Innovation and Development Policy

Available online at http://idp-journal.casisd.cn/

Mission-Oriented Mega-R&D Programs: Governance and Policy

Yutao Sun[a*], Cong Cao[b]

[a] School of Economics and Management, Dalian University of Technology, Dalian 116650, China

[b] Business School, University of Nottingham Ningbo China, Ningbo 315000, China

Abstract

Using the concepts of technology goal (T), effective organization (O), and market end-user (M), this paper proposes a TOM framework for analyzing the contextual characteristics of adoption of the MMRD model as a tool of R&D governance. Applying the framework to cases across multiple historical periods, sectors, and countries, we find that R&D with a clear and specific technology goal, dominance of R&D by government agencies, and public sectors as end-users create an appropriate scenario for a government to adopt the MMRD model, while in doing so the government should also take into consideration such factors as economic efficiency, national security, and public interests. We evaluate the TOM framework based on its application to China's practice, particularly its ongoing mega-engineering programs (MEPs). Only a few MEPs under its national development plan are likely to be successful while others will likely not achieve their original aims.

Keywords

mission-oriented R&D; TOM model; governance; state-led innovation

*Corresponding author at: sunyutao82@dlut.edu.cn

https://doi.org/10.3724/SP.J.2096-5141.2021.0007

1. Introduction

Currently, many long-term challenges, ranging from public health, food security, climate change, and energy to sustainable development, are both grand in scale and global in scope. Such challenges inevitably call for the introduction of state-led or sponsored measures, including publicly funded mission-oriented mega-research-and-development (MMRD) programs. For example, there is a call for a Manhattan-Project-style "big science approach" to contain the pandemic caused by coronavirus disease 2019 (COVID-19) (Berkley, 2020). The question, then, is how to know when a big science approach is the right choice.

Mission-oriented mega-R&D programs are technology- and engineering-oriented, using scientific discoveries to solve grand societal problems and to meet long-term needs. They also rely on large-scale budgets, staff, facilities, and laboratories. Such programs cover experimental development, applied research, and user-inspired basic research since these activities are often closely linked (Foray *et al*., 2012; Sun and Cao, 2014; Wittmann *et al*., 2021). The first and most notable MMRD programs were the U.S. government-sponsored Manhattan Project and Apollo Program. Some MMRD programs have been initiated to respond to short-term pressures (i.e. an emergent strategy,) while others have been initiated through careful deliberation on future or long-term interests (i.e. a deliberate strategy) (Mintzberg and Waters, 1985). The Manhattan Project and the Apollo Program are typical examples of MMRDs prompted by emergent strategies.

Meanwhile, Foray *et al*. (2012) argued that there are significant differences between the Manhattan and Apollo Projects and the programs currently addressing new global challenges. The Maastricht Memorandum, a policy for European innovation and technology diffusion, has also provided a detailed analysis of the differences between old and new mission-oriented projects. The old ones involved the defense, nuclear, and aerospace sectors, whose decision-making was geared toward long-term interests under grand contemporary pressures. The new ones are oriented toward environmental and societal challenges and should be initiated for long-term interests even without grand current pressures (Soete and Arundel, 1993; Janssen *et al*., 2021).

Several doctrines underlie the evoking of MMRD programs. The first is Keynesian government intervention (Mahdjoubi, 1997). Keynesianism posits that the government intervenes in the economy through investing in research and development (R&D), especially basic research, out of concern for the public good and market failure (Mowery, 2009; Stephan, 2011). The second was promulgated by Vannevar Bush in his *Science: The Endless Frontier* (US OSRD, 1945). Bush transformed the Keynesian theoretical rationale into a policy practice in which market failure becomes the central concern of science and technology policymaking. The third is the concept of the "entrepreneurial state," which argues that the state needs to take risks and create a highly networked R&D system for the national good over a medium-to-long-term time horizon (Mazzucato, 2013; Galaso and Rodríguez Miranda, 2021).

MMRD programs have been introduced in different countries such as the U.S., France, the U.K., and Germany, involving different sectors such as the military, health, agriculture, and energy sectors (Foray *et al*., 2012). A range of existing mission-oriented R&D programs can provide useful guidance for the design of new programs. For example, by highlighting the characteristics that distinguish mission-oriented R&D programs in defense-related sectors from those in other sectors, Mowery (2012) argued that government agencies use results of R&D programs financed by themselves, although these results have also spilled over for civilian uses; and that there is a close organizational relationship between the agency or agencies that fund and apply the results of R&D. Sampat (2012) describes a continuing struggle between two perspectives regarding how funds should be allocated at the National Institutes of Health (NIH). One argues that the allocation of a large share of NIH funds should be aimed narrowly at identifying and evaluating promising ways of dealing with diseases. The other argues that the NIH should largely fund basic research into these diseases. Mazzucato (2017) defined policies for mission-oriented R&D as systemic public policies that draw on frontier knowledge to attain specific goals, or "big science deployed to meet big problems," and argued that the need to reinvigorate capacity building, competencies, and expertise within the state is crucial to the implementation of a mission-oriented innovation policy.

In summary, the question is not whether governments should intervene, but rather under what contextual characteristics they should proceed with the MMRD model rather than an investigator-initiated or other model. Case studies have indicated that mission-oriented programs differ across sectors and countries because of different institutional environments (Foray *et al*., 2012). However, these case studies do not necessarily identify the contextual characteristics necessary for governments to successfully implement the MMRD model. Unfortunately, just as Mowery argues, policy debate has often failed to address the characteristics of R&D activities and the market for the optimal results of mission-oriented R&D programs (Mowery, 2009). Our question is: What is government's appropriate approach for R&D governance in tackling public health challenges such as COVID-19, which has significant global political, economic, and societal implications? Or, what are the contextual characteristics for the successful adoption of a model of mission-oriented mega-R&D programs?

Taking into consideration the existing literature and especially its limits, we intend to propose a theoretical framework that examines and identifies contextual characteristics that predict possible results of R&D programs-succuss or failure so as to expand our understanding of MMRD programs across times, countries, and sectors. We attempt to reveal the prerequisites for government's choices of action by analyzing the nature of technological sectors and economic institutions so as to deepen our understanding of the government–market relationship in general and the role of the state in R&D in particular. Nevertheless, we surely do not want to claim that the framework exhausts all *necessary* conditions, nor do we want to claim that these conditions are *sufficient*.

2. Methodology

2.1. A framework of TOM

In order to improve our understanding of government's role in R&D governance, the paper develops a multidimensional framework–technology–organization–market (TOM)–based on the analysis of technology goal (T), effective organization (O), and market user (M).

An important original contribution of this study is to establish a general theoretical framework of TOM which extends beyond a specific technological sector, a specific country, or a program's outcome of success or failure. Through this theoretical framework, this paper addresses a general question: under what contextual characteristics should governments intervene in R&D using the MMRD model?

Different contextual characteristics entail different types of government intervention in the creation of new R&D programs. Our effort is therefore to contextualize the characteristics of the MMRD model. Hitch and McKean (1960) as early as 1960 proposed three criteria for evaluating the success of major mission-oriented programs: meeting product development goals, finishing the mission within the original limits of time and cost, and achieving commercial success. Combining the existing literature with Hitch and McKean's criteria, we propose a useful framework for adoption of the MMRD model (see Fig. 1).

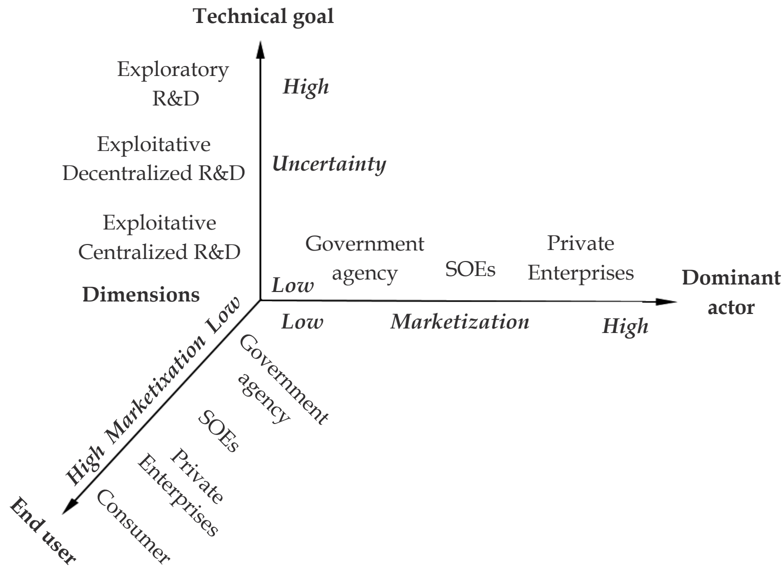

Fig. 1 A Framework on the contextual characteristics of MMRDs

Technology goal: The most important strategy for R&D programs is to avoid technological uncertainty. Policymakers should distinguish types of R&D programs according to their technical goals: an exploratory or exploitative R&D program, a centralized R&D program, or a decentralized R&D program. An R&D program with an exploitative and centralized technical goal is suitable for adoption of the MMRD model.

Effective organization: R&D programs need effective organization based on either market mechanisms or administrative mechanisms. Government domination of an R&D program based on administrative mechanisms is an important precondition for adoption of the MMRD model because the MMRD program requires the investment of large-scale resources and the effective coordination of firms, universities, and research institutions across the country.

Market user: Market users of R&D programs are very important determinants of the mode of organization. R&D oriented toward private users should be organized based on market mechanisms. Government-led MMRD programs should be oriented toward public users, i.e. government agencies or SOEs, either at all times or at least in the early stage.

2.2. Method

Empirically, this paper attempts to explicitly explore the appropriate context for adopting the MMRD model so as to test the validity of our proposed theoretical framework. We will use case studies as primary evidence. The case study methodology examines the details of cases and their contextual conditions (Yin, 2014). More importantly, it allows us to use a small number of cases to test a general phenomenon or theory (Eisenhardt, 1989)[1]. Although fulfillment of the necessary conditions of government intervention through the MMRD model does not guarantee that an MMRD program will succeed, chances are higher

[1] The case study approach is effective for generalization using the Karl Popperian criterion of falsification, which forms part of critical reflexivity (Popper, 2002). Falsification offers one of the most rigorous tests to which a scientific proposition can be subjected: if just one observation does not fit with the proposition, it is considered generally invalid and must therefore be either revised or rejected. Verification is nearly impossible for a theoretical proposition; however, it is accepted as true before falsification.

for the failure of such a program if such necessary conditions are not met.

