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Bilateral S&T Organisation as an Innovation Intermediary: Case Study of Indo-French Cell for Water Sciences

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ABSTRACT
Different theoretical models and empirical studies increasingly highlight the importance of networks and strategic linkages in research and innovation and commericalisation process. This has motivated policy action at different levels for creation of organisations that can facilitate the varied types of networks and linkages among the actors in the innovation system. These organisations are expected to perform various types of activities that bridge user needs and supply side, skill and human resources, financial support, business and innovation strategy, knowledge about new technology and in implementation. These varied types of organisations now are defined under 'Innovation intermediary'. Innovation intermediary is contextualised within the national, regional or sector innovation systems. These systems are influenced by global innovation networks, production and innovation value chains and through varied types of formal and informal linkages. One of the ways a country develops formal linakges with other countries are through bilateral organisations. Bilateral S&T organisations is generally seen as a long term strategic partnership between countries that can positively contribute towards strengthening innovation ecosystem of each of the partnering countries. Can the innovation intermediary thesis help us to understand the bilateral organisations in this context? Or in other words, can a bilateral S&T organisation be seen as an innovation intermediary between two partnering countries? The paper investigates this proposition by examining the influence of Indo-French Cell for Water Sciences (IFCWS) in strengthening the water innovation ecosystem of the two countries namely India and France. A singular case study can be too limited to draw any strong conclusion. However, within this limitation we argue that this study can be useful for policy makers in looking at bilateral organisations as an innovation intermediary between two countries and for innovation scholars to examine this organization more deeply within innovation systems studies.

Keywords: Innovation, System of Innovation, Innovation Intermediary, Indo-French Cooperation, Bilateral S&T Organisation, Water Sciences.

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INTRODUCTION

Innovation as a key determinant of competitiveness, long term economic growth and development is being increasingly accepted by policy makers.[1,2] As a consequence of this accepted rationale, in policy interventions of many countries at different levels (national, regional or sectoral) the focus is placed explicitly on promoting innovation. Policy interventions are influenced by theories/models and empirical studies and in policy makers own process of experimentation and learning.[3] Different socio-economic conditions and technological capability influences policy makers own process of learning and experimentation and leads to difference in 'policy mixes'/ policy interventions in different countries. As Laranja *et al*.[4] argue, theories are seldom directly taken by the policy makers and transformed into policy rationale. In spite of various competing theories which influence specific policy rationale, System of Innovation (SI) perspective has emerged as a dominant influence in policy articulation in many countries.[5] The core element of the SI approach is that (a) national systems differs in terms of specilisation in production, trade and knowledge[6,7] (b) elements of knowledge are important for innovation performance and are localized and not easily moved from one place to another and (c) importance of

interactions and relationships; relationships seen as carriers of knowledge and interactions as processes where new knowledge is produced and diffused.[8,9] A particular aspect of SI framework that has influenced policy making in many countries is its emphasis on the interaction between different system actors (firms, research and educational institutes) in fostering innovation and need for creating and developing institutions that can facilitate this interaction process. This has directed attention towards creating institutions that can help overcome barriers for developing linkages among different actors and can facilitate interactions. In this context, research and innovation intermediaries are being increasingly discussed and are primarily seen as an institution that can facilitate this process.[10] Studies of different entities of this type highlight the evolution of the role and functions of research and innovation intermediary.[11] particularly their involvement in co-creating knowledge and innovation.

In line with this, the aim of this paper is to examine the proposition *whether bilateral S&T organisations working at interface of two nations can play a role of innovation intermediary for strengthening the national innovation ecosystem of partnering countries*. We investigate this proposition by examining a bilateral Indo-French laboratory in Water Sciences; the Indo-French Cell for Water Sciences (IFCWS). Sectoral system of innovation is used as a conceptual framework, the rationale for taking this as a framework is argued later in this paper. Water sciences is an important area of concern for both the nations (India and France) and they have retained scientific and technological research in this area on priority which is reflected from their policy framework.

Water is one of the biggest challenges of 21st century[1]. It is a sector where 'return to investment' is not defined strictly in economic terms but defined more in terms of addressing developmental challenges. By 2050, the world's population is expected to become 9 billion and it is estimated that among various other consequences of this growth one key impact will be on water; the need for water is expected to increase by 50 percent. A study by OECD[12] estimates that about 1.5 billion people are living in the areas seriously affected by water scarcity and this number will increase to almost 4 billion by 2050. Table 1 provides some statistics on the present freshwater resources in different regions across the world.

Table 1: Renewable Internal Freshwater Resources.

2014 (total billion cu m)	Region/country	2014 (per capita cu m)	% change since 1962
13,868	LAC	22,162	−62 ↓
5,668	North America	15,991	−42 ↓
10,466	OECD Members	8,222	−37 ↓
42,801	World	5,925	−55 ↓
1,505	EU	2,960	−16 ↓
1,982	South Asia	1,152	−66 ↓
114	Arab world	296	−78
2,813	China	2,062	−51
1,446	India	1,116	−64

Source: Constructed from World data bank

The above Table highlights the decreasing fresh water resources globally. This decline is more visible in emerging countries and in the Arab regions. Apart from this there are number of other issues associated with this sector like food scarcity, pollution and climate change. The water-food-energy are interlinked and is being seen as central to sustainable development. As sustainable development concern emerge, it highlights the scarcity of water resources, the dependence of energy and food sectors' on water and increasingly focusses on water resource management, ecosystem protection and water supply and sanitation as critical for sustainable development. *This itself makes the study significant to examine a bilateral instituion working in this important area and how it makes an impact.*

Theoretical Background

This study applies Sectoral System of Innovation (SSI) framework to study the key factors, concepts, or variables and the presumed relationships among them for understanding the IFCWS role in influencing Water network. Borrowing from Edquist *et al.*[13] The Sectoral System of Innovation may be defined as a collection of activites organised around a common technological or knowledge base in which individual enterprises are likely to be either actual or potential competitors with one another. SSI is embedded within the System of Innovation (SI) conceptual framework which implies that the systems of concepts, assumptions, expectations and beliefs of this approach also defines sectoral system framework. SI can be distinguished by the boundries of the systems: National, Regional, Technological and Sectoral system. Sectoral system is distinguished by the boundaries of a sector; however like all the other system there is overlapping between the different sectors and also embeds within the national and regional boundaries. Thus while they (national, regional, technological and sectoral system) emphasize different dimensions of the system, they share a common conceptual framework and are strongly interrelated.

