Mission-Oriented Innovation Policies in Singapore: Research, Innovation and Enterprise Planning and National Innovation Challenges

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Abstract

Countries worldwide seeking innovation-driven economic growth face the increasing complexity and uncertainty of grand societal challenges. The new generation of mission-oriented innovation policy (MOIP) is led by societal challenges to spearhead transformative system change. Despite the centrality of existing innovation system structures to transformative system change and mission-oriented innovation, there has been limited attention to their role. This article contributes to the agenda by investigating how existing innovation system structures should be reconfigured by MOIP to produce relevant outcome, and how stakeholder commitment can be shaped by the legitimacy of MOIP. It also examines how the tension between new and existing innovation pathways should be managed. Using the triple helix and problem-solution perspectives, we studied the cases of Singapore's research, innovation and enterprise plans, as well as its national innovation challenge programmes during the 2010-2020 period. Our findings demonstrate the critical role of institutional legitimacy in reconfiguring existing actors for successful mission outcome. Our analysis shows the importance of social legitimacy among the expanded helix structures of government, university, industry and civil society to increase stakeholder commitment. To manage the tension between different innovation pathways, Singapore policymakers adopted a portfolio approach to pursue novelty in solutions to accomplish the mission.

Introduction

The traditional approach of focusing on specific domains of science, technology and innovation (STI) and addressing market failures is not sufficient in tackling grand societal challenges. Nor is economic growth the only reason for accelerating technological development. Instead, there is rising concern in academic discussions and public discourse about how research and innovation policies should solve the grand societal challenges. Mounting pressures have been exerted on policymakers to seek new approaches of innovation policy to address the challenges. The search has also triggered renewed interest in the mission-oriented types of innovation policy (MOIP) that were popular in the 1960s and 1970s. However, the meaning of MOIP today differs from that in the past. Past policies involved missions to achieve technological progress with man-on-the-moon projects to meet specific objectives (Nelson, 1974). These technology-led missions address 'tame' problems or problems that are clearly defined with solutions known, but had limited socio-economic impact (Mowery et al., 2010). Today's missions, on

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the other hand, focus on societal problems that are more unstructured, ambiguous and complex. Also known as grand societal challenges, these problems are persistent and can range from ageing population to climate change, calling for solutions that require not only technological changes, but also behavioural and institutional transformations (Alkemade et al., 2011).

According to Wanzenbock et al. (2020: 3), the new generation of MOIP is 'a directional policy that starts from the perspective of a societal problem, and focuses on the formulation and implementation of a goal-oriented strategy by acknowledging the degree of wickedness of the underlying challenge, and the active role of policy in ensuring coordinated action and legitimacy of both problems and innovative solutions across multiple actors.' While many governments have embarked on MOIP to direct research and innovation resources to achieve lofty goals of their country ranging from clean energy to waste reduction, they still struggle with translating mission objectives into policy actions. As observed by Janssen et al. (2021), the pursuit of MOIP has its own set of challenges. Some scholars have tried to unpack them by distinguishing between past and present mission approaches (Mowery et al., 2010; Mazzucato, 2018), contextualizing societal challenges (Wanzenbock et al., 2020) and identifying different types of MOIP (Wittmann et al., 2021). However, others cautioned that MOIP do not operate in isolation for three reasons. First, technological trajectory builds on past scientific developments and is primarily path-dependent (Hansen and Coenen, 2015). Second, market and product knowledge may be 'sticky' and hard to diffuse across regions, and is location-dependent (Fabrizio and Thomas, 2012). There is therefore a need for further research to shed light on how existing structures of innovation system can play an effective role in the transformative change pursued by MOIP (Janssen et al., 2021; Bugge, Andersen and Steen, 2021). Third, prior studies have shown that while government policies could catalyse innovation beyond trajectories of existing technologies to tackle challenges such as clean energy, the policies might have the negative effects of encouraging firms with more mature technologies to exploit rather than explore less mature technologies in response to policy incentives (Hoppmann et al., 2013). Through exploitation, these firms would reap benefits such as learning-by-doing, economies of scale and lock-in of mature technologies, which in turn would create entry barriers to firms with less mature technologies that could only explore and benefit from learning-by-searching.

To advance our understanding on MOIP, this article aims to address three research questions: (a) how should existing structures of innovation system be reconfigured by MOIP to produce outcome that is relevant to the mission, (b) how can stakeholder commitment be shaped by the legitimacy of MOIP, and (c) how to manage the tension between exploration of new pathways and exploitation of existing ones to achieve a mission. This article will draw on two distinct literature strands to investigate the research questions.

