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Government Policy and Innovation Activity: A Patent Study of Solar Photovoltaic Balance of System in Japan

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Government Policy and Innovation Activity: A Patent Study of Solar Photovoltaic Balance of System in Japan

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Report

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Public Affairs

The University of Texas at Austin

August 2014

Acknowledgements

A great many people have contributed to production of this Professional Report. I owe my gratitude to all those people who have made this report possible. I would like to thank my colleagues in the Energy System Support Transformation Research Group. Maureen Metteauer helped data collection in the patent search process and provided crucial advice on methodologies. Erik Funkhouser helped data cleaning and model building for the regression analysis. Special thanks are given to my writing instructor Sasha West. Sasha patiently guided me and offered valuable suggestions in the writing process. I would like to express my deep gratitude to my supervising committee. Jay Zarnikau provided insightful feedback and suggestions for modeling and analysis of the regression study. Finally, Varun Rai made this report possible by generating the initial research proposal and offering constructive feedback. I am sincerely grateful to him for the opportunity to explore the subject matter.

Abstract

Government Policy and Innovation Activity: A Patent Study of Solar Photovoltaic Balance of System in Japan

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Abstract: This report studied innovation activity in four areas of the solar photovoltaic balance-of-system (BOS) technologies (inverters, mounting equipment, monitoring systems, and site assessment) in the Japanese market. Through patent searches with specific keywords, this study found that innovation activity in these four technology areas increased and decreased responding to both supply-side and demand-side policies. This report also empirically studied effects of demand-pull policies on innovation activity in the BOS technology areas. The regression analysis of the patent data found that the demand-side policies such as residential subsidy programs employed by the Japanese government were a major factor which influenced innovation activities in these technology areas in the Japanese market. Finally, the regression analysis also found that the termination of the residential subsidy program by the government in 2006 had a negative effect on the innovation activity of the four BOS technologies.

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Chapter1: Introduction

Reflecting concerns over the environment, health, and security stemming from consumption of traditional fossil fuel energy such as oil, gas, and coal, renewable energy has been expected to substitute for fossil fuels for decades. In addition to these concerns, rising prices of fossil fuel has also moved many nations around the world to pursue various measures to nurture and support the growth of renewable energy sources.

Among these renewable energy sources, solar energy is one of the most promising and environmentally-friendly energy sources. Solar photovoltaic (PV) technology is one of the key approaches for converting solar energy into electricity. In PV, the technical components that generate electricity are called solar cells and modules, which are made from semiconductor materials.

Over the past decades, solar photovoltaic markets dramatically evolved around the world. In fact, global annual photovoltaic installations significantly increased from 293 megawatts in 2000 to 31095 megawatts in 2012 (European Photovoltaic Industry Association 2013). This trend is also notable in the counties whose firms lead in solar PV technologies. One of the examples of such countries is Japan. The Ministry of Economy, Trade and Industry of Japan (METI) recently stated that Japan now has 5,172 megawatts (MW) of installed solar PV capacity (Ministry of Economy, Trade and Industry 2014), with installations doubling between 2009 and 2011 alone. According to a report by the Ministry of Environment, solar power in Japan is the fastest growing renewable energy source with a growth rate of 40 percent in 2010 (Ministry of Environment 2012).

This increased scale of production has contributed to reduction in manufacturing costs of solar PV systems in recent years. In the United States, for example, the installed prices of solar photovoltaics declined by 50 percent between 1998 and 2011 (David Feldman *et al.*

2012). Also in Japan, the METI's Energy Whitepaper points out that prices of the solar PV system have declined by as much as 85 percent since 1993 (Ministry of Economy, Trade and Industry 2013). However, the rapid decline in the price of solar PV has caused financial troubles for the solar PV industry. While consumers increasingly benefit from price reduction triggered by the growing competition, profits of solar PV firms shrinks. Therefore, firms have to make further efforts to cut the production cost of the solar PV system to keep business profitable. Reducing the cost of solar PV power generation also helps PV compete with conventional fossil fuel energy in the energy market. As solar energy technology is not fully developed yet to compete with fossil fuel sources in terms of price, shares of solar energy among other energy sources in various countries remain low. In Japan, solar energy currently accounts for less than four percent of total electrical generation (Ministry of Economy, Trade and Industry 2013), even though domestic demand for solar PV has been increasing. To compete with traditional energy sources, the price of solar PV needs to go down further.

Responding to the shrinking potential for cost reduction in PV cells and modules, firms have been shifting their cost reduction target from cells and modules to other components of the full PV system. These non-cell/module parts of solar PV systems are called the solar "balance of system (BOS)." The BOS typically includes "design, site preparation, system installation, support structures, power conditioning and management, maintenance, and storage" (U.S. Department of Energy 2014). The production cost of the BOS components now accounts for larger parts of the cost of the entire solar PV system. In the U.S., for example, the BOS cost accounts for approximately 60 percent of the entire system cost (Barbose, Darghouth, and Wiser 2012). In Japan, the BOS now represents about 42 percent of the cost of a residential solar system according to a report by the Japan Renewable Energy Foundation (Kimura and Mano 2013). Therefore, the BOS is a good candidate for further cost reduction of the entire PV system. Accordingly, solar PV firms have been focusing on this area to survive fierce competition in the solar PV market.

It is almost axiomatic that reducing technology costs technological innovation. This study tries to shed light on the innovation activities in solar BOS by Japanese solar firms. This study focuses on the Japanese solar PV market because previous studies have not fully explored the development of BOS technologies in Japan from innovation and policy perspectives, despite this issue being critical to the current and future deployment of PV.

In order to measure the innovative activities of solar PV firms, this study primarily uses publicly available patent data for four component areas of BOS: solar PV inverters, mounting equipment, monitoring equipment, and site assessment. This study tries to track the rate and nature of innovation in solar BOS in Japan by systematically recording and analyzing patent activity.

In this study, patents and patent applications that were filed at the Japanese Patent Office (JPO) in the last two decades were collected and compiled through Boolean searches of the Industrial Property Digital Library, JPO's online patent database. The patent search employed specific keywords to extract inventions related to the four BOS components. Such keyword searches found 5,674 patents and patent applications in total. Among them, 1,191 patents and patent applications were truly related to inverter, mounting equipment, monitoring equipment, site assessment. These search results were classified into subcategories and recorded.

In addition to the examination of patent data, this report studies influences of government policy on the innovation activities in the BOS technology space. In particular, this study pays attention to government policy supporting technological innovation and market creation. In the Japanese solar industry, government policy has been playing an important role in market creation and technology development. Beginning in the 1970s, Japanese lawmakers, focused on energy security and environmental degradation, have employed a range of policy tools to increase demand for solar products and to advance technological innovation. As a result, Japanese solar PV technology has become increasingly competitive and domestic demand for solar has risen dramatically in the last decade.

