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Future of Indonesia's Industrial R&D Using System Dynamics

Erman Aminullah

*Former Research Professor in Science and Technology Policy, National Research and Innovation Agency (BRIN), Jakarta, Indonesia**

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ABSTRACT

This study attempts to forecast the future of Indonesia's industrial R&D intensity based on historical data trends. A systemic approach and system dynamics modelling were used to explain Indonesia's high reliance on public funding for R&D activities. The simulation results show that: i) the policy of increasing industrial R&D investment can be implemented by transferring research outputs from research institutions to the industrial sector, as well as increasing R&D investment in the mission-oriented industrial sector. This is a challenging scenario for the most ambitious future R&D trends by 2045. ii) Limited R&D spending can have a tangible economic impact if public R&D organisations implement researcher performance evaluations based on R&D results' application in industry. Transferring government R&D outputs to the industrial sector will boost future industrial R&D in a moderate scenario by 2045. iii) Prolonged reliance on government R&D funding has the unintended consequence of lock-in dependence on public R&D funding, and further delays in increasing industrial R&D trends are most likely in a BAU scenario by 2045. The long-term policies should be executed integrally in realizing Indonesia's transition to industrial R&D. This study's scientific contribution is a model of lock-in dependence on public R&D funding based on historical data.

* Corresponding Author.
E-mail: aminullahe@yahoo.com

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I. INTRODUCTION

Indonesia experienced a sharp decrease in R&D intensity in the long run. Indonesia has maintained a low level of R&D intensity since 1970, reaching the top of 0.54% of GDP in 1982 and continuing to rapidly decline since then. R&D intensity decreased from 0.17% in 1993 to 0.08% of GDP in 2000 and remained stable at around 0.1% of GDP from 2000 to 2022. (Pappiptek-LIPI, 2014; BRIN, 2023). The literature explained the symptoms of low R&D intensity in Indonesia marked by: i. The industrial sector is generally dominated by the industry that produces low-technology products that do not require R&D facilities; ii. the government's attention to the development of science and technology has steadily decreased since the 1990s, from 2.5% of the total government budget in the 1990s to around 0.5% in the 2000s; iii. the capacity of public R&D institutions to spend on R&D is limited due to a lack of R&D researchers and less sophisticated R&D facilities; and iv. the private sector is generally less interested in reinvesting production yields into R&D activity, with industrial R&D expenditure being very small, accounting for around 0.01- 0.02% of GDP in the of 2000-2010 (Aminullah, 2015; Aminullah et al., 2018).

From 1980 to 2000, Indonesia developed a high technology-based industrial transformation in a real, staged process with clear concepts and objectives at 10 government-owned strategic companies (Hermawati & Aminullah, 2023); however, this was insufficient to leverage an increase in R&D intensity. In general, a country's R&D intensity increases as middle-income countries are shifting towards high-income countries. Malaysia's R&D spending has continued to increase in the long run. Since 2018, it has reached 1% of GDP and has approached that of a high-income country, with high-tech industrial product exports serving as the primary driver. Chile, the developing country with a stable R&D intensity in the long run with 0.36% of GDP in 2021 (World Bank, 2024a), was ranked as a high-income country by integrating and adapting imported knowledge and technologies with local knowledge through R&D in marine, agriculture, forestry, and mining (Lebdioui et al., 2020).

It is imperative for Indonesia to increase R&D intensity by government intervention. As Mazzucato (2013) argues proactive government involvement is critical in shaping markets and enabling breakthrough innovations that would be too risky for private firms to pursue alone. Governments should therefore intervene by investing directly in R&D activities for R&D institutions, such as a single agency in Indonesia, National Agency of Research and Innovation (BRIN), and by using tax breaks and grants as incentive mechanisms to increase industrial R&D activity. The complementarity of public R&D spending intervention and industrial R&D spending stimulation at the national and company levels has been investigated and documented in the literature (Ebersberger, 2005).

The literature generally discusses the long-term increase in R&D intensity (Chang et al., 2023) and sectoral trajectories in R&D investment in the long run (McCormick et al., 2020), as scientific progress through an increase in R&D takes decades. Only two countries in the world experienced a sharp decrease in R&D intensity in the long run: Ukraine and Indonesia. In Ukraine, R&D intensity fell from high (1.19% of GDP) in 1997 to low (0.33% of GDP) in 2023 (World Bank, 2024b); it could be related to difficulties in transforming R&D systems (Yegorov, 2009). The long-term decline in Indonesia's small R&D intensity was a rare phenomenon. However, there is no literature explaining, thus far, the unusual phenomenon of a more than four-decade decline in such a small R&D intensity in Indonesia.

In light of the aforementioned phenomenon, BRIN, the Indonesia's new integrating agency for R&D governance since 2019, should serve as the implementer of the presidential directive, which typically chairs the STI policy council of developed countries; however, Indonesia lacks such a STI policy council level. The existing vertically coordinated Research and Innovation (RI) policy direction, led by the BRIN's directive council, should be functioned to select strategic sectors for public-private interactions that can generate new innovation, new industrial landscapes, and new directions of change in industrial R&D-based competitiveness (Mazzucato, 2016). The winning industrial sectors could be built on Indonesia's comparative advantage in minerals and biological diversity, both on land and at sea (Aminullah, 2020).

This article attempts to forecast possible trends in industrial R&D scenarios based on the current and past phenomena of Indonesian research intensity from a systemic perspective. Pointing out that Indonesia's high reliance on public funding for R&D activities has a long history. This article made a scientific contribution by suggesting a model of lock-in dependence on public R&D funding based on historical data. Such a reliance on public funding is compatible with low creation to stimulate private R&D funding. Model simulation was used to develop scenarios and proposed a transition from path dependence on public R&D to path creation for industrial R&D.

The central questions to be addressed are: i. How did Indonesia's long-term dependence on public R&D funding occur? ii. How could Indonesia transition to industrial R&D funding in the future? and iii. What are the scenarios of Indonesia's R&D intensity in the next 20 years by 1945?

II. ANALYTICAL FRAMEWORK

A. Path Dependence and Path Creation

The theoretical foundation is based on path dependence theory, which refers to how past choices and structures shape the direction of development in the present, resulting in institutions/actors becoming trapped in the specific paths of lock-in (Page, 2006; Staber, 2005; Arthur, 1989). Radical change is difficult because transition costs are high, actors are used to old ways, and vested interests exist (Hannan & Freeman, 1984). Path dependence consists of four major components: initial conditions, contingencies and exogenous shocks, self-reinforcing mechanisms, and lock-in (Vergne & Durand, 2010). The details of each component are in the following.

According to Garud et al. (2010), initial conditions are not given but rather constructed by actors who mobilise specific sets of past events to pursue their initiatives. Similarly, exogenous and endogenous are not predetermined; it rather depends on how actors define and redraw their boundaries. Emergent situations are not 'contingencies' in the sense of unpredictable events; they rather provide embedded actors with opportunities to pursue certain courses of action while making others more difficult to pursue (Arthur, 1988). Self-reinforcing mechanisms are cultivated rather than simply existing (Giddens, 1984). Lock-in occurs when actors are unable to transition to a new state; in such cases, outsiders (e.g., policymakers) can intervene to 'steer' these processes out of lock-in. Thus, path creation provides an alternative perspective for exploring and understanding emergent phenomena.

Path creation involves all three moments of time: the past (as in the term 'path'), the future (as in the term 'creation'), and the present (as in the combination of the two terms) (Garud et al., 2010). The trajectory of past events should be explained using data (Bijker et al., 1987; Porac et al., 2001). Otherwise, it would be tempting to regard any sequence of events (later referred to as a path) as unavoidable. Future possibilities should be forecasted by creating new initial conditions and self-reinforcing mechanisms strategically intervened by actors to create provisional stabilisations within a larger structural process (Kemp et al., 2001).