First, we build on the triple helix approach to understand the role of existing innovation system structures (Etzkowitz, Mello and Almeida, 2005). According to Nelson and Rosenberg (1993, p. 4), the national innovation system is 'a set of institutions whose interactions determine the innovative performance ... of national firms'. In the triple helix model, universities, industry and government are important structures of innovation system that work together closely to support system-oriented innovation policies (Cheah, 2016; Cheah and Yu, 2016). However, there is still room to improve the explanatory power of the current helix approach about the role of the existing innovation system structures in the transformative change promoted by MOIP (Hjalager and von Gesseneck, 2020).

Second, this article will draw on the problem-solution perspective that regards MOIP as solving societal problems in socio-technical systems by linking these problems with MOIP solutions. Recent works have been significant in decomposing the societal problems and MOIP solutions based on wickedness dimensions (contestation, uncertainty and complexity), and advocating a process-oriented view to identify 'pathways along which convergence between problems and solutions can be achieved to come from wicked problems to legitimate solutions' (Wanzenbock et al., 2020: 474). While it seems clear that the strategic orientation, design and implementation of MOIP should be articulated in the context of the problem heterogeneity, there is scarcity of knowledge about the tensions between the different pathways, in particular, exploratory and exploitative pathways (Janssen et al., 2021).

In this article, we build on these notions to understand the role of existing innovation system structures in MOIP through case study of Singapore's research, innovation and enterprise (RIE) and national innovation challenge (NIC) programmes during the 2010-2020 period. Over the decade, the country has formulated MOIP with significant investment in research and innovation that has made strong socio-economic impact. In 2022, Singapore was ranked in the Global Innovation Index as the seventh most innovative economy globally, and second in Asia after occupying the top spot for seven consecutive years (WIPO, 2022). In the Startup Ecosystem Index 2022 that compared the startup ecosystem of 100 cities around the world, Singapore was ranked seventh globally and first in Asia (StartupBlink, 2022). The country was also ranked the most liveable location globally for 15 consecutive years by global mobility expert ECA International (2021). Singapore is relevant for our study because it can provide insights on how existing helix structures—government, industry, universities and civil society—play a significant role to succeed in its RIE and NIC missions.

2. Conceptual Framework

2.1 Expansion of Triple Helix Model

With its roots in classical sociological theory and institutional economics since 1996, the Triple Helix model of innovation has attracted policymakers across multiple levels of governance and geographies (Viale and Etzkowitz, 2010). In the sociological domain, the concept of triad is considered more stable than a dyad due to the third sphere's potential role as a mediator in the event of tension or conflict between the first two spheres. From the perspective of institutional theory, the environment comprising the interaction patterns among the triple helix structures may evolve over time. However, the triple helix model is not the outcome of evolution, but that of a development process that has to be coordinated through innovation policies and legitimized through agency (Cheah and Ho, 2020). For the past three decades, the model has been refined and used to explain the dynamic interactions among three institutional spheres of university, industry and government. In 2015, Ranga and Etzkowitz posited that the Triple Helix systems are characterized by their components, functions and the relations between components. Each sphere can comprise 'a wide array of actors, among whom a distinction is made between: (a) individual and institutional innovators; (b) R&D and non-R&D innovators; and (c) 'single-sphere' and 'multi-sphere' (hybrid) institutions' (Ranga and Etzkowitz 2015: 238). To examine the growing significance of civic engagement and sustainable development in the innovation system, more recent studies have added the civil society as the fourth helix (Carayannis et al., 2019; Boelman et al., 2014). This article will build on the expanded definition of triple/quadruple helix systems to distinguish between the existing structures of innovation system—government ministry, public agency, public research institutes, universities, industry and non-government organizations (NGO)—and their role in MOIP.