This professional report is comprised of nine chapters. Chapter 2 will introduce an overview of solar technology. Chapter 3 will explain the current situation of the Japanese and global solar market. Chapter 4 will explore previous research on innovation activities as well as on the topic of patents as a measure for innovation. Chapter 5 will introduce the methodology of the patent search and patent data collection. Chapter 6 will provide the findings from patent search result. Chapter 7 discusses policy influences on the creation of the solar market and how policy has affected innovation in BOS technologies. Chapter 8 will provide empirical analysis of innovation activities in the Japanese solar market, including regression analyses of the patent data in hopes of identifying which factors contributed to changes in innovation activities. Finally, in conclusion Chapter 9 offers insights on future solar policy for increasing the adoption of solar PV.

Chapter2: Solar Photovoltaic Technology Development and Innovation

Photovoltaic cells, which convert sunlight into electricity, can be made from several different materials. Traditional photovoltaic cells are typically made from monocrystalline silicon (c-Si) or polycrystalline silicon (poly-Si). Currently, silicon-based photovoltaic cells account for a large share of the solar photovoltaic market due to their higher efficiencies. In addition to c-Si and poly-Si, second generation of photovoltaic cells have also been developed. These cells are made with new materials such as amorphous silicon (a-Si) or cadmium telluride (CdTe). While their efficiencies have not reached the level of the traditional silicon-based PV cells, the second-generation PV cells are typically cheaper to manufacture. As these materials are as thin as a few micrometers, these newer PV cells are known as "thin-film" solar cells. Because thin-film solar cells are flexible, new uses, such as building-integrated solar products, are possible (Go Solar California 2014) (National Renewable Energy Laboratory 2014).

SOLAR PHOTOVOLTAIC SYSTEM

A solar photovoltaic system comprises of multiple components. A solar module, which is mounted in a supporting structure or frame, is the main component of a photovoltaic system. A solar module is an assembly of a number of individual photovoltaic cells, which are electrically connected to each other. The remaining components of a solar system are called supporting, or balance of system (BOS), components. The supporting components include batteries (if used), a charge regulator, mounting hardware, electrical wiring, an inverter, which converts direct current (DC) to alternating current (AC), and any additional system diagnostic and monitoring equipment. The term solar balance of system (BOS) is used to refer to a part of the supporting components. The definition of BOS, according to the Department of Energy's Office of Energy Efficiency and Renewable Energy, is: "all components and costs other than the photovoltaic modules/array, including design costs, land, site preparation, system installation, support structures, power conditioning, operation and maintenance costs, indirect storage, and related costs" (U.S. Department of Energy 2014).

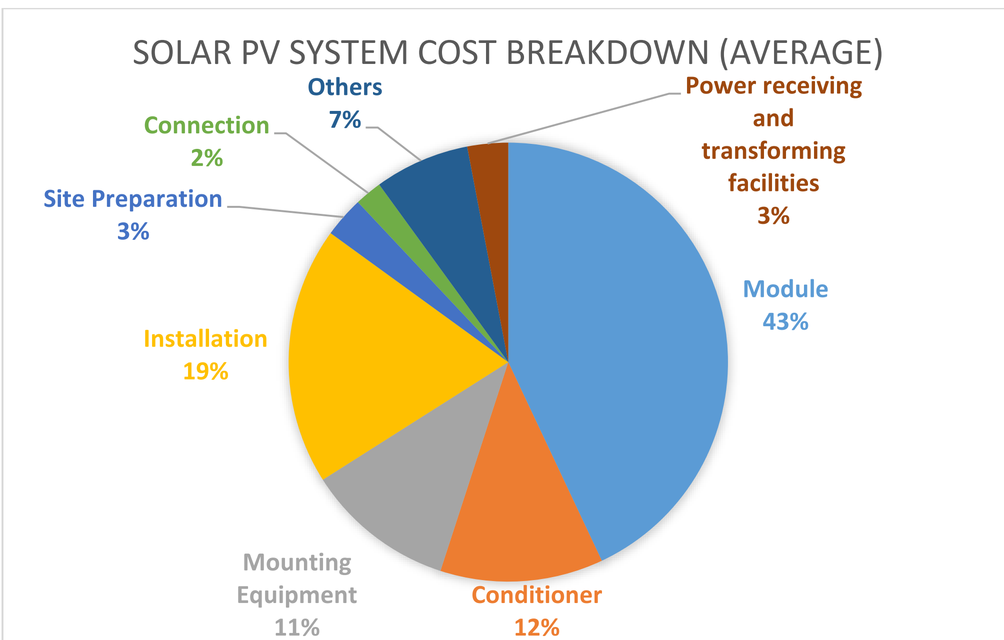
BOS Components

Among BOS components, this study will focus on four specific component categories: inverters, mounting systems, monitoring equipment, and site assessment. Inverters generally are large units that are centrally located within the overall system. Inverters can convert DC to AC for use in isolated environments or route the generated electricity back to the public utility electrical grid. Mounting systems physically support solar PV modules and/or arrays. PV system monitoring includes methods and devices that monitor the health, connectivity and output of solar PV systems. Site assessment relates to methods or mechanisms of appraising the photovoltaic output potential of a land parcel. These four technology areas represent the major BOS functions. Therefore, technological innovation in these BOS technology areas will reduce the cost of PV systems.

Cost of Solar PV modules and BOS Components

This section examines costs of BOS components. Since the price of solar PV cells and modules have been dramatically decreasing in recent years, expectations for cost reduction in the BOS technologies are growing. **Error! Reference source not found.** provides an overview of the cost breakdown of an average solar PV system. According to the data compiled by the Japan Renewable Energy Foundation, BOS components in total account for 42 percent of the entire solar PV system cost. Among the BOS components, power conditioners including inverters represent 12 percent of the average cost of a residential solar system. Similarly, mounting equipment accounts for 11 percent. The biggest cost component is installation, which accounts for 19 percent of the entire cost. The cost of the BOS components caught the attention of solar PV producers as cost of PV cells and modules have dropped over the last few years. In response to this, the solar industry has shifted to focus on reducing BOS costs, hoping to impact the total installed cost per watt even further.

