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Integrating Technologies as Spillover Infrastructures

—Understanding the Hidden Dynamics of Knowledge Distribution in an Innovation System—

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Abstract - Though spillover potential has been identified for the betterment of economic growth, the studies on necessary infrastructures to induce spillovers is still in their early stages. This paper discusses how integrating technologies function as spillover infrastructures in the advanced stage of technological development. Taking the case of robotic technology as an integrating technology, this paper argues the important role of certain integrating technologies in creating a medium for knowledge distribution in an innovation system. Utilizing the Techno-Economic Network framework, this paper provides empirical evidences to show how the robotic technology in Japan, has been functioning as an invisible infrastructure to induce spillovers. This paper concludes that as intangible factors becomes important for building technological infrastructure, identifying the characteristics of integrating technologies in national systems will be an important policy issue.

INTRODUCTION

Recently, it is widely accepted that “technological infrastructure” should be considered separately from the socio-economic structures as it includes delicate and distinguishably different components. Technological infrastructure (TI) building process has been considered as a process not only just to accelerate economic activity but also bring the system more efficient and productive [1][5]. Three infrastructures are highly interdependent and jointly determine the capabilities and competitive positions of national innovation systems. They "co evolve" with one another and dynamically determine their trajectories generally to promote the national objectives. TI generally includes the existence of conventional infrastructure (transportation, communication, power, etc.), human capital (engineers, scientists, etc.), institutional infrastructure (patent system, bridging institutions), firm based capabilities in production, investment and interdependencies of investment decisions. It is a set of collectively supplied, industry specific, industry-relevant capabilities, intended for several applications in two or more firms or user organizations [4]. In recent years, most of the studies recognized the "intangible components" in the infrastructure development and increasingly value importance especially in advanced industrial economies [1][3][4]. As intangible component increases in the infrastructure building process, it becomes more dynamic than static

Justman and Teubal [4] distinguish between two extreme type of TI: basic and advanced. Basic TI comprises routine or conventional capabilities that support low to medium technology activities and advanced TI serves high tech and leading edge industries providing necessary R&D inputs to the specific innovations or developments. Tassy [1] defines as an element of an industry’s technology that is jointly used by competing firms. He categorizes the advanced TI under three broad topics. (1). Generic technologies - core product and process technologies from which specific commercial applications are developed through subsequent applied R&D by competing firms. (2). Methodological technologies - techniques, methods and procedures necessary to implement firm’s strategies e.g. TQM, JIT, ISO 9000, heuristics methods developed internally. (3). Technology-based infrastructure a set of “technical tools” for making the entire economic process efficient and collectively these tools are called as “Infratechnologies”. Infratechnologies are embodied in or support generic technology and its applications. It includes scientific and engineering data, measurement and test methods, production practices and techniques and interfaces and act as intermediaries for efficient transfer of knowledge and information and supports all phases of R&D, production and market development.

Many research in recent years identified the enormous social and economic benefits of encouraging the technology spillovers over limiting the spillovers excessively to motivate innovators [17]. Knowledge distribution infrastructure, which is a subset of a broader definition of technological infrastructure, should consider factors that encourage spillover [3][11][17]. Developing the TI to encourage the knowledge spillovers has different explicit objectives from the concepts of advanced TI discussed above. Though both mainly consider how to improve the knowledge flows within the system, the concepts of advanced TI focus on improving efficiency of the infrastructure. Infra-technologies are encouraged basically to improve the overall efficiency and productivity of the system by improving the intermediary technical tools. One of the main difference of above system with that of spillover biased infrastructure would be the focus on “medium”. We argue in this paper that spillover biased TI needs to consider also an effective medium to carry the knowledge from one point to the other. The medium can be a tangible (visible) component or an intangible (invisible) component. Spillover component is largely neglected in the infrastructure building process until recently as the notion of spillover still in the process of development. Furthermore, it’s sensitivity with positive and negative effects make it difficult to explicitly strike a balance at the policy level. We identify the role of integrating technologies in spillover biased infrastructure building process. We propose in advanced TI, in addition to generic, methodological and infra technologies, we have to consider integrating technologies, which have different characteristics from the above three with respect to spillovers. Improving the spillover characteristics should be viewed differently than improving efficiency. In this paper, we discuss how an integrating technology acts as medium of spillover taking the case of robotics in Japan. We further argue that inherent characteristics of a technology itself with activities in research, development and market, importance and pattern of distribution at national level, linkages with other technologies and the evolutionary trajectory over the years distinguish the capacity of the spillover effects of integrating technologies.