B. From Conceptual Framework to Conceptual Model

The concept of shifting the burden, which is based on system thinking (Senge et al., 1994), is used to frame the transition from the aforementioned path dependence to solution creation. Path dependence typically begins with a problem symptom that requires attention. The first balancing loop is straightforward, and the symptomatic solution usually resolves the problem symptom the quickest. The second balancing loop is a fundamental solution that employs corrective actions to address the source of the problem. The third loop is reinforcing where the symptomatic solution has long-term consequences and diverts attention away from the fundamental solution to the root of the problem. Avoiding routine responses and maintaining a fresh perspective on options are critical for preventing the addiction effect and moving forward with the fundamental solution via corrective actions. This is a conceptual framework for path dependency and creation, see Figure 1.

Figure 2 depicts the Indonesian context on the conceptual model of lock-in dependence on public R&D funding, demonstrating how path dependence has historically limited Indonesian research. As a result, the prolonged reliance on public R&D funding has the unintended consequence of lock-in dependence. Path creation necessitates creative policy implementation by actors (researchers, industry, and government) to create the new pathways of increasing industrial R&D through funding diversification, R&D investment incentives, and institutional management change. This allows private industries to forge new paths of R&D investment despite the presence of conventional innovation with less or without R&D investment.

Putting mission-orientated innovation at the centre of growth policy requires a focus on shaping and creating markets, rather than simply fixing the system of market failures (Mazzucato 2016, 2018). The market-creating view requires public sector actors to create and co-shape markets in order to address major societal challenges or create public value (Mazzucato, 2022). By directing policy-driven change to create new market and public value while also stimulating public and private interaction in R&D spending, all can generate systemic change. The primary impact of R&D spending is to advance industrial technology through R&D innovation, which drives GDP growth. Secondary effects of industrial technology advancement on stock market valuation contribute to a country's economic growth (Kim 2025). The systemic change is indicated by the relationship that the higher the economic growth resulting from technological advancement, the greater the feedback to increase R&D spending for future growth. This feedback process is referred to as a path creation loop in the above lock-in dependence model.

The lock-in dependence model, like any model of system dynamics, has a unique position because of its nature as a constructivism modelling. The construction of lock-in dependence model is based on mixed inductive process from historical data with a deductive process from a conceptual framework based on theoretical foundations.

The process of model construction determines the position of system dynamics model. First, the system dynamics model is typically built solely on cause-and-effect logic (Meadows et al., 1972). Critics of this model construction due to the lack of data support may result in like models of doom (Cole et al., 1973). Second, the system dynamics model is constructed from narrative stories or historical data patterns (Kim & Anderson, 1998). Critics of this model construction without the guidance of a conceptual framework based on theoretical foundations may contain false feedback loops (Spescha, 2021).

Third, a system dynamics model built by combining an inductive process from historical data with a deductive process from a conceptual framework based on theoretical foundations would yield a reliable model (Aminullah, 2024; Aminullah & Erman, 2026). The same research problem could produce different models of system dynamics not only depending on the ways of in constructing the models but also on viewing the models from perspective of other simulation methods (Kunc et al., 2018).

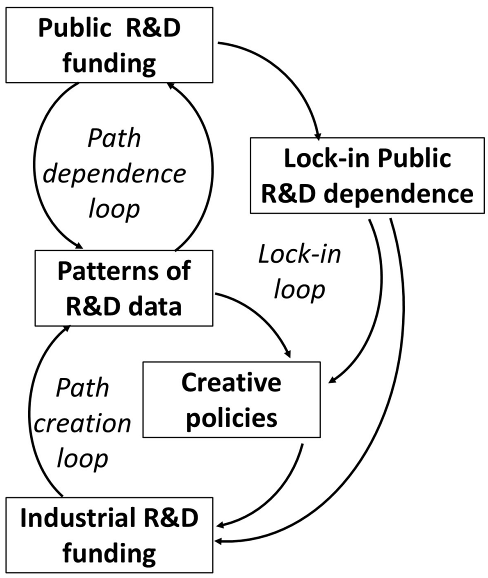

Figure 1. *Shifting the Burden Framework*

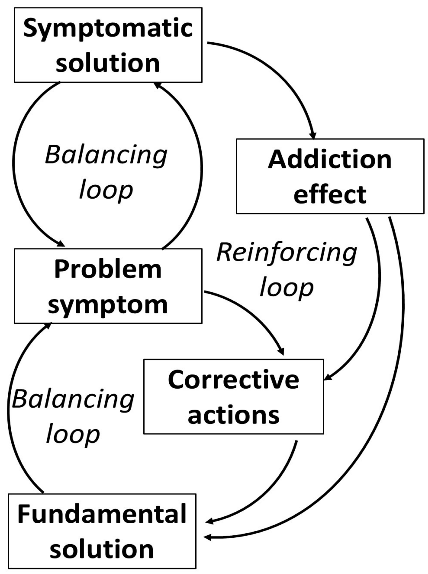

Figure 2. *Lock-in Dependence Model*

III. METHODOLOGY

Figure 3 depicts the stages of system dynamics modelling method for forecasting as follows: i. Formulate a conceptual framework of path dependence and creation based on a theoretical basis; ii. Develop a conceptual model of shifting the burden of R&D funding; iii. Draw patterns of R&D data, which is plotted from statistical data; iv. Build a model structure behind the patterns of statistical data; v. Validate R&D simulation by comparing with R&D data; and vi. Analyse and conclude the future trends of R&D scenarios.

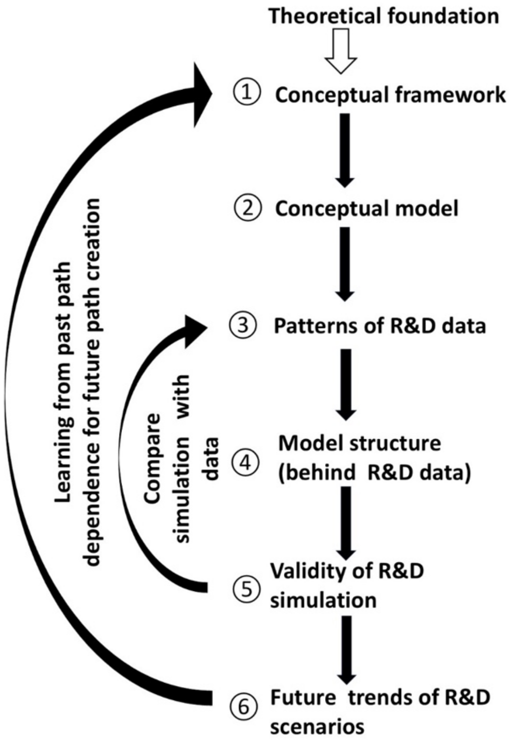

Figure 3. *Stages of System Dynamics Modelling*

A. Conceptual Framework

The conceptual framework of path dependence and creation is based on the archetype of shifting the burden in system thinking (Senge et al., 1994), with the addiction loop being critical to understanding the problem symptom of path dependence in the past. The addiction loop led to the fundamental solution through corrective actions. Thus, path dependence in the past gives way to path creation in the future. This framework is developed based on the theoretical foundation in the previous section.

B. Conceptual Model

The conceptual model of lock-in dependence on public R&D funding is based on the preceding conceptual framework, and dependence on public R&D funding is critical to understanding the R&D funding problem caused by lock-in dependence in the past. The releasing of lock-in dependence on government R&D funding leads to an increase of private industry R&D funding through creative policies. Thus, the previous reliance on government R&D funding will gradually give way to future reliance on private industry R&D funding.