Figure 2.1: Solar PV System Cost Breakdown

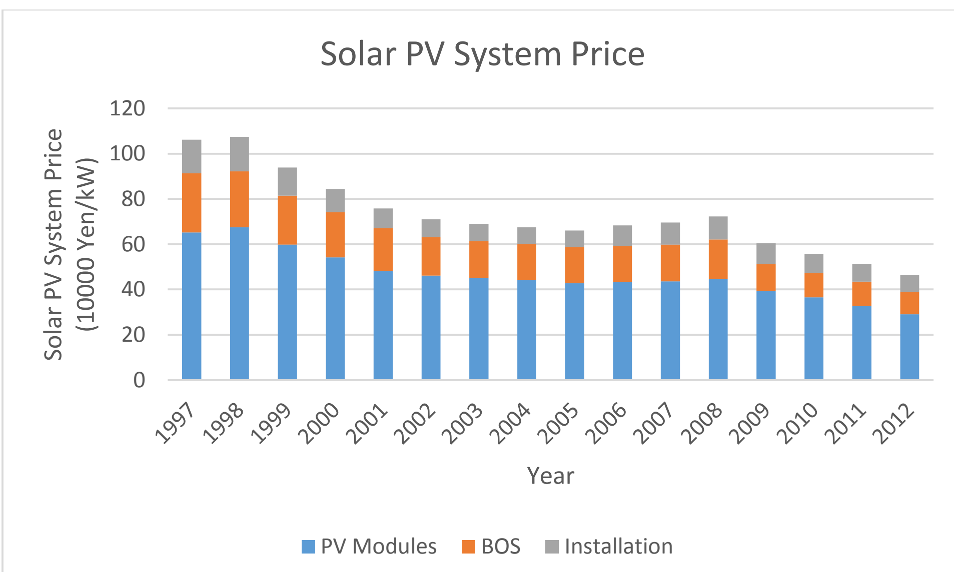


Source: Kimura, Keiji, and Shuta Mano. 2013. *Current Situation and Cost of Solar Photovoltaic Business*. Japan Renewable Energy Foundation. http://jref.or.jp/images/pdf/20131220/reports_20131220.pdf.

TREND OF BOS TECHNOLOGY COST IN THE JAPANESE MARKET

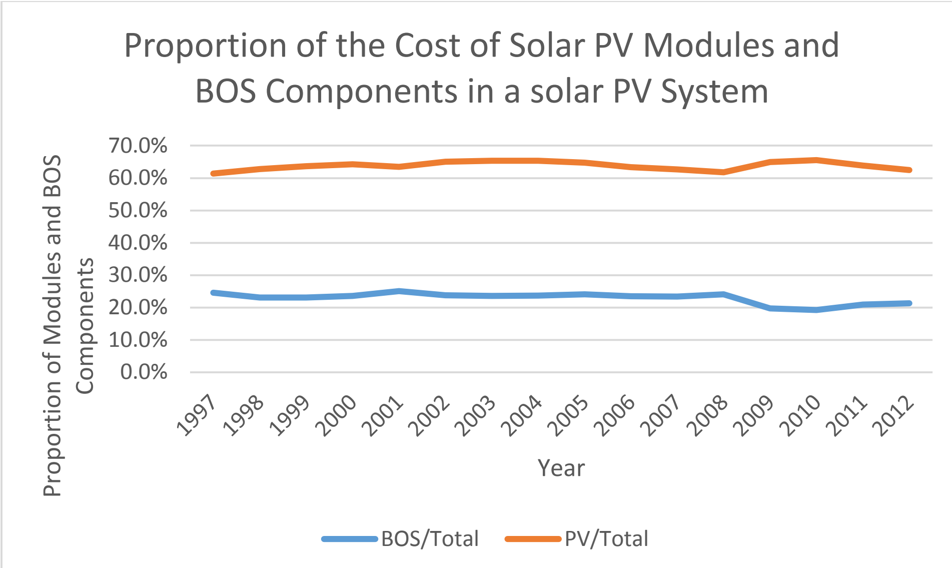
Owing to the rapid cost declines in PV cells and modules, while the relative cost of BOS components compared to that of PV cells and modules are increasing globally, this trend does not seem to apply to the Japanese market. Figure 2.2 from the METI's Solar PV System Diffusion Report illustrates the change in PV systems cost for the past fifteen years. It shows that in Japan, while the cost of entire PV systems declined, the *proportion* of PV module and BOS component costs did not change. In other words, the rate of declining costs of modules and BOS components have been almost the same over time (see Figure 2.3). For example, while the cost of PV modules and BOS components accounted for 61.4 percent and 24 percent, respectively, in 1997, the costs were nearly the same in 2012, accounting for 62.5 percent and 21.3 percent, respectively.

Figure 2.2: Solar PV System Price in Japan, 1997-2012



Source: Ministry of Economy, Trade and Industry. 2012. *Study of Diffusion of Solar Photovoltaic Generation Systems*.
http://www.meti.go.jp/meti_lib/report/2013fy/E002502.pdf.

Figure 2.3: Proportion of the Cost of Solar PV Modules and BOS Components in Japan, 1997-2012



Source: Ministry of Economy, Trade and Industry. 2012. *Study of Diffusion of Solar Photovoltaic Generation Systems*. http://www.meti.go.jp/meti_lib/report/2013fy/E002502.pdf.

Chapter 3: Solar photovoltaic market overview

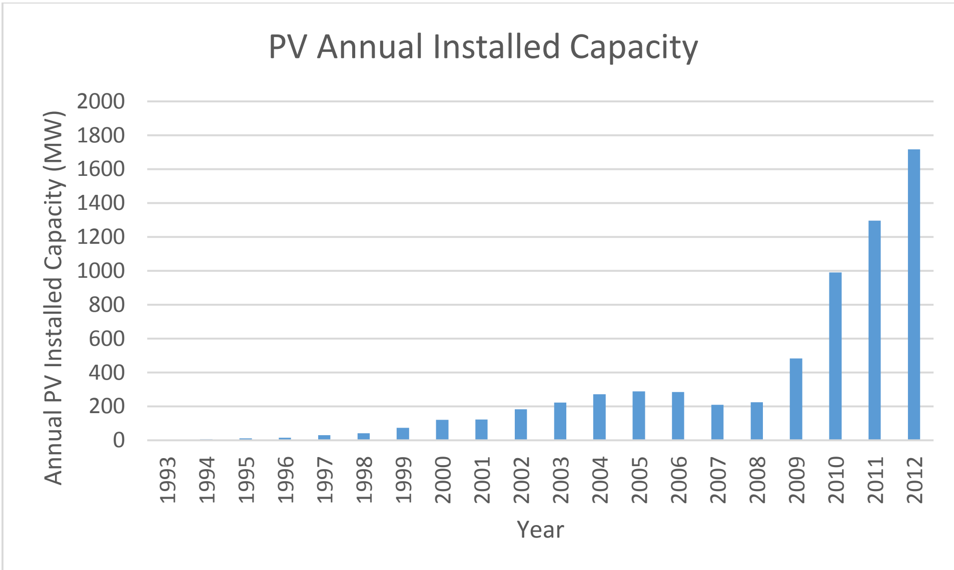
This section will provide an overview of the Japanese and the global PV market. In particular, this section will describe historic trends in the shipment volume of PV systems, and of PV system prices. In addition, this section will introduce the major trends and recent changes in the global solar photovoltaic market.