FRAMEWORK

The spillover network and its characteristics have been analyzed under the basic framework of Techno-Economic Network [6] [7]. Techno-Economic Network can be defined as a coordinated set of disparate actors such as firms, universities, research centers, financial and other organizations, which participate collectively in the design, development, production and diffusion of goods and services some of which give rise to commercial transaction. It has been organized around major poles and each of which are defined by the type of intermediaries circulated by the members of the network.

Each of the poles are defined in the following way,

Science Pole: Mainly the activities of producing certified knowledge are considered in this pole. Output intermediaries are generally publications (includes articles, reports, working papers), embodied knowledge (graduates, trained scientists moving to industry) and sometimes technical devices, etc.

Technology Pole: Mainly characterized by the conception and development of material products that are coherent (durable and reliable) and capable of rendering specific services. Intermediaries of this pole can be patents, prototypes, standards, rules and methods etc.

Market Pole: Mainly refers to the users' state of demand (identity of consumers, the nature of their needs, their priorities, etc.). The primary intermediary here is money. The transaction in this pole reflects the utility of the goods and services.

Integratedly the networks in all three poles identify how knowledge flows within and between these three poles and characteristics of knowledge distribution power of integrating technology.

DATA SOURCES AND METHODOLOGIES

Data bases and interview data were used in our research and in,

(a) Science Pole: The publication activities are considered specifically as one of the main activity to represent the science pole for the analytical purposes. Compendex Engineering database, a specialized engineering and technology database developed by an American company called Engineering information is widely used in the science pole of our analysis.

(b). Technology Pole: Patenting is considered as a representative activity for the empirical analysis in the technology pole. Though the patents do not cover the entire domain of technological inventions [21][23] and all patents do not lead to innovation, it has some strength to use as representative tool[24].

(c). Market Pole: International trade data taking into account of the national difference compiled by International Federation of Robots (IFR), a body comprising most of the robot producing countries, data taken annually by Japan Robot Association (JARA) are used specifically to analyze the market pole.

A combination of co-word and co-classification techniques is used for data analysis in Science and Technology poles. Co-word analysis uses a combination of carefully selected keywords in the respective fields to extract the information from the database. Co-classification technique, on the other hand, uses the existing classification codes of the databases. The classification analysis considers the entire spectrum of the publications and has a consistent meaning in its entire domain. It is also easy to analyze without any information loss.

KNOWLEDGE DISTRIBUTION POWER OF TECHNOLOGIES

The concept that "knowledge is infrastructural" is largely a contemporary construct reflecting the growing importance and complexity of knowledge used in the production of goods and services [3]. Though technology sectors, national innovation environment, global competition also largely determine the distribution power thus spillover of technology, we analyze the capabilities of technologies as spillover infrastructure. Largely agreeing with the earlier definition of advanced technological infrastructure, we consider "integrating technologies" in addition to generic, methodological and infra type of categories.

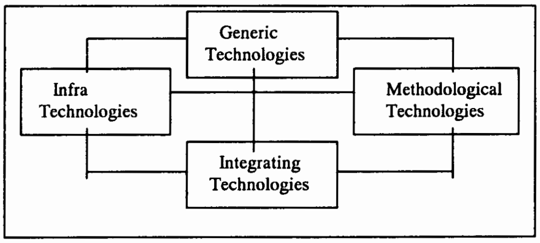

FIGURE 1: TECHNOLOGY GROUPING FOR SPILLOVER INFRASTRUCURE

Generic technologies have come to be viewed as a public or quasi-public good and therefore easily accessible. Methodological and infra kind of technologies can be categorized as "quasi public" goods or services with its inherent characteristics as intermediate technologies. But the integrating technologies in contrast are mostly "private" in nature and corporations are willing to spend on their own to accumulate knowledge in these technologies. Integrating technologies are application level technologies and "customization" and "system integration" are the two core technological competence required for the technological accumulation.