C. Patterns of R&D Data

The patterns of R&D data are based on statistical data compilation (see Appendix A), which was used to validate the R&D simulation shown in the following subheading of Validity of R&D Simulation. The R&D data was compiled over the years 1969-2022. The source of R&D data for the years 1969-2013 was collected from the Indonesian S&T Indicators published by former Indonesian Institute of Sciences (Pappiptek-LIPI, 2014; Aminullah, 2015). The national R&D expenditure data for the years 2014-2020 are estimated to rise from 0.1 to 0.14% of GDP, reflecting the government's increased budget for science and technology development ahead of the amendment of the national S&T system law. The national R&D expenditure data estimation of 0.14% of GDP in 2020 is based on the patterns of historical data that 50% of the supposed S&T budget data of 0.28% of GDP in 2020 (World Bank, 2024c) contains the R&D expenditure data, because the data was not based on R&D expenditure survey. Following the formation of BRIN 2020-2022, the data for national R&D expenditure decreased again from 0.14 to 0.1% of GDP. The R&D data for 2022 was obtained from the National Research and Innovation Agency's publication (BRIN, 2023).

D. Model Structure

Figure 4 shows the model structure in the form of Stock Flow Diagrams (SFDs), which was generated using Powersim Version 2. The SFDs were created through an iteration process, referring to the conceptual model as explained in the previous section on the theoretical foundation. The elements and variables of model were derived from the model framework based on the theoretical foundation while taking into account historical data for model validation. The details of variables and parameters are displayed in Appendix B. Thus, the model structure can be viewed as scientific knowledge of the real system under study. The SFDs were created in accordance

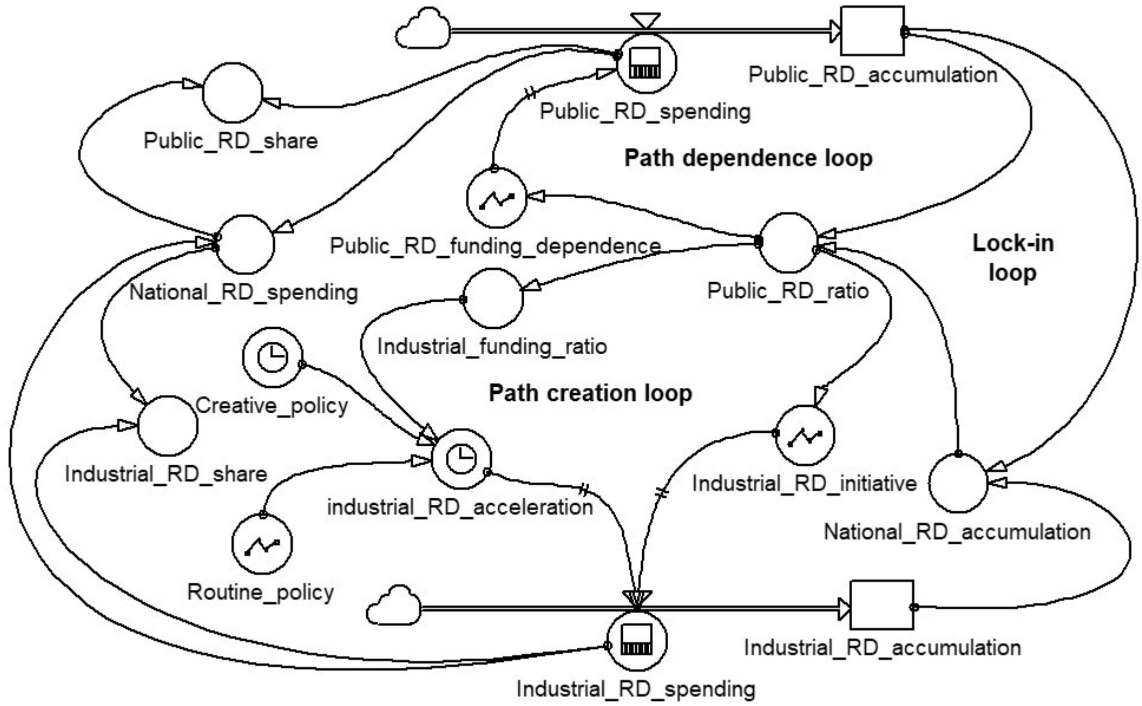

Figure 4. *Stock-Flow Diagrams of Lock-In Dependence on Public R&D Funding Model*

with Forrester's basic rules for system dynamics model building (Forrester, 1968). The documentation of equations and variables' notations of SFDs as empirical model is available in Appendix B.

According to the conceptual model as explained inside the previous section of the theoretical foundation, the structure of SFDs above is divided into three loops: path dependence loop, path creation loop, and lock-in loop. First, the path dependence loop is shaped by public R&D dependence as the result of a long-term high public R&D ratio. Dependence on public R&D funding leads to increased public R&D spending, a continuous increase in public R&D accumulation, and a coming back to a high public R&D ratio. Second, the path creation loop is constructed by industrial R&D acceleration as a response to low industrial R&D ratios, through creative policies either by incremental upgrading policy or by mission-oriented industrial policy. This enables an increase in industrial R&D spending to generate a rapid increase in industrial R&D accumulation. Third, the lock-in loop made by prolonged public R&D funding dependence has the effect of lock-in public R&D dependence and delaying industrial R&D initiatives, resulting in low industrial spending, a slow increase in industrial R&D accumulation, and a return to maintaining a high public R&D ratio. The high public R&D ratio led to maintaining existing industrial RD initiatives by routine policy.

E. Validity of R&D Simulation

A valid model of R&D spending in Indonesia was obtained by validating simulation outputs with data. The simulation curves for R&D funding nearly matched their actual data curves. Figure 5 depicts a graphically validated model of lock-in dependence on public R&D spending.

The validation procedure went through four stages of testing: empirical structure, theoretical structure, stability structure, and behaviour patterns [Barlas, 1996].

(1) Empirical structure checking was performed by comparing model equations to knowledge of the actual system being modelled. The model equations in Appendix B followed the conceptual knowledge of the real system in Figure 2.
(2) Theoretical structure checking was done by comparing model structure to generalised or theoretical knowledge of the system under consideration. Figure 4 on model structure corresponded to the

system's theoretical/conceptual framework shown in Figure 1.

(3) Stability of structure checking was achieved by modifying model parameters and then comparing the patterns of model simulation behaviour to the patterns of actual data. After parameter changes, the simulation behaviours were visually similar to the patterns of real data shown in Figure 5.

(4) The patterns of prediction behaviours or robustness checks by model intervention with creative policies revealed a shift from public to industrial R&D funding. The system's performance after the intervention supported future trends in R&D scenarios, specifically the shift from path dependence to path creation behaviour, as discussed in the results section 4.

F. Future Trends of R&D Scenarios

The simulation curves show past R&D trajectories as well as future trends of R&D scenarios after model intervention. Learning from past path dependence is to create future paths for preventing the government's R&D funding addiction. The future trends of R&D scenarios are forecasted based on valid model simulation. Future trends are represented by graphs, and R&D scenarios are explained using model structure based on the conceptual model as shown in the following results.

