Demand Articulation of Emerging Technologies

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Investigating the Longitudinal Dynamics of Innovation

By

Fumio Kodama

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PREFACE

The concept of "demand articulation" came to my mind in the late 1970s, when my colleague and I were teaching a course of science and technology policy at a liberal arts college in upstate New York. It was in a context of why nuclear energy application to submarines was so successful while its application to merchant ships had failed all over the world.

After I came back to Japan, I tried to find a Japanese word for demand articulation. However, I could not find any appropriate expression. Some executive directors in some major Japanese companies, though, had a deep understanding of this English expression, since they had been trying to find the reasons why some of them did not manage the corporate R&D well. And they came to appreciate the concept of demand articulation, although they also could not find an appropriate translation.

Then at the beginning of the 1990s, when I was teaching at Kennedy School of Government at Harvard University, I expanded the use of this concept in explaining, for example, Japanese successes in developing LCD (Liquid Crystal Display) technologies. And I found that many of the graduate students were interested in this explanation. Moreover, I found that a teaching colleague for this class, Lewis Branscomb, who had been a chief scientist at IBM and became a Harvard professor, appreciated this concept as well. I also met several US corporate executives who liked my expression of demand articulation.

After I came back to Japan, again, I was striving to find a good translation, but did not succeed. When several Internet sites compiling citation data of refereed papers in academic journals became available, I found that not a few papers cited some of my papers about demand articulation. And I also find that this concept has become somewhat standard terminology in some areas, including marketing science. Due to the reasons mentioned above, I came to write about this concept in a more systemic way.

I would like to express my thanks to many people who helped me in this endeavor. My sincere thanks go to Dr. JinHyo Yun of DGIST in Korea, who encouraged me to contribute several papers, some of which are chapters of this book, to his international journal of the Society of Open Innovation (JOItmC). My thanks also go to Mr. Sozaburo Okamatsu, a director of Syoukoukaikan (Japanese clubhouse on commerce and industry) in Tokyo, who has let me organize a research meeting on the subject of this book every year since 2011. I had several important inputs to this book from all the members of this research meeting, and in particular from Prof. Tamotsu Shibata, Prof. Jun Suzuki, and an IT journalist, Mr. Yasushi Baba.

May 2019

Fumio Kodama
Professor Emeritus
University of Tokyo

INTRODUCTION

Many scientists have become aware that scientific leadership does not necessarily translate into industrial or product leadership. Therefore, they have begun to consider the connection between science and product[1]. Usually, this connection is described as a type of *pipeline* in which a new technology emerges successively from basic research, applied research, exploratory development, engineering, and manufacturing[2]. Gomory[3] has called this progression the *ladder process*: the step-by-step reduction of new scientific knowledge into a radically new product. In the ladder process, a new technology *dominates*, and a product is *created* around it. The customers' needs are *taken for granted*.

Economists, on the other hand, have noted the intrinsic *dynamics* of technology development. Rosenberg[4], for example, argues that the ordinary messages of the marketplace are not *specific* enough to indicate the *direction* in which technical change should be sought. He concludes, therefore, there must be forces *outside* the marketplace that point in certain directions. Furthermore, Hippel[5] of MIT studied several cases in which users who understand the needs of the market usually develop the technology first. He has come to propose a concept of “user innovation.” From the technologists' viewpoint, Kline[6] argues that innovation can be interpreted as a *search* and *selection* process among technical *options*. In this *intricate* process, Nelson’s "alternatives out there *waiting* to be found" is somewhat force[7]. The most important element in technology development, therefore, is the process in which a specific demand for a technology *emerges* and R&D effort is targeted toward developing and *perfecting* it.

In the 1960s, meanwhile, most markets were relatively *homogeneous*, based on a mass-production and mass-consumption society. The marketing discipline responded to this situation by developing and refining theories that centered on *customers* and *markets*. Sheth and Sisodia[8] labeled these theories as *market-driven* orientation. In recent years, however, the market orientation literature's core message is "be close to your customers"—listen to your customers—while the *innovation* literature's core message is "being *too close* to the customer can *stifle* innovation." This dichotomy needs to be resolved by studying the applicability of the *market-driven* and *market-driving* mind-sets. They argue that *market-driving* firms seek to *uncover* the latent *undiscovered* needs of current and potential customers, while *market-driven* firms reinforce *existing* frameworks. This *market-driving* view, moreover, suggests an *iterative* process in which marketing strategy *shapes* as well as *responds* to buyer behavior. By doing so, the firm obtains a competitive advantage, which *in turn* shapes the *evolution* of the marketing strategy.

