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Agenda for Technology Management caused by Shifting Innovation Trajectories in Research Innovation Systems

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Abstract- This paper discusses the technology management issues related to the 4 layers in the research innovation system, based on an empirical analysis in a high tech sector where changes are taking place in the S, T and M poles. This paper discusses the streamlined type of innovation trajectory and complex type of innovation trajectory.

I. INTRODUCTION

Innovation is considered as a complex interactive process that involves many disparate actor groups. Unlike traditional demand-pull and market push concepts, complex interactions among various interest groups considerably stimulate the innovation process and thus innovation process is better seen from the system perspective. For example, innovative performance of a country depends to a large extent on how these actors primarily private enterprises, universities, public research institutes and other contributing individuals, relate to each other as elements of a collective system of knowledge creation and use. National Systems of Innovation is basically considered as the network of institutions of disparate actors whose interactions lead to initiate, develop and diffuse new technologies. Similarly, organizational innovative performance depends on the external and internal interactions of divisions and individuals within that organization.

Innovation not only depends on new technology invention but many other factors including maker-user-supplier relationships, diffusion mechanisms, competitive structures, education structures, government policies, role of intermediaries etc. New technologies, new actors, new markets all integratedly change the structure and the dynamics of an industry.

In our previous papers [5], [6], [7], we studied the national innovation system and innovation trajectories extensively. We showed how Innovation trajectories should be analyzed and what structural impacts it causes. In this paper, we discuss about the technology management issues that may arise due to shifting innovation trajectories.

II. MAPPING INNOVATION TRAJECTORIES

"Innovation Trajectories" which maps out the innovation process and its evolution dynamics are much broader in scope than the Technology trajectories [3]. Mere technology trajectory will not reveal the complete picture of the innovation process. Innovation trajectories depend on the evolution at research (Science), development (Technology) and together with the market activities, the role of dominant actors and their inter-linkages.

Unlike traditional input/output methodologies, which only show a snapshot picture of the system, the network approach facilitates analyzing the dynamics of the evolutionary process of innovation. We chose a network-based framework called "Techno-Economic Network (TEN) [1], [2] to understand the inter-linked characteristics of innovation process. TEN is regarded as being organized around "poles", such as Science, Technology, Market, Regulation and Finance, etc. Poles are primarily defined by the intermediaries circulated by the members of the network. Regulatory and Financial poles, mostly indirectly, play a considerable supportive role in the innovation system and Science, Technology and Market poles play a direct role in the innovation process for the analysis. The TEN concepts broadly analyze a system by activity and actor networks. Refer the following for details about TEN concepts, and application [1], [2], [5], [6], [7]. There are number of ways a corporate strategy or national policy can be formulated around these Science, Technology and Market poles. Companies sometimes import a product and start their activity from the Market side and then develop their technologies or start from the basic research and push towards market. Similarly from industry perspective innovation dynamics can be traced by tracing the activities of Science, Technology and Market poles.

III. SHIFTING INNOVATION TRAJECTORIES – WHY SIGNIFICANT

The dynamic characteristic of an innovation system is a key component in deciding the sustainable innovative capabilities. A shift in an innovation trajectory can occur due to several reasons. A new discovery in science, a new technology invention, a new application identification, a change in the market and its structures etc. can cause a shift in the innovation trajectories. The origin of the shift can emerge from any of the poles we defined. The rate of change in different structures by these shifts can also vary depending on the case. Innovation trajectories would need to re-align and adapt within it and among other systems in major technological shifts. Co-evolutionary structure and its trajectories would begin to re-align themselves and the capability to re-align in the innovation system, determines the dynamic capabilities of innovation process. Nature of complex relationships and understanding these dynamics are important to understand the overall dynamics of innovation process.

Innovation trajectories are by definition, "complex trajectories" where there is no clear direction in any of the poles. Constantly changing the actors' network and their activities in each pole are typical phenomena of complexity. Ability to predict the trajectory is difficult and therefore there are difficulties in formulating policies at national level and strategies at corporate level. On the other hand, forces both at national and organization level work to stream line the innovation trajectories. A "streamlined" trajectory, we define as a trajectory in which the main actors can easily predict with considerable certainty the direction of the innovation trajectory. In the streamlined trajectory, there are clear and less uncertain situations prevailing in the Science, Technology and Market poles. It is possible to create virtuous loops in these three poles by manipulating market-pull and technology-push strategies with limited uncertainty. Actors in the Regulatory pole had clear vision that made them formulate policy directives to create momentum in virtuous cycle. Streamlining an innovation trajectory needs careful planning and visions and it is impossible to completely streamline an innovation trajectory. National level institutions and corporate organizations work in many ways to improve the predictability and to streamline the trajectories. A shift in innovation trajectories can also shift the streamlined trajectory to a complex trajectory and again new structural re-alignment should be done to streamline the trajectory.