Malerba[14] defines sectoral system of innovation as "A sectoral system of innovation and production is a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products. A sectoral system has a knowledge base, technologies, inputs and an existing, emergent and potential demand. The agents composing the sectoral system are organizations and individuals

1 http://www.un.org/sustainabledevelopment/sustainable-development-goals/

(e.g. consumers, entrepreneurs, scientists)". This notion of sectoral system places emphasis on the structure of the system in terms of products, agents, knowledge and technologies and on its dynamics and transformation. In broader terms, one could say that a sectoral system is a collective emergent outcome of the interaction and co-evolution of its various elements and system as well.

Actors remain similar across and within these different systems and include individuals, firms, research institutes, financial institutions and universities etc. However, each system tends to co-ordinate the activities of these agents in different ways and the spatial boundaries of these SI differentiates them. System of Innovation is also significantly influenced by evolutionary theory[15] which argues that innovation is a never ending process i.e. novelties are introduced on continual basis and present developments are also based in prior activities. Path dependency is an important concept emphasized by evolutionary theory which primarily implies that every system has a memory and it influences the development of a system.[16]

Traditional SI analysis was primarily based on examining the structure of the system of innovation. This is regarded as a static mode of analysis.[17] SI framework has evolved to address the complexity and dynamics of the innovation/innovation process. Rickne[18] and Liu and White[19] provides a useful delineation to capture the functions that define the performance of a system. Johnson and Jacobsson,[20] Edquist,[21] Hekkert *et al*.[17] among others have enriched this delineation by arguing that SI can be analysed by examining how the different functions have been served by different actors in the system. Table 2 underscore the key functions of SI based on synthesis of the above research.

Table 2: Functions of System of Innovation.

Function	Description
Knowledge development and diffusion	Creation of new knowledge and facilitation of information and knowledge exchange
Entrepreneurship	Creation of new business
Infrastructure creation	Development and maintenance of the infrastructure in the system
Resource mobilization	Building and attraction of resources relevant to system
Guidance	Direct attention of internal and external actors towards specific problems and growth opportunities
Market identification and formation	Identification of markets and stimulation of the formation of local markets
Legitimation	Creation and building understanding, support and legitimacy for the system.
Facilitation/ creation of synergies	Identification and utilization of synergies within the system.

Source: Adopted from Rickne 2000;[18] Johnson and Jacobson 2003;[20] Edquist 2005;[21] Hekkert *et al.* 2007.[17]

The importance of the functions depends on the boundary of the system as well as the perspective of analysis. Technical standards, for example play an important role in some of the sectoral system of innovation like nanotechnology and may not be that important in others. The SI approach points out that markets are not the only actors in a country's economic development.[22] Thus along with 'market failure', this framework considers broader set of failures (system failures) to be taken into account for policy intervention. The premise is that there are other actors besides markets that can lead to failures. Borrowing from Woolthius *et al*.[23] the causality of 'System failures' happening can be attributed to infrastructure failures and/or institutional failures and/or network failures and/or capability failures. Thus functions that SI is expected to perform can be possible if 'System failures' do not happen. One of the major argument of SI is that institutions need to be created and should evolve with the changing environment to address system failure. This framework particularly calls for creation of institutions that can help to develop linkages between diverse stakeholders in the innovation value chain/ network. Increasingly the role of bridging actors are becoming important determinant in the SI framework and are termed as Innovation Intermediaries.

Innovation Intermediaries are crucial ingredients of any innovation system. Innovation intermediaries are type of superstructure organisations which act as a bridges between actors and market.[24] They connect, translate and facilitate the flow of knowledge and perform the functions of brokers between the various parties.[25] Intermediaries link and transform relationships within an innovation system by facilitating the flow of information to substructure firms.[24] Specifically, intermediaries can facilitate innovation processes by performing activities that bridge user needs and the supply side with respect to many areas, including technology, skill and human resources, financial support, business and innovation strategy, knowledge about new technology, implementation and other matters.[26] In addition, intermediaries can help to solve the 'systemic failures' in the innovation system.

The different type of bridging institutions that have been extensively examined and have operationalised includes science parks,[27] innovation consultants,[28] knowledge intensive business services (KIBS) firms[29] and innovation brokers.[30] These varied types of organisations now are defined under innovation intermediary. The functions performed by innovation intermediaries have evolved with time. Traditionally it included scanning, gathering and communicating information; linking together actors and brokering relationships; and supporting and facilitating steps in the innovation process.[10] While in recent literature, the concept and functions of innovation intermediaries has broadened to innovation system level for example the role in developing complex

coordination of different actors to solve complicated societal issues. These types of intermediaries include brokers, bridging organizations, technology transfer intermediaries and boundary organizations.[31] *The innovation intermediaries can be seen as a constructed institution to address different systemic failures.* Innovation intermediaries have been extensively studied in the context of developed countries while such studies are limited in case of developing countries. Van Lente *et al*.[25] For example use a case study of the Californian Fuel Cell Partnership (CaFCP) in the Californian transport sector to illustrate the efforts of intermediaries to mitigate systemic failures by articulating options and demand, by aligning various actors and activities and by supporting learning processes at the system level. Howell[10] investigates the issue of intermediation and the role of intermediaries in the innovation process using case-study materials from the United Kingdom in 22 organizations. Chappin *et al*.[32] examines the intermediary roles of an industry association in policy-making processes by examining the Dutch paper and board industry.

In developing economies, innovation systems are weak and fragmented because of the high number of aforementioned systemic failures.[33] By tying different actors together and enabling them to engage in interactive learning processes, intermediary organizations in developing economies can perform a key task in 'building' innovation systems.[34,35] This differentiates the roles that intermediaries play in developing economies from roles that they play in developed economies with well-established innovation systems. Intarakumnerd[36] investigates the roles of different types of intermediaries in three industrial clusters in Thailand: hard disk drives, software and chilli paste. Intarakumnerd *et al*.[37] identify the key success and failure factors of actors in triple helix projects: (1) the willingness, readiness and learning and absorptive capacity of participating firms (2) the capability and credibility of university experts and (3) the capability and dedication of intermediaries. Szogs *et al*.[38] use data from Tanzania and El Salvador to examine four types of interactive learning in innovation systems. In user–producer interactive learning, the intermediaries main role is to transfer information from users to producers and help the latter meet the demands of the former.