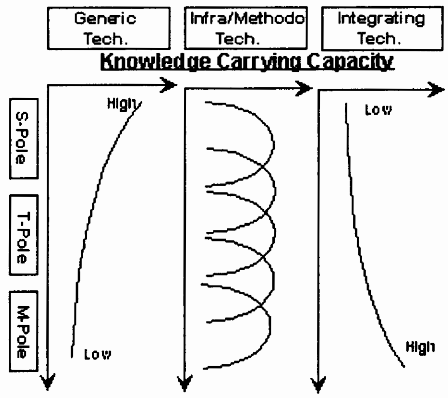

FIGURE 2: CHANGING KNOWLEDGE CARRYING CAPACITIES OVER THE VALUE CHAIN

The knowledge carrying capacity of each technology groups differs based on several factors. As a product or service moves through its value chain from the Science to Technology and then to Market, generally the identity of the generic technology gets blurred and mostly integrated technologies becomes apparent. Generic technologies for example, a new material or chemical compound or electronic device, can carry an inherent and complementary knowledge component mostly in the Science and Science – Technology interface and in Technology pole. When it comes to Technology – Market interface and then to Market pole, it gets integrated into the application models and the integrating technologies takes over the knowledge carrying capacity. Methodological and infra technologies on the other hand, in general carries the knowledge component within a limited space. It may be within the poles or interfacing space. Figure 2 shows the conceptual model to show the knowledge carrying capacity of each technology in the value chain.

Figure 3 conceptualizes a general pattern of knowledge carrying capacity of technology groups and the extent of the knowledge carrying space may differ depending on the technology. Consider for example, the combinations of generic technology and integrating technology of transistor and television, microchip and controllers, engine and motor vehicle, in each case, the generic technology would be the core technology for the integrated technology. It forms the advanced infrastructure for the development of integrated technologies and functions as an independent knowledge component. Integrating technologies on the other hand forms the "platform" for integration.

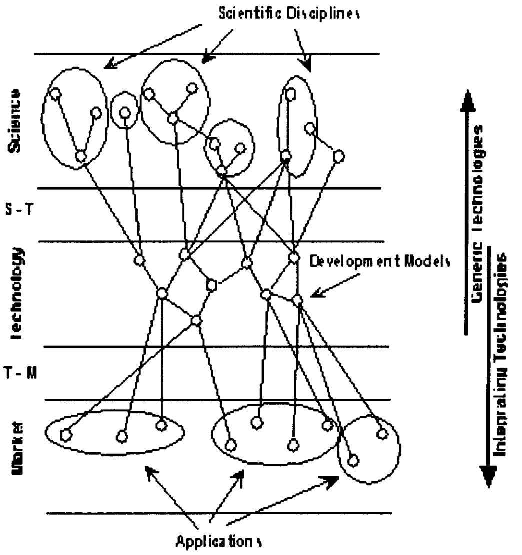

FIGURE 3: PLATFORM FORMATION OF INTEGRATING TECHNOLOGIES

Figure 3 above shows how an integrating technology functions as a platform to integrate. The platform of an integrating technology forms nationally and its knowledge carrying features depend on several factors both endogenous and exogenous to the technology. The rest of the portion of this paper concentrates on knowledge carrying capability and spillover infrastructure of the integrating technologies taking the case of Robotics technologies in Japan.

CASE OF ROBOTICS IN JAPAN

Robotic technology can be a typical example for an integrating technology group. Any application model of a robot depends on successful integration of number of generic (controlling, sensing, communication etc.), methodological (system configurations like CIM, operational sequence specifically designed to meet the applications, heuristic methods developed internally etc.) and infra-(interface standards, design architectures, monitoring and calibrating methods etc.) technologies. As the application spectrum widens the number of integrating technologies also proportionally increase. One can observe another co-evolutionary dynamics between these technology groupings. Robotics has been widely quoted as an example for the equipment embodied knowledge diffusion. When a robot diffuses into the users, the technology, which is embodied and transferable may also, diffuses into user side. Of course, the intensity of knowledge diffusion highly depends on the assimilation capacity of the user. When user starts using the robot, there is a strong possibility of knowledge, which is obtained through the robot installation, usage and maintenance, spillover to other areas of the user firms. This had been the orthodox explanation of knowledge diffusion, which primarily takes place when a technology intensive capital good diffuses to a user with absorptive capacity. Market mechanism plays an important role in shaping the diffusion process of this kind. An exploratory research on Japanese robotic industry reveals very interesting knowledge spillover characteristics. We found robotics in Japan functions as "an invisible knowledge flow infrastructure", which supports heterogeneous knowledge, not only directly related to robotics but also different, flow through this network. Many cases the network itself functions as a link, we call it as "knowledge cross links", medium to transfer knowledge. It can be inferred that it could also lead to knowledge spillovers from one technology to the other.

