2C09 Comparing Solar Photovoltaic (PV) deployment in Japan and the USA

— *its implications to the Science of Institutional Management of Technology (SIMOT)*

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In this paper, we studied and compared the actual historic solar photovoltaic installation data in Japan and the USA and proposed two deployment[1] models to account the differences. Japan deploys PV as a manufactured technology focusing on the niche of grid tied small scale residential system; USA deploys PV as a broadly defined innovation using a customization strategy emphasizing user-oriented innovation in both on grid and off grid applications. Different institutions to support different deployment strategies are necessary. Technology diffusion analysis must therefore consider the physical technology and the institutions as a unit of analysis. A notion of co-evolution of institutions and technology, upon which a Science of Institutional Management of Technology can be built, is then proposed.

1. Introduction

As energy resources and global environment issues are emerging domestically and abroad, the importance of carbon saving renewable energy such as solar photovoltaic is ever increasing. Yet, introduction of renewable energy such as solar PV to existing fossil fuel energy regime faces different types of barriers due to carbon lock-in [Unruh 2000][2] arise through a combination of systematic forces that perpetuate fossil fuel-based infrastructure that includes physical, social and informational elements. These barriers put renewable energy at economic, regulatory or institutional disadvantage relative to the incumbent forms of energy supply. Three major categories of barriers [Beck and Martinot 2004][3] are: 1) costs and pricing such as high transaction cost for distributed renewable energy projects; 2) utility interconnection requirements hurdles and costs; 3) market performance such as lack of technical or commercial skills and information and access to credit. General as they are, these barriers are often quite situation specific contingent upon local regional or country situation. Indeed, a review of the historic solar PV installation data in Japan and the USA shows a marked contrast. According to IEA [2003] Japan's cumulative PV installation is three times that of the USA. In the specific category of grid tied small PV residential system, Japan's cumulative installation is almost eight times that of USA despite that Japan has only one tenth of the BIPV area potential (roof + façade) of that of the USA. This paper proposes that this dramatic difference in the solar PV installation experience is due to differences in barriers in respective national contexts which are in turn driven by policy and PV productization strategy. Existing studies on renewable energy policy have mostly focused on subsidiary or financial based instruments and incentives to compensate for market distortion renewable energy facing. However, a more fundamental issue is the economics of production of the renewable energy. The economics are jointly determined by the cost of the constituent components making up a PV system such as solar cell module [Watanabe et al. 2000] and other BOS (Balance of Systems) [4] components and also how the PV technology is productized.

PV small system, no matter on or off the grid, while bearing the nature of consumer electronics appliance, is basically a small project that needs extensive on-site integration and installation works. Standardization in design, installation and interconnection [if applicable] will greatly optimize ex-post transaction and installation cost. During the period of 1992 – 2003, Japan has focused on productizing PV as grid tied small scale PV residential system accounting for over 90% of its cumulative installation. On the other hand, USA has productized PV as a broadly defined innovation or general purpose technology, *customizing* the technology to end user oriented requirements as on and off grid small systems [5] for residential and commercial applications. Different institutions are necessary for the success of each of these strategies. Our aim in this paper for this conference is as follow:

1) Explain the differences of these productization strategies and the characteristics of the innovation process;

[1] Hereafter, deployment and productization are exchangeable.
[2] Unruh, G. (2000). Understanding carbon lock-in. Energy Policy 28 (2000) 817 – 830
[3] Beck, F and E. Martinot (2004). Renewable energy policies and barriers. Forthcoming in Encyclopedia of Energy, Cutler J. Cleveland, ed. Academic Press/Elsevier Science 2004

[4] These include inverter, two way net meters and other installation accessories and they jointly account for ~ 50% of the cost of a PV generation system.
[5] Besides small system, IEA also defined another category of PV application known as grid tied centralized power plant like the conventional fossil fuel based power plant.