We argue that innovation intermediary which is typically seen as an institution helping in catalysing linkages among and between various actors stakeholders in the innovation system can be further exploited in understanding various types of linkages in developing international STI collobaration between countries or multi-lateral institutions. This motivates us to investigate to what extent bilateral institutions created through bilateral collaboration to develop STI cooperation acts as an innovation intermediary between the two countries. We have taken Indo-French Cell for Water Sciences to make this investigation. Our investigation is directed to examine its influence in the innovation ecosystem; in this case in developing the STI Water ecosystem. Drawing from Klerkx and Gildemacher[39] we define 'bilateral S&T organization' as a systemic intermediary, as an entity that operates at the interface between two nations, involving multiple innovation actors, working to facilitate and coordinate innovation activities at the system-level.

Background of Indo-French Cell for Water Sciences (IFCWS)

Indo-French Cell for Water Sciences (IFCWS) was established as a bilateral laboratory in 2001 between the Indian Institute of Science (IISc), India and the Institut de Recherche pour le Développement (IRD) at the IISc campus, Bangalore, India. IISc is a premier research and training institution of India and IRD is a French government funded organisation under the supervision of the Ministry of Higher Education and Research and also Ministry of Foreign Affairs and has international presence mainly in Southern countries. The other partners of IFCWS are National Institute of Oceanography (NIO), Indian Institute of Tropical Meteorology (IITM) in India and National Center for Scientific Research (CNRS), National Center for Space Studies (CNES) and National Institute for Agricultural Research (INRA) in France. IFCWS research activities are in different domains of water sciences like hydrology, remote sensing, geochemistry, oceanography, atmospheric sciences, ecology, biology, modeling and agronomy. Recently, six new units have joined this laboratory as partners under the leadership of IRD namely Géoscience Environnement Toulouse (GET), Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), Centre Européen de Recherche en Géosciences de l'Environnement (CEREGE), Centre d'Etudes Spatiales de la Biosphère, (CESBIO) Toulouse, Biogéochimie et écologie des milieux continentaux (BIOEMCO), Paris and Laboratoire d'Océanographie Dynamique et de Climatologie (LOCEAN), Paris. From 2010, the laboratory has been recognized as an *International Joint Laboratory*. In 2014 with expansion of its vision, the laboratory has further expanded its collaborations at regional (Indian Ocean countries, SE Asia) and international levels (Africa, Europe, Japan and USA).

Distinguishing the different functions that can be constructed by applying system of innovation framework (Table 2) provides a good analytical approach to examine whether a bilateral laboratory plays an important role in innovation/innovation system. In the broader sense, a bilateral laboratory is a body that operates in the space between other actors. These type of organizations can make connections, enable a relationship between different persons or organizations in different country playing an active role in ordering and defining relationships of two countries like other systemic innovation intermediaries.

A bilateral laboratory can thus play a direct role in co-development of knowledge and innovation involving the various institutions of the two countries. Other activities that it can perform include helping to provide information about potential collaborators in the partner country, brokering a transaction between two or more organization in partner countries; acting as a mediator between organisations that are already collaborating; and helping find advice, funding and support for the innovation outcomes of bilateral collaboration. Thus the functions they perform are similar to an innovation intermediary acting as a broker or mediator at different stages of the innovation process and involved in co-development of knowledge involving heterogeneous actors. *Such laboratories established under bilateral agreements have not been studied to that extent particularly in the context of innovation system as compared to the other actors like universities, research organisations and multinational firms. In particular bilateral laboratory as an innovation intermediary has not been examined.*

The focus of this paper is on investigating the role of the bilateral laboratory IFCWS in influencing the research and innovation in water sciences between India and France. In doing so it draws attention to whether we can postulate a bilateral laboratory as an innovation intermediary i.e. how such organisations may contribute as the bridging role to fill in the systemic gaps, address system failures in a particular sector of a country and take up a larger role in co-development of knowledge.

Methodology

To understand properly the role of bilateral laboratory IFCWS in the innovation system, we first examine the water research network that has developed between the two countries i.e. India and France. We apply co-authorship linkages constructed from research papers to capture the structure and dynamics of this network. Research publications form one of the key knowledge outcomes of a research laboratory.[40] They are not only produced from intellectual/scientific knowledge but also include the sociological contexts of the scientific/technical system,[41,42] According to Callon,[40] the power of intellectual knowledge is built on the evolution of actor-networks which includes heterogeneous agents.[43,44] Co-authorship analysis has emerged as a useful approach to understand the structure and dynamics of a research network including the social network that is formed among actors.[45,46] These considerations motivate us to apply this approach for this study in exploring the Indo-French water research network.

Centrality measures from social network analysis were calculated for the authors: degree, betweenness and closeness centrality. Degree centrality equals the number of ties that a vertex has with other vertices. Generally, vertices with higher degree or more connections are more central and tend to have a greater capacity to influence others. Closeness centrality emphasizes the distance of a vertex to all other vertices in the network by focusing on the geodesic distance from each vertex to all others. Betweenness centrality is based on the number of shortest paths passing through a vertex. Vertices with a high betweenness play the role of connecting different groups. Co-authorship network is constructed for Indo-French cooperation in water sciences through research publications covering the period 1991-2015 from web-of-science. Papers having author from India as well as France were downloaded for period 1990-2015 in web of science category 'water sciences'.

We apply descriptive case study approach[2] to examine the influence of IFCWS in the water innovation ecostem. Case studies are considered useful in research as they enable researchers to examine data at the micro level[47] and can be a practical solution when a big sample population is difficult to obtain, one needs to present data of real-life situations and to provide better insights into the detailed behaviours of the subjects of interest.[48,49] These considerations make case study a rational choice for this study.