Given this, we have to find a new and *accurate* way of describing the *dynamic* process of technology development. We have to give science policy administrators and research managers a *vocabulary* and a framework for talking *proactively* about the choices they must make in the high-tech environment. In this context, it is important to conceptualize "a sophisticated translation skill that *converts* a vague set of *wants* into well-defined products". To do so, we will come to the concept of "demand articulation." According to Webster's dictionary, *articulate* comes from the Latin *articulare*. The word "articulate" has two conflicting meanings: (1) to *divide* into parts; and (2) to put together by *joints*. Thus, the word encompasses two opposite concepts: analysis (decomposition) and synthesis (integration). In fact, both are necessary in technology development, and the heart of the problem concerning technology development is how to manage these conflicting tasks[9]. Therefore, we can define demand articulation as a dynamic *interaction* of technological activities that involves *integrating* potential demands into a product concept and *decomposing* this product concept into development agendas for its individual component technologies. Articulating demand, therefore, is a *two-step* process: market data must be *integrated* into a product concept, and the concept must be *broken* into development projects. However, potential demands are often derived from *virtual* markets. The fact that the technology is still considered *exotic* should not be a *deterrent* in setting development agendas.

Indeed, Sheth and Sisodia[10] summarized that "demand articulation" is an important *competency* of market-driving firms. Most firms are more comfortable in a world of *pre-articulated* demands, wherein customers know exactly what they want, and the firm's challenge is to *unearth* that information. Firms that are able to sustain success over a long period of time, therefore, need to be market-driven and market-driving *simultaneously*; most corporate cultures, however, are attuned to one or the other orientation. Over its history, they argue, the marketing function and discipline have been shaped by a number of *contextual realities*. On the basis of this fundamental contextual change, they classified their arguments into *four* categories:

location-centric, *time*-centric, *market*-centric, and *competition*-centric.

In order to better understand the concept of "demand articulation," therefore, we will organize this book based on our *four* categories, which are slightly different from these categories suggested by Sheth and Sisodia. The *first* two categories for a contextual change in innovation are: *defense* policy-centric and *commercialization* policy-centric (in public and corporate policy). These are based on the accumulation of technology management in the defense sector first and in its subsequent transfer from the defense to the civilian sector. They are also based on a shift in pattern of innovation from the product to the manufacturing.

As to the *first* category, we will *revisit* the origin of demand articulation in the US defense sector with regard to nuclear and IC (Integrated Circuit) development. We will demonstrate how the concept of demand articulation was decisive in setting the development agenda and also in ensuring the successful outcomes. The first analysis is about the technology development process in the application of *nuclear energy.* However, as everyone knows, this longitudinal outcome is very mixed between the successful accomplishment or the termination of a project. Then, we will move to the technology whose longitudinal achievements are obviously successful. This is the development process of IC technologies. We will analyze how this development was triggered by defense strategies, in the context of how a *defense strategy* articulation was implemented.

As to the *second* category, we will analyze how the *commercialization* of the IC technologies is implemented by industrial policies in Japan. Specifically, we will describe the commercialization in the context of how an industrial research consortium led to a solid building of manufacturing infrastructure, *i.e.* an idea of *collective* articulation by a research consortium. And this idea of collective research was later implemented in US public policy. In the public policy area of environmental protection, past industrial experiences will be formulated as the regulatory articulation in terms of interindustry competition and collaboration.

The demand articulation will be also found to be effective in corporate policies for *competency* building. This core competency articulation is a critical factor in the diversification strategy and its successful management. More recently, many of the innovations and cost savings that could be achieved have already been achieved. Our greatest focus is on business *model* innovation, which is where the greatest benefits lie. It is not enough to make a difference to product quality or delivery readiness or production scale. It is important to innovate in areas where competition does not exist[11]. In this context, the creative part of activity in business model innovation will be formulated as a *proactive* mode of demand articulation.