JAPANESE SOLAR PV MARKET OVERVIEW

Installed Capacity

As Figure 3.1: shows, the annual installed capacity of residential solar PV systems in Japan has gradually increased since the 1990s. However, Japanese annual installed capacity dropped between 2006 and 2008. One of the factors that contributed to the decline was the termination of a residential subsidy program initiated by the government in 2006. After 2008, when the government resumed the subsidy program, solar PV installed capacity began to grow exponentially. Capacity grew eightfold from 210.4 MW in 2008 to 1717.7 MW in 2012. The introduction of a Feed-in-Tariff program in 2009 contributed to this dramatic growth in installed capacity.

Figure 3.1: Domestic Annual Installed Capacity of Solar Photovoltaic System in Japan, 1993-2012

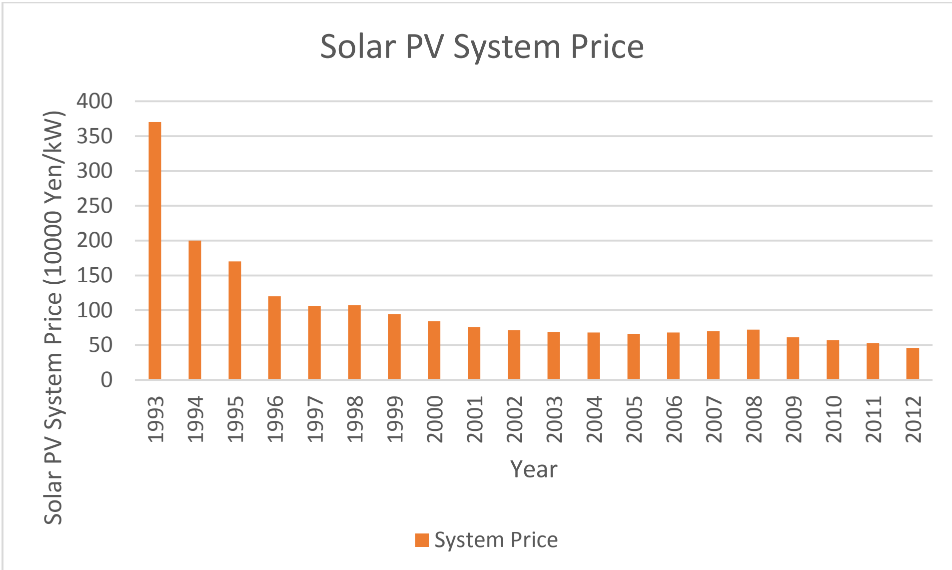


Source: International Energy Agency. 2013. *Trends in 2013 in Photovoltaic Applications: Survey Report of Selected IEA Countries between 1992 and 2012*. Report IEA-PVPS T1-23:2013. International Energy Agency. http://iea-pvps.org/fileadmin/dam/public/report/statistics/FINAL_TRENDS_v1.02.pdf.

System Price Declines

As installation volume gradually increased, the price of PV systems dropped after the residential subsidy program was introduced in 1994 (Figure 3.2). In fact, the system price declined almost by half between 1993 and 1994. Subsequently, the system price steadily declined until 2006. Following the termination of the residential subsidy program, the progress in PV system prices and installed capacity slowed. The price increased between 2006 and 2008. In 2009, when the program was in place again, the system price began to decline again. By 2012, the price of solar PV systems decreased by roughly 85 percent to 0.46 million Yen/kW compared to the price of 1993.

Figure 3.2: Price of Solar PV Systems in Japan, 1993-2012



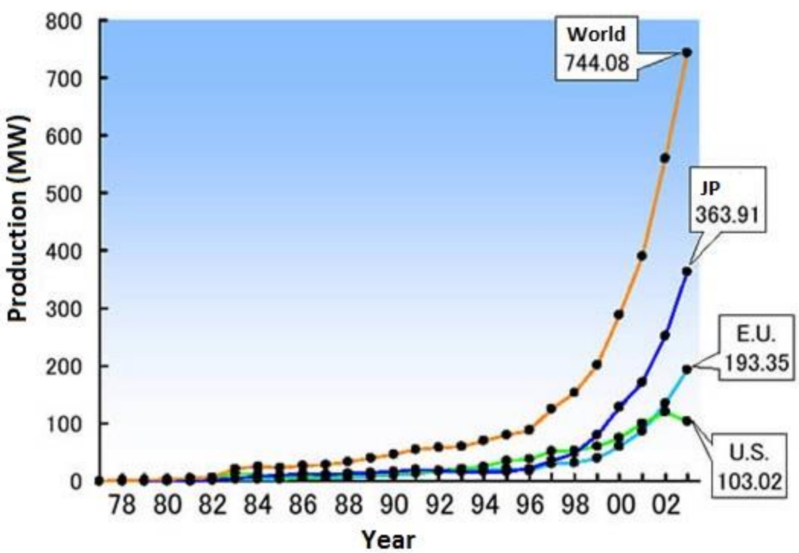
Source: Source: Ministry of Economy, Trade and Industry. 2012. *Study of Diffusion of Solar Photovoltaic Generation Systems*. http://www.meti.go.jp/meti_lib/report/2013fy/E002502.pdf.

Ministry of Economy, Trade and Industry.2013. Energy Whitepaper. http://www.enecho.meti.go.jp/about/whitepaper/2013pdf/.

In addition to the government residential program, rapid expansion of solar PV system production pursued by Japanese firms led price reduction. In fact, the volume of PV systems produced in Japan gradually increased over time, and dramatically grew from 1996 forward (Figure 3.3). Along with the expansion of production capacity, the price of solar PV systems declined by approximately 40 percent between 1996 and 2002. Rogol (2007) points out that the residential subsidy program worked as an incentive for Japanese solar firms to expand their production capacity. The major factor that led a number of Japanese solar manufacturers to invest in production capacity was prospects for a large return on investment (ROI) (Rogol 2007). The government subsidy influenced the decision-making of firms in the industry and led to an expectation of production capacity.