Based on the system of innovation function (Table 2) and innovation intermediary literature, seven functions are constructed (Table 3) for capturing the activities of bilateral S&T laboratories. Further the sub-activities are identified under each function. How well these sub-activities are served

2 Case study in which theory guides the collection of data is classified under descriptive case study (Johnsson 2003)

Table 3: A Typology of Functions and Sub-Activities of a Bilateral S&T Organisation.

Functions	Sub-Activities
Research and Development	1. Research projects
Knowledge Co-development and Diffusion	2. Complementary skills
	3. Exchange visits
	4. Niche development
	5. Joint Publications
Network Building	6. New Actors
	7. Extension to European Union Network
	8. Networks with Southern countries
	9. International collaborations
Capacity Building	10. PhD program
	11. Training programs for graduate students
	12. Summer schools
	13. Improved opportunities for young scholars
Social Capital	14. Trust development
Infrastructure Support	15. Physical Laboratory space
	16. Development of Observatories
	17. High Tech Instrumentation Platforms
Technology Transfers	18. Commercialization

Source: Data collected from primary and secondary survey

is identified on the basis of primary survey (interview) and by close reading of various documents of this laboratory.

The activities are explored through mapping of projects, focused interviews and examining activities of this laboratory as reflected in various documents. The first author visited the IFCWS, IISc Bangalore in the month of March, 2016. Interviews were conducted with the chairman of IFCWS, Dr. M.S. Mohan Kumar from IISc, India and Dr. Jean Riotte from IRD/GET, France. Interaction with other scientists in the laboratory and students working with these scientists were also undertaken. Subsequent visit was undertaken by the second author to further substantiate the findings. Close reading was done of various documents of this laboratory which include printed/electronic publications, websites, news release and other available materials. The interviewers were selected to cover broad range of expertise and different level of actors. Interviews were documented and coded manually. The interpretation of findings is carried out on the basis of interviews and available documents and strength of different roles is on the basis of author's perception after the analysis.

RESULTS

Role of Bilateral Laboratories in Indo-French Cooperation: Co-authorship Network[3]

The co-authorship network of Indo-French water sciences that has evolved over a period of time provides an idea about the changes in core and peripheries of network. The co-authorship network helps us to reveal: Who all are highly connected in the network? Who are central players and are connecting the sub-networks? How the roles of different authors have changed over a period of time?. Drawing from these indicators and field study that was done the dynamics of the water network was captured.

We find that a large number of countries are involved as collaborative partners with India and France. Indian authors had partnership with 161 countries in their research papers in water sciences whereas France had 192 partners. The papers published in Indo-French cooperation in the area of water sciences are 824 from 1991-2015[4]. Water sciences have always been a priority area of Indo-French cooperation with increasing number of formal agreements between the two countries[1]. Indo-French Water Network (IFWN) was launched in early 2013 with an aim to bring together private and research entities from both the countries together to create structured dialogue of two countries in water sector[5]. During French Foreign Affairs Minister's visit to India in 2014, he promised France's cooperation to clean river Ganga through IFWN.

The evolution of the water network between India-France is analysed in three phases i.e. 1991-2000, 2001-2010 and 2011-2015. Three important events happened during this period: establishment of Indo-French Center for Groundwater Research (IFCGR) in 1999, establishment of Indo-French Cell for Water Sciences (IFCWS) in 2001 and recognition of IFCWS as an international laboratory. We posit that these events played an important role in strengthening intellectual and innovative linkages in water network within and between the two countries.

In order to show the main co-authorship structure of the network, we selected authors with atleast 3 papers in each time period. This threshold resulted in 21, 42 and 30 authors respectively in these three periods. Figure 1 is a co-authorship map of these authors exhibiting the structure of author's collaboration network in these three time periods. The map is composed of core sub-networks which are not connected with each other. The shape of nodes represents the affiliated country of the authors. Square represents the authors from France, circle represents the authors from India and triangle represents the authors from other countries. The thickness of the line represents the number of papers in cooperation and size of vertex represents the relative frequency of papers.

We observe different structures of the networks in three time periods. In 1991-2000 there are distinct group of authors. In 2000-2010, the network is getting denser and some level of interconnectivity is visible in different groups. The network is further scattered in 2011-2015. However, unlike 1991-2000 the group size has increased and also there are linkages emerging atleast in two important groups through a common node. Marechal JC has emerged as a common node in later time periods, playing an important role in connecting two groups working in two different Indo-French laboratories i.e. IFCWS and IFCGR.

After the initiation of this formal cooperation some scholars were specifically deputed for research in this area of water sciences from both the countries. It is interesting to see these scholars as prolific authors in the Indo-French water network. Few of the authors with high centrality values are indirectly associated with these laboratories. These authors form the core (degree centrality), have direct

3 This section draws heavily from our earlier paper 'Indo-French Cooperation in Water Sciences: Capturing Research Dynamics through Co-Authorship Analysis published in *Current Science*, Shilpa and Bhattacharya (2017), 113(09), 1668-1674. This is authors own work and authors have taken approval from concerned authorities to re-use this.

4 This study is part of extensive study of two Indo-French laboratories in India. Through our primary survey, it is observed that the key results are jointly published by scholars from India and France targeting high impact journals. While many other publications emerge which are published by these cooperative partners individually. This cannot be strictly quantified but in general we found this in the ratio of 1:3. This reveals that joint partnership is much more influential then visible in real statistics. This may be true for other joint cooperations in water sciences. This may also be true for other international co-authorships.