The remaining *two* categories are related to the long term perspectives on technologies: the *third* category concerns the long *wave* of innovation and the *fourth* category concerns the industrial *revolution*. As is widely discussed, the duration of the Kondratief cycle is estimated to be 50–54 years. Indeed, the Japanese machine tool industry stayed at the top in the world for almost 40 years. By analyzing the longitudinal development of this industry in Japan from 1975 to 2015, therefore, we will demonstrate that the *wave* articulations in the arriving patterns of innovation were implemented in the right timing and the right sequence.

The *final* category is related to the forthcoming industrial revolution, in order to demonstrate the effectiveness of demand articulation and of its updated version in the coming age of the 4th industrial revolution. Indeed, the introduction of the IoT (Internet of Things) and services into the manufacturing environment are leading the 4th industrial revolution. Therefore, we will present several case studies on how the IoT evolved, particularly in contrast to the IT (Information Technology) revolution. The IoT is described: the system itself is embedded with network *connectivity*. Based on these case studies, we will discuss how the concept of demand articulation can survive in quite a new environment, in terms of *connectivity* articulation.

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CHAPTER ONE

ORIGIN OF DEMAND ARTICULATION: NUCLEAR POWER AND INTEGRATED CIRCUITS (IC) DEVELOPMENT

It was the US navy's development of the nuclear *submarine* that established "technology management" as a *discipline*. Admiral Hyman G. Rickover played a decisive role in the historic event where an *explosive* nuclear bomb was successfully transformed into a *sustainable* energy source [1]. He confirmed the way he went about the project and the lessons his experiences could teach were as important as the project itself[2].

However, as is well known, the long term outcome of nuclear applications is very mixed between the successful accomplishment or the termination of a project. Therefore, we will study the context in which the four applications (submarine, aircraft carrier, electric power generation, and merchant ship) have been implemented, and find that a good *articulation* of demand, rather than good technology management, has been a critical factor for the success of nuclear projects. Without good demand articulation, some nuclear application projects could not sustain the momentum of further progress, or have been terminated.

George Kennan maintained in *retrospect* that it would not be until the Kennedy administration that an awareness of "the basic *unsoundness* of a defense posture based primarily on nuclear weapons" would begin to develop[3]. Indeed, the shift from a strategic stance emphasizing "massive retaliation" under the Eisenhower Administration to the Kennedy Administration's goal of achieving capabilities for a "flexible response" put a *premium* on precision *delivery* of nuclear weapons[4]. Prior to the development of IC (Integrated Circuits) technology, programs sponsored by the US Department of Defense were driven by technology rather than by the *need* for technology.

In the case of IC technology, however, the US Government *articulated* and *shaped* the problem which the innovative candidate technology was required to address. The resulting "articulated demand" for *miniaturization* and *reliability* in missile control systems went beyond what was possible using vacuum tubes or transistors. Although they did not receive direct government funding for their work, Texas Instruments and Fairchild *responded* to this military demand in developing the first IC.

1. Comparing Nuclear Applications

1.1 Nuclear Submarines

The US Congress passed a bill establishing an Atomic Energy Commission (AEC) in 1946. By the end of 1946, however, the AEC and the Bureau of Ships had no *articulate* policy concerning nuclear propulsion. Meanwhile, World Wars I and II had demonstrated to the world that the *submarine* was a critical weapon. However, the *old* S-48 submarine was a "cramped boat," and was limited in its submersion and speed capacities[5]:

> The submarine was powered by storage *batteries* when submerged and by *diesel* when surfaced. The submersion period was limited by battery life: the boats had to surface frequently to recharge the batteries and to resupply the crew with fresh air. In addition, a battery fire could produce toxic gases and multiple explosions. A submarine was almost called as "dangerous as the enemy".

A critical issue of submarines was that, as long as they relied on *diesel* and the storage *battery* to power the electric motor, they would be limited in their utility. In 1947, the "true submarine" conference was organized and recommended operational *criteria* for the design of new submarines in the light of the experience of World War II.