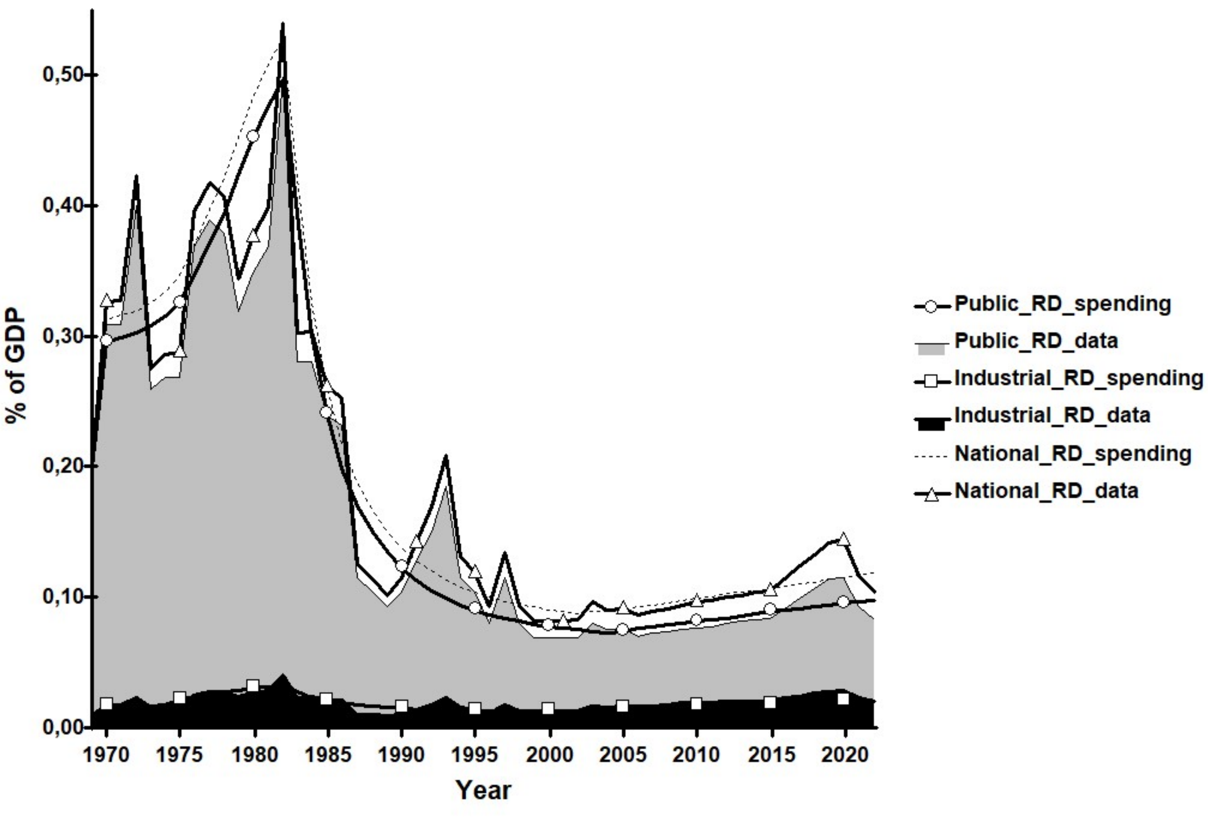

Figure 5. *Graphically Validated Model of Lock-in Dependence on Public R&D Funding*

IV. RESULTS

A. Business as Usual (BAU) Scenario

Figure 6 depicts the scenario of business as usual (BAU). Assuming that Indonesia implements routine policy or there is no policy initiative but continues to rely on public R&D funding to meet R&D spending requirements, it results in increased public R&D accumulation and a high public R&D ratio. Public R&D spending would only slightly rise from around 0.1% of GDP in 2025 to about 0.13% of GDP in 2045. Such a reliance on public R&D funding would continue to stall industrial R&D initiatives, resulting in low industrial spending, a slow increase in industrial R&D accumulation, and a return to a high public R&D ratio. Industrial R&D spending would also slightly increase, from around 0.02% of GDP in 2025 to around 0.03%. In 2045, the public and industrial R&D share would be at 83:17. See Appendix C1

The BAU scenarios would last until 2045, as the public R&D share of national R&D remained stable at 80%. This would imply that Indonesia would be unable to exit the lock-in situation. According to our model structure, the lock-in situation for Indonesian research activities has the following characteristics: Public R&D funding dependence increases exponentially at a public R&D share of 0.5-0.8; the highest dependence occurs at a public R&D share of 0.8; the lowest dependence occurs at a public R&D share of less than 0.7; and freedom from dependence can occur at a public R&D share of less than 0.5 or greater than 0.82.See the patterns of lock-in dependence on public R&D funding in appendix D.