For the calculation of investment return, the Japanese firms assumed that the residential subsidy program would reduce prices by 20% annually (Rogol 2007). Since these firms believed sustained price reductions spurred by the government subsidy would increase demand for PV systems, they made large investments. The aggregate result of large, sustained investments by firms led to further reduction in PV system prices owing to economies of scale. Thus, the demand-pull policies of the Japanese government clearly influenced supply side investments. In this sense, the demand-pull policies were deeply intertwined with the supply-side economics.

Figure 3.3: Production Capacity of Solar PV systems by Selected Country, 1978-2002

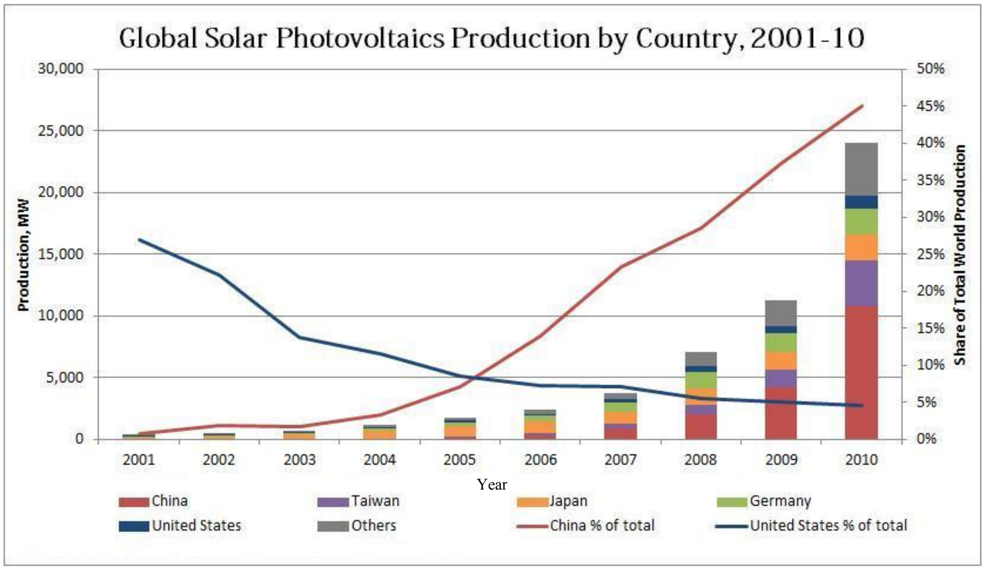


Source: Virtual Center for Environmental Technology Exchange. 2014. "Global Production Volume of Solar Photovoltaic." Accessed August 3. http://www.apec-vc.or.jp/j/modules/tinyd00/?id=82?kh=0&kh_open_cid_00=45.

Another factor that could have contributed to price declines is competition among firms. Especially in recent years, the prices of solar PV cells and modules dramatically dropped due to the influx of inexpensive solar panels from China. China's share in the global PV module market increased from one percent to 64 percent between 2001 and 2012 (Mehta 2013) (Rai, Myers, and Takeda 2013). The influence of Chinese firms on solar PV prices in the global market seems to be apparent. After 2007, when the share of Chinese firms exceeded 20 percent in the global market (Figure 3.4), solar PV prices began to decline dramatically (Figure 3.5). Between 2007 and 2012, the price dropped by 77 percent (Mints 2012). Fierce competition with Chinese firms forced non-Chinese firms to lower the price of solar PV systems (Metteauer 2012). Chinese firms also entered into the Japanese market around 2008 and have been dramatically increasing their share (Figure 3.6). Currently, solar PV modules imported from China account for about 20 percent of the Japanese market1 (Ministry of Economy, Trade and Industry 2012) (Nomura, Yoshioka, and Osawa 2013). However, unlike the experience in other countries, such as the U.S, where Chinese firms supply a large share of PV cells and modules, in the Japanese market PV system prices did not dramatically decline after the entrance of Chinese firms. The reason for this limited influence of Chinese firms on the PV system price in Japan might be due to relatively lower shares of Chinese firms in the Japanese market compared to other countries.

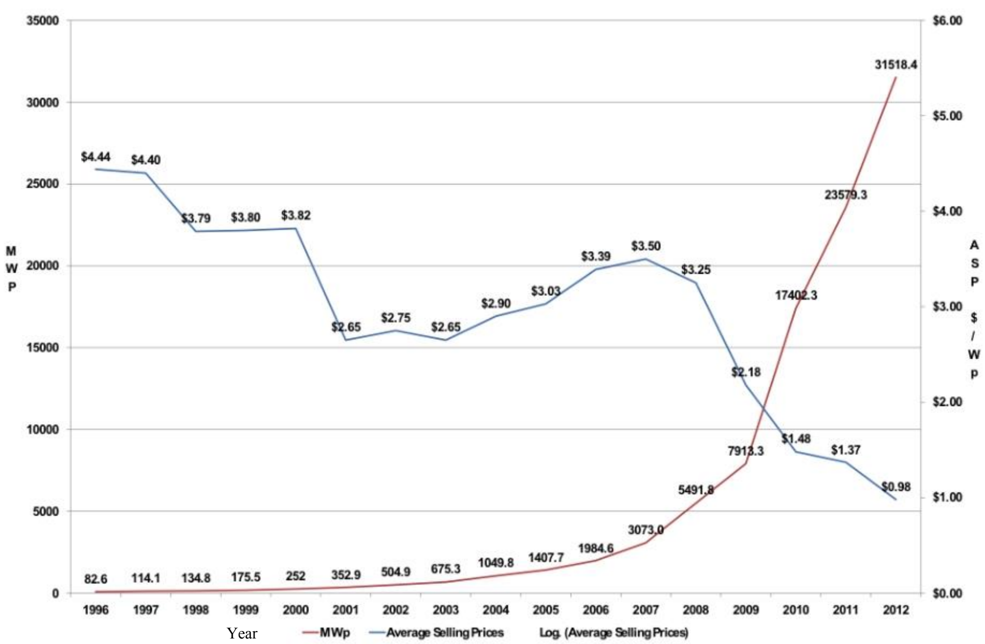
[1] Calculated by the author based on the figures from the Study of Diffusion of Solar Photovoltaic Generation Systems by Ministry of Economy, Trade and Industry and "Estimation of Import Share Elasticity of Photovoltaic Modules" by Nomura *et al*.