> The "true submarine" would be an *underwater* craft that would *remain* submerged *indefinitely* and that would operate in the sea much as *aircraft* did in the sky. Such a craft had to be able to dive to great depths to reduce *detectability* and had to be able to cruise beneath the surface for *unlimited* time at a rate which would approximate the speed of surface vessels.[6]

The conference suggested *nuclear* propulsion as the *answer*. When an Undersea Warfare Symposium was held afterwards, most of the AEC commissioners were there. Admiral Earle W. Mills claimed that the naval reactor had not really been given any *priority*, and urged that the Commission should establish a high priority for a naval reactor program as soon as possible[7]. By the spring of 1948, the AEC had confirmed the Navy's position that the challenge of the naval propulsion reactor was a *distinctive* one. The Navy brought private contractors into the new project. By the end of 1950, the pressurized light-water thermal reactor known as *Mark I* was being constructed by Westinghouse. In 1953, the Mark I went *critical*. Then, it accomplished a test which simulated a submerged trans-Atlantic voyage. This test was solid *evidence* that the world of undersea propulsion had fundamentally changed. It was a great achievement. It can be thought of as a *landmark* in the history of technology, because it was the first time that a nuclear reactor had produced s*ustained and usable* amounts of energy.

1.2 Aircraft Carriers

The *criticality* of demand articulation as a determinant to the performance of nuclear energy in various applications was further validated by another example of its application in the Navy. The demand for an aircraft *carrier* can be well *articulated*, *i.e.* a carrier can stay on the ocean for almost several years without any *refueling*[8].

In addition to the two submarine projects, Rickover was soon involved with the study of nuclear aircraft *carriers*[9]. He and his people had investigated the possibility of nuclear propulsion for large *surface* ships in early 1950, and they had recommended that so long as uranium was in short supply, it did not seem wise to use it for this purpose. Indeed, they viewed the idea of a nuclear-powered carrier as a *distraction* from the important task of developing the nuclear submarine, where the advantages of nuclear propulsion were unquestionable.

But Admiral Forrest P. Sherman had become CNO (Chief of Naval Operations), and he was a strong believer in *carriers*. After the invasion of Korea, and about the same time that President Truman authorized the construction of the Nautilus, Sherman asked the Bureau of Ships to *examine* the feasibility of constructing *a large carrier* with an *atomic* power plant, and to determine time factors, cost factors, and characteristics. Meanwhile, Westinghouse completed its study in 1952, and presented *six* possible reactor types. The Naval Reactors group was asked to choose one. The group recommended that the pressurized-water design was best, and this choice was endorsed by both the Navy and the AEC. The AEC assigned the development of the carrier prototype to Westinghouse and asked Rickover to direct the project. In 1961, the construction of the nuclear aircraft carrier, the USS *Enterprise*, was completed. After 1975, the constructions of the USS *Minitz*, the USS *Dwight D. Eisenhower*, and the USS *Carl Vinson* followed. In order to accompany the aircraft carriers, several nuclear guided-missile cruisers including the USS *Long Beach* had also been built[10]. Thus, the demands for nuclear aircraft carriers have been well *articulated*.

We can make a tentative summary of the analysis in terms of the "demand articulation" scheme. First of all, we have to ask why the utilization of nuclear energy was first realized successfully in the navy (submarine and aircraft carrier), rather than in electricity power stations on land. This was because there was no *alternative* but nuclear as the energy source for realizing the ideal of the "true submarine" and the "true aircraft carrier." In order to make the concept of demand articulation *explicit*, however, these trajectories of the technology's developmental paths should be contrasted with those of other applications of nuclear energy, in particular, in the context within which the electric power station and the merchant ship projects were conducted.

1.3 Electric Power Stations

The nuclear navy was progressing. The second nuclear submarine, the *Seawolf,* would take the liquid sodium-cooled plant being developed by General Electric (GE). But President Eisenhower was dreaming: to develop the "Peaceful Atom" to counteract the image of Hiroshima as the atom's only *legacy*. The United States organized the first international "Atoms for Peace" conference in Geneva, and succeeded in the establishment of an International Atomic Energy Authority, headquartered in Brussels.