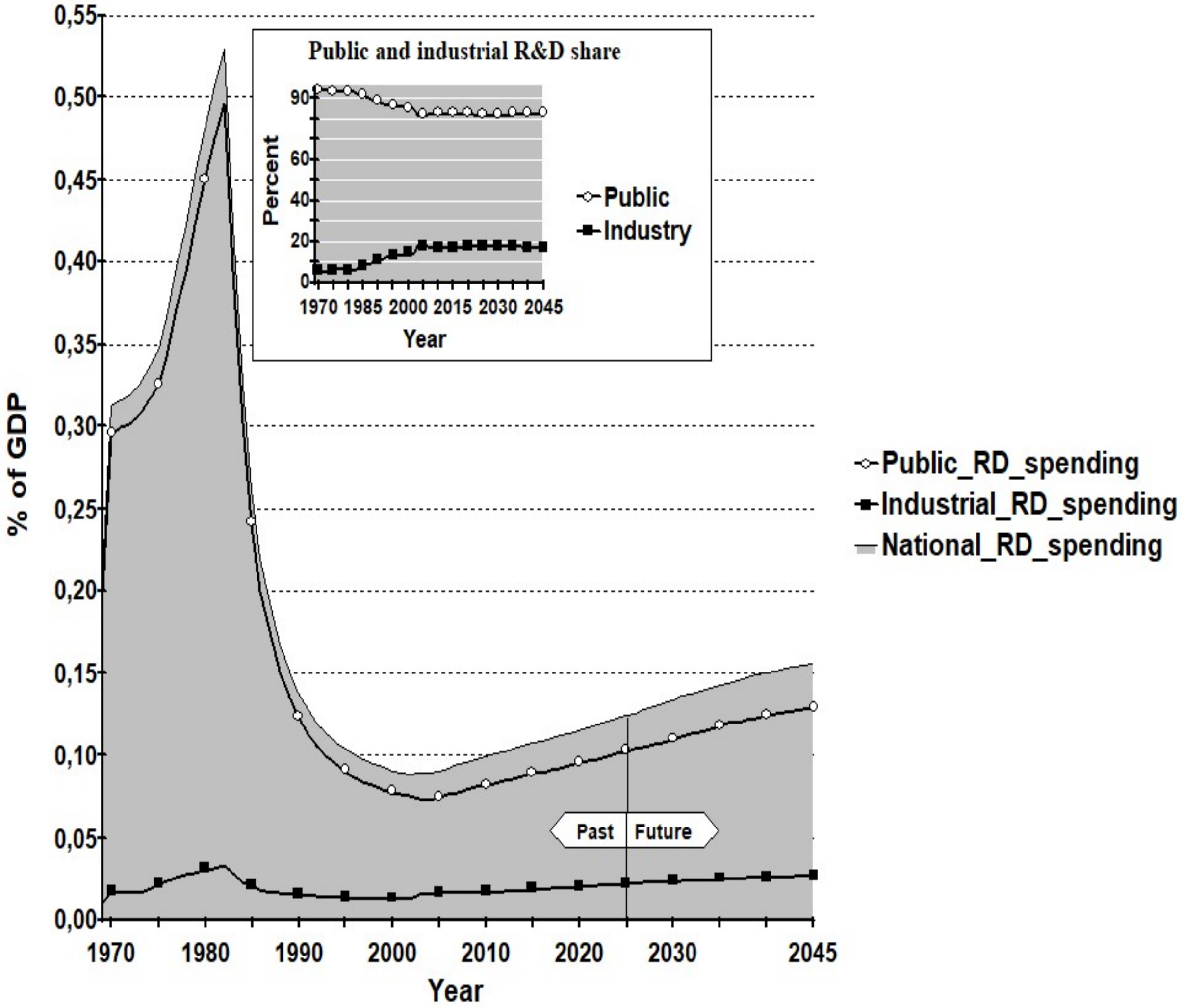

Figure 6. *Future Trend of R&D Spending in the BAU Scenario*

B. Moderate Scenario

Figure 7 depicts a moderate scenario. Assuming that the industrial R&D acceleration is a response to low industrial R&D ratios by implementing an incremental upgrading policy. Government R&D organisations must transfer their R&D output to the industrial sector in a streamlined manner. Transferring government R&D output to the industrial sector will improve R&D capabilities and encourage industrial innovation. The transfer of government R&D results to industry must align with industry capabilities. The majority of industries employ product quality control in laboratories. The transferred R&D results must be close to commercial readiness so that industries can continue testing product quality in the lab. By implementing domestic technology transfer, industrial R&D spending would increase from about 0.02% in 2025 to around 0.13% of GDP in 2045, and the public-industrial R&D share would shift to 74:26, with national R&D spending at approximately 0.54% of GDP. See Appendix C2.

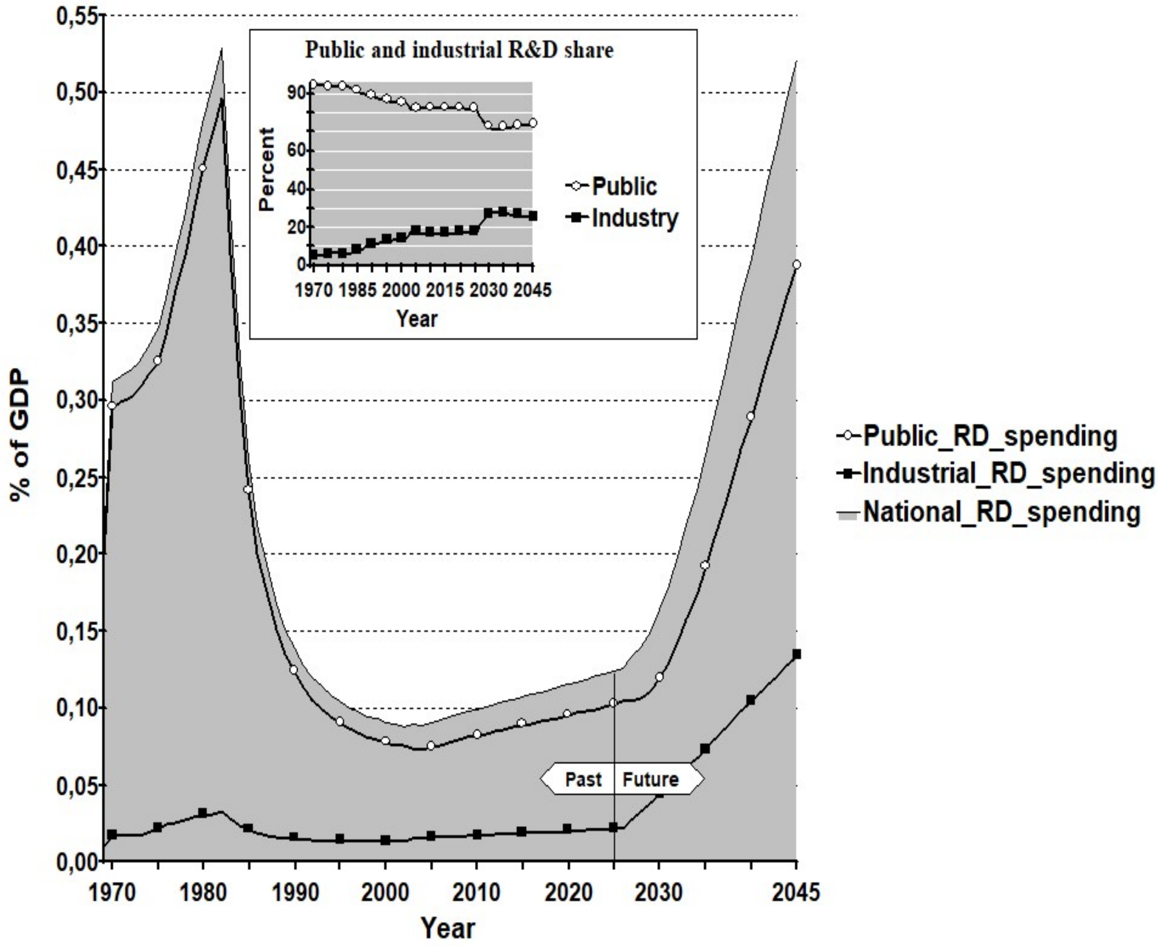

Figure 7. *Future Trend of R&D Spending in the Moderate Scenario*

C. Challenging Scenario

Figure 8 shows a challenging scenario. Assuming that industrial R&D acceleration is achieved through the implementation of both incremental upgrading and mission-oriented industrial policy. The implementation of innovative industrial policy in the mission-oriented industrial sector, which focusses on the down-streaming of natural resource-based industries, requires investment in R&D in addition to capital investment. The sectoral down-streaming of mining (nickel, copper, iron), forestry (wood products, biomaterials), agriculture (palm oil, rubber, cocoa), marine (tuna, seaweed), and manufacturing (phytopharmaceuticals) industries develops through domestic and foreign R&D investment; thus, the FDI should invest in both physical-capital to exploit natural resources and R&D to facilitate international technology transfer.

Referring to the conceptual framework, the transition from path dependence of public R&D funding to path creation of industrial R&D funding would be achieved by implementing a fundamental solution known as mission-oriented industrial innovation. The implementation of mission-oriented industrial innovation requires a fresh perspective on critical options for

moving forward, specifically fostering R&D-based technological innovation in the down-streaming of natural resource-based industries to generate future market demand. The R&D-based technological innovation for natural resource-based industries necessitates the establishment of "the down-streaming industrial technology complex" within existing technology parks. How this industrial technology complex functions to facilitate international technology transfer and technology digestion through R&D is explained in the discussion section.