2.2 Typology of MOIP

In the MOIP literature, initial studies adopted the problem-solution perspective to understand how MOIPs vary according to the wickedness of the challenges they aim to address. In general, two broad categories of challenges are identified (Wanzenböck et al., 2020). One category describes challenges that can be solved with technological development and addressed by missions that accelerate scientific achievements ('accelerator' mission). The second category depicts challenges that are more wicked (more contested, uncertain or complex) and addressed by missions that make systemic transformations ('transformer' mission) (Kuittinen, Polt and Weber, 2018). Apart from the wickedness dimensions, other studies have posited the scale and scope of the mission as an important characteristic of MOIP (Larrue, 2021). The scale and scope of missions can range from being narrow and involve less actors (e.g. challenge-based MOIP) to being broad and involve more actors (e.g. overarching mission-oriented strategic frameworks). More recent studies have proposed a general affinity between overarching national strategic program and 'transformer' mission, as well as between challenge-based program and 'accelerator' mission. Others have proposed thematic mission-oriented and ecosystem-based mission programs. The former aim at the 'competitiveness in the research consortia of the 1980s -1990s' to address 'a mix of societal and competitive challenges' (Larrue, 2021: 20). The latter focus on 'innovation agenda developed by the actors themselves, with neutral support from public authorities' (Larrue, 2021: 20). These MOIP types vary along three dimensions: strategic orientation, policy coordination and policy implementation. To achieve mission objectives, strategic orientation informs and chooses particular societal challenge(s) while enforcing legitimacy. Policy coordination ensures the divergent goals and programs are well coordinated across multiple stakeholders using a portfolio approach to pursue novelty in solutions to accomplish the mission. Policy implementation, on the other hand, focuses on consistency in policy mix, effectiveness in resource deployment through continuous impact evaluation and improvement.

This article refers to two of the four main types of MOIPs—overarching mission-oriented strategic frameworks and challenge-based programmes—along the dimensions of strategic orientation, policy coordination and policy implementation to analyse the Singapore's RIE and NIC mission.

3. Case study of Singapore MOIPs

3.1 Singapore RIE2015-2020 Case – Overarching mission-oriented strategic framework

Singapore's investments in R&D started in 1991, with the setup of the National Science and Technology Board, and initiation of its first five-year National Technology Plan. The Plan aimed to build a strong pool of scientists, researchers and engineers and move Singapore up the economic value chain while supporting the growth of multinational corporations in Southeast Asia. The Plan was refreshed every five years to fuel the growth of a knowledge-based economy. It was the highest level of planning framework as it targeted to structure the interactions between economic and societal missions, possessing the characteristics of an overarching mission-oriented strategic framework, with a 'whole-of-government' approach (Larrue, 2021)

Strategic Orientation

Following the review of the early national science and technology (S&T) plans from 1991 to 2005, several key recommendations were made by the Ministerial Committee on R&D and approved by the government. First, the government should set up an overarching structure to 'provide a coherent strategic overview of R&D at the national level, and to allocate funding to longer term R&D programmes.' (MTI, 2006: 6). Second, research should be focused on areas of economic significance to the country, such as life sciences, environment and water, as well as interactive and digital media. Third, research capabilities from basic research to mission-oriented research should be developed to ensure good science at universities and public research institutes would be translated for industry applications. Fourth, the private sector including multinational companies should be encouraged to increase their R&D expenditure in Singapore to increase talent flow between industry and academia in open collaboration. Finally, the connection between industry and public R&D performers should be strengthened through co-funding frameworks to transfer knowledge from public research to businesses to enhance their human and technological resources. Based on these recommendations, the government approved the S&T2010 Plan in 2006 with the commitment of S$13.55b for R&D investments and the target of achieving gross expenditure on R&D of 3 percent of gross domestic product by 2010.

To enforce legitimacy, the government enacted the National Research Fund Act to establish the National Research Fund (SSO, 2007). The objective of the Fund was to provide funding and administration of R&D activities to foster (a) development of innovative products, processes and services, (b) R&D investments by public and private sectors to raise the country's competitiveness, (c) technological progress of public and private sectors through innovation, and (d) a conducive environment for commercializing new process and product technologies (MOF, 2006). To guide the government in legislation and policymaking to achieve the objective, the National Research Fund Act provided the establishment of a new body known as the RIE Council (RIEC) chaired by the Prime Minister and comprising cabinet ministers, leaders from the industry, scientific and academic communities. The RIEC members clearly reflected the government's espousal of the triple helix model in building the country's national innovation system (Cheah, Ho and Lim, 2016).

In September 2010, the Prime Minister of Singapore announced the expansion of the country's strategy to include R&D performance, innovation management and enterprise development (RIE). The national RIE planning was launched then as a holistic framework to harness the power of R&D to address complex challenges (NAS, 2011). The planning started with RIE2015 which would be refreshed every five years with a new budget. The RIE2015 with budget of S$16b comprised research translation and commercialisation to create high value employment and wealth for Singaporeans for the 2010-2015, focusing on societal challenges of ageing population and urban sustainability.

In January 2015, the Prime Minister launched RIE2020 with S$19b budget for Singapore to implement four major thrusts: 'closer integration of research thrusts', 'stronger dynamic towards the best teams and ideas', 'sharper focus on value creation' and 'better optimized RIE manpower' (NRF, 2016: 5).