Indeed, Eisenhower had been anxious to demonstrate some concrete action toward achieving the goal of the commercialization of atomic energy, in particular, nuclear programs for power stations:

> President Eisenhower was dreaming of developing the Peaceful Atom, to "deliver electricity to the factories, farms, and homes of all the peoples of the world." He was determined that the atomic arrows in one *talon* of the American eagle would be complemented by a credible atomic *olive branch*. And Rickover's commercial central station power plant at Shippingport, Pennsylvania, was to be his means to that end.[11]

Since Eisenhower was keen on achieving the goal of commercial atomic power, his ceremony at Shippingport in September of 1954 took place before many of the key design *parameters* for the plant had been set. In April of 1955 Rickover made the important decision that the reactor fuel elements would be made of uranium oxide clad in zirconium-alloy tubes. This was a totally *different* design concept from the naval reactors and required the development of an entirely new technology. But this development was remarkably successful, and it became the basis for nearly all the world's nuclear power plants. In October of 1957 the first reactor *core* was installed, and in December the plant reached *criticality*. On 23 December of 1957, Shippingport reached a design capacity. Commercial atomic power was now realized. It was only four and a half years after the task had been assigned to Admiral Rickover. Three years later, commercial plants based on this design began to emerge around the country, and shortly after that, around the whole world.

Indeed, the nuclear power generation projects did demonstrate spectacular success in the early stages. However, in retrospect, as everyone knows, they were destined to follow a mixed *trajectory* of development. In this context, we will make a comparison between the demand articulation for submarines and for electric power generation. We can notice that demand articulation for nuclear submarines was much different from that for power stations. A major difference was that the *former* articulation can be translated into the *intrinsic* demand characteristics of the project to be produced, while the *latter* was a *political* articulation rather than a techno-economic one. And what is more important is the fact that the nuclear submarine had no alternatives to nuclear power in terms of the intrinsic nature of the product, so the demand articulation was *straightforward*, while, in retrospect, power generation had several alternatives besides nuclear. After all, the nuclear option in power stations turned out to be not quite what Eisenhower had hoped for in his political statement. When we entered the twenty-first century, the nuclear option for power stations had become dubious and uncertain. While US nuclear power generation still composes about *one third* of the world's total nuclear power generation, its share in the total US electricity generation decreased drastically in the 2000s.

1.4 Merchant Ships

The importance of demand articulation in nuclear projects become even more conspicuous when the utilization of nuclear power for *merchant* ships was attempted in various countries including the United States, Germany, and Japan. However, these civil merchant ships did not develop beyond a few experimental ships.

In 1955, President Eisenhower proposed building a nuclear-powered merchant ship as a *showcase* for his "Atoms for Peace" initiative. The following year, Congress authorized the *Savannah* as a governmental project. It was completed in 1962, but it was too small and expensive to operate economically as a merchant ship. The design was neither that of an efficient freighter nor of a viable passenger liner. Civilian nuclear ships also suffered from the costs of specialized infrastructure specific to the merchant ship. The *Savannah* was expensive to operate since it was the only vessel using its specialized nuclear shore staff and servicing facility. A larger fleet could share fixed costs among more operating vessels, reducing operating costs.

In Germany, the construction of the *Otto Hahn* as an ore carrier was initiated in 1964. It sailed some 650,000 nautical miles (1,200,000 km) on 126 voyages over 10 years *without* any technical problems. However, it proved too expensive to operate commercially and was converted to a diesel-driven “container” ship. In 1969, Japan launched the *Mutsu* project for the purpose of constructing a nuclear ship for oceanographic observation. However, this project was dogged by technical and political problems. Its reactor had significant radiation leakage and fishermen protested against the vessel's operation. In a context that is somewhat different from the above-mentioned countries, the first nuclear ship program had been launched already by the USSR in 1957. The purpose of the nuclear ship program, however, was to develop an *icebreaker*. A comparison of these programs is depicted in **Table 1-1** below[12].

Table 1-1. Country comparison of merchant ship programs

Name	Country	Launched Year	Original Use	Changed Into	Terminated Year
Savanna	USA	1959	Cargo/ Passenger	Cargo	1971
Otto-Hahn	Germany	1964	Ore Carrier	Container	1982
Mutsu	Japan	1969	Oceanic Observation	Special Cargo	1996
Lenin	USSR	1957	Icebreaker	None	(Continued)

As can be seen in the table, we can discover that there were big and varied differences among these four countries concerning how the nuclear ship was to be used originally, how each country changed the original purpose as the project progressed, and when the project was finally terminated. Among the various programs, it has been said that the Japanese nuclear ship was inaugurated on the basis of the definition which had been given at the International Conference on Safety of Life at Sea, which was held in London on June 17, 1960. In this conference, a nuclear ship was defined as "a ship with a nuclear power plant." Compared with the cases of the nuclear submarine projects described before, therefore, we can say that the demand for nuclear merchant ships was far from being *articulated*, except for the development in the USSR where the objective was clearly set to build an *icebreaker.* In the frozen North Sea, cargo transportation is only possible by using a nuclear icebreaker that has a long cursing range with a strong capacity of ice-breaking and that does not need any intermediate refueling. Indeed, the Russian nuclear ship project is still alive today.

