

Overcoming Structural Constraints in Nascent Innovation Systems: A Comparative Analysis and Policy Framework for Zambia

Bruce M. K. Mwiya^{1*}

¹*Kwame Nkrumah University, Kabwe, Zambia*

* Corresponding Author

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Abstract

This article examines the structural constraints hindering nascent innovation systems, utilising Zambia as a primary case study. While developing nations display high entrepreneurial energy, systemic barriers—specifically institutional silos across the innovation lifecycle—prevent translating this energy into measurable intellectual property (IP) and export-driven industrial growth. Through a comparative analysis of Research and Development (R&D) expenditure, researcher density, Global Innovation Index (GII) rankings, patent filings, and manufacturing data across Zambia, Africa, Europe, the USA, and Asia, this study highlights stark disparities in innovation infrastructure. A Pearson correlation analysis empirically tests these relationships, revealing a statistically significant decoupling between early-stage academic inputs and late-stage commercial outputs. Evaluated through the lens of Technology Readiness Levels (TRLs), the findings reveal that Zambia's institutional silos—where the National Science and Technology Council (NSTC), National Technology Business Centre (NTBC), Citizens Economic Empowerment Commission (CEEC), and Zambia Development Agency (ZDA) operate in isolation—stall the transition to a knowledge economy. To overcome these constraints, the article proposes a targeted policy framework that focuses on Triple Helix integration, enables the NTBC to bridge the TRL 4-6 "Valley of Death", and leverages Multi-Facility Economic Zones (MFEZs) to commercialise domestic IP for global export.

1. Introduction

The transition from a resource-dependent economy to a knowledge-and-innovation-driven paradigm is arguably the most complex structural shift a developing nation can undertake (Kim, 2017). For countries like Zambia, the desire to innovate is palpable, yet the macroeconomic environment and fragmented institutional frameworks often stifle commercialisation (Phiri & Manchishi, 2020; Phiri et al., 2023). Approaching this disparity requires empathy for the historical infrastructural hurdles developing nations face, alongside rigorous candour regarding the data: without targeted, sustained investment mapping to both the inputs and outputs of innovation, economic leapfrogging remains an illusion (Lee, 2019). This article contextualises Zambia's current innovation ecosystem by comparing its core metrics against global counterparts and statistically testing the viability of its structural pathways (Mwiya, 2026). Furthermore, it enlarges the analysis by mapping Zambia's specific statutory bodies to the technology lifecycle, ultimately delivering a pragmatic policy framework for leveraging industrial zones to overcome systemic constraints (Phiri & Manchishi, 2020).

2. Literature and Theoretical Review

The concept of a National Innovation System (NIS) posits that the flow of technology and information among people, enterprises, and institutions is key to the innovative process (Lundvall, 1992). The trajectory of this flow—from basic research to market commercialisation—is best mapped using Technology Readiness Levels (TRLs), a 9-point scale where TRL 1 represents basic principle observation and TRL 9 denotes a fully deployed operational system (Mankins, 1995). The critical gap between early-stage research (TRL 1-3) and market commercialisation (TRL 7-9) is widely known as the "Valley of Death" (TRL 4-6), where nascent technologies frequently fail due to capital starvation.

Mature innovation systems (e.g., the USA, Europe, and Asia) seamlessly bridge these TRLs using integrated public-private funding models and robust venture capital. In Sub-Saharan Africa, however, funding for TRL 1-3 relies overwhelmingly on foreign donor aid, while funding for TRL 4-9 is largely absent. Phiri et al. (2023) identified this as a profound "Triple Helix disconnect" in Zambia, where academia, industry, and government fail to synchronise.

Applying the TRL framework to Zambia's statutory environment reveals precisely where this disconnect occurs:

- **TRL 1–3 (Basic & Applied Research):** Governed primarily by the National Science and Technology Council (NSTC), established under the Science and Technology Act of 1997. The NSTC is mandated to regulate, promote, and fund early-stage science. However, chronic underfunding limits its capacity to generate a critical mass of research working with universities in Zambia and other research institutes, such as the National Institute for Scientific and Industrial Research (NISIR) and the Zambia Agricultural Research Institute (ZARI).
- **TRL 4–6 (The Valley of Death):** The National Technology Business Centre (NTBC), operational since 2002, is explicitly tasked with technology transfer, incubation, and commercialisation. Despite its critical mandate to bridge the Valley of Death, the NTBC lacks the state-backed venture capital required to prototype, audit, and validate university and research institute discoveries.
- **TRL 7–9 (Commercialisation, Scaling & Export):** Driven by the Citizens Economic Empowerment Commission (CEEC) and the Zambia Development Agency (ZDA). The CEEC focuses on financing SMEs. Concurrently, the ZDA manages Multi-Facility Economic Zones (MFEZs)—such as the Lusaka South (LS-MFEZ)—which offer tax holidays to promote high-tech manufacturing and exports.