Policy Coordination

Policy coordination was a key strength of Singapore's policymaking process. To ensure that national R&D projects are approved and executed in a coherent manner, the National Research Fund Act provided for the establishment of the National Research Foundation (NRF) as a new department under the Prime Minister's Office to fulfil this responsibility to support the RIEC. The NRF Board was chaired by the Deputy Prime Minister and staffed by the representatives from at least nine ministries. To align the diverse goals and programmes across the academic, government and industry helix structures, the RIEC and NRF adopted a portfolio approach by allocating pre-defined proportions of funding by project type ranging from small-scale investigator-led academic research to create a robust science base through mid-sized multi-disciplinary research to develop good science in strategic areas, to mid-sized grants to build centres of excellence. Such portfolio approach enabled the government to pursue novelty in their solutions to societal challenges.

To identify critical issues, global trends and new areas of research where Singapore can develop international competitiveness, the NRF established a Scientific Advisory Board (SAB) comprising international experts in broad technology areas. The SAB members would convene annually to advise NRF on its proposals, plans, R&D management and research outcome assessment.

In RIE2020, four strategic technology domains were identified for prioritizing research funding to achieve high impact: (a) Advanced Manufacturing and Engineering (AME) at S$3.3b, Health and Biomedical Sciences (HBMS) at S$4b, Urban Solutions and Sustainability (USS) at S$0.9b, and Services and Digital Economy (SDE) at $0.4b. The activities in the four strategic technology domains were coordinated with horizonal programmes to optimize efficiency in resource utilization. These horizontal programmes comprised academic research (S$2.8b), manpower (S$1.9b), innovation and enterprise (S$3.3b) and white space (S$2.5b).

To support the growth of Singapore's manufacturing and engineering sectors, eight industry verticals (e.g. aerospace, electronics and chemicals) and four enabling technology areas (e.g. robotics and automation, additive manufacturing) were identified in the AME domain. The national research agency Agency for Science and Technology Research (A*STAR) under the Ministry of Trade and Industry (MTI) played a key in facilitating grant calls open to all public research performers to propose ideas for further R&D to support thematic programmes for future industry needs. For example, A*STAR launched in 2020 a public-private platform Model Factory that would enable more than 100 companies with over 2,500 technologies to improve operational efficiency and productivity (NRF, 2020: 14).

To advance health and wellness, the HMBS domain saw the deployment of over 10 research grant schemes by the National Medical Research Council (NMRC) under the Ministry of Health (MOH) and A*STAR to advance research in five therapeutic areas comprising cancers, cardiovascular diseases, diabetes mellitus and other endocrine conditions, infectious diseases, and neurological and sense disorders (NRF, 2020). Some of these schemes were open to clinic researchers in public healthcare institutions, while others were available to public research performers.

To build a sustainable and liveable city, NRF coordinated the efforts of various ministries such as the Ministry of Sustainability and Environment (MSE), the Ministry of National Development (MND) and the Ministry of Transport to initiate over 30 schemes. These schemes included competitive research programmes for water, urban mobility, energy (e.g. renewables, green buildings and data centres). In 2013, the MND and NRF launched the Land and Liveability NIC with $135m fund for five years to address the country's land constraints (NRF, 2021). Of over 100 proposals that responded to the challenge, 24 were awarded. Among the research projects were design of age-friendly neighbourhoods and sustainable nursing homes.

To grow Singapore's digital innovation capabilities, three critical national needs were identified in in the SDE domain: healthcare info-communication technology, urban mobility and services productivity. Key schemes such as Smart Systems strategic research programmes building R&D capabilities in areas led by public sector, and commercialisation of public R&D led by private sectors. Among these schemes, one was a national programme in artificial intelligence AI.SG launched by NRF in 2017 to build capabilities in AI. Established as a multi-agency effort, AI.SG has by 2020 engaged more than 300 companies and initiated over 60 projects as part of the 100 Experiments programme that focused on key sectors such as fast-moving consumer goods, finance and healthcare (NRF, 2020).

Policy Implementation

In Singapore, the RIE plans were implemented through schemes and programmes. Their effectiveness was tracked via indicators, and reviewed on a regular basis. A host of indicators would be used to measure the efficiency of activities in each phase spanning from research to innovation and enterprise—the RIE value chain (Cheah, 2016; Cheah and Yu, 2016). See Table 1 for RIE2020 indicators, targets and the actual accumulative achievements from financial year (FY) 2016 to 2020 that were measured against targets.