We studied Japanese robotic industry over the years and identified a shift in innovation trajectory. We studied the shift using the TEN framework. Robotic innovation has been undergoing drastic technological changes, application diversification and market challenges. It has been traditionally thought that robots are of use only for manufacturing applications. Recent technological changes taking place in this sector show that robots are no longer restricted to manufacturing. Emerging new directions is shifting the existing innovation trajectory. With the emerging structural changes in recent years, we may say that it pushes a streamlined trajectory towards a "complex trajectory", in which the drivers of the virtuous loop in the course of the industrial robot trajectory have been changing.

The shift has changed the existed innovation structures and their dynamics. We summarize some of the structural changes caused by this shift.

Science and Technology structure:

There were changes in the structure of component of component technologies both in Science and Technology poles. Dominant technology clusters changed both in Science and Technology poles and new technologies emerged by coalescence of activities was taking place among the component technologies. Increasing technology convergence and structural changes in component technologies both directly and indirectly affect and accelerate shifts in innovation trajectory.

Market Structures:

A major structural shift in the product structure of industry was observed and traditional product line was shifting towards new diverse product portfolio.

We observed major changes which directly or indirectly have impacts on the innovation trajectory. First, as we observed in the product structure, industrial robots are slowly saturating in the Japanese market. But at the same time, we noted a high replacement rate of industrial robots and increasing export demand. We also observed a reduction in the number of makers and models of industrial robots. The other kinds of non-industrial types of robots, on the other hand, are slowly establishing their commercial markets. Evolutionary forces in the product structure have been steadily shifting towards exerting structural changes in the innovation trajectory.

Regulatory structure:

The government and its policies executed through its agencies shapes the diffusion process, competitive environment, and manipulate market forces.

In industrial robots case, Government played mainly a promotional role, aimed largely at encouraging competition and strengthening demand in market pole. One of the key success factors in robotic evolution in Japan would be the correct identification of strategic importance of robotics potentials in its early stages.

Market pole has been strengthened using several policy tools such as financial assistance to users, loan guarantee schemes, leasing schemes. Financial incentives have been in the form of low-interest loans, depreciation schemes in order to encourage robot introduction mainly in small and medium enterprises. The shifting trajectory requires new policy tools and manipulation techniques unlike in the earlier streamlined trajectory where the predictability rate was high.

Actors' structure:

The changes were observed in the actor structure too, complying with the changes in the other structures. In the Market pole, as new users with disparate (especially non-industrial) applications enter, traditional industrial robot users remain intact by replacing their stocks. In other words, the structure keeps on expanding with its own segmentation. In contrast, in the Technology and Science poles, we see the entry of new actors especially for non-industrial robots, and exit in traditional industrial robot sectors. Our empirical results also showed a decline in the number of robot makers of manufacturing applications and also a decline in the number of models in the market.

Socio Economic structures:

We believe that the robotics industry will have to manage another socio-economic change with this emerging structural change in the innovation trajectory.

On the one hand the new emerging trajectory is expected to increase the standard of living, thus being economically positive. On the other hand, intelligent, relatively cheap and technologically easily transferable evolution can cause a potential threat to human beings, as for instance robotic technology can be easily used to carry potentially dangerous weapons. Potential threat may even be viewed further with robot technologies converging with many other technologies. One could expect this shift may be the major social issue next to industrial robot introduction. This is just one example of structural changes in socio-economic environment by the shifts in innovation trajectories.

As discussed in this section with an example case study, a shift in innovation trajectory causes wide spread impact on several structures. Managing these structural changes effectively at national and organization level is important to shape the shift to achieve better results.

planning innovations. By "actor level", we refer to corporate level or department level decision-makers who are concerned with innovation itself and its integrated impacts. Policy level decision-makers are directly working for development and are assumed to come in at the "network level", such as bridging institutions, promoting institutions or those who can influence the innovation policy at the national level. This level is considered as an interface between corporate or university and the national levels. Finally the "national level" means the technology policy-makers at the national level. Their consideration is how technology innovation would be translated into a nation's economic growth and the well-being of people. By combining the first two, we call them the "management level" issues and the other two the "policy level" issues. Taking the case of innovation trajectory shift in Japanese robotic industry, we summarize technology management issues using four layer analysis.