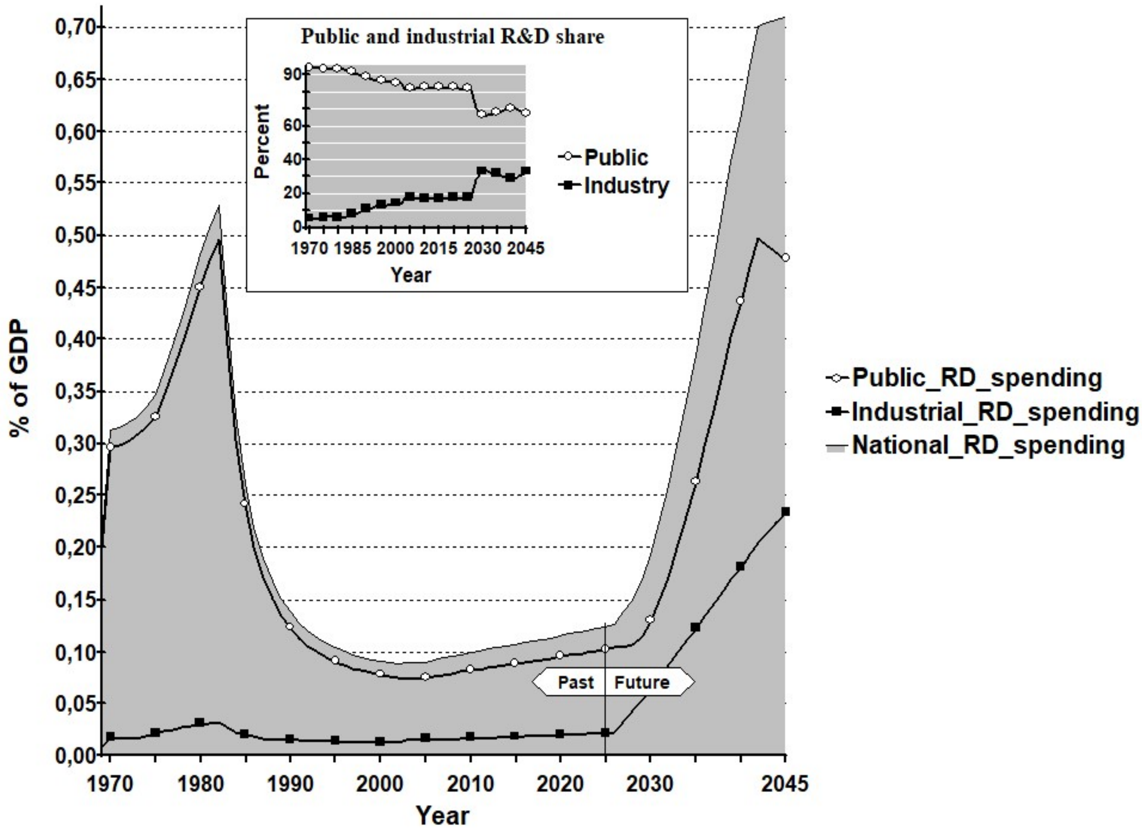

Figure 8. *Future Trend of R&D Spending in the Challenging Scenario.*

The down-streaming industrial technology complex will facilitate international technology transfer, the existing life science park in Cibinong and the engineering technology park in Serpong must begin R&D collaboration with MNCs that run the down-streaming programme of Indonesia's natural resource-based industries. R&D collaborations in science and technology parks should lead to the development of new industries and products for the export market through the implementation of down-streaming programmes. By implementing international technology transfer, industrial R&D spending would rise from about 0.02% of GDP in 2022 to around 0.23% of GDP in 2045, and the public-industrial R&D share would shift to 67:33, with national R&D spending at about 0.71% of GDP. See Appendix C3

V. DISCUSSION

A. Difficulties Releasing From Dependence on public R&D Funding

Based on our model of lock-in dependence, difficulties releasing from dependence on public R&D funding is a significant challenge because it can be rooted in Indonesian science and technology history, from colonial times to the present day. During the colonial period, the colonial government-owned research organisation was the most powerful force in the development of S&T in the Dutch East Indies (Akbar & Handayani, 2021). The colonial state agencies and companies conducted scientific research on plantations at Buitenzorg Gardens in Bogor (Goss, 2011), public health at the Pasteur Institute in Bandung (Doornum et al., 2020), tin mining exploration at Banka Tin Winning (Dipowijoyo et al., 2018), coal at Ombilin Coal Mining (Erman, 1999), and petroleum at Royal Dutch-Shell (Harnawan, 2023). During the old order, the government was influential in encouraging and facilitating the formation of S&T institutions such as the Research Organization for Natural Sciences (ONO) to maintain institutional collaboration with Dutch scientists, the Indonesian Science Assembly (MIPI) to guide S&T development in Indonesia, and the Special Agency for National Research (DURENAS) to coordinate national research (BRIN, 2025). During the new order, the state was in charge of identifying S&T problems, developing policies, and implementing them to promote S&T development, with national development planning serving as the primary source (Akbar et al., 2022). This historical path dependence would lead to a lock-in dependence on public R&D funding.

The previously mentioned reliance on government sources for research funding may be exacerbated by the researcher's performance evaluation system under the bureaucratisation in academic research policy (Bozeman & Jung, 2017). Furthermore, there is little interest in R&D investment in industry, and government researchers are used to receiving government funding. Although the National Research and Innovation Agency (BRIN) is currently attempting to reduce the dependence on public R&D funding by encouraging collaboration with private, international, or philanthropic funding, development remains challenging due to sunk costs, regulations, and a lack of an industry-friendly research culture. The bureaucratisation in governing researcher performance evaluations would impede the development of a creative research culture that benefits industry. Thus, due to the difficulties in transitioning to industrial R&D funding, future R&D trends are most likely to follow a BAU scenario around 0.16% of GDP by 2045. Indonesia would be the country to have experienced a six-decade decline in R&D intensity.

B. Creating More Effective R&D Institution

Imagine that the some relevant public R&D organisations within BRIN dealing directly and indirectly with industry implement researcher performance evaluations based on the use of R&D results by industry; then the fusion of several previous R&D institutions with different resources and orientations will be united by a single goal: to drive beneficial innovation or market entry to solve specific industrial problems in the future. Transferring government R&D output to the industrial sector will boost industrial R&D and drive innovation.

Public R&D funding from the government budget will have a significant impact on the development of innovative products and industrial growth, leading to higher industrial taxes that will certainly be returned to the public to finance future economic development. As a result, public R&D funding is beneficial in stimulating economic growth. This is truly efficient public R&D spending that generates an economic return. In the long run, public R&D funding to support industrial R&D for future economic prosperity will raise the gain of the programme to provide Free Nutritious Meals (FNMs) for future generations. Because FNMs will promote higher educational attainment and health outcomes, and the greatest gains in health outcomes occur when the economy transforms from a conventional (brown) to a knowledge-based (brain) economy (Guan et al., 2025; Hinrichs, 2010; Costa, 2015). The knowledge-based economy is characterised by the high intensity of industrial R&D.

An effective R&D institution should support industrial catch-up, which will increase the institution's importance in the future (Mazzoleni & Nelson, 2007). Using government R&D output to advance domestic industry, boost industrial R&D and drive industrial innovation is an appropriate way for BRIN to demonstrate its economic contribution. Thus, BRIN will become a more effective R&D institution, with truly efficient public R&D spending that yields an economic return. The effective R&D institutions are demonstrated by A*STAR in Singapore (Wang, 2018), which successfully realised innovation as a driver of economic growth through the creation of new industries, and CORFO in Chile (Lebdioui et al., 2020), which successfully encouraged investors to invest in green industry research. By creating a more effective R&D institution, Indonesia's future R&D trends are likely to follow a moderate scenario around 0.52% of GDP by 2045.

C. Implementing Mission-Oriented Industrial Policy

The implementation of mission-oriented industrial policy through the optimisation of BRIN's science and technology parks: Soekarno Science Park in Cibinong district and Habibie Technology Park in Serpong district. (Aminullah, 2024). The mission is to establish a positive feedback cycle between the diffusion of down-streaming technology and the structural adjustment toward the knowledge-based economy, which is being driven by the establishment of the down-streaming industrial technology complex. The greater the diffusion of technology, the greater the shift to a knowledge-based economy, which in turn boosts the next diffusion of technology. The Soekarno Science and Technology Park, which conducts leading biotechnology research, should house domestic companies in agriculture, marine, and forestry, whereas Habibie Science and Technology Park, which conducts leading nanotechnology research, should house foreign and domestic companies in mining and manufacturing, respectively. In terms of ICT innovation, BRIN's technology parks lag far behind Bangalore Technology Park, which mostly houses foreign companies in India, and Zhongguancun Science Park, which mostly houses domestic companies in China (Wang et al. 2012).

In line with the current and future government programme priorities on down-streaming, the sectoral down-streaming of natural resource-based industrial technologies includes mining (nickel, copper, iron), forestry (wood products, biomaterial products), agriculture (palm oil, rubber, cocoa), marine (tuna, seaweed), and manufacturing (phytopharmaceuticals). The down-streaming industrial technology complex becomes the place for i. creating start-up and spin-off companies, ii. producing down-streaming innovative products, iii. providing technical services for companies' technological capability upgrading, iii. learning by DUI (doing, using, and interacting) from existing innovation through experimental development, and iv. pushing company shifts from innovation without or less formal to innovation based on formal R&D (Aminullah, 2024).