5 https://in.ambafrance.org/Launch-of-Indo-French-Water

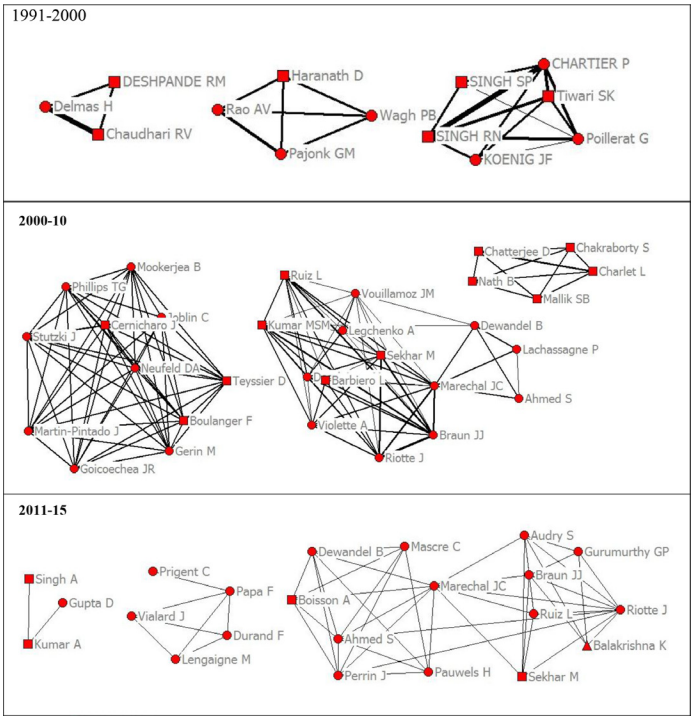


Figure 1: Co-authorship Map in Three Different Time-period.

connections (closeness centrality) and connect different groups (betweenness centrality).

In the later time periods, the highest degree centrality is of JJ Braun. It is an indication of his influence and control over the whole network. He was deputed in India and was directly associated with IFCWS as co-chairman from 2001 to 2014. This plausibly played a key role in his emergence as a central node in the whole network. On the other hand we observe Marechal JC has highest 'betweeness centrality' which plausibly indicates his primary role in influencing different strands of research groups i.e. acting as a bridge betweem different research groups. He connects with different groups frequently as one of the authors of their research papers. Marechal JC was chairman of IFCGR from 2000 to 2003 and is also involved as a lead in many research projects. Marechal JC again has the lowest closeness centrality which indicates that he possessed and controlled a great deal of research and is in a core position of the whole network and this control is also distributed among the other network members who possess high closeness centrality like Riotte J, Perrin J, Ahmed S, Braun JJ and Audry S.

The co-authorship network gives a broad outline of the knowledge links among India-France in water sciences as underscored through research papers. The network also highlights the important role played by a bilateral laboratory in strengthening and stabilising the knowledge network. Bilateral laboratory is playing an important role in connecting different sub-domains of research in water sciences.

We further examine the role and functions of IFCWS by applying the framework of sectoral system of innovation. Functions wer distinguished from primary field study and close reading of secondary literature. Section below highlight the influence of IFCWS under each function.

Research and Development

Solving complex problems require multi-expertise, resources and institutional support. As solutions to complex problems have wide reaching impact, different countries have strategic interest for investing their efforts in solving the problems. Issues pertaining to water also falls in this category. Joint research projects take into consideration local knowledge, participatory research and ecosystem approach involving all stakeholders and also use instruments of bi-national or international co-operation. Some of the good examples include, the UN Convention on Biological Diversity[6] and the Ramsar Convention[7]. IFCWS is another unique initiative in this direction. The research priorities of IFCWS are under four major themes 1) Environmental Biotechnology and Bioremediation; 2) Adaptation of pristine and agro-systems to climate and anthropogenic forcing; 3) Continuum ocean-continent-atmosphere Hydro-logical cycle and climate variability; 4) Urban catchments and water systems.

Initially a project was funded by Indo French Center for Promotion of Advanced Research (CEFIPRA) in the area of 'environmental biotechnology and bioremediation'. CEFIPRA was established to develop and synergise the overall science-technology-innovation (STI) collaboration between India and France in 1987. It has established itself as a model organization for developing STI cooperation. For example, CEFIPRA's model is being used to construct Indo-EU joint house in New Delhi. CEFIPRA role has also been active in establishing IFCWS by funding projects at different periods of time. CEFIPRA involvement in supporting IFCWS highlights the unque linkages between two bilateral entities. It is interesting to draw some insights of this project initially funded by CEFIPRA. This project was on 'Environmental impact on metal mining' which used bilateral, interdisciplinary expertise (petrographical, mineralogical, geochemical and microbiological studies) to understand the behavior of contaminant and possible toxic elements in some sulfide mines of the Karnataka State, India, involving mineral microbe water interactions. It composed of core team of Dr. Jean-Jacques BRAUN from IRD, France as the principal investigator from France with specialization in the area of geochemical tracers or weathering and hydrological processes, impact of silicate weathering on atmospheric CO_2 consumption and metal cycling in soils and Prof. K.A. Natarajan as principal investigator

6 https://www.cbd.int/
7 http://www.ramsar.org/

from IISc, Bangalore, India with specialization in biometallurgy, hydrometallurgy and mineral processing.

> *….An innovative approach utilising industrial wastes such as red mud and fly ash with respect to pH control as well as biomass namely rice husk and tree bark as growth medium for sulfate reducing bacteria such as Desulfatomaculum nigrificans was adopted for remediation of acid mine water".*

Preliminary research included determining acid production potential of sulfide mine tailings and remediation of acid mine drainage; bioremediation of chromium from effluents. Molecular biology approaches and surface characterization tools using microscopy and spectroscopy has been adopted to gain a fundamental understanding of the processes. Later research includes, developing effective and viable technologies adopting novel strategies of chemical and biologically assisted processes for the abatement of the chosen elements from aqueous systems; formation of nano-particles through bio-precipitation routes; development of bioreagents from extra cellular secretions of micro-organisms for surface modification of minerals in flotation processes.

Another area where the laboratory has been actively involved is Adaptation of pristine and agro- systems to climate and anthropogenic forcing. Initially, watersheds were implemented (initiated with 'watershed project' in 2001) led to the characterization of physical and chemical properties of different compartments. The long term strategy was initiated for delineating the effect of agriculture from climatic fluctuations, to compare the functioning of both agro-systems and pristine ecosystems, by using an integrated approach that consists of (1) long term monitoring of meteorological, hydrological and geochemical parameters (mass balances), (2) identification of water-soil-plant interaction processes and (3) modeling. For this, experimentation watersheds were initiated in 2003 within the framework of the Environmental Observatory i.e. Mule Hole and Maddur. In 2008, it was further extended to the Kabini River Basin. Later on from 2010, water and biogeochemical mass balances were established to model the hydrological cycle and weathering fluxes exported from the watershed. The laboratory is now continuing monitoring of the experimental watershed network for the long term gain and thorough understanding of the hydro-biogeochemical functioning and dynamics in order to develop more accurate hydrological and biogeochemical models. The new actors entered the network recently, which will provide further competencies to study pristine ecosystems and agro-systems from a dynamic point of view, such as in remote sensing, agronomy, economics, social sciences (agro-systems) and ecology (in agro and pristine systems). Table 4 highlights the other focus areas of IFCWS.