Because the NTBC cannot effectively bridge TRL 4–6, indigenous Zambian research rarely reaches TRL 7–9. Consequently, the ZDA's high-tech MFEZs rely almost entirely on foreign direct investment (FDI) utilising imported IP, bypassing the domestic innovation system entirely.

2.1 Theory

This study is grounded in Catch-up Theory and the Triple Helix Model of Innovation (Etzkowitz & Leydesdorff, 2000).

- Catch-up Theory suggests that latecomer economies can accelerate development by adopting and adapting existing technologies and subsequently building indigenous R&D capabilities to advance their own TRL pipelines.
- The Triple Helix Model emphasises the overlapping interactions between academia, industry, and government. In nascent systems, government policy must act as the binding agent, utilising structured institutional pathways (NSTC - NTBC - CEEC-ZDA/MFEZs) to safely transfer academic knowledge into industrial manufacturing.
- The analysis of institutional pathways can be further enriched by incorporating the concept of the innovation policy mix. This refinement moves beyond the broad synchronisation proposed by the Triple Helix Model (Etzkowitz & Leydesdorff, 2000) to emphasise the coherence and sequencing of multiple policy instruments—such as the subsidies, regulatory frameworks, and public procurement managed by the NSTC, NTBC, CEEC, ZDA and other government entities and ministries. This perspective is critical for nascent systems, as targeted, government-led incentives are often required to stimulate non-incremental technical change and overcome early market failures in technology-push strategies (Nemet, 2009).

2.2 Hypotheses

Based on the theoretical frameworks and existing literature, this study tests the following hypotheses:

- H1: A critical mass of R&D expenditure (exceeding 1% of GDP) is required to successfully bridge the TRL 4–6 "Valley of Death," correlating with higher Global Innovation Index (GII) performance.
- H2: High volumes of resident patent outputs are positively associated with structured state funding at the TRL 7–9 stages, leading to a higher share of high-tech manufacturing exports as a percentage of GDP.
- H3: Nascent systems like Zambia will exhibit a statistical and institutional decoupling, where basic academic inputs (TRL 1–2) fail to correlate with commercial outputs (TRL 8–9) due to a funding collapse in the middle stages.

3 Methods

This study utilises a comparative quantitative approach, aggregating secondary macro-level data from the World Bank (2024), the World Intellectual Property Organisation (WIPO, 2025), and UNESCO (spanning 2023–2025). We analyse six specific variables:

- R&D Expenditure: Measured as a percentage of GDP (NSTC domain).
- Human Capital: Researchers per million inhabitants.
- Academic Output: Scientific journal articles published per annum (Proxy for TRL 1–2).
- System Performance: Global Innovation Index (GII) 2025 rankings.
- IP Output: Resident patent applications (Proxy for NTBC TRL 4–6 progression).
- Industrial Output: Manufacturing value added as a percentage of GDP (Proxy for ZDA MFEZ TRL 9 outputs).

Statistical Analysis

To empirically test the stated hypotheses, a Pearson correlation analysis was conducted on the macroeconomic indicators across the five comparative regions (n=5). The variables were standardised into numerical continuous data. Given the small sample size (representing aggregated regional macro-data), statistical significance is evaluated at the standard $\alpha = 0.05$ level. The resulting matrix calculates the correlation coefficient (r) to determine the strength and direction of the relationships, while the p-value tests the null hypothesis that no linear relationship exists.

(Note: In the Global Innovation Index, a lower numerical ranking indicates a better performance. Therefore, a negative correlation between an input like R&D and the GII ranking indicates a positive systemic outcome.)

4 Results

4.1 Global Comparative Metrics

The comparative macro-data vividly illustrate the structural gaps between nascent and mature innovation systems.