Imagine that Indonesia succeeds in creating new R&D-based industries within existing BRIN's science and technology parks in the long-run; Indonesia may be able to break free from the constraints of public R&D funding. The increase in industrial R&D is expected to be primarily driven by technology transfer from R&D institutions, as well as international technology transfer facilitated by R&D collaboration in down-streaming natural resource industries. To meet the demand for a large number of qualified researchers, BRIN and the Ministry of Higher Education, Science and Technology should coordinate the pool of domestic researchers while also inviting reverse immigration for Indonesian scientists from abroad; the role of the state is crucial to attract the brain gain (Zweig et al., 2021). Interaction between researchers and industry in commercialising R&D results can lead to knowledge spillover, researcher mobility, the development of R&D ideas, and the development of industrial products based on collaborative and indigenous R&D (García-Vega and Vicente-Chirivella, 2020; Herrera et al., 2010).

The implementation of mission-oriented industrial policy would propel social change at the level of industrial society. The industry players would gradually shift their mindset to become more dominant as industrialists in strengthening industries with their own R&D products, and business people accustomed to trading by purchasing technology and licences would begin digesting the technology through research. Implementing mission-oriented industrial policy requires policy coordination between BRIN and relevant ministries such as Higher Education, Science and Technology; Marine; Agriculture; Forestry; Mining, and; Industry. According to this future narrative, the most difficult or challenging scenario for Indonesia would be plausible R&D trends around 0.71% of GDP by 2045.

D. Policy Implications

The scenarios provide future policy learning on what policies are desirable and feasible to implement. Routine policies that rely solely on public R&D funding are undesirable and unfeasible. If reliance on public R&D funding is desired to ensure the continuity of current S&T programmes and projects, routine policy remains unfeasible because it would perpetuate the decay of less effective R&D institutions, which is exacerbated by the output-based evaluation system. Although routine policies governing the quantity of outputs used to evaluate researcher performance could be improved by the quality of outputs, the decline of less effective R&D institutions would persist.

The implementation of a creative policy on incremental upgrading would accelerate the transition to industrial R&D. The incremental upgrading policy would transform the less effective into a more effective R&D institution by transferring government R&D output to the industrial sector. Although this is a desirable policy, the feasibility is determined by the success of substituting the output-based evaluation with the outcome for industrial use of the research output as an evaluation system. This policy needs institutional arrangements with the relevant ministry dealing with public servants; the industrial use of the research output for the evaluation system needs to be the basis of the researcher's career system as a public servant.

The implementation of creative policy on mission-oriented industrial policy would serve as a leverage point for transitioning to industrial R&D. The success of this desirable policy is dependent on the implementation of the previous policy on incremental upgrading. Policy coordination among various ministries and agencies to achieve the mission of creating new industries based on R&D investment within science and technology parks determines its feasible implementation. To facilitate integrally coordinated policies the "Joint Ministerial Committee for Industrial Research Acceleration" should be established to realize Indonesia's transition to industrial R&D.

E. Limitations and Further Research

This study's limitations include two aspects: First, the system modelling in this study focused on increasing industrial R&D investment, whereas innovation systems in several industrial sectors could occur with little or no R&D investment, as stated in the introduction to this article; thus, analysing in-depth empirical data on innovation with little or no R&D at the firm, sector, industry, or country level could be a further study. Second, industrial policy can be thought of as a policy process that cannot be adequately represented by a parameter in the model. The industrial policy process must be included as an interactive variable in the modelling process; thus, modelling analysis of policy content, implementation mechanisms, and outcomes in terms of impacts on firm innovation and capability development could be a viable option for further research.

VI. CONCLUSION

This article has built a model of lock-in dependence on public R&D funding based on historical data. The model explains Indonesia's research reliance on public funding, which is consistent with low creation to stimulate private R&D funding. The model ran a simulation to generate scenarios and propose a transition from relying on public R&D to creating paths for industrial R&D. The long-term policies should be executed integrally in realizing Indonesia's transition to industrial R&D. This study's scientific contribution is a model of lock-in dependence on public R&D funding based on historical data.

Indonesia needs to increase its industrial R&D contribution to the national economy. To accomplish this goal, R&D spending in public research organisations must be targeted, resulting in increased industrial R&D investment. The policy of increasing industrial R&D investment can be implemented by transferring research outputs from relevant research organisations to the industrial sector, as well as increasing R&D investment in the mission-driven industrial sector. This is a challenging scenario for future R&D trends, which could be around 0.71% of GDP in 2045.

The limited R&D spending of a public R&D institution can have a tangible economic impact if the public R&D organisations within BRIN implement researcher performance evaluations based on the outcome for industry use of R&D results. Transferring government R&D output to the industrial sector will stimulate industrial R&D and innovation. As a result, BRIN will be more significant in demonstrating its economic contribution. By establishing a more effective R&D institution, future R&D spending trends are likely to be moderate, at around 0.52% of GDP in 2045.

Dependence on public R&D funding is a fundamental obstacle because it is deeply embedded in Indonesian science and technology history. The prolonged reliance on government R&D funding has the unintended consequence of lock-in dependence on public R&D funding and further delays in increasing industrial R&D. The reliance on government sources for research funding may be exacerbated by the output-based evaluation system. Difficulties in overcoming reliance on public R&D funding: future R&D spending trends are most likely to follow a BAU scenario of 0.16% of GDP in 2045. Indonesia could be a country to have experienced six decades of low R&D intensity by 2045.

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Appendix A: Statistical data

Statistical data of Indonesian R&D spending

Year	Public_RD_data	Industrial_RD_data	National_RD_data	Public_share	Industrial_share
1969	0,19	0,01	0,20	95	5
1970	0,31	0,02	0,33	95	5
1971	0,31	0,02	0,33	95	5
1972	0,40	0,02	0,42	94	6
1973	0,26	0,02	0,28	94	6
1974	0,27	0,02	0,29	94	6
1975	0,27	0,02	0,29	94	6
1976	0,37	0,03	0,40	94	6
1977	0,39	0,03	0,42	93	7
1978	0,38	0,03	0,41	93	7
1979	0,32	0,02	0,34	93	7
1980	0,35	0,03	0,38	93	7
1981	0,37	0,03	0,40	93	7
1982	0,50	0,04	0,54	92	8
1983	0,28	0,02	0,30	92	8
1984	0,28	0,02	0,30	92	8
1985	0,24	0,02	0,26	92	8
1986	0,23	0,02	0,25	92	8
1987	0,12	0,01	0,13	91	9
1988	0,10	0,01	0,11	91	9
1989	0,09	0,01	0,10	91	9
1990	0,10	0,01	0,12	90	10
1991	0,13	0,01	0,14	90	10
1992	0,15	0,02	0,17	89	11
1993	0,19	0,02	0,21	89	11
1994	0,12	0,02	0,13	88	12
1995	0,10	0,01	0,12	88	12
1996	0,08	0,01	0,09	87	13
1997	0,12	0,02	0,13	87	13
1998	0,08	0,01	0,09	86	14
1999	0,07	0,01	0,08	86	15
2000	0,07	0,01	0,08	85	15
2001	0,07	0,01	0,08	84	16
2002	0,07	0,01	0,08	84	16
2003	0,08	0,02	0,10	83	17
2004	0,08	0,02	0,09	83	17
2005	0,08	0,02	0,09	82	18
2006	0,07	0,02	0,09	82	18
2007	0,07	0,02	0,09	81	19
2008	0,07	0,02	0,09	81	19
2009	0,08	0,02	0,09	80	20
2010	0,08	0,02	0,10	80	20
2011	0,08	0,02	0,10	80	20
2012	0,08	0,02	0,10	80	20
2013	0,08	0,02	0,10	80	20
2014	0,08	0,02	0,10	80	20
2015	0,08	0,02	0,11	80	20
2016	0,09	0,02	0,11	80	20
2017	0,10	0,02	0,12	80	20
2018	0,11	0,03	0,13	80	20
2019	0,11	0,03	0,14	80	20
2020	0,12	0,03	0,14	80	20
2021	0,09	0,02	0,12	80	20
2022	0,08	0,02	0,10	80	20