2. A new cooperation scheme: Option sharing

After three nuclear disasters were experienced (the 1979 Three Mile Island (TMI) accident in the USA; the 1985 Chernobyl *disaster* in the USSR, and the 2011 Fukushima accident caused by a tsunami in Japan), it became clear that various factors (safety and fuel recycling) were more serious than previously thought. Ironically, we can say that the demand for nuclear power generation has now been newly *articulated*, but the technical *routes* to be taken have not yet been articulated.

In 2006, meanwhile, the Toshiba Corporation made a bold decision to purchase Westinghouse Electric Corporation for ¥490 billion, in order to become a sole supplier of both types of light water reactors: PWR and BWR. At that time, Toshiba seemed to manage a deliberately research *portfolio*, but they are indeed within the same form of technology. Thus, we will find that Toshiba's action was not based on the idea of portfolio research management, but rather to accommodate the nuclear renaissance which advocated clean energy and being environmentally friendly, which was triggered in 2005 by the Bush administration's initiatives in the United States and later diffused all over the world. And the implication of Toshiba's bold decision became especially obvious after the 2011 *meltdown* accident at the Fukushima nuclear power plant caused by a tsunami due to an earthquake, and the construction and operation of nuclear power plants came to a *standstill*, at least in Japan[13].

The advanced reactor technologies being developed in the United States are *safer*, more *efficient* and need a fraction of the *space area* compared to existing LWRs. New plants could be powered entirely with *spent* nuclear fuel, built at a lower cost than LWRs and *shut down* more *easily* in an emergency. While *water* does a good job of cooling and moderating the atomic fissions of nuclear reactors, the next generation of nuclear reactors is looking to broaden our *options*[14]. These include liquid metal, high temperature gases, and molten salt. Nuclear reactors using these coolants can be even safer than most light water reactors. Small modular reactors (SMRs), defined by the International Atomic Energy Agency as anything less than *300 MWe* (or less than one quarter of the size of a typical LWR), might hold the key to a transition toward advanced nuclear reactors. SMRs are at the final stages of commercial development. With a lower initial capital investment and a shorter construction time than LWRs, SMRs could replace aging and carbon-emitting coal power plants. Third Way has found nearly *50* projects in companies and organizations that are developing plans for new nuclear plants[15]. In short, we can find a trend in the evolution from the light water reactor to the small modular reactor and to the advanced reactor.

The cumulative nature of technological advancement has been described by Nelson and Winter[16] as following a natural *trajectory*: today's research produces successful new technology and the natural beginning place for tomorrow's searches. They discuss a "neighborhood" concept of a quite *natural* variety: once a system has proved to be a success, it is possible only to make minor changes. However, a set of technological possibilities sometimes consists of a number of different classes of technology. Within any of these classes, however, technological advancement may follow a particular trajectory. At any given time, all R&D may be focused on one class of technologies with no attention paid to other classes of technologies. These path *dependencies*, which are often involved in technology development, indicate the possibility that the system will *lock* into paths that are not globally optimal[17]. Therefore, our task right now is to *unlock* the path dependencies and to explore all the possible technology *options* which might satisfy the newly-articulated demands. In other words, we should try to create new varieties of natural trajectories which might accommodate these newly articulated demands.

In order to accommodate the intrinsic dynamics of national programs, we are proposing international cooperation based on *option sharing*. Option sharing entails dividing up the burdens and responsibilities for pursuing each possible scientific and technological option in a given area. A thorough search of all possible options, therefore, should be the main objective of future international cooperation. Conventional schemes of international cooperation, such as cost-sharing and task-sharing, have been developed by economists, not derived from the logic of science and technology itself.

In option sharing, in the early phase of the development of large projects involving international cooperation, scientists in each nation would pursue the approach of their own choosing, which would be explored on an affordable scale. By international agreement, all information about each approach would be open to scientists pursuing complementary projects in other countries, and, as each project matured, scientists could elect to work on the project of their own choice, regardless of national location.