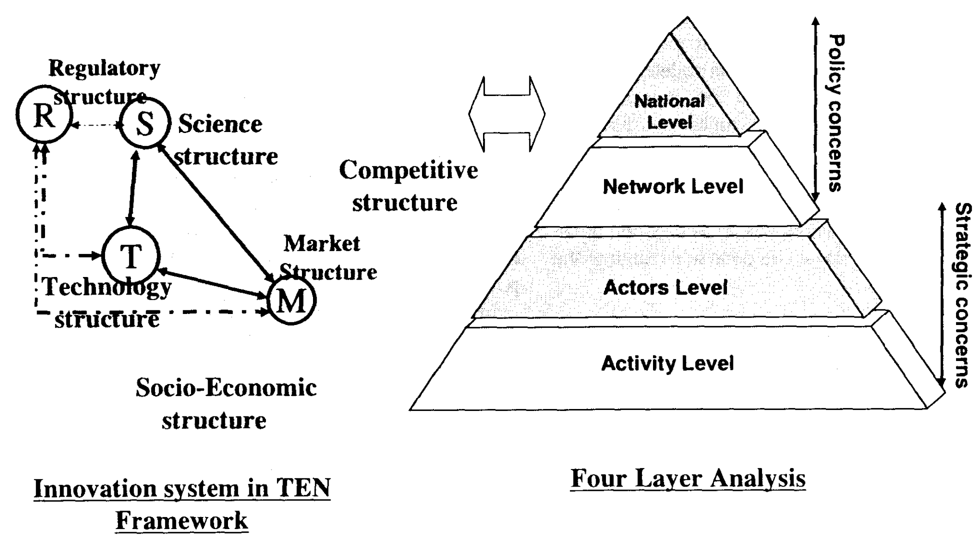

Figure 1: Four Layer Analysis of innovation trajectory

IV. AGENDA FOR TECHNOLOGY MANAGEMENT BY SHIFTING INNOVATION TRAJECTORIES - FOUR LAYER ANALYSIS

In this section, we summarize the possible management and policy level issues that need attention resulting from the shifts in innovation trajectories. To understand the issues, we categorize the analysis at the four levels as activity, actors, network and nation based on decision hierarchy. We mean by "activity level", the people directly involved in innovation activities such as corporate, university or public research institutes, R&D labs and activities involved in

Activity Level: Innovation shift caused structural changes in Science, Technology and Market poles. New technologies were introduced in research (Science) and development (Technology) and a higher rate of technology convergence within Science and Technology. Changes between linkages between component technologies also observed. This requires continuous skill search and building of dynamic knowledge bases at the activity levels. Thus there could be changes Research and development networks (research groups) and their technology portfolio. It can also change the spill over dynamics within and between Science, Technology and Market poles. Inter-linkages between the distinct entities in Science, Technology and Market poles

facilitating new knowledge creation could easily be transferred to the other technologies in the integrated network. Therefore we emphasize the need for understanding the dynamics of the spillover during the innovation trajectory shifts.
Further more, as new technologies and markets emerges by the shift, it is important to maintain and improve the R&D productivity at actors' level. Effective knowledge transfers and networking can substantially affect the overall productivity of the Science and Technology poles.

Actors Level: Managing the actors' network and their integration is one of the key factors during trajectory shifts. As technologies, products, and their use changes there will be changes in the actors' networks and their level of integration. New alliances and joint research groups may need to face the challenges caused by the shifts. The dominant actor group may change and if the shift is science biased, then the role of university may also change. Joint activities and infrastructure promotions mechanism may change by the shifts and knowledge networks between various actor groups can achieve overall effectiveness.

We believe that there should be awareness and flexible approaches at each actor level and allowance of successful links to be created between them. Our research on robotic innovation showed that though there are concerns on networking between actors, regulatory and administrative systems, especially in government-controlled institutions including universities, faced some barriers for effective integration. Effective strategies may be required to promote better linkages and ease the barriers cost effectively.

Network Level: As the innovation shift towards complex trajectory, one of the prime forces that streamline the innovation trajectory is the network level intermediaries. Managing different networks with different customized policies would be one challenge at the network level. Our analysis stresses that creating awareness of the distinguishing differences and similarities at the network level is vital for shaping the innovation trajectory. Organizing knowledge sharing conferences, standardizing technologies and products, promoting through incentive schemes, recommending national policies are some of the streamlining activities at network level. The lessons learned from one network would be useful and resource-efficient for other networks. Policy tools on how those competencies can be transferred and utilized effectively need network-level awareness and attention. The characteristics of industrial convergence and technology fusion need delicate policies, which could integratedly shape the disparate industrial innovations. Managing linkages with external networks would also be a critical challenge, arising from the shifting innovation trajectories.

National Level: Unlike the other three levels, the national level relates to the overall economy and the well-being of its nationals. Thus we believe that shifts in the innovation trajectory need considerable policy-level attention. The new emerging trajectory may have the potential to develop new frontiers in the Science, Technology and Market poles and concerns over regulatory pole. For example, robotics in welfare, medical, entertainment, safety (e.g. minesweeping), underwater explorations, etc. are recent emerging developments and, if properly shaped, can form new economic frontiers. Japan can have economic and social opportunities as we discussed in terms of socio-economic structures above. Turning these frontiers into growth fields is a challenge at the national level.

Furthermore, another example for national level issues would be, in robotic innovation shift, for the first time ever in history, these machines come closer to human beings and in some ways may threaten human life. Therefore innovation shift may require national-level attention and may even lead to formulate a new social order to shape the innovation trajectory in a useful as well as safe direction.

V. SUMMARY

This paper discussed innovation trajectories and how any shifts in those trajectory changes the several innovation structures. As discussed in this paper, innovation shift can arise due to several factors and depending on the case, it should be managed both at organizational and national level to achieve better results. Innovation trajectory shift was analyzed based on the example case of Japanese robotic innovation trajectory shift and discussed some of the agenda for technology management using a four layer analysis framework.

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