Case selection should consider issues of strategic importance that underly research questions. We have addressed this in three ways. First, it is indeed the case that the MMRD model has already been applied in many different technological sectors and different countries. It is, therefore, important to explore more fundamental characteristics beyond industry and country scenarios. Our framework attempts to form a general theory, which extends beyond a specific technological sector and/or a specific country. Thus, we need to select cases that cover both defense- and non-defense-related R&D, as well as those falling into the entrepreneurial model of innovation, the public-private partnership, and the developmental state. This explains why the cases we chose for study are from different industries such as defense, aviation, railway, computer, communications, semiconductor, and healthcare, all of which have different technological characteristics, as well as different countries such as the U.S., Japan, China, and member states of the European Union, representing a range of national political and economic institutions.

Second, our cases include successes, failures, and partial successes. The existing literature prefers to use successful cases[2] when comparing and contrasting the roles of government in innovation and the impact of science and technology (S&T) policies on industrial development (Breznitz, 2007; Giesecke, 2000; Vasudeva, 2009). For example, the Manhattan and Apollo programs have been extensively studied, but the Strategic Defense Initiative (SDI, or Star Wars) and the War on Cancer have been largely ignored. In fact, success is not the only criterion for measuring the appropriateness of government intervention. Whether a program is successful depends upon a complex set of factors and mechanisms that can also cause an R&D program to fail. In addition, the consequences of government intervention are highly uncertain and often seriously lagged. There is no way to predict a program's outcome before its initiation.[3] Thus, an investigation of both the successful and failed cases around the world can help to reveal the general preconditions for adopting the MMRD model.

Third, most of the cases we selected have been documented or analyzed by scholars or policymakers. From the Manhattan Project in the U.S. to the core electronic components, high-end generic chips, and basic software (CHB) program in China, these cases clearly show that the MMRD model has been governments' and particularly developmental states' favorite policy instrument. These cases are also related to programs' different phases of technological development (finished or ongoing) so as to allow us to further examine the role of government.

2.3. Sources of materials

This study primarily relies on secondary materials for three reasons. First, because MMRD programs have huge economic and social influence, representing national strategies from defense to industrial development and innovation, it is possible to collect relevant information on them from open sources. Second, most cases are historical in nature. As such, it has proven difficult, if not impossible, for us to obtain firsthand information on these programs. Meanwhile, compared to interviews, published

[2] A simple rule of thumb of the success of an MMRD program is whether the program actually achieved its technical goal and completed its R&D mission. If not, it is considered to be a failure even if the program has substantially advanced knowledge at the frontier. Furthermore, if a program has been launched without a clear and singular goal or mission, the program itself represents a government failure.

[3] Some scholars attribute China's rapid economic growth in the reform and opening-up era to several forms of appropriate government intervention. However, Coase and Wang (2012) show that it is a series of marginal revolutions rather than radical reform initiatives that have quickly brought market forces back to the Chinese economy. China's state-led reform started in cities, but did not succeed there, while the successful household responsibility system was initiated in rural areas and later endorsed and promoted by the central government.

secondary sources are more likely to be objective and comprehensive. Third, published materials allow us to achieve data triangulation for verification (Yin, 2014).

This paper collected research materials through two primary approaches. The first was through government reports such as *The Manhattan Project: Making the Atomic Bomb*, published by the U.S. Department of Energy (DOE). The second approach is through scholarly literature, such as the book *Sources of Industrial Leadership: Studies of Seven Industries* (Mowery and Nelson, 1999) (see Table 1).

Table 1 Research sources of materials

Case No.	Name	Country	Collection approach	Sources
Case 1	Manhattan Project	The US	Scholarly literature	Hewlett and Anderson, 1962
Case 2	War on Cancer	The US	Scholarly literature	Spector, 2010; Kolata, 2009
Case 3	Airbus A300	EU	Scholarly literature	Baldwin and Krugman, 1988
Case 4	VLSI	Japan	Scholarly literature	Sakakibara, 1983
Case 5	FGCS	Japan	Scholarly literature	Cross, 1989; James, 2008
Case 6	Yun-10	China	Scholarly literature	Chen, 2009; Zhao, 2005
Case 7	HSR	China	Scholarly literature	Zhou and Shen, 2011; Bullock *et al.*, 2012
Case 8	TD-SCDMA	China	Scholarly literature	Gao, 2014 and Min, 2014
Case 9	CHB	China	Government's reports	http://www.most.gov.cn/kjbgz/201103/t20110324_85613.htm
Case 10	AHT	China	Government's reports	http://news.xinhuanet.com/2011-03/29/c_121243113.htm

3. Development of a Framework for Adoption of the MMRD Model

We start with a review and synthesis of the literature on the three concepts of technology, organization, and market, then explain in detail why these three factors have a significant impact on the MMRD model.

3.1. Technology: a clear and specific goal

The creation of an MMRD model has to consider issues related to distinct technological features of the sector in which the program is to be initiated. In theory, a government should either tailor different intervention strategies to different sectors or apply the same or similar intervention to the same or similar sectors, according to their technological characteristics (Dolfsma and Seo, 2013; Pavitt and Walker, 1976; Alam *et al.*, 2019). In reality, national governments tend to intervene in the same sector with different strategies or intervene in different sectors with a similar strategy without considering the technological differences in the sectors (Anadón, 2012; Appelbaum *et al.*, 2012).

Indeed, a great challenge is the embeddedness of risk and uncertainty in the technologies underlying the MMRD programs, which are also fraught with rising costs (Van Waarden, 2001). Thus, it is useful for policymakers to distinguish among different types of R&D programs according to their technical goals, which determine the degree of uncertainty. For example, an exploratory R&D program, which is radical and transformative, creates new knowledge. Such programs do not have clear technical goals, cost more, and take longer to produce returns (Jansen *et al.*, 2006; Xie and Wang, 2021). An exploitative R&D

program, on the other hand, is incremental and builds on existing knowledge. It reinforces existing skills, processes, and structures, and the exploitative program can be either centralized or decentralized.

A centralized R&D program is conducted around a single goal or multiple clear and specific goals for technological development, aimed at generating a technology or product that has a larger and broader impact on subsequent technological evolution (Argyres and Silverman, 2004; Nelson, 2011). By contrast, a decentralized R&D program aims to fulfill a large number of goals or an obscure goal covering several aspects of technological development. For example, the goals of energy R&D range from energy savings to emissions reduction, with each goal related to a number of energy-using sectors ranging from automobile, petroleum, and electric power, to new and clean energy (Anadón, 2012; Nelson, 2011).

Regarding the policy framework for government intervention into industrial innovation, Abernathy and Chakravarthy (1979) argue that the technology creating actions of mission-oriented R&D programs include development of a prototype or feasibility model, funding on basis of each program's risk/benefit profile, and funding only certain prototypes- in other words, exploitative R&D. Yet Ergas (1987) and Chiang (1991) argue that mission-oriented programs should focus on radical innovation or the early phase of the technology life cycle, i.e. exploratory R&D. Mowery (2012), Sampat (2012), Anadón (2012), and Mazzucato (2017) have all emphasized that mission-oriented programs should have single or multiple well-defined specific missions.

As the private sector is likely to refrain from investing in exploratory R&D programs out of market failure considerations, government needs to step in to support such programs at universities or national labs by way of individual-investigator-initiated rather than mission-oriented programs. In fact, government also favors supporting exploitative research with less risk and uncertainty. Innovation coming from the catching-up countries is mostly of the "new-to-the-country" type (Amsden, 1998; Hobday, 1994; Hu and Mathews, 2005; Mathews, 2002), following the leaders who engage in the "new-to-the-world" frontier, which has "primary uncertainty" because there is no role model to follow (Wong, 2011).

Thus, the first precondition for the adoption of an MMRD model is that the model must target challenges that have a clear, well-defined, and specific technological goal and that the R&D programs solving the challenges should be exploitative and centralized.

3.2. Organization: government dominated R&D network

The question of how to organize an MMRD program, which is a big system or network, is central to its outcome. The network consists of enterprises, universities, and government agencies as well as individuals such as consumers, government officials, entrepreneurs, and researchers. Interactions between organizations and/or individuals form an R&D network. The question of who dominates the R&D network differs across economies, while the coordination, property rights, and so on are critical to the organization of the network (Abernathy and Chakravarthy, 1979; Johnson, 1982; Henderson and Appelbaum, 1992).

As the MMRD model represents a government's policy or action, we also need to examine the government's role. Ergas (1987) argues that a mission-oriented program entails the centralization of decision-making, implementation, and evaluation. For example, government concentrates its R&D subsidies on a small number of large firms. Mazzucato (2017) stressed reinvigorated capacity building, competencies, and expertise within the state. Based on a case study of the Defense Advanced Research

Projects Agency's Microsystems Technology Office from 1992 to 2008, Fuchs (2010) suggested embedded network governance in which government agencies restructured social networks among researchers so as to identify and influence the directions of new technology in the U.S. to achieve an organizational goal.[4] Anadón (2012) also pointed out that countries differ significantly in whether their government's various activities are coordinated or autonomous.

Moreover, regardless of whether there is a strongly centralized or coordinated system, the government should dominate its R&D network. The dominant power of an R&D network is a kind of institutional condition, which changes with the economic and political environment and the state's handling of its relationship with the market.[5] Depending on a country's innovation model – entrepreneurial, public-private partnership, or developmental state - whoever dominates the network will influence the organization of the MMRD program (Zhang *et al*., 2011; Shen *et al*., 2020).