Figure 3.4: Global Solar Photovoltaic Production by Selected Country, 2001-2010



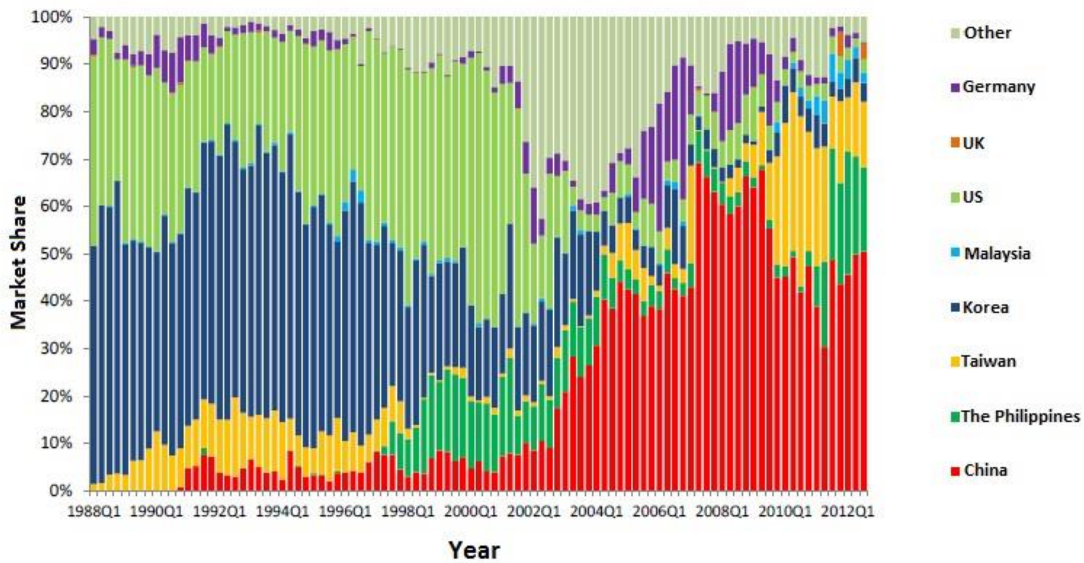
Source: Solar Market Tracker. 2014. "Global Solar PV Production by Country, 2001 – 2010." *Solar Market Tracker*. Accessed August 13. http://solarmarkettracker.org/annual-solar-pv-production-in-selected-countries/.

Figure 3.5: Solar PV Module Average Selling Prices & Shipments in the Global Market, 1996-2012



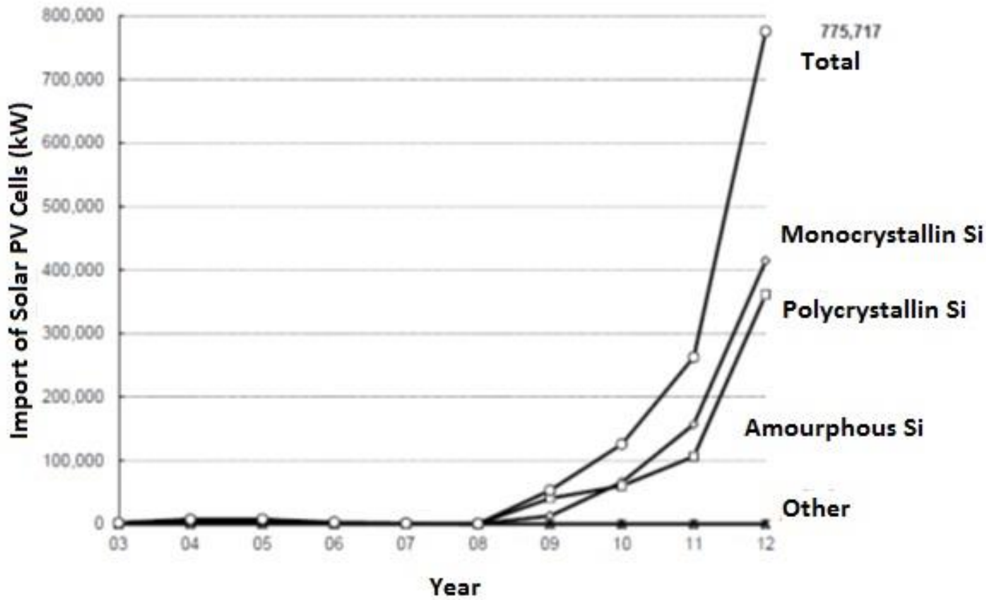
Source: Mints, Paula. 2012. "The Solar PV Ecosystem, A Brief History and a Look Ahead." *Renewable Energy World.Com*. http://www.renewableenergyworld.com/rea/news/article/2012/11/the-solar-pv-ecosystem-a-brief-history-and-a-look-ahead.

Figure 3.6: Import Share of Solar PV Cells in Japanese Market by Selected Countries, 1988-2012



Source: Nomura, Koji, Kanji Yoshioka, and Shiori Osawa. 2013. "Estimation of Import Share Elasticity of Photovoltaic Modules." http://www.sanken.keio.ac.jp/publication/KEO-dp/131/KEO-DP131.pdf.

Figure 3.7: Imported Capacity of Solar PV Cells 2003-2012



Source: Ministry of Economy, Trade and Industry. 2012. *Study of Diffusion of Solar Photovoltaic Generation Systems*.
http://www.meti.go.jp/meti_lib/report/2013fy/E002502.pdf.

Electricity Price

Although the price of electricity generated by solar PV has been declining, the current price is still relatively high, but closing in quickly. Whereas the grid price of electricity is 24 yen/kWh, the price of solar PV electricity is about 30 yen/kWh (Myoujyou and Oohashi 2011). This higher cost of electricity generation is one of the bottlenecks that restricts the diffusion of solar PV. Therefore, cost reduction is an essential part of diffusion of solar energy. The government develops a blueprint for further diffusion of solar PV by setting future targets for production cost and technology development. The "PV Roadmap Toward 2030+" is a technological development plan prepared by the New Energy and Industrial Development Organization (NEDO), which sets targeted costs of electricity generation that should be achieved by further technological development. The current targeted costs of solar PV electricity generation are 14 yen/kWh by 2020 and 7 yen/kWh by 2030 (New Energy and Industrial Technology Development Organization 2009). The roadmap also specifies technology areas where further development is needed to fulfill these targets and provides specific targets for technology development.

Chapter 4: Literature Review

This chapter is a review of previous studies of the factors that drive innovation and how to measure innovation activities. This review of previous literature on the sources of innovation and patent data as a tool for innovation studies is based on the work by Maureen O'Donnell Metteauer (2012).

"Demand-pull" and "technology-push" are two major policy mechanisms recognized by economists as drivers of innovation. Both approaches employ government policies to spur innovation activities by firms. Demand-pull describes the use of policy instruments for the development of new markets. Technology-push describes the support of R&D through direct funding. Market competition is another driver of innovation, which encourages firms to engage in invention of new technologies to secure their profits and survive competition, although the exact impacts of competition on innovative activity depends heavily upon context of the industry and its market structure. For innovation research, a large body of previous studies use patent data as a measure of innovation activities. This chapter introduces previous research that studied innovation with patent data and also highlights the limitations of patent data as proxy for innovation activities.