Robotics in Japan unlike many other countries is having wider knowledge network from top to down streams, crossing many disparate industries [23]. Differing from the narrower definition of embodied knowledge diffusion, which takes place only through market mechanism, it considers the knowledge diffusion network structure of total innovation cycle, from creation to commercialization. The integrated network functions in a disparate way and identification of such networks together with their knowledge flows mechanism in many ways help to build the national knowledge networks. In addition to related technologies and applications, there have been many other factors decide the extent and coherence of the overall network. Some common factors linking the robotic technology in to a single platform are (1). Term "ROBOT"- widely used not only for academic and industrial purposes but also in media, entertainment sectors, etc. (2). Promoting institutions – JARA(Japan Robot Association), RSJ (Robotic Society of Japan), JSME (Japan Society of Mechanical Engineers) etc. (3). Promoting national institutions – MEL (Mechanical Engineering Lab), ETL (Electro Technical Lab), IROFA (International Robotic and Factory Automation center). (4). Publication Journals. (5). Patenting class (USPTO office (901), Japan Patent Office (361)).

EMPIRICAL EVIDENCES

In this section, we discuss some empirical evidences found through our research in three poles, about the characteristics of the "platform" the robotics technology forms in Japan. This could help to visualize the knowledge carrying capacity of this integrating technology.

(a) Market Pole

A country deserved to be called a "Robot kingdom" presently holds around 60% of the world robot stock. . Japan supplied around 80% of the world demand in 1997. There were around 300 robot producers at the peak in 1990s and the market structure was highly competitive and segmented. Japan overtook US in robot diffusion in early 1980s and the recent figure shows that in 1996, Japan had 6 times more stocks than US. Almost all-Japanese manufacturing industries utilize robotic technology much higher rate than any other country in the world. Recently it shifted further into non-manufacturing technologies and evidences show that there is considerable movement towards non-manufacturing type robots in Japan in all three poles [23].

In order to identify the spillover infrastructure the robotics form in the Market pole, we mapped the inter-linkages between application spectrum using "technology-market" matrix. Based on the makers and their application spectrum we identified the clusters of application sectors based on their proximity. It is assumed here that two applications are close to each other if one maker targets the both applications. In other words, there is a strong possibility for the spillover between two application sectors, if similar makers serve them.

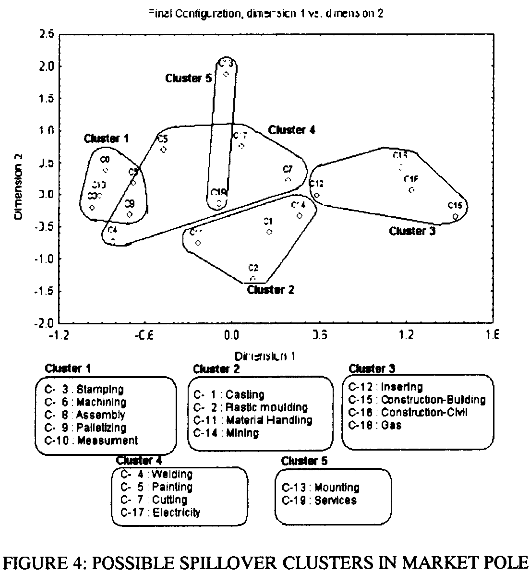

FIGURE 4: POSSIBLE SPILLOVER CLUSTERS IN MARKET POLE

Figure 4 identifies five separate clusters and their closest linkages. One interesting feature in this cluster segments is that there appears to be close links within clusters and overlapping of clusters. It mapped out the possible spillover pathways in the Market pole of Japanese robotics. This network is very dynamic and changes with year. By tracing dynamically, one could identify the changes in the spillover infrastructure in the Market pole robotic technology forms. As the users in the Market pole have been mostly corporations and the nature of the technology needs intense involvement of the user, the knowledge could spillover in the Market pole. In Japan, we found, it has been relatively long term and large network with effective knowledge carrying capacities.

(b) Technology Pole

We found through patent analysis, Japan has been given more importance nationally to robotic technology compared to other advanced countries [23]. Table1 shows the percentage of patenting of top robot makers and their respective patenting in overall Japanese patenting. It shows that first 25 top makers who have approximately 45% in robotic patenting also have around 21% patenting overall in US patents in 1991-95. Overall patents include all kind of patents and if we limit over analysis to engineering related patents, the percentage will be much higher. It reveals that the size of the possible knowledge spillover network, the robotic technology has been having in Japan.