There are at least two reasons why government agencies, rather than state-owned enterprises (SOEs) and private-owned enterprises (POEs), should dominate the R&D network of MMRD programs.[6] First, government agencies are responsible for decision-making, funding distribution, R&D implementation, and program evaluation. Second, the U.S. government-sponsored Manhattan and Apollo programs not only serve as role models of MMRD programs and have demonstration effects but also determine the current behavior of the state in handling its relationship with the market (Acemoglu *et al*., 2005).

Therefore, government domination of an R&D network is an important precondition of the MMRD model's successful adoption; otherwise, the MMRD model should not be considered. When Mowery *et al*. (2010) and Foray *et al*. (2012) argue that the Manhattan and Apollo programs are not the right models for new programs tackling global challenges, they mean to suggest that it is difficult for governments to dominate an R&D network for such challenges. However, this does not mean the government should remain idle; instead, the government must simply adopt other models.

3.3. Market: public actors as end-users

A demand-pull approach stresses the necessity of R&D activities based upon an identified market need and an identified broader set of market features, including characteristics of the end market and the economy as a whole. Thus, demand-side policy cannot be neglected in the initiation of an MMRD program. Indeed, there must be a clear articulation of demand, which is key to successful programs (Kodama, 1992; Boon and Edler, 2018).

In addressing a societal demand or need, the MMRD program should have usable results. Chiang (1991) argues that mission-oriented programs emphasize performance more than cost, but diffusion-oriented programs should increase efficiency or enter niche markets. However, this does not mean that mission-oriented programs should not think about the market or users. Anadón (2012) indicated that the

---

[4] In this role, these agents do not give way to the invisible hand of markets, nor do they step in with top-down bureaucracy to "pick technology winners." Instead, they are in constant contact with the research community, understanding emerging themes, matching these emerging themes to military needs, betting on the right people, connecting disconnected communities, setting up competing technologies against each other, and maintaining a birds-eye perspective that is critical to integrating disparate activities across the national innovation ecosystem (Fuchs, 2010).

[5] For example, the British economy became liberal in the 19th century, but its nationalization was pervasive after 1945, followed by the returning of the market mechanism in the 1980s (Foreman-Peck and Federico, 1999). China also has been transforming from a centrally planned economy to a socialist market-oriented economy since 1978.

[6] POEs include indigenous invested enterprises (IIEs) and foreign invested enterprises (FIEs); SOEs are also a substantial part of IIEs. In fact, China's indigenous innovation strategy attempts to support SOEs so that they can replace FIEs.

degree of business community involvement in the design and running of such programs differs among the U.S., U.K., and China. Mowery (2012) considered that users of defense mission-oriented R&D should be government agencies, while those of other mission-oriented R&D should be private firms or individual consumers.

Our argument is that mission-oriented R&D programs should be used by public actors: government agencies or SOEs, either at all times or at least at the early stage, regardless of whether their mission is defense or not. There are a number of reasons for this. First, when R&D outcomes addressing a societal demand are used by private firms or consumers, the government should intervene by such policy tools as fiscal subsidies, tax deductions, public procurement, etc. In the development of new energy technologies, for example, the government can introduce fiscal subsidies to encourage consumers to buy new energy vehicles, use tax deductions to stimulate enterprises to buy advanced manufacturing equipment, and implement public procurement to support new product development (Edquist and Zabala-Iturriagagoitia, 2012).[7] Nevertheless, public procurement is a short-period and early-phase policy of new products for private firms or consumers.

Second, even if private firms or consumers can use the outcomes of non-defense mission-oriented R&D programs, the public actors should still be the main users at the early stage. From an industrial life-cycle perspective, product development can be divided into the "fluid phase", "transition phase", and "specific phase" (Utterback and Abernathy, 1975). The fluid phase is the period from the development of a new product to the emergence of a dominant design, which is the appropriate period for government intervention. The development of the U.S. semiconductor industry is a typical case for understanding this phase. During the Cold War era, the user-demanders of semiconductor technology in the U.S. were the military and space sectors (Nelson, 2011: 688). At that time, the industry was in the fluid phase and performance mattered more than price (Mowery and Nelson, 1999: 68). Then, military demands provided "spillovers" of semiconductors from military to civilian applications, and users shifted to civilian enterprises, thus giving birth to Silicon Valley.

Third, the economic system is also important to government adoption of mission-oriented R&D in other fields. In Japan, where there was a lack of significant military demands compared to those in the U.S., the government stepped in from time to time to create a market to support the development of specialized high-performance telecommunication devices. Nippon Telegraph and Telephone (NTT),[8] Japan's telephone monopoly, created demands for the high-quality memory chips used in telecommunication switchers to help Japan focus on a strategy of specialization in DRAMs (Mowery and Nelson, 1999). It was only in 1985 when NTT was privatized to encourage competition in the telecommunications market that users shifted from government to enterprises.

3.4. *Uncertainty oriented decision-making*

According to our technology–organization–market (TOM) framework, the necessary conditions for adopting the MMRD model include technology goal, effective organization, and market user. Of course,

---

[7] As the main process of acquiring national security related technology and products, government procurement has directly influenced the development of the semiconductor, computer, energy, and healthcare industries in the U.S. (Weiss, 2014).

[8] NTT was established in 1952 as a monopolized government-owned corporation. In fact, there was no significant difference between a monopolized corporation and a government agency for NTT before 1985. Even after NTT was listed on the Tokyo, Osaka, New York, and London stock exchanges, the Japanese government still owned roughly one third of NTT's shares, regulated by the NTT Law (Mowery and Nelson, 1999:43).

adopting the MMRD model is also a strategic decision, and the motivation behind that decision is also important.

MMRD programs are the result of scientific and technological creativity creating new technology, new products, new equipment, and even new ways of living and a new world. However, just as Verschraegen and Vandermoere (2017:5) argue, "making promissory stories about future scientific and technological developments credible and obtaining enduring support to channel resources into rise projects is a huge challenge". But uncertainty is inherent in the TOM framework. *For the technology*, although we argue that MMRD programs should solve challenges with a clear, well-defined, and specific technological goal, we do not mean that these imaginary goals for the future will necessarily be realized as expected. There are too many cases in which this has not been the case, such as the War on Cancer.

For the organization, the fact that a government dominates the R&D network doesn't necessarily mean that an MMRD program will succeed. Aiming at overcoming market failure, such programs may face two other types of failures: government failure and system failure. An MMRD program is inherently risky because of the uncertainties associated with the organization and coordination of complementary actors (Adner, 2006; Helveston *et al*., 2019; Vargo *et al*., 2020). If government dominates the MMRD program, its failure to coordinate agencies with different interests in the MMRD program could lead to government failure (Krueger, 1990). If government makes an effort to organize and coordinate its activities with enterprises, public research institutes, universities, and individuals, either in a hands-on or hands-off fashion through interactions with other actors in the network, some sort of system failure could occur (Woolthuis *et al*., 2005; Tödtling and Trippl, 2018).

For the market, public actors as end-users could reduce the uncertainty caused by the free market. However, public actors, whether government agencies or SOEs, also bring a great deal of uncertainty. Government agencies face fiscal budget constraints and public procurement requires long-term fiscal planning (Boston and Prebble, 2013). MMRD programs could demand that SOEs follow national strategies and policies, but SOEs as enterprises also need to consider costs and benefits.

Therefore, the MMRD model entails deep uncertainty (Lempert *et al*., 2009). Vink *et al*. (2016) distinguished between two kinds of uncertainty: cognitive uncertainty (i.e. "What is the future?") and normative uncertainty (i.e., "What should the future look like?"). MMRD programs face both kinds of uncertainty, which makes the decision of adopting the MMRD model important but difficult. Even while trying their best to reduce uncertainty, policymakers may never be able to eliminate the fundamental uncertainty of actors' behavior and unpredictable and unforeseeable factors (Verschraegen and Vandermoere, 2017).

In summary, our theoretical framework suggests that government can intervene in R&D through the MMRD model depending upon the contextual characteristics of the R&D activities: a clear and specific goal, government domination of the R&D network, and public actors as end-users. But there is a caveat that this framework only identifies several *necessary* conditions for the introduction of the MMRD model; the fact remains that such conditions are not *sufficient*. Certainly, adoption of the model is an uncertain process, and reducing uncertainty is central to decision-making. There are cases in which governments have also introduced the MMRD model through organizing exploratory R&D activities and activities involving the private sector. Unfortunately, most of these programs have failed to achieve their original goals, suggesting that the government could fail if it plays a role beyond its capacity.

4. Empirical Application of the Framework to Selected Cases

In order to test the validity and explanatory power of our theoretical framework, we here analyze the details of some MMRD programs. In particular, we discuss these cases by country to control for the impacts of political institutions on the progress of these programs (see Table 2 and Fig. 2).