Knowledge Co-development and Diffusion

Collaboration has emerged as a key determinant of successful innovation as it helps to bring together complimentary strengths of two or more entities. This can be observed in IFCWS also. IISc was working on the water issues before the establishment of IFCWS with its core strength in modeling. The interaction with French scholars and establishment of a physical laboratory helped them to go to the fields, establish and maintain watersheds and measuring water cycle in terms of rainfall and bring more sophisticated tools for enriching research.

> *…….this cooperation has really helped and tend us to establish several such monitored sites (physical zone observatories) and also helped us to build other collaborations bigger…..*

Along with the above, the major benefit of interaction led to the association of pool of experts with this laboratory. This helped IFCWS to broaden their scope of studies, identifying and working in areas that were not only pertinent to the two countries but also having high relevance in the global contexts. One of the very initial studies funded in IFCWS was the environmental impact on metal mining. Through an inter-disciplinary approach involving petrographical, mineralogical,

Table 4: Other Focus Areas of IFCWS.

Continuum Ocean-Continent-Atmosphere: Hydrological cycle and climate variability With respect to the understanding of highly complex and variable system of Indian oceans particularly in monsoons, IFCWS has proposed the work in four major domains i.e. large-scale continental hydrology, water cycle, climate variability and monsoon and biogeochemistry of the Northern Indian Ocean. The area of *Northern Indian Ocean water cycle* is activity between IRD and the Indian partners, including IISc, NIO and IITM. Further, *climate variability* brings existing collaborations with both NIO and IITM within the IFCWS. The last area on *oceanic biogeochemistry* is developed at the request of NIO, which want to develop a modeling activity in that field.	**Urban catchments and water systems** Management of water supply to an urban city has become a challenging task owing to population growth, expansion in industrial activities, changing climatic scenarios, rapidly depleting water resource, increased demand for water, deteriorating infrastructure and water quality and contamination of precious resource. One of the eight Millennium Development Goals (MDGs) of United Nations is to reduce by half the proportion of population without sustainable access to safe drinking water and basic sanitation by 2015. A reliable supply of high quality water at a reasonable cost is of utmost importance for all types of consumers. In this context, at IISc several research studies are conducted to address many of the issues such as chemical and bacteriological effects on water quality in water networks, inverse modelling to estimate system parameters in water networks, application of ANN models for water quality (chemical / biological) transport and transformation in water networks, role of controllers in equitable distribution of water in urban water networks to name a few

Source: Constructed from Activity Reports CEFIPRA

geochemical and microbiological studies, the behavior of contaminant and possible toxic elements during water-rock interactions in the Chitradurga sulphide mines of Karnataka State, India was studied. The role of microorganisms in the formation of acid mine drainage and toxic metal dissolution was extensively studied with respect to microbial ecology, microbe-mineral interaction and evaluation of acid production potential. This was a highly successful project….

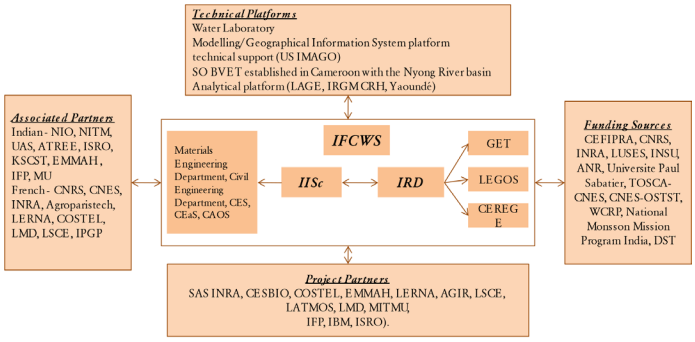
> *…..started with small way with experimental water shed in forest, we moved to agricultural water shed, bigger scale, environmental impact mining issues, we moved to urban water shields, common theme is either water or effect of water.*

The success of this project also underscored how the project not only benefitted IISc but also supported the objective of IRD, the French partner. IRD has a mandate to do S&T research outside France with an emphasis on research, training and innovation activities intended to contribute to the social, economic and cultural development of southern countries through its international network. The project success was also measured in terms of cross-learning, primary data generated, exchange of young scholars and joint publications; indicators seen important for both the partners. This project provides a good benchmark for further follow up projects.

Network Building

Emergence of IFCWS in India since 2001 has seen involvement of diverse actors. Broadly it includes government agencies that fund and promote research, scientists in universities, research laboratories who are involved in research then some people associated with the fields under study. Under the Ministry of Science and Technology, the primary agency involved is Department of Science and Technology from India and IRD from France. Figure 2 highlights the key actors primarily involved in ICFWS in various capacities, roles and functions.

The IFCWS primarily comprises of two institutions: IRD and IISc. Six French laboratories with IRD co-leadership (GET, LEGOS, CEREGE CESBIO, BIOEMCO and LOCEAN) and five departments and centres from IISc (Materials Engineering Department, Civil Engineering Department, Center for Ecological Sciences, Center for Earth Sciences, Center for Atmospheric and Oceanic Sciences) are involved. From the inception, the laboratory has included number of different stakeholders from India as well as France (Figure 1). In 2010, the laboratory got recognition as International Joint Laboratory. It has built long-term networks with many actors like Institut Francais de Pondicherry, University of Agricultural sciences, Karnataka Forest Department, Water Database Development and Management, Planning Commission India, Karnataka State Council for Science and Technology.



Source: Author's own construction

Figure 2: Actor Network Organization for IFCWS.