	1986-90		1991-95	
	Robot	Overall	Robot	Overall
	% of total robot (US patents)	% of total (US patents)	% of total robot(US patents)	% of total (US patents)
First 25 Robot Makers (Japan)	46.0	17.4	45.2	21
First 25 Makers + 6 Users (Jap.)	50.3	27.2	49.2	29.1

TABLE 1: PERCENTAGE OF PATENTING OF ROBOT MARKES IN ROBOTS AND TOTAL

Further, in order to identify the spillover potential within the technology cluster of robotics (Japan's case), we calculated the spillover potential within robotic technology pole using below equation [11].

Where,

$$SP_j = \sum_{k \neq j} P_{jk} \; / P_{jj}$$

SP_j - Spillover Potential of j technology

P_{ij} - Number of patents co-classified both with i and j

It measures the potential of each technology's spillover potential with other technology within particular domain. Table 2 lists the spillover potential of technologies within Japanese robotics technology pole for two periods, 1986-90 and 1991-95.

	Spillover Potentials		
Technology Classifications	**1986-90**	**1991-95**	**Diff**
	[a]	**[b]**	**[b]-[a]**
Data Processing:Calibration	0.62	0.67	0.05
Data Processing:navigation	0.60	0.63	0.03
Computers and data process	0.62	0.59	-0.03
Motor Vehicles	0.56	0.59	0.03
Communications: electrical	0.57	0.56	-0.01
Optics:measuring	0.50	0.55	0.05
Information processing system	0.60	0.50	-0.10
Image analysis	0.59	0.50	-0.09
Surgery	0.00	0.50	0.50
Coating appartus	0.18	0.45	0.28
Electricity: motive power	0.57	0.43	-0.14
Mechine Element & Mechanism	0.37	0.39	0.01
Material or article handling	0.36	0.38	0.02
Metal Working	0.34	0.32	-0.02
Electric heating	0.36	0.19	-0.17
Total Difference in Spillover potential			0.41

TABLE 2: SPILLOVER POTENTIAL IN TECHNOLOGY POLE

Table 2 list out key technology classifications based on US patent classification in descending order of 1991-95 figures. It clearly shows strong linkages with other technology groups. The difference in spillover potential column shows a net positive figure (0.41), indicating a net increase in spillover potential. It also shows the variation of spillover potential among technology classifications were not very different from 1986-90 to 1991-95. In other words, there are technologies that have more potential to spillover than others and those act as even links to many other within the Technology pole.

(c) Science Pole

Japanese Robotic technology improved its position in the Science pole after gaining the strength in Technology and Market poles. We found that recently national importance to robotics has been increasing in Japan with compare to many other advanced countries [23]. It also indicated that there had been increase in activities of all main actors as companies, institutions and universities. Similar to Technology pole, we identified the top companies active in the Science pole and found out their activities in robotics and other engineering related fields. Table 3 shows the changing concentration of top robot companies active in Science pole in 1987-88 and 1995-96 period. The analysis based on the engineering database showed that companies active in robotics were also active in the other engineering fields. Though the gap widens in recent years, the possible spillover network has been still high in Japanese companies.

	1987-88		1995-96	
	Robot	Overall	Robot	Overall
	% of total robot pub of firms	% of total publication of firms	% of total robot pub of firms	% of total publication of firms
First 12 Robot Makers	46.0	35.0	53.0	35.0
First 12 Makers + 5 Users	61.0	57.0	78.0	57.0

TABLE 3: PERCENTAGE OF PUBLICATIONS OF ROBOT MARKES IN ROBOTS AND TOTAL.

We have shown [23] earlier that the changing trend in technology activities in the Science poles. Using co-classification mapping as we did in the market pole, we found that the technology coalescence taking place in the Japanese robotic Science pole. It was clearly observed that the activities of computer cluster and control cluster which were operated mostly in a separate manner have now been integrating together and becoming closer to other structures.