Table 2 Detailed summary of ten case descriptions

Name	Country	Time period	Money spent	Technical goal	Dominant actor	End user	Industrial phase	Outcome
Manhattan Project	The US	1942–1946	$2.2 billion	The creation of a nuclear bomb	Top Policy Group, OSRD, NDRC, USACE	Interim Committee	Fluid	Success
War on Cancer	The US	1971–	over $105 billion	Finding a cancer cure	NCAB, NIH, NCI	Patients	Fluid	Failure
Airbus A300	EU	1967–1972	– –	The creation of a 300-seat airplane	Airbus Industrie	Air France and Lufthansa	Transition	Success
VLSI	Japan	1976–1980	$288 million	Creating integrated circuits by combining thousands of transistors into a single chip	MITI, VLSI-TRA, five major companies	Private companies	Fluid	Success
FGCS	Japan	1980–1988	$400 million	Computers processed knowledge rather than numbers	MITI, ICOT, ten companies and two MITI's laboratory	Consumer	Fluid	Failure
Yun–10	China	1970–1984	RMB350 million	The creation of a large passenger-aircraft	TMOMB, MODSE	CAAC	Transition	Failure
HSR	China	1999–2008	$13–20 million/km	The creation of high-speed rail system operated with speeds between 200 and 300 km/h	MOR, SOEs	MOR/CRC	Transition	Success
TD-SCDMA	China	1999–2009	RMB200 billion	The creation of 3G wireless communication standards	PTI, Datang, MOIIT	China Mobile	Fluid	Success
CHB	China	2006–2020	RMB60 billion	Catching up international technological development	MOST, MOIIT, SOEs and public R&D sectors	Consumer, SOEs and POEs	Specific	On going
AHT	China	2008–	RMB3.4 billion (2008–2010)	Control and treatment of AIDA, Hepatitis and Tuberculosis	NHFPC, HD-GLD-PLA; hospitals and universities	Patients	Fluid	Ongoing

Source: *Manhattan Project* (Hewlett and Anderson, 1962)-These costs were adjusted to 2008 dollars using the price index for gross domestic product (GDP), available from the Bureau of Economic Affairs, National Income and Product Accounts Table webpage, Table 1.1.4, at http://www.bea.gov/bea/dn/nipaweb/ (assessed April 21, 2017). *War on Cancer* (Spector, 2010; Kolata, 2009). *Airbus A300* (Baldwin and Krugman, 1988) – The size of the subsidy provided to

the A300 is a matter of dispute for the simple reason that it is not a directly measurable quantity. *Yun-10* (Chen, 2009; Zhao, 2005); *VLSI* (Sakakibara, 1983); *FGCS* (Cross, 1989; James, 2008) – At the end of the ten-year period, the project had spent over ¥50 billion (about US$400 million at 1992 exchange rates) and was terminated without having met its goals; *HSR* (Zhou and Shen, 2011; Bullock *et al.*, 2012) – The construction cost naturally depends on the proportion of such tunnels and structures but typically ranges from RMB80–120 million per km (US$13-20 million) excluding stations. TD-SCDMA (Gao, 2014 and Min, 2014); *CHB* – The staged achievements of CHB. http://www.most.gov.cn/kjbgz/201103/t20110324_85613.htm. *AHT*- http://news.xinhuanet.com/2011-03/29/c_121243113.htm (assessed April 21, 2017)
Note: Same as Fig. 2 and CAAC: The Civil Aviation Administration of China (CAAC); CRC: China Railway Corporation; HD-GLD-PLA: Health Department, General Logistics Department, People's Liberation Army; ICOT: Institute of New Generation Computer Technology; MITI: Ministry of International Trade and Industry; MODSE: the Ministry of Defense's Sixth Establishment; MOIIT: Ministry of Industry and Information Technology; MOR: Ministry of Railways; MOST: Ministry of Science and Technology; NCAB: National Cancer Advisory Board; NCI: National Cancer Institute; NDRC: National Defence Research Committee; NHFPC: National Health and Family Planning Commission; NIH: National Institutes of Health; OSRD: Office of Scientific Research and Development; PTI : The Post and Telecommunications Institute of the former Ministry of Post and Telecommunications; TMOMB: the Third Ministry of Machine Building; VLSI-TRA: VLSI Technology Research Association.

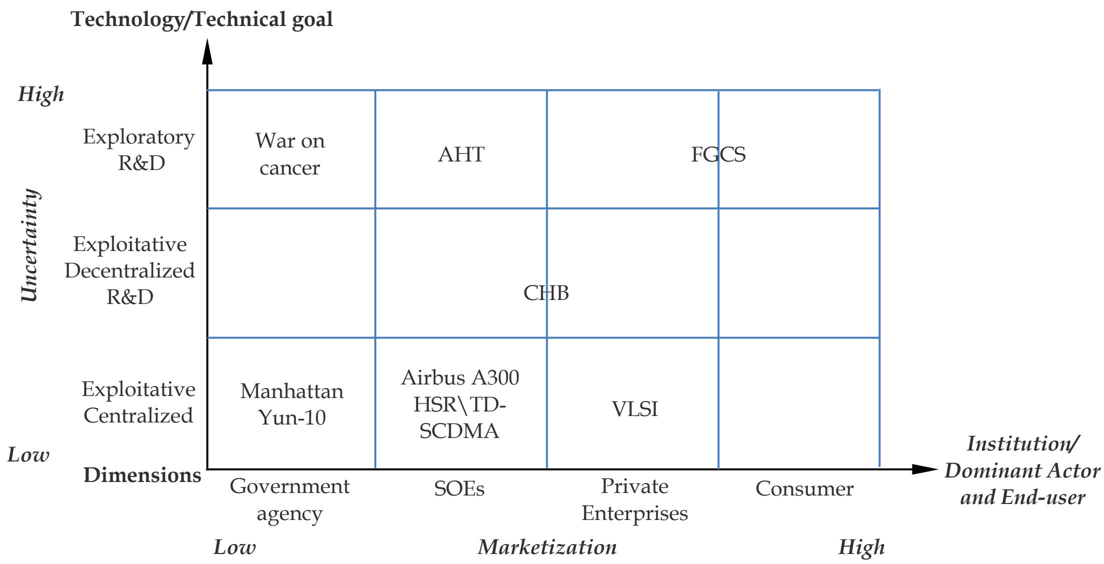

Fig. 2 Overall summary of the ten cases

Note: VLSI: the Very Large Scale Integrated Program; HSR: High Speed Railway Program; FGCS: the Fifth Generation Computer System Program; Yun-10 and A300 are the large passenger-aircraft programs, respectively; AHT: China's MEP of control and treatment of AIDS, hepatitis, and other major diseases; CHB: China's MEP of core electronic components, high-end generic chips, and basic software.

4.1. The American cases

The U.S. is a laissez-faire market-oriented economy, but it was the American government that launched the Manhattan Project under the stress of World War II. This not only opened the door for direct government intervention into R&D but also created the MMRD model. Subsequently, there were the Apollo Program to land astronauts on the Moon and return them safely to earth and SDI that attempted to use ground- and space-based systems to protect the U.S. from attack by strategic nuclear ballistic missiles. The Manhattan and Apollo programs have been known for their success, but SDI was suspended in 1994.

In the organization of the Manhattan Project, a government agency – the U.S. Army Corps of Engineers – dominated the R&D network, which also included universities and newly and purposefully established national labs under the Department of Energy (DOE). In May 1945, another government agency, the Interim Committee, was created to advise on wartime and postwar use of nuclear energy. The government functioned as both a supplier of R&D and as an end-user-demander of the program, thus forming a basic model for either defense-related programs such as the Apollo Program and SDI (Mowery *et al.*, 2010) or civilian R&D mega-programs such as the Very-High-Speed Integrated Circuits (VHSIC) project, although the latter was also involved with the military early on (OUSD, 1990). In retrospect, the Manhattan Project was exploitative in nature, set up with a clear and singular technical goal of exploding an atomic bomb. More importantly, before the Manhattan Project was launched, the scientific advances in nuclear reactor technology proved it was feasible to create a nuclear bomb (Vincent, 1985:35–36). Similarly, the Apollo Program aimed at landing the first humans on the Moon in response to the Soviet effort that flew Yuri Gagarin to space first in 1961.

Some twenty years later, SDI was launched with a vague mission of protecting the U.S. The ambitious initiative was widely criticized as unrealistic and even unscientific (Nolan, 2002:1600). Specifically, SDI focused on large-scale systems including computer systems, component miniaturization, sensors, and missile systems whose technological goals were largely vague. Retrospectively, SDI was an exploratory R&D program, perceived to be unable to solve a large number of technical problems in a short time. Thus, it is not surprising that it was terminated because of its high cost and the many more years of research that would be needed to determine its feasibility.

The Manhattan, Apollo, and SDI programs were carried out in different periods to respond to perceived threats. Of them, SDI received much criticism. Although we argue that the MMRD program was not an appropriate model for SDI, we do not mean that SDI was a failure. SDI was launched during the Cold War under an intensely competitive national security environment as an effective defensive system that would deter potential Soviet attacks. Ultimately, the U.S. abolished the program because it reached a deal with the Soviet Union.[9] When the external pressure was lifted, it became difficult for the government to continue the program. Thus, it is inappropriate to simply use a cost-benefit analysis to evaluate a long-term program born out of short-term pressure.

Motivated in part by the success of the Apollo Program and aimed at eradicating cancer as a major cause of death (Sampat, 2012), the U.S. government launched the War on Cancer in 1971. The NIH had been involved in cancer research since the early twentieth century. The National Cancer Institute (NCI) was founded in 1937 as part of the NIH, which was concerned more with basic medical research than finding cures for specific diseases. The War on Cancer itself began with the National Cancer Act of 1971, a U.S. federal law, which stipulated that new cancer research would be carried out at the NCI rather than at a separate agency, although an additional National Cancer Advisory Board (NCAB) was created with members appointed by the President. The NCI also departed from the NIH's peer-review process and allocated funds for building cancer centers and contracting out research (Sampat, 2012).

[9] According to the U.S. Department of State Archive, the Soviet Union expressed its concerns about SDI almost as soon as it learned of it. The prospect of the U.S. developing such a defense system thus became a hindrance to the pursuit of future arms negotiations between the two powers. Soviet leader Mikhail Gorbachev linked his demands that the U.S. drop SDI to negotiations over the Intermediate-range Nuclear Forces Treaty (INF Treaty) and the Strategic Arms Reductions Talks (START). Over the course of the 1980s, Reagan's refusal to give up SDI became the sticking point that prevented the two countries from reaching a deal on other arms control measures. It was only when the two sides agreed to delink defense and intermediate-range forces discussions that they managed to sign the INF Treaty. START was completed after Reagan left office, and government commitment to the SDI project waned. See https://2001-2009.state.gov/r/pa/ho/time/rd/104253.htm.

In particular, the U.S. Army's breast cancer program, a collaboration between the National Breast Cancer Coalition and the DOE, failed due to a lack of the money and control needed to coordinate all the players in the network and a failure to hold them accountable for working toward a common goal. This program provided grants for innovative, high-risk proposals that might not have been funded by the NCI (Sarewitz, 2016). Although between 1970 and 1980 the NCI's funding grew nearly three times in real terms - twice the growth for the rest of the NIH over the same period (Sampat, 2012) - the program did not achieve its original goal. In his final State of the Union address, the then U.S. President Barack Obama outlined a new Precision Medicine Initiative to cure cancer (2016). The program was dubbed the "Cancer Moonshot," a name chosen specifically to evoke images of the successes of the U.S. space program.