The laboratory is trying to extend its network to other European countries by submitting joint research projects in European calls like INCOLAB[8]. Some recent examples highlight how this laboratory is reaching beyond bilateral framework. Dedicated efforts to strengthen linkages can be observed through the different conferences and summer schools in which scholars from this laboratory are participating. For example, S. Subramanian and J. J. Braun visited the University of Narvik, Norway in June 2011 to attend a workshop and formulate a proposal for submission to the Indo-Norway Collaborative Project; Mohan Kumar with Prof. Majid organized a Summer school at IISc, Bangalore with the Utrecht University. Many such examples are visible. The laboratory is also making efforts to enhance collaboration with South Asian countries and international community. Two projects have been submitted to NSF, exchange of students between India and USA are some of the recent examples.

Capacity Building

IFCWS supports capacity building through Doctoral Training, which aim to provide students with a 'whole systems' understanding of the water system. The doctoral training places a strong emphasis on gaining experience of working scientist from either France or India. Students are supported with fellowships for exchange visits and attend training programs. This arrangement builds valuable links between the two countries. Apart from this number of graduate students are trained in this laboratory. To complement these capacity building functions, IFCWS also supports a number of other initiatives like Summer School which gives a mixture of both domestic and international PhD students an opportunity to develop a wider understanding of the domain and also network with students internationally.

8 In 1983, European Commission launched a dedicated programme called the Science and Technology for Development Programme with a focus on international research cooperation. In 1992, the Programme was integrated into the Fourth Research Framework Programme (1994-1998) as the International Cooperation Programme (INCO) and has, ever since, been an integral part of all Framework Programmes.

These capacity building activities are supported by different funding organizations from the two countries. Furthermore, it is been supported by some of the Research Councils (e.g. EPSRC), project-based studentships also exist, which attach PhD funding to a wider research project.

Social Capital

One programme of this laboratory is 'French scientists on deputation' which means that these deputed French scientists stay in India in specific associated laboratory for long-term (1-10 years) and work on specific designated projects. This provides opportunity to Indian scholars to work with French specialists in different areas. These deputed French scientists have also helped in providing scholarships to French students to work in Indian laboratories and develop complementary skills. This initiative has strong support from IRD, the French partner in this cell. As Wagner,[50] Altenberg, *et al*,[2] Bhattacharya *et al*.[51] among others argue that the evolution of global science i.e. emergence of new interdisciplinary fields is directly linked the increasing global networks of researchers. These studies identify how networks can provide unique opportunities for developing countries to tap their research and innovation potential. Role of government of developing countries in facilitating international networks of their top notch scientists by providing incentives to focus on research that addresses the local issues of broader concern also emerges from this scholarship. In underscoring the role of government in building networks, this thesis also highlight the role of personal contacts of scholars in developing scientific competency and addressing global challenges through S&T interventions. Ernst[52] says that personal contacts are invaluable and exchange visits and long term stays in laboratories in different countries provide foundation of common understanding and is the most efficient way of establishing long term associations.

Close reading and interview highlight that long term associations in the influence of IFCWS have helped to build trust and long term linkages among individual scholars. Many of the French scholars whose deputation is over are still associated with the Indian scholars.

> *……more important is trust and this long term association helps to build this.*

Infrastructure Support

Major financial support is provided by IRD and infrastructure support primarily through IISc. CEFIPRA is another major organization, initially supported number of projects which further helped in infrastructure development of this laboratory. The two major environmental observatory, in IFCWS is 'Kabini Critical Zone Observatory' in India and 'Service d'Observation Bassins Versants Expérimentaux Tropicaux (SO BVET)' in France. The SO BVET is supported by IRD, CNRS and Université Paul Sabatier and the 'Kabini Critical Zone Observatory'. DST, Government of India, has acknowledged Kabini Critical Zone Observatory considered as a model for the development of a network of environmental critical zones (CZOs) in India.

The two major platforms developed include water (and soil) analysis and other on modeling. The water analysis platform provides major anions, cations, silica and carbon analyses. The modeling platform is dedicated to GIS, hydrological modelling and crop modelling.

Technology Transfer

Projects implemented in IFCWS are mostly basic research projects in water sheds. Through applied projects the laboratory is trying to address urban water issues and water supply issues. Scientists are also trying to conduct applied research dedicated to the service of local communities, water agencies and farmers. Table 5 provides some indications of its outreach to the community.

DISCUSSION AND CONCLUSION

The paper has made the proposition that a bilateral S&T organisation can also be understood as an innovation intermediary. It is different than a typical conceptual understanding of innovation intermediary as it acts as a bridge between two countries, involving multiple innovation actors and facilitate the innovation activities at system level. Sectoral System of Innovation (SSI) was used as a conceptual framework as study examined the performance of an actor (i.e. bilateral S&T organization) in a specific sector. This paper has developed systemic functions within this framework and has attempted to apply this within the context of bilateral S&T organisation. In this context we have defined seven major functions and have further delineated them to sub-activities. The paper highlights the importance of these functions to understand a bilateral laboratory (or bilateral S&T organisation) as an innovation intermediary and the influence of bilateral laboratory at system level.

We have examined a case of bilateral laboratory established between India and France i.e. Indo-French Cell for Water Sciences (IFCWS).[53] Sectoral system of innovation provides an important framework as actors and institutions associated with IFCWS evolve in the sectoral dimension of water sciences. IFCWS have developed knowledge domain expertise in different sub-areas of water sciences. It is playing an important role in linking different actors in this area including academia, financial institutions, government agencies, industry from two countries. This functional framework can also be useful for other bilateral organizations and can be suitably modified to understand the role of other actors in the SSI. This will be useful for policy makers and democrats as this study

Table 5: Technologies Transferred.

Area	Technologies Transferred
Water cycle and biogeochemical cycles in a context of global change	Sensors (optic fibers); SEW characterization; SEW hydro(geo)logical and geochemical survey (sensors); Implementation of experimental watersheds and monitoring; Numerical modeling; CAL/VAL procedures; Coupling hydrological and geochemical models
Hydrology from space and Agro-hydrology and landscape management	Megha Tropiques algorithms; Retrieval of soil moisture from SAR; Retrieval of LAI from SAR; Disaggregation algorithms for ET from RS; Groundwater recharge models using assimilation of RS products; Algorithms for estimation of SHPs and development of soil maps using RS STICS model
Environmental impact of mining	Use of red mud and fly ash for pH control and removal of metals; Utility of Sulfate Reducing Bacteria for sulphate removal and heavy metal precipitation

Source: CEFIPRA

will provide an additional framework for strategic implementation of bilateral organisations.