Table 1: Global Comparative Metrics

Metric	Zambia	Africa (Avg.)	Europe (EU Avg.)	USA	Asia (East)
R&D Expenditure (% of GDP)	~2.8%	~0.50%	~2.11%	~3.40%	~4.50%
Researchers (per million)	<100	~150	~4,000	~4,800	~8,000+
Publications (per year)	<1,000	~100,000	1 Million	~700k	1.5 Million
Global Innovation Index (2023)	118th	100th	15th	3rd	12th
Resident Patent Filings	<50	~1,000	>100,000	>250,000	>1 Million
Manufacturing (% GDP)	~9.2%	~10.0%	~15.0%	~11.0%	~25.0%+

4.2 Correlation Matrix Findings

The foregoing data were mathematically analysed to test the hypotheses. The correlation matrix graph is displayed as Figure 1 with the calculated Pearson correlation coefficients (r) alongside their corresponding p-values to determine statistical significance. The statistical analysis reveals distinct clustering between innovation inputs and commercial outputs. The correlation matrix yields the following key coefficients (r) and significance levels (p):

- R&D Expenditure & Researchers: Strong positive correlation ($r = 0.959$, $p = 0.010$).
- R&D Expenditure & GII Ranking: Strong negative correlation ($r = -0.960$, $p = 0.009$).
- Researchers & GII Ranking: Strong negative correlation ($r = -0.964$, $p = 0.008$).
- Patents & Manufacturing (%GDP): Strong positive correlation ($r = 0.938$, $p = 0.018$).
- R&D Expenditure & Patents: Moderate, non-significant correlation ($r = 0.528$, $p = 0.360$).
- Researchers & Manufacturing: Weak, non-significant correlation ($r = 0.370$, $p = 0.540$).

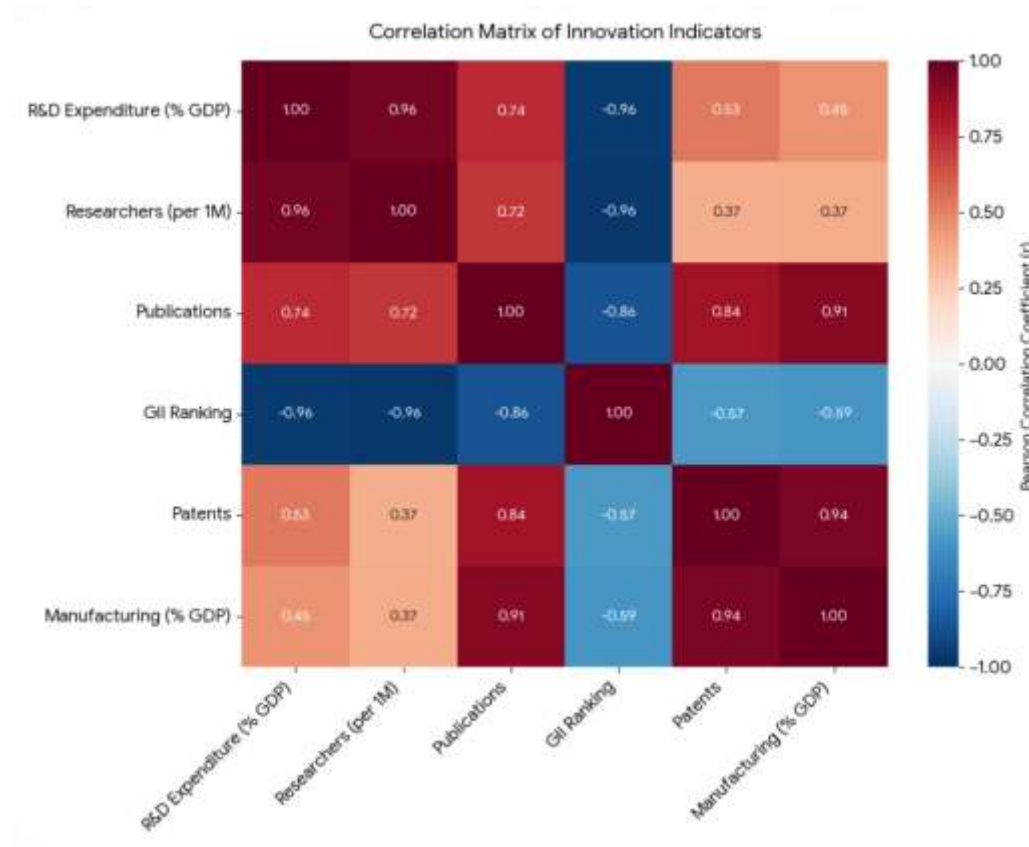


Figure 1: Correlation Matrix Findings

4.3 Hypothesis Testing Validation

- H₁ Supported (R&D & GII Performance): The hypothesis that a critical mass of R&D expenditure and researcher density drives GII performance is highly supported. Both R&D expenditure ($r = -0.960$, $p < 0.01$) and researchers per million ($r = -0.964$, $p < 0.01$) show statistically significant, near-perfect correlations with a better (lower) GII ranking. This confirms that basic institutional inputs (governed in Zambia by the NSTC) are non-negotiable prerequisites for systemic baseline performance.
- H₂ Supported (Patents & Manufacturing): The hypothesis that high resident patent outputs drive higher manufacturing as a percentage of GDP is statistically supported ($r = 0.938$, $p = 0.018$). This validates the premise that commercialisation of protected IP (TRL 7-9) is the primary driver of

high-tech industrial output, reinforcing the necessary role of MFEZs and the ZDA in scaling validated technologies.