Based on the reviews, the plans would be refreshed every five years to ensure they stay relevant. The allocation of white space funding in the plan provided the agility to respond to unforeseen opportunities and needs arising from market changes or technology transitions. This approach of policy implementation through continuous impact evaluation and improvement would ensure optimal policy mix and efficient resource deployment. In addition, the structure of the government helix was continuously streamlined to enforce the legitimacy of new roles and responsibilities. For example, the public agency promoting the growth of local enterprises SPRING and the public agency supporting the internationalisation

Table 1 Key performance indicators for tracking research, innovation and enterprise activities from FY2016 to 2020 against the RIE2020 targets

			Achievement Cumulative				
Category	Key Performance Indicators	RIE2020 Target	FY2020	FY2019	FY2018	FY2017	FY2016
Research	Industry R&D Projects	3,315	7,492	6,056	4,433	4,000	1,800
	Industry R&D Spending (S$m)	1,200	1,384	1,136	813	570.5	233.61
Innovation & Enterprise	Number of Licenses	450	1,133	977	771	498	235
	Number of Spin-offs	52	92	68	51	31	17
	Industry Cash Funding Received (S$m) (subset of indicator no 2)	322	477	396	308	210	107.1
	Licensing Revenue (S$m)	15	26.6	23.6	20.4	14.4	9.05
Talent	Number of Research Scientists and Engineers from Research Institutes seconded to Industry	275	324	255	187	127	66
	Number of PhD Postgraduates trained or being trained	545	607	542	426	261	126

Source: A*STAR (2020, 2019, 2018, 2017, 2016) efforts of local enterprises IE Singapore merged in 2018 to become Enterprise Singapore. The Enterprise Singapore Board Act was passed by the Parliament in February 2018 to provide for its function 'to enable Singapore-based enterprises and other enterprises requiring assistance to create and expand their businesses in domestic and foreign markets', among other functions (SSO, 2018).

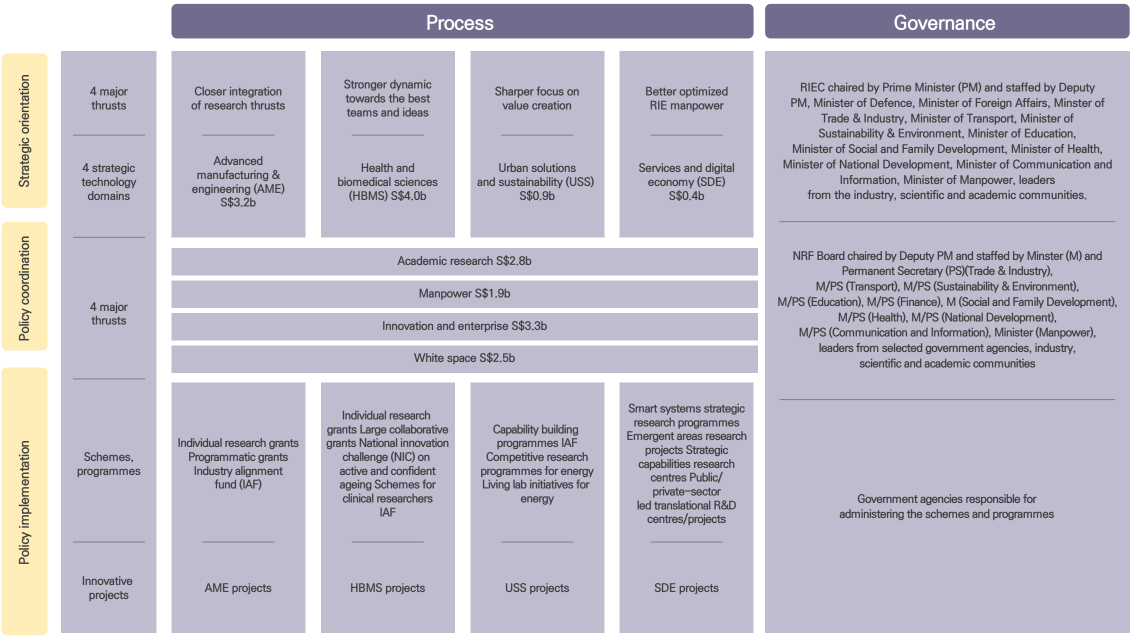
3.2 NIC on Active and Confident Ageing Case - Challenge-based programmes

With rising life expectancy and declining fertility rates, the proportion of citizens aged 65 and above has increased steadily from 11.1 percent in 2012 to 18.4 percent in 2022 (Chin, 2022). The proportion was projected to grow to 23.8 percent by 2030. To manage the escalating healthcare costs, the government has embarked on multiple initiatives to encourage its citizens to manage their health and attain healthy longevity goals.