Note: spending in % of GDP and share in percent; data for the years 2014-2021 are estimation.
Sources: Processed from Indonesian S&T Indicators, Pappiptek-LIPI, 2014; Indonesian S&T indicators, research and innovation, BRIN, 2023; see also Aminullah (2015)

Appendix B: Model equations and its documentations

Empirical model of lock-in dependence on public R&D funding

```
init  Industrial_RD_accumulation = 1
flow  Industrial_RD_accumulation = +dt*Industrial_RD_spending
init  Public_RD_accumulation = 1
flow  Public_RD_accumulation = +dt*Public_RD_spending
aux   Industrial_RD_spending =
      DELAYINF(Industrial_RD_initiative,1,1,0.01)+DELAYINF(industrial_RD_acceleration,1
      ,1,0)
aux   Public_RD_spending = DELAYINF(Public_RD_funding_dependence,1,1,0.2)
aux   Creative_policy = RAMP(0.005,2025)
      doc    Creative_policy is  parameter RAMP value 0.01 for mission-oriented industrial
             policy with start time in 2025 and value 0.005 for incremental upgrading policy
             with start time in 2025.
aux   Industrial_funding_ratio = 1-Public_RD_ratio
aux   industrial_RD_acceleration =
      STEP((Routine_policy+Industrial_funding_ratio),2002)*0.01+Creative_policy
aux   Industrial_RD_initiative =
      GRAPH(Public_RD_ratio,0,0.05,[0,0,0,0,0,0,0,0,0,0.017,0.017,0.017,0.017,0.023,0.027
      9,0.033,0.0094,0.0048,0.002,0"Min:0;Max:0.05;Zoom"])
      doc    Industrial_RD_initiative is the XY graph, where input X is Public_RD_ratio and
             output Y is Industrial_RD_initiative. The initiative is zero for the ratio less than
             0.45, increases linearly for the ratio between 0.45 and 0.50, and again increases
             linearly for the ratio between 0.65 and 0.80. After that the initiative decreases
             exponentially to zero at the ratio between 0.80 and 1. The maximum value of
             Industrial_RD_initiative is 0.033 at the public R&D ratio of 0.80.
aux   Industrial_RD_share = (Industrial_RD_spending/National_RD_spending)*100
aux   National_RD_accumulation = Public_RD_accumulation+Industrial_RD_accumulation
aux   National_RD_spending = Industrial_RD_spending+Public_RD_spending
aux   Public_RD_funding_dependence =
      GRAPH(Public_RD_ratio,0,0.05,[0,0,0,0,0,0,0,0,0,0,0.296,0.3,0.303,0.311,0.329,0.397,0.5
      ,0,0,0,0"Min:0;Max:0.5;Zoom"])
      doc    Public_RD_funding_dependence is the XY graph, where input X is
             Public_RD_ratio and output Y is Public_RD_funding_dependence. The effect of
             dependence is zero for the ratio less than 0.5 and greater than 0.85, increases
             exponentially for the ratio between 0.5 and 0.80, and decreases linearly for the
             ratio between 0.80 and 0.85. The maximum value of public R&D funding
             dependence is 0.5 at the public R&D ratio of 0.80.
aux   Public_RD_ratio = Public_RD_accumulation/National_RD_accumulation
aux   Public_RD_share = (Public_RD_spending/National_RD_spending)*100
aux   Routine_policy =
      GRAPH(TIME,1969,10,[0,0.01,0.02,0.07,0.23,0.46,0.76,0.92,1"Min:0;Max:1"])
      doc    Routine policy is parameter of Graph_TIME from 1969 to 2045, with a time
             period of 10 years. The graph is a sigmoid curve with values from zero to 1.
```

Appendix C: Simulation results of scenarios

Appendix C1: Simulation results of BAU scenario

Year	1969	1973	1977	1981	1985	1989	1993	1997	2001	2005	2009	2013	2017	2021	2025	2029	2033	2037	2041	2045
Public_RD_spending	0,20	0,31	0,37	0,48	0,24	0,14	0,10	0,08	0,08	0,07	0,08	0,09	0,09	0,10	0,10	0,11	0,12	0,12	0,13	0,13
Industrial_RD_spending	0,01	0,02	0,03	0,03	0,02	0,02	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,03	0,03	0,03
National_RD_spending	0,21	0,33	0,40	0,51	0,26	0,15	0,11	0,10	0,09	0,09	0,10	0,10	0,11	0,12	0,12	0,13	0,14	0,15	0,15	0,16
Public_RD_share	95	95	93	94	92	90	88	86	85	82	83	83	83	83	82	82	82	83	83	83
Industrial_RD_share	5	5	7	6	8	10	12	14	15	18	17	17	17	17	18	18	18	17	17	17

Note spending in % of GDP; share in %

Appendix C2: Simulation results of Moderate scenario

Year	1969	1973	1977	1981	1985	1989	1993	1997	2001	2005	2009	2013	2017	2021	2025	2029	2033	2037	2041	2045
Public_RD_spending	0,20	0,31	0,37	0,48	0,24	0,14	0,10	0,08	0,08	0,07	0,08	0,09	0,09	0,10	0,10	0,11	0,16	0,23	0,31	0,39
Industrial_RD_spending	0,01	0,02	0,03	0,03	0,02	0,02	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,02	0,02	0,04	0,06	0,09	0,11	0,13
National_RD_spending	0,21	0,33	0,40	0,51	0,26	0,15	0,11	0,10	0,09	0,09	0,10	0,10	0,11	0,12	0,12	0,15	0,22	0,32	0,42	0,52
Public_RD_share	95	95	93	94	92	90	88	86	85	82	83	83	83	83	82	74	72	73	74	74
Industrial_RD_share	5	5	7	6	8	10	12	14	15	18	17	17	17	17	18	26	28	27	26	26

Note spending in % of GDP; share in %

Appendix C3: Simulation results of Challenging scenario

Year	1969	1973	1977	1981	1985	1989	1993	1997	2001	2005	2009	2013	2017	2021	2025	2029	2033	2037	2041	2045
Public_RD_spending	0,20	0,31	0,37	0,48	0,24	0,14	0,10	0,08	0,08	0,07	0,08	0,09	0,09	0,10	0,10	0,12	0,20	0,33	0,47	0,48
Industrial_RD_spending	0,01	0,02	0,03	0,03	0,02	0,02	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,02	0,02	0,05	0,10	0,15	0,19	0,23
National_RD_spending	0,21	0,33	0,40	0,51	0,26	0,15	0,11	0,10	0,09	0,09	0,10	0,10	0,11	0,12	0,12	0,17	0,30	0,48	0,66	0,71
Public_RD_share	95	95	93	94	92	90	88	86	85	82	83	83	83	83	82	68	67	70	71	67
Industrial_RD_share	5	5	7	6	8	10	12	14	15	18	17	17	17	17	18	32	33	30	29	33

Note spending in % of GDP; share in %

Appendix D: The patterns of lock-in dependence