2) Propose an evolutionary-theoretic technology diffusion framework by considering, as a unit of analysis, both the physical technology and the institutions;
3) Motivate a concept of institutional co-evolution to study and manage technical change or management of technology

2. Different PV Productization Strategies

2.1 Japan

As of FY 2003, PV cumulative installation in Japan reached 860 MWp with approximately 623 MWp installed as grid connected residential PV systems. As mentioned in the introduction, Japan adopted a mass production strategy to productize the PV technology focusing small scale grid tied PV residential application, this draws upon her excellence in manufacturing technology [Watanabe and Kondo 2004] featuring TQC, JIT, Kaizen and other organizational innovations such as *Keiretsu* or closed networks of interlocking suppliers. Within these close networks, implicit transaction rules among related entities and specific communication languages are developed to coordinate product development. In fact[6], a special condition of the Japanese PV industry is the fact that a few large companies internalize the whole or at least large portions of the PV value chain inside their own company offering solar cell, module, BOS components financing and installation and maintenance. A lot of the houses in Japan are either pre-fabricated or that construction companies use standardized building components, favorable for the integration of solar module. Solar cell manufacturers therefore have either bought or forged strategic alliance with housing or construction companies leading to vertical integrated entities. The integration of the PV system at an early stage in the planning of pre-fabricated and mass manufactured houses offers the chance for a significant price reduction of PV systems compared to individually built houses or retro-fit projects. The pre-installation and mass fabrication of the unit homes in Japan enables the manufacturers to limit actual installation work of the PV system on the building site leading to considerable savings for the installation. The vertical integrated infrastructure in the PV industry [Figure 1] is very conducive to the mass production approach to productize PV technology in Japan for a specific standard application.

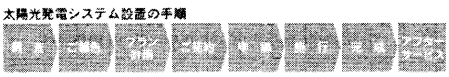


Figure 1 – an integrated PV value chain *within a firm boundary* in the PV industry in Japan. Source: Sekisui Ltd. Japan.

2.2 USA

On the other hand, as of FY 2003, PV cumulative installation in USA reached 275.2 MWp with approximately 95.6MWp installed as on grid distributed application. In fact, USA PV installation in the small systems category (exclusive of on grid centralized application) is well spilt among off grid domestic, non domestic and on grid distributed. However, the PV market has been dominated by off grid applications (~60% of total cumulative application). These off grid installations include remote residential power, industrial applications, telecommunications and infrastructure, such as highway and pipeline lighting or buoys. For these applications, they are competitive already since costly grid extension is avoided. The drawback is that these applications are mostly non-standardized and systems integration is project by project rendering any type of systemic learning[7] impossible as is usually the case for user-oriented innovations in renewable.

2.2.1 PV value chain issue:

In addition, a long history of PV spending on R&D to bring down the cost of PV cells and modules has created an industry focused primarily on component manufacturing. As a result, the majority of engineers employed in the PV industry in the USA are engaged in technology development rather than product development. A large percentage of PV sales to final customers flows through small systems integrators who assemble custom systems for individual customers. This market structure necessitates a large value-added component to each system, adding more than 50% of the final per-kilowatt cost of PV in many end-use applications. That is, many different firms participate in the PV value chain, and each requires an acceptable profit margin, thus raising the price of the final product substantially. More importantly, this market structure insulates primary manufacturers from PV customers. It keeps the markets small, because each small company lacks the economies of scale of the large manufacturer. The small companies serving end-use markets do not have the resources to manufacture and further innovate standardized PV products that serve whole market segments rather than just a few customers.[8] As a result, one of the most conspicuous differences between the Japanese and US PV industry can be seen not only in terms of the

[6] The rest of this sub-section draws heavily upon Jager-Waldau [2004] PV Status Report 2004 – Research, Solar Cell Production and Market Implemenation of Photovoltaics by the European Commission

[7] Ornetzeder M. and H. Rohracher (2006). User-led innovations and participation processes; lessons from sustainable energy technologies. Energy Policy 34 (2006) 138 – 150.