Strategic orientation

One such initiative was the NIC on Active and Confident Ageing launched by the NRF in 2015 with S$200m from RIE2020 over two years. The NIC invited proposals from all institutions to focus on three strategic areas. First, the NIC aimed to identify ways to prolong the health span of elderly people by 'delaying the onset of disease and disability' so that they could 'continue to lead economically and socially active lives for much longer' (NMRC, 2016). Second, research and innovation that could 'unlock the talent, energies and productivity in longevity, for the benefit of individuals, society and our nation' would be encouraged (NMRC, 2016). Third, the NIC looked at scientific and technology research to enable physically frail elderly people to live in dependently.

Figure 1 provides an overview of the RIE2020 mission, process and governance.



Source: Overview of RIE2020 mission, process and governance (NRF, 2016)

Policy coordination

The main government agency coordinating and implementing the NIC was the NMRC under the MOH. The NMRC initiated seven grant calls covering sub-areas comprising care-at-home innovation, cognition, ageless workplace innovation, enabling innovation, healthy ageing, falls prevention and chronic diseases management. To ensure that the selected proposed solutions would be adopted by the healthcare service providers and end-users upon project completion, NMRC required their participation in the proposal development and implementation stages (NMRC, 2016).

Policy implementation

To be eligible for participation in these grant calls, the proposing teams should comprise not only researchers or innovators from public and private entities registered and/or incorporated in Singapore, but also implementation partners in the healthcare sector. These implementation partners could be service provider, solution provider or community organisation that would be willing and committed to test-bed the proposed solutions. Among the proposals accepted, one multi-disciplinary team comprising academia in psychology, neurotechnology and engineering, as well as non-government organisation elder care centre, was awarded over S$700k to develop a bilingual programme using novel touch-screen tablet to slow down cognitive decline among elderly folks (SUTD, 2022).

4. Discussion

4.1 Reconfiguring existing innovation system structures - institutional legitimacy among helix structures

To our first research question on how existing structures of innovation system should be reconfigured by MOIP to produce outcome that is relevant to the mission, our analysis of the Singapore RIE2020 case demonstrated the critical role of institutional legitimacy among helix structures. Multiple levels of governance were put in place, creating new structures (e.g. RIEC, NRF, Enterprise Singapore) as well as building on existing structures (e.g. ministries, universities, industry associations) to guide them towards mission objectives that were collectively defined.

In 2020, the Ministry of the Environment and Water Resources was renamed to MSE to reflect its new role because 'sustainability has become an increasingly important part of our national agenda', as observed by the Prime Minister (Low, 2020). The new MSE would focus on building a clean and sustainable environment, and ensuring resilient supply of safe food and water. To oversee food safety and security from farm-to-fork, a new statutory board Singapore Food Agency (SFA) was enacted in 2019, based on the consolidation of food-related functions under existing statutory boards Agri-Food and Veterinary Authority (AVA), the Health Sciences Authority (HSA) and National Environment Agency (NEA) (AVA, 2019). With the reconfiguration of their new roles, MSE and SFA played a critical role in the Urban Solutions and Sustainability (USS) domain with the budget of S$1b in RIE2020. Of this budget, SFA and A*STAR awarded over S$50m to more than 30 projects in the agri-food sector (MSE, 2021).

In the Health and Biomedical Sciences domain, four new institutions were established in 2020 under the MOH to focus on areas such as cancer research, precision medicine, cellular based therapeutics, as well as clinical research and translation. In 2016, the Parliament approved new laws to merge two existing statutory boards Infocomm Development Authority (IDA) and Media Development Authority (MDA) to create a new statutory board Info-communications Media Development Authority (IMDA), due to the 'blurring of the traditional divide between these previously distinct industries'—infocomm and media industries (Hio, 2016). The new agency would oversee promotion and regulation of the infocomm and media industries. At the same time, a new Government Technology Agency (GovTech) was established to continue IDA's existing efforts on smart nation engineering initiatives. Both IMDA and GovTech would play an important role in the Services and Digital Economy domain.

See Table 2 for a summary of the institutions that have been reconfigured or newly created during the 2016-2020 period.