Endogenous Factors and Exogenous Factors of Innovation

Prior work discusses two types of factors when identifying drivers of innovation: endogenous and exogenous growth factors. Endogenous growth theories argue that investment in human capital, knowledge, and innovation are significant contributors to economic growth. For innovation activities pursued by firms, endogenous growth factors are internal factors, such as production processes and R&D. These factors stimulate both incremental and dynamic innovation typically over the long run (Antonelli 2009).

On the other hand, exogenous factors are external factors, including market competition and government policies aimed at creating an environment that encourages innovation. Policy instruments such as tax incentives or upfront capital rebates can create market demand. Such government policy further creates market competition, which provides firms with an incentive for innovation in order to remain profitable. Also, policy interventions into the market with a form of regulation could put pressures on firms to pursue innovation to comply with the regulation (Braun *et al*. 2010)

INNOVATION AND DIFFUSION IN THE RENEWABLE ENERGY SPACE

This section identifies issues when spurring the growth of renewable energy technologies and the instruments to address them. Basically, there are three major barriers to development of environmentally-friendly technologies: underinvestment in R&D, an adverse effect of knowledge spillover, and a lack of economic incentives. In order to address these issues, government policy intervention in terms of demand-pull and technology-push is typically necessary.

Issues in Spurring Environmental Technology Innovation

In spurring environmental technology innovations, policy support has been widely recognized as a necessity. Behind this recognition, there are three main issues that policy instruments are expected to address (Peters *et al*. 2012). The first issue is underinvestment in R&D. A range of important environmental technologies are still either technologically or in cost-terms behind conventional technologies. Therefore, substantial R&D investment is needed to support development of such technologies until they become competitive. Also, firms suffer from an adverse effect of knowledge spillover (Rennings 2000). Since knowledge created or accumulated by a particular firm will spread out within or beyond an industry (knowledge spillover), such a firm cannot appropriate all the profits that would be potentially generated from the resulting knowledge/innovation. Second, the uncertainty associated with future returns to R&D investments is often particularly large (Jaffe and Trajtenberg 2002). Third, there is a lack of economic incentives for firms to develop environmentally-friendly products (Horbach 2008).

TECHNOLOGY-PUSH AND DEMAND-PULL

Technology-push and demand-pull mechanisms mentioned above are widely used to address the three problems described in the previous section (Peters *et al*. 2012).

Technology-Push

Technology-push mainly deals with the linear process from research and development (R&D) to diffusion of innovation (Bush 1945). Bush (1945) proposed the earliest model that illustrates an innovation process. Sequential follow-up stages of innovation are characteristic of this model. A process of technology development goes through the stages of "pure basic research (curiosity-oriented research)," "applied research," "experimental development," and finally "innovation" (Schmoch 2007). Myers and Marquis provide empirical evidence for the model (Myers and Marquis 1969).

A typical technology-push policy instrument is public R&D funding, which can directly address the issue of underinvestment in R&D. In the PV space, Watanabe *et al*. conducted an empirical study of the technology-push theory (Watanabe, Wakabayashi, and Miyazawa 2000). They examined the effect of national public R&D funding on innovation in the Japanese solar PV industry and concluded that the funding created a "virtuous cycle" of innovation activities. The “virtuous cycle,” according to Watanabe *et al*, connects a series of phases of innovation: cost and price reductions, subsequent market growth, and further research and development in the industry (2000).

Demand-Pull

Demand-pull focuses on the importance of market demand as a major driver of innovation. Schomookler, who first examined effects of demand on spurring innovation, asserts that market demand is a key determinant of technical change that indicates new directions for R&D (Schmookler 1962). Therefore, one would expect that lack of demand would slow the development of new technologies. In agreement, Weyant has argued that new technologies would experience difficulty in innovation and diffusion without market opportunity in their development stage (2011).

Policy instruments that the demand-pull theory employs are typically based on a market based approach that spurs innovation (Jaffe and Trajtenberg 2002). These policy instruments include feed-in tariffs, tax breaks, and regulations. Demand-pull policies, could reduce the uncertainty associated with R&D investment for firms by creating demand and developing a new market for new technologies. Therefore, demand-pull policy addresses the first and third issues of innovation of environmentally friendly technologies: underinvestment in R&D and a lack of incentives. In this sense, demand-pull policies provide opportunities and incentives for firms to pursue development of environmentally friendly technologies.

Beyond the Dichotomy

The debate around the driving forces of technological innovation has reached a consensus that because technology-push and demand-pull closely interact both are necessary (Mowery and Rosenberg 1979) (Swann 1994). Previous innovation research of solar energy technologies also embraces the coupling of technology push and demand pull factors. Watanabe *et al.* argured a combination of technology-push and demand-pull policies played an important role in inducing collaboration among firms (2006). Also, Watanabe asserted that collaboration among firms within the solar supply chain created opportunities for knowledge spillover across different industries (Watanabe, Wakabayashi, and Miyazawa 2000). As previously mentioned, this "virtuous cycle" of innovation and knowledge spillover led cost declines and further innovation, and contributed to expansion of market demand.

FACTORS THAT INDUCE INNOVATION

Induced innovation theory provides another perspective when examining sources of technological innovation. This theory focuses on cost reduction as a purpose for firms to pursue technological innovation. It hypothesizes that technology advancement and innovation often occur as a result of firms' efforts to reduce their production costs. In fact, Sir John Hicks suggested that, "a change in the relative prices of the factors of production" was a factor that induces innovation (1932). Although Hicks mainly studied labor cost as the factor of production in his research, recent studies have expanded the scope into other production factors such as regulation and policy (Metteauer 2012). As these factors also could increase production cost, they are agents to create incentives for innovation. (Newell, Jaffe, and Stavins 1998) (Popp 2001) (Jaffe and Trajtenberg 2002) (Fischer and Newell 2008) (Altwies and Nemet 2013). According to the recent research, environmental and energy related policy mandates and regulations, which increase production costs, would also work to spur innovation in the environmental technologies. Firms tend to pursue development of new technologies in order to comply with such mandates and regulations.