IFCWS is an organization established in a high priority area and has performed several roles including the intermediary roles for the development of the area of water sciences. IFCWS has implemented joint research projects which have solved some critical issues relevant for the government. One of the major project of this cell is maintenance of watersheds for improving on the understanding of hydro-biogeochemical functions and dynamics. The other important projects include the building up of standard models to predict the monsoons and the state of Indian Ocean and providing flooding maps for Bengal Delta. Both the countries has bought complementary capabilities in developing projects. These complementary research capabilities have not only helped in solving these specific problems but have also developed expertise in the area of research-gap. Research in cooperation stimulated by bilateral entity provides a kind of an open research platform where different organisations are encouraged to work together. IFCWS has developed R&D network with inclusion of different type of actors i.e. different funding organisations, project partners and different associated actors from both the countries. The laboratory is now reaching beyond bilateral framework and is associating with actors beyond India and France. A key point to note here is the vision provided to the scholars associated with the network. The bilateral cooperation has itself inspired them to realize the importance of development of regional or international network.

Further, it has helped in building capacity of human resource and laboratories in the different sub-domains of water sciences by organizing workshops and seminars, training programs and by engaging young scholars by various means. The long term stay of French scientists in India has evolved as an efficient way of building trust and a long term association between two countries. Many scholars who were earlier connected with the IFCWS are still informally part of this network. So, we can say that these organisations play an important role in strengthening the bi-national cooperation. It has also helped in building infrastructure at different locations in both the countries. This has also lead to the transfer of technologies to different organisations in both the countries. These technologies are from different priority sub-domains of IFCWS. A key feature missing is this network is linkage with the industries. Further cross-linkages with French and Indian industries can helps to strengthen the innovation capacity of firms in this sector in the two countries. This will also help in getting the private sources of funding to the IFCWS. The study has revealed that bilateral S&T organisations provide a much wider and more varied role then innovation intermediaries discussed in literature.

The study has also found the important role of scholars associated with this laboratory (i.e. IFCWS) in developing and sustaining Indo-French research network in water sciences through co-authorship analysis. The case study approach/ interviews data further compliments as well supplements this result by investigating more deeply its influence in research and innovation ecosystem of the two countries in water sciences.

The roles discussed, to a certain extent, mitigate systemic failures. Table 6 draws from the two strands of literature in SI i.e. 'functions' and 'systemic failures' in the context of IFCWS. The roles, capabilities and systemic failures addressed by IFCWS are summarized in Table 6.

It is evident from the above table that the different kinds of intervention by IFCWS have played an important role in mitigating the different systemic failures. The findings from this study show to a large extent that IFCWS plays an important role of linking different actors working in different dimensions of water sciences from two countries. It has also helped in co-creating knowledge and innovations. *The proposition that bilateral organisation can act as innovation intermediary is supported to a large extent. However, it would be fallacious to generalize this from a single case study.* This calls

Table 6: IFCWS: Interventions to Address System Failure.

Functions	Systemic Failures	Interventions by IFCWS
Research and Development	Research capability failures (in interdisciplinary research expertise is not available in every sub-fields)	Provided platform to bring different organisations together to work on common issues of interest (organisations in India, France as well as other countries)
Knowledge Co-development and Diffusion	Research capability and learning failures (limited research capability of an organisation and limited visibility in research community)	Provided platform to bring different organisations together with complementary skills and also facilitated cross learning through various modes like exchange visits. Interaction with industry was largely absent. This can impede development of tradable knowledge and technology transfer exchange.
Network Building	Network failures (limited associations between different stakeholders)	Provided platform to bring in new organisations with formal cooperation structures to bring in new capabilities and to work on bigger challenges
Capacity Building	Capability and learning failures (limited development of human capital/resource)	Provided formal training and skill development programs for students from different areas and countries
Social Capital	Social cooperation failures (limited trust and social bonds between different scholars)	Acted as a social bridge by bringing in policies of long term stay of researchers from different countries specially specifically the stay of French scholars in India
Infrastructure Support	Infrastructure and investment failures (limited finances and resources)	Provided required space and equipments to required to tackle different research problems and is also regularly improving on these facilities
Technology Transfer	Technology diffusion failures (limited absorptive capacity)	Provided not only the diffusion of science and technology but also effective absorption by developing human resource

Source: Constructed by authors[1]

1 [i]http://www.ambafrance-in.org/Indo-French-Water-Network-launch

for expanding this further to examine whether other bilateral organisations in India and in other countries also show similar behavior. The divergence between bilateral organisations involving North-North countries and those between South-South countries can be significant and may point out other aspects which may further ehrich the proposition.

An important area where further work is required is also in the understanding the effects of system functions and activities. It is also observed that the varied type of activities performed by the IFCWS play an important role in not only creating the niche domain in water sciences area but also in the sustenance of the areas already present. Such effects may also vary with organisations in different domains. The bilateral S&T laboratories are important structures that require further investigation in the context of the development of innovation ecosystem. To what extent political and socio-economic factors play a role in organisations of this type in the STI partnership also needs further study.

Based on the results and discussion of this study we provide some recommendations which may help policy-makers and concerned authorities to improve the effectiveness of such organisations and establish more effective bilateral organisations. The policy suggestions/recommendations we propose are: (a) Concerned authorities should be proactive in evaluating bilateral STI entities, their roles and functions in terms of their relevance in meeting innovation demands of the society and market. This will help such bilateral organisations to have contemporary relevance; (b) Bilateral STI entity as an 'innovation intermediary' can have useful implications for strengthening research and innovation ecosystem of partnering countries. This can be explored by policy makers; (c) Bilateral STI entities can be influential in building up skills and resources and can have long term impact on human resource development. For innovation scholars we argue that the role of bilateral entity in examining STI linkages between countries can provide new insights. This is an area which has not been explored extensively in innovation studies.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ABBREVIATIONS

IFCWS: Indo-French Cell for Water Sciences; **OECD:** The Organisation for Economic Cooperation and Development.

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