- **H₃ Supported (Structural Decoupling & The Valley of Death):** The statistical data perfectly illustrate the "Valley of Death" institutional decoupling. While inputs correlate strongly with other inputs, and outputs correlate strongly with other outputs, the relationship between early-stage inputs and late-stage outputs breaks down. For example, the correlation between R&D Expenditure (Input) and Patents (Output) is non-significant ($p = 0.360$), and researchers (input) to Manufacturing (Output) is equally non-significant ($p = 0.540$). This mathematical disconnect empirically proves that simply funding early-stage science without a dedicated bridging institution (like an empowered NTBC to bridge TRL 4–6) will not organically result in commercial manufacturing outputs.

4.4 Discussion

The empirical data clearly delineate Zambia's innovation trap. A national research and development (R&D) expenditure hovering at approximately 0.28% of GDP severely starves early-stage research at the National Science and Technology Council (NSTC) level, falling far below the 1% threshold typically required for sustainable economic transformation (Choongo et al., 2026). More critically, the statistical disconnect between researcher output and manufacturing value addition ($p = 0.540$) mathematically underscores that simply funding early-stage science without a dedicated bridging mechanism will not organically result in commercial outputs.

The lack of structural venture funding at the National Technology Business Centre (NTBC) ensures that whatever meagre research is produced cannot be prototyped, stranding potential intellectual property (IP) in what innovation literature terms the "Valley of Death" (Nemet, 2009).

The most glaring symptom of this structural failure is the current utilisation of Multi-Facility Economic Zones (MFEZs). Because domestic IP fails to cross the Valley of Death, MFEZs operate predominantly as enclaves for foreign capital and direct investment rather than springboards for local innovation (Böhmer & Farid, 2010). Zambian universities produce graduates, but without institutionalised patent filings and prototyping, the Citizens Economic Empowerment Commission (CEEC) lacks the risk-adjusted justification to fund high-tech Zambian SMEs. Consequently, the Zambia Development Agency (ZDA) cannot place indigenous tech firms into the MFEZs, leaving the country ill-equipped to leverage the African Continental Free Trade Area (AfCFTA) through high-value tech exports.

Comparative Analysis: Overcoming the Valley of Death

To contextualise Zambia's structural deficits, it is instructive to compare this ecosystem with countries that have successfully deployed bridging institutions to link early-stage R&D with industrial manufacturing.

Regional Benchmark: South Africa

While Zambia struggles with early-stage commercialisation, South Africa has proactively addressed the Valley of Death through the establishment of the Technology Innovation Agency (TIA).

- **The Bridging Mechanism:** Unlike the NTBC, which operates with severely limited structural venture capital, the TIA is explicitly mandated to provide early-stage risk funding, prototyping grants, and commercialisation support directly to researchers and high-tech entrepreneurs.
- **The Result:** South Africa maintains an R&D expenditure closer to 0.7% of GDP and produces a measurable pipeline of tech-enabled products into local manufacturing. This dedicated funding allows domestic SMEs to secure IP and scale within their own Special Economic Zones (SEZs) rather than being crowded out by foreign entities.

Global Benchmark: South Korea

South Korea serves as the definitive global model for escaping the middle-income and innovation traps through aggressive, state-backed technology bridging.

- **The Bridging Mechanism:** South Korea established the Korea Institute of Science and Technology (KIST) early in its industrial development. Rather than passively waiting for university research to reach the market, KIST actively adapted foreign technologies, funded domestic prototyping, and acted as the explicit bridge between academia and industry.
- **The Result:** South Korea elevated its R&D expenditure to over 4% of GDP (Bassanini & Scarpetta, 2001). Crucially, their economic zones were strictly tied to local capacity building. Foreign capital was only permitted if it included joint ventures and technology transfers to local firms, ensuring that domestic IP eventually dominated the manufacturing floors and export markets.