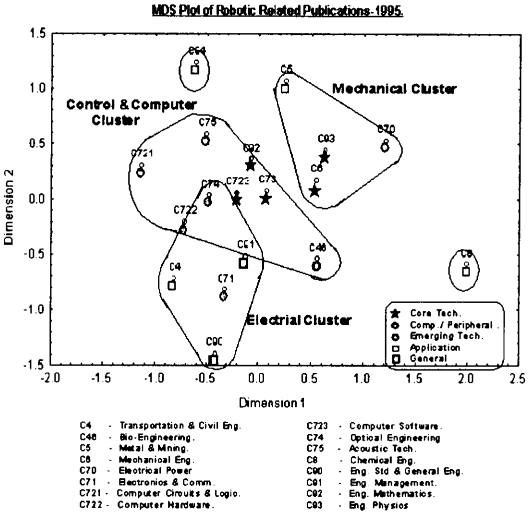

FIGURE 5: CO-CLASSIFICATION MAP OF SCIENCE POLE

Figure 5 above shows the main clusters operating in the Japanese robotic Science pole in 1995. We observe closely linked three clusters as controls & computer, electrical and mechanical. It can be seen that clusters have been overlapping and exist with close proximity. The core technologies were observed to be closer to each other and centered in the knowledge network.

Complementary/Peripheral and other technologies were surrounded by the core technology cluster and then by application oriented technologies. The main features in the structure were (a) almost all engineering fields (based on Compendex engineering database) have some linkage with the knowledge networks of robotics (b) core technologies centered in the overall network (c) structure is highly connected and coalescence taking place within the network.

These features elaborate the spillover pathways with the Science pole knowledge network.

We could easily identify the possible spillover pathways for each technology classifications. As we mentioned above, network operates in three distinguishable clusters and core technologies are centered. This reveals strong spillover possibilities among technology groupings. The knowledge can cross through technology groupings and can form cross-links which facilitates strong spillover possibilities. Further, the overall network shows the robotic structure connects disparate technology groupings and forms a technology infrastructure.

NATIONAL INFRASTRUCTURE BUILDING PROCESSES

In the Japanese Robotics network, we identified all four national level infrastructure initiatives (demand driven, supply driven, network based and infrastructure building) in order to strengthen the network under the TEN framework. TEN framework helps to visualize the national initiated overall linkage infrastructure of the Japanese Robotic Innovation system.

- Supply driven initiatives - National projects, National Labs
- Demand driven initiatives - Special projects based on demand conditions e.g. incentives for companies, initiating application projects
- Network based initiatives - Bridging institutions especially JARA, academic associations, etc..
- Infrastructure building - IROFA , a robot promoting institution under MITI, organizing exhibitions and events, etc.

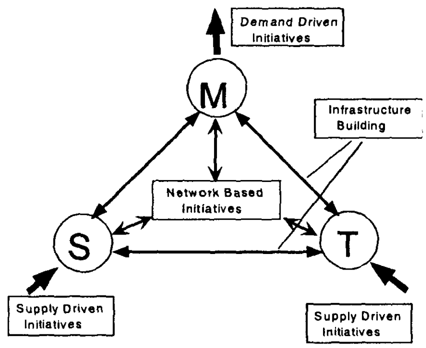

FIGURE 6: NATIONAL INFRASTRUCTURE INITIATIVES IN TEN FRAMEWORK

The above figure explains the government initiatives to promote the robotic technology from catch up stage to world leader. As technology develops and diffuses, government progressively introduced new measures to shape the trajectory. This process of national level infrastructure building process not only considered the technological development but also encouraged collaborations between various actor groups. There were some arguments about the effectiveness of these initiatives (Interviews data) but from the spillover point of view, these initiatives provided cooperative opportunities in a highly competitive environment. We found that these initiatives helped as an indirect spillover platform to encourage knowledge flows between different entities. Besides these robot specific initiatives, there have been many other system specific components such as diffusion inclined IPR policies, in Japanese national innovation system promote the spillover component.

DISCUSSION AND CONCLUSION

The main aim of this paper is to emphasize the importance of integrating technologies in advanced spillover infrastructure building process. Generic, methodological and infra technologies play an important role in advanced infrastructure process but when it comes to spillover infrastructure, the role of integrating technologies also becomes prominent. As we discussed above, the integrating technologies form a "dynamic platforms" to knowledge flows within the technology itself and other technologies consider this as a medium for knowledge flow. In our case, the robotic technology as an integrating technology found to be functioning as a dynamic platform connecting all three poles in Japan. The characteristics of the technology and other national level factors (discussed above) identify the knowledge carrying capacity of the integrating technologies.

As countries become technologically advanced, intangible components than tangible components play an important role in formulating the infrastructure. Encouraging spillover components in the infrastructure building process become an important consideration in the advanced stage of infrastructure building. It makes policy makers to consider intangible components, which encourage the spillover naturally as they develop in an innovation system. Therefore identifying the nature of different integrating technologies and their knowledge carrying capacity within the innovation system becomes policy task that can not be ignored.

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