Both SDI and the War on Cancer were exploratory in nature and required long-term fundamental research. However, the War on Cancer was not under the same short-term national security pressure as SDI. The War on Cancer was a response to a crucial health threat but there was no solution on a short-term horizon, even though, at the time the program was initiated, scientists were more optimistic. In other words, the goal that the MMRD model set to cure cancers was unrealistic. Cancer treatment also had no concrete technical goals. The nature of uncertainty with basic research or scientific exploration determined that the mission-oriented program was not the best organizational model, a least at its early stage (Nelson, 1974: 407). Meanwhile, it was hard to measure the program's progress. It was most suitable to organize a program whereby individual-investigator-initiated research projects operated through the peer-review mechanism.

Indeed, as mentioned, uncertainty accompanies any MMRD program. The War on Cancer had many scientific unknowns, unlike the Apollo Program in which the unknowns were less scientific than technological in nature. Under its current political system and institutional arrangements, the U.S. is less likely to launch and organize a new MMRD program with long-term influence like the Manhattan Project or the Apollo Program, unless it is again under great immediate external pressure.

4.2. The European cases

The economy in many continental European countries, such as Germany and France, operates on public-private partnerships (Zhang *et al*., 2011). However, this does not prevent governments in these countries from adopting the MMRD model to gain international competitiveness in ways similar to that in the U.S. The Airbus A300 Program is one such case.

In 1967, the British, French, and German governments signed a Memorandum of Understanding to launch the Airbus A300 Program to challenge the global dominance of the Boeing Corporation.[10] The program had a clear and singular goal: the creation of a large passenger aircraft fitted with two engines and having a seating capacity of 250 to 300 in a twin-aisle configuration. Because of the likelihood of market failure of the newly created European aircraft industry, most notably due to the tremendous R&D and production costs, these governments decided to lend their help (Neven and Seabright, 1995). Not only did the states subsidize the Airbus program, but also SOEs were the main users in the early stage.[11] In 1970, Airbus Industrie was formally set up as the manufacturer of A300, following an agreement

---

[10] At that time, McDonnell Aircraft and Douglas Aircraft were two independent companies, which were merged on April 28, 1967 into the McDonnell Douglas Corporation (MDC). MDC then merged with Boeing in August 1997.

[11] Governments around the world have supported and encouraged commercial aircraft production in both covert and overt ways (Neven and Seabright, 1995).

between Aérospatiale;[12] the antecedent of Daimler-Benz's aerospace interests, MTU München;[13] Dornier Flugzeugwerke;[14] and Deutsche Aerospace AG.[15] Product marketing is crucial for government-launched programs that are separated from the market, and A300 was no exception. At the early stage, most clients came from European airlines – notably Air France and Lufthansa, both SOEs – that were obliged to support homemade aircraft and carve out a market for them.[16] These end-user–demanders helped Airbus to get the time and funding that enabled it to compete with American companies.

Clearly, the situation in Europe is very different from that in the U.S., although politicians in many European countries are also largely dependent on elections and may stay in office longer. But the question now facing Europe is, how can EU member states reach a consensus, given the necessity of long-term MMRD programs? Issues to be considered include political asymmetry, cost-benefit asymmetry, interest group asymmetry, and others (Boston and Lempp, 2011).

4.3. The Japanese cases

Unlike the U.S. and European countries, Japan is politically and economically state-centered; the state negotiates with and delegates social and economic functions to private organizations (Zhang *et al*., 2011). As both an initiator and a practitioner of the "big-push" developmental state model, Japan has deliberately and strategically supported large enterprises to strengthen their industrial competitiveness. The Very-Large-Scale Integrated Circuit (VLSI) Program represents such an example.

The program was set up to develop the technology necessary to integrate circuits containing thousands of transistors on a single chip in order to catch up with IBM's technology. In 1976, the then Ministry of International Trade and Industry (MITI) established a VLSI Technology Research Association (TRA) as the core of a cooperative public-private partnership (PPP) program. The TRA then established a collaborative laboratory consisting of five private and competitive enterprises – Fujitsu, Hitachi, Mitsubishi Electric, Nippon Electric, and Toshiba – and 50 additional small companies to share both costs and outcomes (Sakakibara, 1983). Research outcomes from this laboratory could be used by these companies to reduce imports of foreign semiconductor production equipment. MITI's role was to coordinate the program and to provide 30% of the program's funds. The ministry acted wisely on the market mechanism, realizing that the semiconductor market was one of free competition. If the Japanese government had organized this program directly instead of depending on competitive companies, the outcomes would likely have been different.

Late in the 1970s, Japan was in the midst of its transition from borrowing to creating technology, and the success of the VLSI Program motivated and inspired MITI to launch other, similarly ambitious programs (Chiang, 1991; Cross, 1989). Of these, the Fifth Generation Computer (FGC) Program was intended to help the Japanese computer industry catch up with the rest of the world in the new technologies of artificial intelligence (AI). The program engaged network actors similar to those in the VLSI Program with MITI again implementing the program and adopting a similar mode as before by establishing an Institution of New Generation Computer Technology.

---

[12] A French state-owned aerospace manufacturer.

[13] A German aircraft engine manufacturer, which later became MTU Aero Engines AG.

[14] A German aircraft manufacturer founded in Friedrichshafen.

[15] A German state-owned aerospace manufacturer.

[16] Many of the world's airlines are wholly or partially government owned, and aircraft procurement decisions are often made politically as well as commercially.

However, this time, the same mechanism did not succeed. The Japanese government inappropriately got involved in the FGC Program despite its striking differences from the VLSI Program. The VLSI Program was an exploitative development program following the first mover – the U.S. - by which Japan or Japan Inc. gradually surpassed IBM, the world's leader in the technology, and moved into first place as measured by technical performance and product cost (Cross, 1989). By contrast, in attempting to produce a new class of computer, the FGC Program was essentially exploratory in nature. MITI chose an obscure direction for the program based on a misunderstanding of the current development trends of computing technology (Cross, 1989; Nielsen, 1988). It was difficult to change the goal, a critical factor for the program's success, in the middle of the program even when the initial direction was found to be infeasible. In hindsight, by choosing AI as the direction of the FGC Program, MITI missed other opportunities for next-generation information and communications technology such as the Internet, mobile telephony, and mobile Internet.

In addition, unlike the VLSI Program in which enterprises were the major demanders of semiconductors, the primary user of the FGCs was supposedly consumers. The closer the end-users are to consumers, the closer R&D will be to the market, and thus the more suitable it will be for the government to adopt policies to create an innovation-friendly environment. More than 30 years after the FGC Program, despite tremendous progress, research on AI is still exploratory.

After World War II, the Japanese government initiated several future-oriented MMRD programs with both successes and failures. As the degree of marketization continues to increase, including SOE reform, the government has decreased its intervention in R&D activities. However, Japan has started to formulate the Basic Plan of Science and Technology every five years since 1995 as a comprehensive exercise in accordance with the Science and Technology Basic Law. That law promotes S&T in Japan over a five-year term based on a ten-year forward outlook, under which the government may initiate new MMRD programs.

5. Evaluation of the Framework Against the Chinese Cases

China is not a stranger to mission-oriented R&D programs. In the 1960s, it initiated strategic weapons programs (liangdan yixing) aiming to develop an atomic bomb, a missile, and a man-made satellite. Examined within our framework, such programs had clear technological goals with the government both organizing and using their outcomes (Feigenbaum, 2003). The success of these programs has inspired China's S&T and indeed its political leadership to adopt the MMRD model whenever and wherever possible (Huang and Sharif, 2016) (see Table 2 and Fig. 2). These programs can be divided into two parts. The first part is the programs that were organized and implemented before the Medium- and Long-Term Plan for the Development of Science and Technology (2006−2020) (MLP) (Cao *et al*., 2006; Serger and Breidne, 2007; Liu *et al*.,2017),[17] including large aircraft, high-speed rail, and TD-SCDMA. The second part is the mega-engineering programs organized and implemented as part of the MLP.

5.1. Large aircraft, high-speed rail, and TD-SCDMA

During China's centrally planned period, government agencies not only dominated the R&D network

---

[17] The State Council issued the MLP to turn China into an "innovation-oriented country" by 2020 through the strengthening of its indigenous innovation capability.

but also were the only users of the R&D outcomes. In the early 1970s, China attempted to develop its own large-passenger aircraft with a capacity of more than 100 seats in a program codenamed 708 or Yun-10 (Y-10). The suppliers of the Yun-10 aircraft, both the then Third Ministry of Machine Building (TMOMB) and the then Ministry of Defense's Sixth Establishment, were government agencies of the aviation industry,[18] and the demander, the Civil Aviation Administration of China (CAAC) (Chen, 2009), was part of the government. In other words, much like the Airbus A300 Program, the Y-10 Program had a clear goal with government agencies dominating both the R&D activities and the product market.

Meeting these contextual characteristics implied the feasibility of applying the MMRD model. The Y-10 Program did produce two prototypes: the first was used for static testing, while the second was used for flight testing. The plane had its first flight on September 26, 1980. Until its retirement in 1984, it made 130 flights to Beijing, Harbin, Urumqi, Zhengzhou, Hefei, Guangzhou, Kunming, and Chengdu. Yet the Y-10 Program failed to reach its initially set goal for several reasons, particularly poor coordination between government agencies. First, in 1981, the CAAC refused to purchase Yun-10 aircraft considering that ten Boeing 707s with low availability could be used for at least 20 years and that it had no program to purchase the Y-10 in the next decade. The CAAC had spent more than $15 billion purchasing 500 large aircraft since 1980 (Chen, 2009). Second, in 1986, the Ministry of Finance stopped financing the program because it could not see the existence of a potential market. Finally, top Chinese leadership decided to give up the program for the strategic reason that the government intended to introduce McDonnell Douglas Aerospace's MD-82 (PLRO, 2004:616). Since the late 1980s, when the assembly of MD-82 aircraft started, the Shanghai Aircraft Manufacturing Factory had produced more than 30.