Table 2 Reconfiguration of existing institutions and creation of new institutions approved by the Parliament during the 2016–2020 period

Legislation	Governance	Organizations established	Year established	Active role in RIE2020 Strategic Technology Domain
Government Technology Act 2016	Prime Minister's Office	Government Technology Agency (GovTech)	1 Oct 2016	Services and Digital Economy (SDE)
Info-communications Media Development Authority Act 2016	Ministry of Communication & Information	Info-communications Media Development Authority (IMDA) – merger of IDA and MDA	1 Oct 2016	SDE
	Ministry of Health (MOH)	National Health Innovation Centre Singapore (NHIC)	21 Oct 2016	Health and Biomedical Sciences (HBMS)
Constitution of the Republic of Singapore (Ministerial Responsibility) Notification 2020 (second schedule – Prime Minister)	Prime Minister's Office	Smart Nation and Digital Government Office (SNDGO)	1 May 2017	SDE
Enterprise Singapore Board Act 2018	Ministry of Trade & Industry (MTI)	Enterprise Sg – merger of IE Singapore and SPRING Singapore	1 Apr 2018	All
Singapore Food Agency Act 2019	Ministry of Sustainability and the Environment (MSE)	Singapore Food Agency (SFA) – merger of food-related functions of AVA, HSA and NEA	1 Apr 2019	Urban Solutions and Sustainability (USS)
	MSE	Ministry of Sustainability and the Environment (MSE) – former MEWR	27 Jul 2020	USS
	MOH	Singapore Translational Cancer Consortium (STCC)	30 Jan 2020	HBMS
	MOH	Consortium for Clinical Research and Innovation Singapore (CRIS)	6 Apr 2020	HBMS
	MOH	Advanced Cell Therapy and Research Institute Singapore (ACTRIS)	20 Apr 2020	HBMS
	MOH	Precision Health Research Singapore (PRECISE)	20 Apr 2020	HBMS

4.2 Shaping stakeholder commitment - social legitimacy

Although the proponents of MOIP acknowledge the need to include new actors in contextualizing societal challenges, there is still limited understanding on who these actors are, how they interact with MOIP, and the role they play in the transformative change promoted by MOIP. To address our second research question on how stakeholder commitment can be shaped by the legitimacy of MOIP, we examined the Singapore RIE2020 and found social legitimacy to be of relevance among the expanded helix structures of university, industry and civil society. In the RIE2020 MOIP, the NRF under the leadership of RIEC actively consulted the views of the industry, academia and civil society to identify mission scope—major thrusts, strategic technology domains and cross-cutting horizontal programmes to address economic growth and national challenges.

One of the platforms that provided input to RIE2020 was the Futurescape 2025 project (Cheah, Yang and Saritas, 2019), where nine multi-disciplinary panels were formed to propose R&D roadmaps for nine technology work streams for the 2016-2025 period. The panels were made up of academic experts, government agency officers and industry representatives. Each panel focused on one of the nine technology work streams (e.g. product-service systems) identified by the A*STAR Science and Engineering Research Council (SERC) in 2014 based on horizon scanning. With foresight techniques, the panel envisaged future scenarios for the society and industries, and generated ten-year R&D roadmaps. The SERC secretariat then compiled the R&D roadmaps from the nine workstream panels, and them to the NRF for RIE2020 MOIP formulation and budgeting.

Having defined the RIE2020 scope, the RIEC/NRF adopted (a) the top-down process of setting research and innovation directions and (b) the bottom-up process of inviting proposals from existing innovation system structures—research performers from academia, innovators from industry and non-government organization. Social legitimacy entails the holding of specific dialogues and consultations involving a constellation of stakeholders representing different and often competing interests. Inviting stakeholders to participate in the co-creation of future scenarios and co-development of projects in the strategic orientation and policy coordination dimensions would increase the likelihood of their buy-in and ownership during policy implementation.

4.3 Managing tension between new and existing pathways – portfolio approach

On the third research question on how to manage the tension between exploration of new pathways and exploitation of existing ones to achieve a mission, the RIE 2020 and NIC programmes of Singapore adopted a portfolio approach in two ways.

First, they recognised that societal challenges would vary in wickedness, and the MOIP would range from 'accelerator' to 'transformer' in scope and scale to address these challenges. Apart from the overarching mission-oriented strategic framework (e.g. RIE2015, RIE2020) that would create socio-economic impact across all sectors, the Singapore government also implemented challenge-based programmes (e.g. NIC) that addressed the country's challenge in the specific energy sector. For example, NIC programmes in energy having a budget of S$300m from RIE2015 were launched with multiple stakeholders—to explore solar energy sources as well as carbon capture and storage with the Energy Market Authority (under MTI), building energy efficiency with Building and Construction Authority (under MND), industry energy efficiency with the National Environment Agency (under MSE), and green data centres with the Infocomm Development Authority (under the Ministry of Communications and Information (MCI)) (NRF, 2022). It is therefore important to ensure a coherent portfolio of policy instruments ranging from overarching mission-oriented frameworks to challenge-based programmes to achieve wide and deep transformations.