[8] Ingersoll, E. et al. Industry development strategy for the PV sector. REPP paper. The section on PV value chain issue of USA is heavily drawn from this paper.

diversity of applications but also in terms of the value chain structure which brings these applications to the markets. We can conceptualize these differences in terms of the physical technology and social technology dichotomy framework by Nelson and Sampat [2002][9]. This is now the theoretical aspect of our paper.

2.3 What is social technology?

Social technology is a concept to elaborate the carrying out of the physical technology recognizing the multi-party interaction involved in the operation of most physical technologies which sometimes goes on within a firm and sometimes between them. Within a firm, the M form of organizing a multi-[products] company can be interpreted as a social technology. Among firms and in the context of joint research and development, a consortium with member firms can be seen a social technology. Social technologies [10] therefore define the productive pathway for doing things and they define low transaction cost ways of organizing that involve coordinated human interaction. The different PV value chain structure of the PV industry suggested above between Japan and the USA can be seen as different social technologies that productize PV industry in the two national contexts.

3. A technology diffusion framework to understand the differences in PV productization strategy:

Our objective now is to understand the implications of different institutions or, broadly defining, social technologies, coupled with different PV productization strategies, upon the dynamics of technology diffusion. We investigated the set of historic installation data of the grid tied distributed small PV system category as a percentage of the cumulative PV installation in each country. Table 1 shows the normalized numbers.

	Japan	USA
1992	0.06	-
1993	0.09	-
1994	0.16	0.14
1995	0.249	0.145
1996	0.343	0.143
1997	0.472	0.155
1998	0.582	0.158
1999	0.714	0.179
2000	0.79	0.202
2001	0.846	0.242
2002	0.88	0.299
2003	0.904	0.3473

Table 1 Normalized installation pattern for on grid small PV system category. IEA [2004] and authors' own calculation.

The individual entry in the table represents the percentage of PV installation in the category of on grid small system design in each country. Indeed, we found that Japan's percentage is increasing monotonically approaching unity verifying our hypothesis that the country is focusing on this category. If we attempt to see these time series as a diffusion curve, what is diffusing is the "singleness" of the installation focus. The "saturation level" is the state at which all the PV installation in the country will be in grid tied small PV system. Now, our objective is to find a way to test if the social technology of integrated PV value chain, coupled with other institutional factors, such as utility interconnection standards or requirements, national subsidiary policies, various information dissemination programs etc. can sustain this productizing focus of PV in Japan.

Japan's data is found to fit the conventional logistic with high significance with an adjusted R square of 0.989. The conventional logistic assumes a word of mouth communication process resulting an epidemic process. Recent evolutionary theory has suggested that re-interpretation of the epidemic approach is necessary and to broaden the inter-agents communication process to a wide class of evolutionary processes and institutional arrangements sustaining the dynamics of diffusion. The fact that Japan's data fits nicely to a single logistics highly suggests that the PV value chain, all the relevant policies and the productizing focus reinforce one another. This characteristic will serve as a benchmark when we analyze the data for the USA. In fact, USA's data did not fit the single logistic and have an adjusted R square of 0.862.

In order to further characterize USA's data, we adopted Davies [1979][11] and Alderman and Davies's [1990] [12] process technology diffusion model and hypothesized that normalized installation patterns in the grid tied small PV system category in the USA may follow either of the two different patterns: that of a simple innovation or of a complex innovation.

Following Alderman and Davies [1990], we Probit transformed the USA data according to the following transformation: $\Phi^{-1}(m_t/n_t) = a + b\log t$ for simple innovation and $\Phi^{-1}(m_t/n_t) = a + bt$ for

[9] Nelson, R and Sampat, B (2001), 'Making sense of institutions as a factor shaping economic performance', *Journal of Economic Behaviour & Organization*, Vol. 44, pp. 31-54

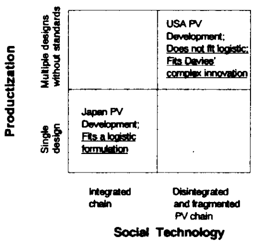
[10] These also include forms of business organizations, management practices, market mechanisms and structures, public policies, legal and regulatory structures etc.