After a series of reforms between 1982 and 2008, the TMOMB reemerged as the China Aviation Industry Corporation (CAIC), a consortium of Chinese aircraft manufacturers, while the CAAC was split into three large state-owned airlines: Air China, China Eastern Airlines, and China Southern Airlines. In other words, both the suppliers and demanders of large-passenger airplanes were transformed from government agencies to SOEs. Under these circumstances, the MMRD model was less likely to succeed, because the government would encounter more difficulties coordinating SOEs than its own agencies. However, as the capability of manufacturing large passenger aircraft is very important to a great power, China decided to restart such a program. Employing a model similar to the Airbus A300 Program, in 2008, China established the Commercial Aircraft Corporation of China (Comac), a state-owned aeronautic manufacturer located in Shanghai, integrating the CAIC, the Aluminum Corporation of China, Baosteel Co., Ltd, and others. It aimed to eventually build large passenger aircraft with a capacity of over 150 passengers to reduce the country's dependency on Boeing and Airbus. Currently, Comac has built the C919, a family of 158–174 seat narrow-body twin-engine jet airliners. Our theoretical framework points to a possibility that China can design and build such an indigenous large commercial airliner successfully if it effectively organizes and coordinates the R&D network, manufacturing, marketing, and services. That being said, inefficient coordination, as part of

[18] China has had several government agencies related to the aviation industry. The Third Ministry of Machine Building (TMOMB) and the Ministry of Defense's Sixth Establishment were central government agencies in charge of the Yun-10 Project. Between 1952 and 1970, China established seven ministries of machine building responsible for civil machinery (the First Ministry of Mechanical Building), nuclear industry (Second), aviation (Third), electronic industry (Fourth), weapons (Fifth), shipbuilding (Sixth) and aerospace (Seventh), respectively. In 1982, the TMOMB was changed to the Ministry of Aviation Industry. The Ministry of Defense's Sixth Establishment (now the Chinese Aeronautical Establishment) was established in 1961. Furthermore, the then State Planning Commission, Shanghai municipal government, and other government agencies and local governments also participated the project.

either government failure or system failure, could still derail the program.

China's development of high-speed rail (HSR) illustrates a different scenario. The government was both the end-user–demander of the upstream production and the supplier of the downstream services. This arrangement is different from the organization and structure of the railway industry in other countries (Amos and Bullock, 2011; Bullock *et al*., 2012).[19] Until its dissolution in 2013, China's Ministry of Railways (MOR)[20] not only administered trains and tracks but also provided services for passengers and enterprises through railway freight transportation (Bullock *et al*., 2012). In particular, MOR was the end-user of the products of the China South Locomotive and Rolling Stock Corporation Limited (CSR) and China North Locomotive and Rolling Stock Industry Corporation (CNR),[21] which, along with the China Railway Construction Corporation (CRCC), were all SOEs. The regional rail authorities were a sub-division of the MOR that provided the freight and passenger services. Currently, the China Railway Corporation (CRC), a centrally-administered SOE, administered trains and tracks (Amos and Bullock, 2011).

China also differs from other countries in its development and deployment of TD-SCDMA, one of the third-generation (3G) standards for mobile telephony. The standard was originally developed by Datang Telecom, a Chinese state-owned multinational telecommunications equipment company, in cooperation with Siemens in Germany. Datang was founded in September 1998, after the 2003 government reform, when the China Academy of Telecommunication Technology (CATT), an R&D institute affiliated with the then Ministry of Post and Telecommunication, transformed from a national R&D institute into a centrally-administered SOE. It is now known as the Datang Telecom Technology & Industry Group, administered directly under the State-owned Assets Supervision and Administration Commission of the State Council. Datang developed SCDMA, the basis for TD-SCDMA, in the mid-1990s and played a leading role in developing the indigenous TD-SCDMA standard. Meanwhile, China's three mobile service providers – China Mobile, China Unicom, and China Telecom – are all SOEs. After TD-SCDMA was approved by the International Telecommunication Union (ITU) as one of the 3G mobile communications standards in 2000, the Chinese government provided substantial support to further perfect the standard. This included allocating frequency spectrum, offering financial support, helping to organize a TD alliance, and mandating that China Mobile, the most financially sound service provider, adopt the standard (Gao, 2014). In 2009, the Chinese government issued 3G licenses to the three service providers with three different 3G standards after TD-SCDMA commercialization trials in ten cities and pre-commercialization network operation in Beijing during the 2008 Olympic Games, although the government did not decide to protect the market for its own TD-SCDMA standard. This indicates that the government intended to wait for the maturity of the TD-SCDMA standard while balancing its interests between the indigenous and international standards (Kennedy *et al*., 2008).

---

[19] For example, the U.S. has the largest number of rail service providers: 23 regional operators, 339 local (or short-line) operators and 194 switching and terminal operators. It is also the most diverse railway country, having 6 main regionally-based service providers (3 private and 3 state-owned), plus 21 large- and medium-sized private companies operating mainly in the suburban or regional passenger railway sector (Amos and Bullock, 2011).

[20] The Ministry of Railways (MOR) was a ministry under China's State Council, or cabinet. The ministry was responsible for passenger services, regulation of the rail industry, and development of the rail network and rail infrastructure in Chinese mainland, although in light of recent accidents, there have been calls to institute independent supervision of the rail industry. On March 10, 2013, the government announced that the ministry would be dissolved and its duties taken up by the Ministry of Transport (safety and regulation), the State Railways Administration (inspection), and the China Railway Corporation (construction and management).

[21] On June 1, 2015, CNR Corporation Limited and CSR Corporation Limited merged into China Railway Rolling Stock Corporation Limited (CRRC), a Chinese state-owned rolling stock manufacturer.

5.2. Mega-engineering programs

Motivated by the success of the HSR Program and the TD-SCDMA Program, the Chinese government in 2006 launched a series of mega-engineering programs (MEPs) in the MLP, including the CHB Program and the AHT program that controls and treats AIDS, hepatitis, tuberculosis, and other major diseases, among others.

The CHB Program is MLP's first MEP, having three components – core electronic components, high-end generic chips, and basic software of the electronic and information industry – with each also including several product lines. It is not easy to assess its results due to the program's large number of missions. For example, the program aimed to develop products oriented partly toward customers, such as operating systems and office software packages, and partly toward POEs and SOEs, such as highly efficient embedded CPUs. To be specific, the high-end generic chips (HGCs) project of the program has characteristics similar to those of the Japanese VLSI Program. Unfortunately, the Chinese government adopted the MMRD model to develop HGCs and implemented the project differently from the VLSI Program. First, the VLSI Program had a clearly defined mission, but the HGCs project was part of a large program whose goals were not explicit. Second, MITI organized the VLSI Program through the integration and coordination of major private enterprises in this sector, whereas in China, government agencies, SOEs, research institutions, and universities, all from the public sector, have dominated the HGCs project in which private enterprises have seldom participated. These factors could explain the extent to which different results have come out of Japan's VLSI Program and China's CHB Program.

The AHT Program in healthcare, on the other hand, is very complex in terms of its R&D network and end-users. China's pharmaceutical industry has gone through marketization for some time, although SOEs, as the suppliers, still play an important role. The demanders of the industry are mainly public hospitals where doctors prescribe drugs for patients. Meanwhile, the prices of most medicines are government-sanctioned. However, both the market and government mechanisms failed here. On the one hand, the government dominates the pharmaceutical product market through SOEs and public hospitals but does not manage them directly. On the other hand, the government attempts to regulate the market through a pricing mechanism, but the price is not determined by supply and demand.

Furthermore, the program involves exploratory research, even though the control and treatment of communicable diseases such as AIDS, hepatitis, and tuberculosis remain sizable challenges in China as well as globally. There is currently no effective cure or vaccine for AIDS, and the control and treatment of hepatitis and tuberculosis have only been partially successful. Considering that the healthcare sector is related to public interests, it is more appropriate and effective for government to sponsor basic research and provide small-scale exploratory funding. Given the similarities between the AHT Program and the War on Cancer in terms of the technical goal of the R&D activities, the MMRD model was an inappropriate model for the War on Cancer may similarly be inappropriate for the AHT Program.

5.3. Discussion

Indeed, as a developmental state, China has a state-led innovation system that prefers to use the MMRD model for intervention in R&D. However, our TOM framework suggests that not every selected MEP has been able to solve the technical goals as outlined. Hence, we may need to consider whether the path through which the state has made its decisions has been politically driven or science-based (Appelbaum *et al*., 2012). Indeed, the development of science follows academic logic, which emphasizes the quest for fundamental knowledge, freedom of inquiry, rewards in the form of peer recognition, and open disclosure of research results (Sauermann and Stephan 2013). However, administrative logic emphasizes meeting major national needs, mission and outcome orientation, and bureaucratic control.

China's political system may be more efficient than America's and Europe's in making long-term policies, such as R&D expenditures and attracting talent (Cao *et al*., 2020). However not every long-term decision is necessarily correct. The advantage of long-term decision-making is to adhere to a long-term goal and make continuous efforts. The effectiveness of long-term decision-making depends on clear and measurable goals and effective organization. Because of the uncertainty of technical activities, long-term decision-making requires relevant assurance and tracking mechanisms.

Meanwhile, as such a system has strong path dependence and goal dependence, more path creation is needed. Understanding dependencies and path creation, rigidity, and flexibility is helpful for understanding the limitations of the Chinese way of intervention in R&D (Van Assche *et al*., 2014). In other words, the government needs to achieve a fusion of administrative logic and academic logic, or governments must consider academic logic when organizing MMRD programs. In addition, governments must consider the commercial logic of MMRD programs. Commercial logic emphasizes bureaucratic control, restrictions on disclosure, and the private appropriation of financial returns (Sauermann and Stephan 2013). Technologies and products for the private market should be guided as far as possible by the government with less interference.

