constraints, demographic change) require separate examination.

For **South Korea** and **Singapore**, the priority is to understand the limits of their models. South Korea's high R&D intensity has produced moderate returns; Singapore's high returns rest on a small base. Whether these configurations can be sustained or scaled is an open question.

The comparison of five Asian economies shows that technological sovereignty is not achieved by maximising any single indicator. China leads on scale but shows negative returns on additional research spending. South Korea combines high intensity with moderate returns.

Singapore achieves high returns on a small base. India shows rapid growth from weak foundations. Japan maintains research intensity while its economic base contracts.

The mechanisms that distinguish successful cases are sustained public commitment, integration of innovation policy with industrial and trade policy, and functioning translation from research to commercial output. These mechanisms are transferable in principle but conditional in practice, since they operate within political and institutional contexts that differ substantially across countries.

The study's limitations: the small sample, the relative nature of the index, the absence of political and cultural variables, and the measurement issues in the underlying data – constrain the conclusions that can be drawn. Further research should examine individual countries in depth and investigate how digitalisation is reshaping the mechanisms of innovation-investment management.

Conclusion

The five Asian economies examined in this study: China, Japan, South Korea, India and Singapore – rely on a common set of instruments to manage innovation and investment. All five combine state support with private investment and research funding, and all five treat technological sovereignty as a strategic objective rather than a by-product of market activity. The differences between them lie not in the presence or absence of these instruments but in how they are combined and how effectively they function together.

China demonstrates that scale alone does not guarantee results. Its index of technological sovereignty reached 0.817 in 2024, the highest in the group, yet its coefficient of innovation-investment return was negative: exports of high-technology goods fell while research spending rose. South Korea shows what sustained commitment produces – R&D intensity of 4.94% of GDP, positive returns, and the highest Global Innovation Index score among the five. Singapore achieves the strongest return on research spending, though from a small base and through a model that depends on integration into global supply chains. India records the fastest growth in exports and patents, but from a starting point so low that its index value remains 0.018. Japan maintains research intensity while its economy contracts, illustrating that stable policy cannot compensate for a shrinking resource base.

Three conclusions follow:

1. The mechanisms that support technological sovereignty are similar across the region: stable public funding, coordination between research and industrial policy, and institutional arrangements that connect research spending to commercial output. None of these is unique to any single country, and none requires a particular political system to function.

2. Technological sovereignty is achieved through a systemic approach rather than through individual measures. Isolated incentives, tax credits or technology parks produce weak results when they are not embedded in a broader development strategy. The economies that perform best on the indicators used here are those where research funding, industrial policy, trade promotion and foreign investment rules operate as a connected system.

3. The Asian experience offers lessons for other countries, but with qualifications. The mechanisms are transferable in principle. Their effectiveness depends on local institutional capacity, on the stage of industrial development, and on political conditions that differ from country to country. What works in South Korea may not work in a smaller economy with weaker industrial foundations; what works in Singapore may not work where foreign investment does not bring technology transfer.

The study's limitations a sample of five countries, a relative index, four years of data and the absence of political and cultural variables – mean that these conclusions should be read as patterns within the selected group rather than as general laws. Further research on individual countries and on the effects of digitalisation would clarify how the mechanisms identified here evolve and whether they remain effective as the technological landscape changes.

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