[11] The diffusion of process innovations. Cambridge University Press, Cambridge.

[12] Alderman, Neil and S. Davies [1990] Modeling the metalworking industries. Regional Studies, vol. 24.6. p. 513 – 528.

complex innovation where Φ is the Probit operator. Our analysis showed that the PV USA data is more close to complex innovation, (adjusted R square for complex innovation is 0.849 vs. the adjusted R square for simple innovation of 0.575). Since we have interpreted the diffusion curve as the diffusion of percentage of PV installation that is in the category of on grid small PV system, this suggests that US PV effort in this category features an initial slow take-off and needs continual social technology adjustments or institutional co-evolution [Kodama 1995][13]. The USA pattern therefore departs from that of Japan and may be due to US's productizing PV as an "information technology" [Watanabe and Kondo 2004] like physical technology emphasizing user-oriented requirements across different applications using a social technology of fragmented value chains of intermediary and independent systems integrators. These combinations are not particularly conducive to productizing of a given single category of PV application unless there are institutions that facilitate significant cross-learning or spillover learning among designs [Shum 2003; Yoshikawa and Watanabe 2005; Ohmura and Watanabe 2005]. These differences are now summarized in the following:

Social technology and Productization matrix



4. Policy implications and future works:

From a policy standpoint, one relevant question is what is the meaning of social technology adjustment or institutional co-evolution? Specifically, what are the *content and objectives* of institutional co-evolution? The SIMOT [Watanabe 2004][14] framework suggests the three dimensions of institutions; namely: national strategy and socio-economic system, corporate or entrepreneurial strategy and historic factors. These three dimensions subsume the more well-known institutional aspects of technology suggested in various settings such as (but not limited to):

1. Vertical and horizontal subcontracting relationships or other inter-firms relationships; aka social technology
2. Cooperation, exchange or movement of skilled labors; aka employment institution such as life time employment to motivate spillover learning
3. Technology standardization as an infrastructure for continual product innovation
4. Consortium policy leading to generation of new technologies in the pre-competitive stage
5. Intellectual Property policy etc.

All of these mentioned and others are highly relevant to the generation, cumulative learning, productizing and appropriating economic rents of new technological innovations. Institutional co-evolution suggests that these and other are the strategic levers or mechanisms that policy makers should turn to in order to facilitate the launching of new technological innovation cycle.

For the specific case of productizing of PV discussed in this paper, we can use a theoretical notion in institutional economics to further conceptualize the differences as a consequence to the differences in productization strategies. Transaction cost is essentially the cost of using the market; it entails the search cost, cost of contracting (ink cost) and other ex-post monitoring cost. Wallis and North [1986] [15] suggested that the larger the transacting sector or the number of intermediary sectors in an economy, the higher the transaction cost. The case of fragmented PV value chain in the USA seems then will have a higher transaction cost than that of Japan. It highly suggests that institutional co-evolution in the productization of PV in the USA will involve the continual economization of relevant transaction cost and emergence of institutions that facilitate spillover learning. For the case of Japan, institutional co-evolution will be more focused on new functionality development such as productizing PV into other applications and new business models of energy service provision. This will be our future joint works with appropriate government organizations in Japan.

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[13] Kodama [1995] The emerging patterns of innovation. Harvard Business School Press. Kodama compared the installation and utilization patterns of computer in Japan's prefectural government during the 60s and 70s. A particular advantage of Kodama's data is that he can interpret the delay in utilizing the personal computer in certain categories of prefectural government jobs as due to those jobs called for institutional adjustments, compared to others which are rather independent in nature.

[14] Watanabe [2004] SIMOT Program proposal submitted to MEXT.

[15] Wallis, J., and D. C. North [1986, page 121]. "Measuring the Transactions Sector in the American Economy," in *Long Term Factors in American Economic Growth,* S. Engerman, and R. Gallman eds., University of Chicago Press.