6. Concluding Remarks and Future Directions

The paper proposed a theoretical framework (TOM) that entails the elements of technology goal, effective organization, and market end-user for determining the conditions under which a mission-oriented mega-R&D program should be adopted. It then empirically tested the framework through the analysis of cross-country and cross-sector cases. The MMRD model is appropriate for R&D intervention when government agencies dominate the R&D network and public actors are end-users, so long as the program has a clear and specific technical goal. We evaluated the framework by applying it to China's practice, particularly its ongoing mega-engineering programs. The significance of this paper is to establish a theoretical framework to help policymakers decide which programs are suitable for adoption of the MMRD model. Indeed, a large number of prior studies on MMRD programs have mainly been based on case-based induction, while this study is based on theoretical deduction. The conclusions of this study have a number of important practical implications for the implementation of MEPs in China.

First, various countries have organized similar or nearly identical mission-oriented mega-R&D programs such as the War on Cancer and AHT programs in healthcare, the HGC and VLSI programs in integrated circuits, and the Yun-10, Airbus A300, and HSR programs in mass passenger transportation, among others. A developmental state such as China is more likely than market economies like the U.S to use the MMRD model for long-term interests. The model may be inappropriate for a particular program that does not meet the criteria of our TOM framework, which explains why some programs have succeeded to achieve their goals while others failed.

It is worth noting that our framework only provides a more substantive foundation for exploring the *necessary* conditions of government intervention through the MMRD model. However, these conditions

[22] Whether private enterprises could participate in the passenger market depends on a country's institutional arrangement. Obviously, the governments of China and the EU countries prefer for SOEs to dominate the passenger market.

are not *sufficient*, and the success of a particular program depends not only on the program's context but also on the ability to overcome uncertainties and risks involved in the program's implementation. The conditions identified for government intervention are dynamic, not static, and real-life characteristics of an MMRD program could depart from the ideal types, thus rendering the intervention anachronistic and ineffective. For example, Yun-10, Airbus A300, and the HSR all had a clear R&D goal, and Yun-10 and Airbus A300 shared an identical goal: developing a passenger aircraft, with government agencies or SOEs dominating the R&D network and providing services to passengers as end-users.[22] Yet, their outcomes were different.

Second, even if an MMRD program possesses all the necessary conditions discussed in the paper, it can still fail because of government failure or system failure. There are typically many organizations involved in an MMRD program, and thus the government needs to coordinate their activities. This provides vital challenges. The state as a monolithic whole is just a theoretical assumption. In practice, it is not easy to coordinate government agencies competing fiercely for their own interests even if the superior authorities intervene. It also is not easy to coordinate the interests of various participants in MMRD programs.

For example, the R&D suppliers and demanders of China's Yun-10 Program were all government agencies. China's HSR Program was organized by government agencies and both its R&D supplier and demander were SOEs, similar to the Airbus A300 Program. According to our theoretical framework, the MMRD model was suitable for all three programs but especially for the Yun-10 Program. However, the Yun-10 Program failed because the government failed to coordinate with relevant departments. Therefore, as the government's coordination and program organization are central to China's ongoing large-passenger aircraft C919 Program, it is necessary to avoid government failure and system failure. Other factors, such as technical complexity, indigenous R&D challenges, access to foreign technology, and managerial arrangements for programs may also complicate implementation of the MMRD model.

Third, government intervention through the MMRD model may be economically inefficient. There are lessons to be learned from historical precedents. The state's mobilization of resources through MMRD programs is intended to achieve a largely political or public policy goal such as national security or public interests rather than an economic goal. In doing so, government agencies allocate resources under the challenges of political or societal pressure rather than out of a purely economic rationale. Under these circumstances, cost usually takes secondary importance. When the MMRD model was introduced during World War II or the Cold War period, national security became the top priority for policymakers and the state had to respond to potential threats regardless of the cost. Given such a situation, it is understandable that government would take the MMRD path, although such programs could fail. During peace, however, policymakers should pay more attention to economic development, employment, and industrial competitiveness. At such times, cost and efficiency matter for both government and enterprises.

Finally, we intend to suggest directions for possible future research related to development of the framework. First, our framework includes technological, organizational, and market factors. Based on the theoretical framework, we have selected ten case studies to demonstrate the validity of the framework. But political contexts and decision-making mechanisms may also motivate governments to adopt the MMRD model. Thus, there is the necessity of integrating other factors of R&D governance into our framework.

---

[23] In this paper, the EU is considered as a whole although it is comprised of some twenty countries, because the EU has unified and self-governed organizations such as the European Research Council, Airbus Industrie, and European Space Agency.

Second, we neglected the role of government entrepreneurship and leadership in the initiation and implementation of MMRD programs. Examples include Admiral Hyman G. Rickover in the development of the U.S. nuclear navy (Duncan, 1990) and Marshall Nie Rongzhen in China's strategic weapons programs (Feigenbaum, 2003). An examination of this critical perspective may extend and strengthen our framework. Third, this study has a national orientation, and thus did not analyze international[23] cooperative mega-programs such as the International Space Station (ISS), ITER, and the Human Genome Project (HGP), as well as pure science mega-programs such as the Laser Interferometer Gravitational-Wave Observatory (LIGO) and the Large Hadron Collider (LHC). International cooperation on mega-programs could reduce budget risk by embracing partners' investment and reduce R&D risk through sharing partners' wisdom but could also increase coordination costs. Future research should try to identify institutional foundations of the contextual characteristics of R&D governance that facilitate cross-country cooperation.

Acknowledgments

This work has been supported by the National Natural Science Foundation of China (71922005 and 71774091) and the EU 7th Framework Programme–Marie Curie International Incoming Fellowship (302303/911303). We also benefit from helpful comments by Richard P. Suttmeier.

References

Abernathy, W.J., Chakravarthy, B.S., 1979. Government intervention and innovation in industry: a policy framework. Sloan Management Review, 20 (3), 3–18.

Acemoglu, D., Johnson, S., Robinson, J.A., 2005. Institutions as a Fundamental cause of long-run growth, in: Aghion, P., Durlauf S., (Eds.)., Handbook of Economic Growth. North Pole, pp. 386–472.

Adner, R., 2006. Match your innovation strategy to your innovation ecosystem. Harvard Business Review, 84 (4), 98–107.

Alam, A., Uddin, M., Yazdifar, H., 2019. Institutional determinants of R&D investment: Evidence from emerging markets. Technological Forecasting and Social Change, 138, 34–44.

Amos, P., Bullock, R.G., 2011. Governance and structure of the railway industry: Three pillars. China transport topics, 2 (12), 53-60 (downloaded on 13 August 2012 from http://documents.worldbank.org/curated/en/272791468025222951/Governance-and-structure-of-the-railway-industry-three-pillars).

Amsden, A.H., 1998. Bringing production back in - Understanding Government's economic role in late industrialization. World Development, 25 (4), 469–480.

Anadón, L.D., 2012. Missions-oriented R&D institutions in energy between 2000 and 2010: A comparative analysis of China, the United Kingdom, and the United States. Research Policy, 41 (10), 1742–1756.

Appelbaum, R., Cao, C., Parker, R., *et al*., 2012. Nanotechnology as industrial policy: China and the United States, in: Harthorn, B.H., Mohr J.W. (Eds.), The Social Life of Nanotechnology. New York, Routledge, pp. 111–133.

Argyres, N.S., Silverman, B.S., 2004. R&D, organization structure, and the development of corporate technological knowledge. Strategic Management Journal, 25 (8–9), 929–958.

Berkley S., 2020. COVID-19 needs a big science approach. Science, 367(6485), 1407.

Boon, W., Edler, J., 2018. Demand, challenges, and innovation. Making sense of new trends in innovation policy. Science and Public Policy, 45(4), 435–447.

Boston, J., Lempp, F., 2011. Climate change: Explaining and solving the mismatch between scientific urgency and political inertia. Accounting, Auditing and Accountability Journal, 24 (8), 1000–1021.

Boston, J., Prebble, R., 2013. The role and importance of long-term fiscal planning. Policy Quarterly, 9 (4), 3–8.

Breznitz, D., 2007. Industrial R&D as a national policy: Horizontal technology policies and industry-state co-evolution in the growth of the Israeli software industry. Research Policy, 36 (9), 1465–1482.

Bullock, R.H., Salzberg, A., Jin, Y., 2012. High-speed rail - The first three years: Taking the pulse of China's emerging program. China Transport Topics No. 2. Beijing, World Bank.

Cao, C., Baas, J., Wagner, C.S., *et al*., 2020. Returning scientists and the emergence of China's science system. Science and Public Policy, 47(2), 172–183.

Cao, C., Suttmeier, R.P., Simon, D.F., 2006. China's 15-year science and technology plan. Physics Today, 59 (12), 38.

Chen, Z., 2009. A brief history of China's Y-10: Imitation versus innovation. Technology in Society, 31(4), 414–418.

Chiang, J.T., 1991. From 'mission-oriented' to 'diffusion-oriented' paradigm: The new trend of US industrial technology policy. Technovation, 11 (6), 339–356.

Coase, R., Wang N., 2012. How China became capitalist. New York, Palgrave Macmillan.

Cross, M., 1989. Japan's fifth generation computer project successes and failures. Futures, 21 (4), 401–403.

Dolfsma, W., Seo, D.B., 2013. Government policy and technological innovation-a suggested typology. Technovation, 33 (6–7), 173–179.

Duncan, F., 1990. Rickover and the Nuclear Navy: The discipline of technology. Annapolis, MN, Navy Institute Press.

Edquist, C., Zabala-Iturriagagoitia, J.M., 2012. Public procurement for innovation as mission-oriented innovation policy. Research Policy, 41(10), 1757–1769.

Eisenhardt, K.M., 1989. Building theories from case study research. Academy of Management Review, 14 (4), 532–550.

Ergas, H., 1987. Does technology policy matter? Technology and global industry: Companies and nations in the world economy. Washington, DC, The National Academies Press.

Feigenbaum, E. A., 2003. China's techno-warriors: National security and strategic competition from the Nuclear to the Information Age. Palo Alto, CA, Stanford University Press.

Foray, D., Mowery, D.C., Nelson, R.R., 2012. Public R&D and social challenges: What lessons from mission R&D programs? Research Policy, 41 (10), 1697–1702.

Foreman-Peck, J., Federico, G., 1999. European industrial policy: The twentieth-century experience. New York, Oxford University Press.

Fuchs, E.R., 2010. Rethinking the role of the state in technology development: DARPA and the case for embedded network governance. Research Policy, 39 (9), 1133–1147.