Second, as deployment policies may have the adverse effect of locking in potentially inferior technologies in an industry, Singapore policymakers mitigated the risk by ensuring diversity in its portfolio of technologies. In tackling the energy problem, for example, the Energy Market Authority (EMA) of Singapore identified four 'switches' to power the country's needs. The first switch was the solar power identified as the most promising renewable source of energy to reach the target of 2 gigawatt-peak (GWp) by 2030—enough to around 350,000 households for a year. Regional power grids made up the second switch, where up to 4 GW of electricity would be imported by 2035, meeting about 30 percent of the country's demand then. The third switch was imported natural gas which currently meets 95 percent of the energy demand. To improve the generation efficiency of existing energy sources, EMA launched a Genco Energy Efficiency Grant to incentivise companies to 'invest in energy-efficient equipment or technologies to improve their competitiveness and maximise the accrued benefits.' (NEA, 2018) The fourth switch was low-carbon alternatives such as hydrogen and carbon capture, utilisation and storage (CCUS). To fund clean energy research and deployment efforts in these low-carbon alternatives, S$49m was set aside by the government in 2020 (Ang, 2020). The tension between exploration and exploitation was achieved by staggering the incentives by technologies, such as offering greater incentives for promising but less mature technologies.

5. Conclusion

Countries worldwide that are seeking innovation-driven economic growth face the increasing complexity and uncertainty of grand societal challenges. The new generation of MOIP is led by societal challenges to spearhead transformative system change (European Commission, 2018). Despite the centrality of existing innovation system structures to transformative system change and mission-oriented innovation, there has been limited attention to their role (Grillitsch and Hansen, 2019). This article seeks to contribute to the agenda by investigating how existing structures of innovation system should be reconfigured by MOIP to produce outcome that is relevant to the mission, and how stakeholder commitment can be shaped by the legitimacy of MOIP. It also examines how the tension between exploration of new pathways and exploitation of existing ones should be managed to achieve a mission. In doing so, it directly responds to the call for a deeper understanding of how to translate mission objectives into policy actions. Using the Singapore cases of RIE2015-2020 and NIC on Active and Confident Ageing, this article makes several contributions to the MOIP literature.

First, our case study of RIE2015-2020 demonstrates the critical role of institutional legitimacy in reconfiguring existing structures of innovation system to produce outcome that is relevant to the mission. Institutional legitimacy in the case relies on the endorsement by the Parliament for the creation of new statutory boards based on the reconfiguration of existing statutory boards to align with strategic plans of the national overarching framework. The reconfiguration or creation of over ten institutions approved by the Parliament in RIE2020 can be understood as an outcome of low contestation and high convergence in mission objectives among multiple actors at various levels.

Second, our analysis shows the importance of social legitimacy among the expanded helix structures of government, university, industry and civil society. Embodying the sub-dynamics of market, knowledge and control, the industry, university and government helix structures perform the traditional economic functions of wealth creation, knowledge generation and market governance (Leydesdorff and Meyer, 2006). More recent literature has suggested the addition of the civil society as the fourth helix structure to include their participation to address grand societal challenges (Carayannis and Campbell, 2010; Hjalager and von Gesseneck, 2020). In the Singapore case, it is evident the civil society was recognised and included as a key stakeholder. The stakeholders' commitment, to a large extent, depended on their perception of how the RIE and NIC processes were carried out, such as the transparency, procedural justice of the processes, and the adequacy of resources allocated by the government.

Third, the transformative change that has taken place in the socio-technical system of Singapore's four 'switch' solution to its energy challenge can be comprehended as an outcome of active portfolio management. Prior work has cautioned policy-induced market growth might encourage exploitation of more mature technologies among firms to the detriment of exploration of less mature technologies. To mitigate the risks arising from use of blunt policy tools, Singapore's MOIP approach was more calibrated and nuanced. With a coherent portfolio of policy instruments ranging from broad to narrow mission scope/scale and a well-designed portfolio of different solution options to a given challenge, the country was better positioned to reduce risks and impact of failure under conditions of uncertainty.

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