4.5 Implications: A Policy Framework for Zambia

To transition from a nascent to an emerging innovation system, Zambia must implement structural reforms that specifically align its statutory bodies across the TRL pipeline. Drawing upon the systemic reconfiguration models proposed by Mwiya (2026), this framework outlines the following:

- **Mandate Sustained R&D Investment (NSTC - TRL 1–3):** The government should commit to reaching the 1% R&D/GDP threshold, directing funds through the NSTC to establish a robust foundation of domestic basic science. This would entail requiring every ministry and every government agency to budget for research, innovation, product/service development and improvement, as well as consultancy and channel the administration of those funds through an NSTC-managed National Research and Innovation Fund by way of competitive calls for research grant funding to address development challenges in the same ministries and agencies and advance the national developmental agenda. This entails establishing a type of South Africa's national research foundation (NRF) that funds research, researchers, and research institution capacity to drive the nation's research agenda and generate basic and applied research and innovation outputs in priority development areas. This would be buttressed by enacting appropriate enabling legislation in research commercialisation (e.g., the Bayh-Dole Act 1984 in the USA and the IPR Rights Act 2008 in South Africa) that prescribes ownership and commercialisation mechanisms for publicly funded research.
- **Capacitate the NTBC with a Transition Fund (TRL 4–6):** The NTBC should evolve from a purely advisory body into a highly capitalised incubation agency. A state-backed "Innovation Transition Fund" should be established under the NTBC to provide non-dilutive grants explicitly for prototyping, patenting university research and market testing, and working with university and research institute-based incubation centres and technology transfer offices in collaboration with PACRA. To ensure the long-term sustainability of this mechanism, the Fund must be structured as a revolving fund

that includes a mandatory recoupment mechanism. Specifically, the NTBC should retain a royalty interest (e.g., 2–5% of net revenue) on all IP successfully commercialised and placed into ZDA's MFEZs via CEEC backing, creating a self-sustaining funding cycle for the TRL 4–6 pipeline (Mwiya, 2026). This would be in line with South Africa's Technology Innovation Agency (TIA), which focuses on innovating tomorrow together. TIA is a national public entity that serves as the key institutional intervention to bridge the innovation chasm between research and development from higher education institutions, science councils, public entities, the private sector, and commercialisation.

- Integrate CEEC and ZDA with Local IP (TRL 7–9): The CEEC's strategy of merging homogenous enterprises should be expanded beyond basic commodities to include tech-based startups graduating from the NTBC.
- Domestic MFEZ Exports: The ZDA should institute policies within the MFEZs (like LS-MFEZ) that provide enhanced tax incentives to foreign firms that form joint ventures with local, CEEC-backed tech SMEs, thereby facilitating knowledge transfer.

4.6 Limitations and Directions for Future Research

This study relies on macro-level, aggregated data, which may obscure micro-level success stories within specific sectors. Furthermore, evaluating institutional efficiency relies on statutory mandates, which may differ from day-to-day operational realities. Finally, the Pearson correlation matrix relies on an aggregated sample size of $n=5$ macro-regions. While this provides a high-level heuristic overview, the small degrees of freedom mean that only extreme linear relationships trigger the $p < 0.05$ threshold.

Future studies should pivot from macro-level analyses to firm-level microdata within Zambia, utilising longitudinal panel data across multiple decades to increase statistical power. Specifically, research should evaluate the empirical effectiveness of NTBC's technology audits, the survival rates of CEEC-funded tech SMEs, and the actual volume of domestic IP being utilised within the Lusaka South MFEZ compared to imported technologies. Given the limitations of Pearson correlation with a small-N sample, future methodological approaches should consider Qualitative Comparative Analysis (QCA) to determine the necessary and sufficient conditions required for successful TRL transition. This technique, which is more robust for cross-case comparisons of a small number of countries or aggregated regions, can move the analysis beyond correlation to identify the required policy configurations—a crucial step toward leveraging structural learning for economic leapfrogging (Lee, 2019).

5 Conclusions

Overcoming structural constraints in a nascent innovation system requires the deliberate alignment of capital and policy across all Technology Readiness Levels. The statistical evidence presented confirms that early-stage inputs do not automatically translate to industrial outputs without deliberate, systemic intervention. Zambia possesses the institutional architecture—the NSTC, NTBC, CEEC, and ZDA—necessary to drive this transition. However, until the nation addresses the severe funding ruptures in its ecosystem, its innovation engine will remain stalled in institutional silos. By embracing a reconfigured Triple Helix policy framework that actively funds the NTBC to bridge the Valley of Death, Zambia can pipeline domestic IP directly into its MFEZs, transforming its economic potential into a measurable, export-driven industrial reality.

Declaration of Competing Interests

The authors declare that they are not aware of any competing financial interests or personal relationships that may have influenced the work described in this document.

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Ethical considerations

The article followed all ethical standards appropriate for this kind of research.

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