Galaso, P., Rodríguez Miranda, A., 2021. The leading role of support organisations in cluster networks of developing countries. Industry and Innovation, 28(7), 902–931.

Gao, X., 2014. A latecomer's strategy to promote a technology standard: The case of Datang and TD-SCDMA. Research Policy, 43 (3), 597–607.

Giesecke, S., 2000. The contrasting roles of government in the development of biotechnology industry in the US and Germany. Research Policy, 29 (2), 205–223.

Haapanen, M., Lenihan, H., Mariani, M., 2014. Government policy failure in public support for research and development. Policy Studies, 35 (6), 557–575.

Helveston, J. P., Wang, Y., Karplus, V. J., *et al*., 2019. Institutional complementarities: The origins of experimentation in China's plug-in electric vehicle industry. Research Policy, 48(1), 206–222.

Henderson, J., Appelbaum, R.P., 1992. Situating the state in the East Asian development process, in: Appelbaum, R.P., Henderson, J. (Eds.), States and Development in the Asian Pacific Rim. London, Sage Publications.

Hobday, M., 1994. Export-led technology development in the four dragons: The case of electronics. Development and Change, 25 (2), 333–361.

Hu, M. C., Mathews, J.A., 2005. National innovative capacity in East Asia. Research Policy, 34 (9), 1322–1349.

Huang, C., Sharif, N., 2016. Global technology leadership: The case of China. Science and Public Policy, 43,62–73.

Jansen, J.J.P., Van Den Bosch, F.A.J., Volberda, H.W., 2006. Exploratory innovation, exploitative innovation, and performance: Effects of organizational antecedents and environmental moderators. Management science, 52 (11), 1661–1674.

Janssen, M. J., Torrens, J., Wesseling, J. H., *et al*., 2021. The promises and premises of mission-oriented innovation policy - A reflection and ways forward. Science and Public Policy, 48(3), 438–444.

Johnson, C., 1982. MITI and the Japanese miracle: The growth of industrial policy, 1925-1975. Journal of Comparative Economics, 6 (4), 436–439.

Kennedy, S., Suttmeier, R.P., Su, J., 2008. Standards, stakeholders, and innovation: China's evolving role in the global knowledge economy. Seattle, WA, National Bureau of Asian Research.

Kodama, F., 1992. Technology fusion and the new R&D. Harvard Business Review, July–August, 70–78.

Krueger, A.O., 1990. Government failures in development. Journal of Economic perspectives, 4 (3), 9–23.

Lempert, R.J, Popper, S.W., Min, E.Y., *et al*., 2009. Shaping tomorrow today: Near-term steps towards long-term goals. Santa Monica, CA, RAND Corporation (downloaded on 13 August 2012 from https://eric.ed.gov/?id=ED506396).

Liu, X., Serger, S.S., Tagscherer, U., *et al*., 2017. Beyond catch-up—Can a new innovation policy help China overcome the middle income trap? Science and Public Policy, 44(5), 656–669.

Mahdjoubi, D., 1997. Non-linear models of technological innovation: Background and taxonomy (downloaded on 13 August 2012 from https://www.ischool.utexas.edu/~darius/04-Linear%20Model.pdf).

Mathews, J.A., 2002. The origins and dynamics of Taiwan's R&D consortia. Research Policy, 31 (4), 633–651.

Mazzucato, M., 2013. The entrepreneurial state: Debunking the public vs. private myth in risk and innovation. London, Anthem Press.

Mazzucato, M., 2017. Mission-oriented innovation policy: Challenges and opportunities. IIPP Working Paper, January.

Mintzberg, H., Waters, J. A., 1985. Of strategies, deliberate and emergent. Strategic Management Journal, 6(3), 257–272.

Mowery, D.C., 2009. Plus ca change: Industrial R&D in the "Third Industrial Revolution". Industrial and Corporate Change, 18 (1), 1–50.

Mowery, D.C., 2012. Defense-related R&D as a model for "Grand Challenges" technology policies. Research Policy, 41 (10), 1703–1715.

Mowery, D.C., Nelson, R.R., 1999. Sources of industrial leadership: Studies of seven industries. New York, Cambridge University Press.

Mowery, D.C., Nelson, R.R., Martin, B.R., 2010. Technology policy and global warming: Why new policy models are needed (or why putting new wine in old bottles won't work). Research Policy, 39 (8), 1011–1023.

Nelson, R. R., 1974. Intellectualizing about the moon-ghetto metaphor: A study of the current malaise of rational analysis of social problems. Policy Sciences, 5(4), 375–414.

Nelson, R. R., 2011. The Moon and the Ghetto revisited. Science and Public Policy, 38(9), 681–690.

Neven, D., Seabright, P., 1995. European industrial policy: The Airbus case. Economic policy, 10 (21), 313–358.

Nielsen, J., 1988. Fifth Generation 1988 trip report. Oxford, Nielsen Norman Group (downloaded on 13 August 2012 from http://www.nngroup.com/articles/trip-report-fifth-generation/).

Nolan, C.J., 2002. The Greenwood Encyclopaedia of International Relations. Westport, CT, The Greenwood Press.

Obama, B., 2016. State of the Union 2016: Full text (downloaded on 13 August 2012 from http://edition.cnn.com/2016/01/12/politics/state-of-the-union-2016-transcript-full-text/index.html).

Office of the Under Secretary of Defense (OUSD), 1990. VHSIC final program report (1980–1990) (downloaded on 13 August 2012 from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA230012).

Party Literature Research Office (PLRO), the Central Committee of the Chinese Communist Party (CCCCP), 2004. A chronicle of Deng Xiaopeng's Life (1975–1997) (in Chinese). Beijing, The Central Literature Press.

Pavitt, K., Walker, W., 1976. Government policies towards industrial innovation: A review. Research policy, 5 (1), 11–97.

Popper, K., 2002. The logic of scientific discovery. New York, Routledge.

Sakakibara, K., 1983. From imitation to innovation: The Very Large Scale Integrated (VLSI) Semiconductor Project in Japan (Working Paper). Cambridge, Mass, Massachusetts Institute of Technology.

Sampat, B.N., 2012. Mission-oriented biomedical research at the NIH. Research Policy, 41 (10), 1729–1741.

Sauermann, H., and Stephan, P. 2013. Conflicting logics? A multidimensional view of industrial and academic science. Organization Science, 24/3: 889–909.

Sarewitz, D., 2016. Saving science. The New Atlantis, 49 (1), 4–40.

Serger, S.S., Breidne, M., 2007. China's Fifteen-Year Plan for Science and Technology: An assessment. Asia Policy, 4 (1), 135–164.

Shen, J., Luo, X., Wu, F., 2020. Assembling mega-urban projects through state-guided governance innovation: The development of Lingang in Shanghai. Regional Studies, 54(12), 1644–1654.

Soete, L., Arundel, A., 1993. An integrated approach to European innovation and technology diffusion policy (a Maastricht memorandum). EUR (Luxembourg).

Stephan, P.E., 2011. How economics shapes science. Cambridge, MA, Harvard University Press.

Sun, Y., Cao, C., 2014. Demystifying central government R&D spending in China. Science, 345 (6200), 1006–1008.

Office of Scientific Research and Development US., 1945. Science, the endless frontier: A report to the President. Ann Arbor, MI: University of Michigan Library.

Tödtling, F., Trippl, M., 2018. Regional innovation policies for new path development–beyond neo-liberal and traditional systemic views. European Planning Studies, 26(9), 1779–1795.

Utterback, J.M., Abernathy, W.J., 1975. A dynamic model of process and product innovation. Omega, 3(6), 639–656.

Van Assche, K., Beunen, R., Duineveld, M., 2014. Evolutionary governance theory: An introduction. Heidelberg, Springer.

Van Waarden, F., 2001. Institutions and innovation: The legal environment of innovating firms. Organization Studies, 22 (5), 765–795.

Vargo, S. L., Akaka, M. A., Wieland, H., 2020. Rethinking the process of diffusion in innovation: A service-ecosystems and institutional perspective. Journal of Business Research, 116, 526–534.

Vasudeva, G., 2009. How national institutions influence technology policies and firms' knowledge-building strategies: A study of fuel cell innovation across industrialized countries. Research Policy, 38 (8), 1248–1259.

Vermeulen, P., Büch, R., Greenwood, R., *et al*., 2007. The impact of governmental policies in institutional fields: The case of innovation in the Dutch concrete industry. Organization Studies, 28(4), 515–540.

Verschraegen, G., Vandermoere, F., 2017. Introduction: Shaping the future through imaginaries of science, technology and society, in: Verschraegen, G., Vandermoere, F., Braeckmans L., Segaert B. (Eds.), Imagined Futures in Science, technology and society. London, Routledge, pp. 1–17.

Vincent, J., 1985. Manhattan: The army and the atomic bomb. Washington, DC, United States Army Center of Military History.

Vink, M., van der Steen, M.A., Dewulf, A., 2016. Dealing with long-term policy problems: Making sense of the interplay between meaning and power. Futures, 76, 1–6.

Weiss, L., 2014. America Inc.? Innovation and Enterprise in the National Security State. New York, Cornell University Press.

Wittmann, F., Hufnagl, M., Lindner, R., *et al*., 2021. Governing varieties of mission-oriented innovation policies: A new typology. Science and Public Policy, 48(5), 727–738.

Woolthuis, R.K., Lankhuizen, M., Gilsing, V., 2005. A system failure framework for innovation policy design. Technovation, 25 (6), 609–619.

Wong, J., 2011. Betting on biotech: Innovation and the limits of Asia's Developmental State. New York, Cornell University Press.

Xie, X., Wang, H., 2021. How to bridge the gap between innovation niches and exploratory and exploitative innovations in open innovation ecosystems. Journal of Business Research, 124, 299–311.

Yin, R.K., 2014. Case study research: Design and methods. Thousand Oaks, CA, Sage Publications.

Zhang, F., Cooke, P., Wu, F., 2011. State-sponsored research and development: A case study of China's biotechnology. Regional Studies, 45 (5), 575–595.