MEASURING INNOVATION THROUGH PATENTS

In examining theories that specify a source of innovation, a method for measuring innovative outputs must be established. One of the measures used by many scholars is patent analysis. Patents are an intellectual property right granted by the government to an inventor. The United States Patent and Trademark Office defines a patent as a right "to exclude others from making, using, offering for sale, or selling the invention throughout the United States or importing the invention into the United States" for a limited time in exchange for public disclosure of the invention when the patent is granted (U.S. Patent and Trademark Office 2014). Similarly in Japan, a patent is defined as a right to exclusively use an invention for business within the duration of 20 years. The purpose of granting a patent right to an inventor is to encourage inventive activities by protecting inventions and promoting use of the invention (Ministry of Economy, Trade and Industry 2014). According to Peter Menell, the monopoly of rights (through patents) drives inventors who seek to make profits from their inventions to bear costs of new discoveries (2000). Therefore, the monopoly rights are the essential part of the patent system. The exclusive rights granted to patent owners, in fact, will address the second issue of innovation as regards environmental technologies. Since exclusive rights granted to an inventor will protect them from imitators, return to their investment in initial research and development will be more secure than otherwise. In this sense, patents stimulate motivation for innovative activities, which would contribute to the development of new technologies.

Without the monopoly rights granted via patents, the value of inventions would be lost as imitators emerge. In summary, patent systems are a necessary measure to protect return to investments made by inventors in their innovative activities and to motivate future innovation by allowing a monopoly on inventions (Menell 2000) (Arrow 1962).

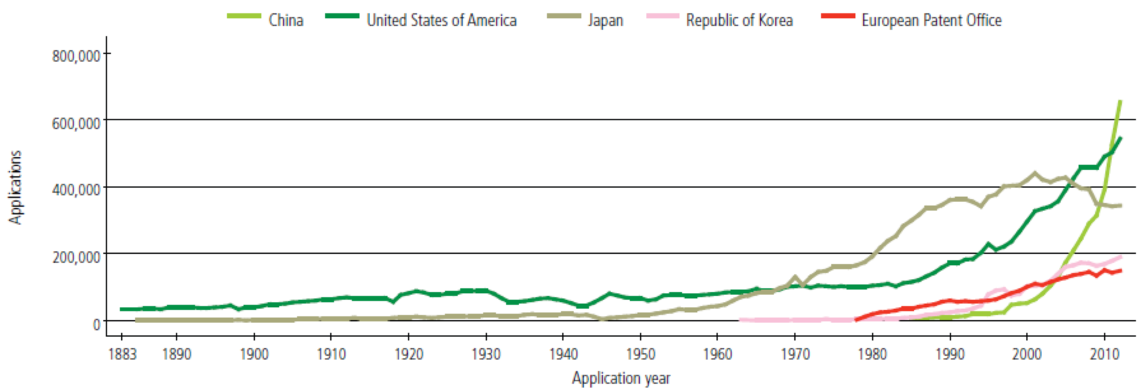
Patent Data in Economic Studies

Patent counts are one of the typical ways to measure innovation. In economic research, scholars have used patents as an analytic tool to study the level of innovation and knowledge spillovers. Schmookler was one of the first economists who studied the relationship between invention and economic activities through patent counts. Later studies also used patents as a tool for examination of various economic indicators including productivity, levels of research and development, and capital investment (Comanor and Scherer 1969) (Griliches 1998). In addition by analyzing frequently cited patents, scholars can study the value of an invention and the role of such inventions in different industries (Jaffe and Trajtenberg 2002).

Limitation to Innovation Study used Patent Data

While patent data is considered to be a useful analytical tool to shed light on innovation activities, some drawbacks exist in measuring innovation activities with it. First, when using patent data for an innovation study, a general upward trend in the number of patents filed for the past twenty years need to be taken into account. The number of annual patent applications has dramatically increased, as shown in Figure 4.1:. To better characterize innovative activity in a specific sector, the rise in the number of patents in specific industries must be adjusted compared to the overall increase in the number of patents.

Figure 4.1: Trend in Patent Applications for the Top Five Offices, 1883-2010



Source: World Intellectual Property Organization. 2013. "Section A Patents, Utility Models, and Microorganisms." http://www.wipo.int/export/sites/www/ipstats/en/wipi/2013/pdf/wipo_pub_941_2013_section_a.pdf.

Second, while patent data could be used to assess the quality of inventions and their economic value, they are not good at tracking trends of innovation within industries (Comanor and Scherer 1969) (Steil, Victor, and Nelson 2002) (Griliches 1990). Furthermore, as pointed out by Scherer and Griliches, classification classes assigned by patent offices could cause some issues. Classifications and subcategories of patents could be vague and it is difficult to capture specific product or market segments (Metteauer 2012). Also, classifications could be arbitrarily applied by examiners (Griliches 1998).

Another weakness is related to purposes of patenting activities. Not all patents may be used in the launching of a new product. In this sense, it would be misleading to use such patents as a measure of innovation (Griliches 1998), although it is difficult to discern such differences between patents.

The final drawback is about patent quality in the various industries (Comanor and Scherer 1969). The economic and technological significance of patents differs among industries. Therefore, patents cannot be treated as equal in measuring innovation activities among different industries. However, as there is no common standard to "weight" a particular invention in an industry, it is quite difficult, if not impossible, to quantify the true innovation content (or their impact on economic output) of particular patents (Griliches 1998).

Patents and Solar Photovoltaic Innovation

Patent data also indicates a number of things relating to technological innovation happening in the solar industry. First of all, innovation activities in the solar industry have been rising according to the past studies. Vidican, Woon, and Madnick confirmed this trend with a bibliometric approach (2009). They found that the publication of solar-related research increased during the period when policy support for such technologies existed. Among various factors contributing to the rise in innovation activities, government regulation and market creation policies played an important role (Braun *et al*. 2010).

In addition to measuring intensity of innovation activities, patent data also allows researchers to study technological knowledge flows and technology spillover among nations (Coe and Helpman 1995) (Metteauer 2012). In the solar industry, patent data shows that patents filed by leading countries such as the United States and Japan served as sources of solar technology knowledge for countries with less competent technologies such as Korea and Taiwan (Wu and Mathews 2012). The patent data indicates that knowledge from leading countries played an important role in helping these countries with their solar PV deployment strategies (Wu and Mathews 2012).

Patent Data Indicator for Solar PV Balance-of-System Technology

The existing literature about innovation activities and patents introduced in this chapter is the theoretical backbone of this report. Based on the theory introduced here, this report examines patent data to measure innovation activities within the solar PV balance of system (BOS) in the Japanese solar industry.

There are two factors that are expected to contribute to the rise in patent activities within the BOS space. One of the factors is policy. In the Japanese solar industry, substantial government support has been provided in the form of subsidies and required renewable energy productions such as Renewable Portfolio Standards (RPS). Thanks to these policy instruments, solar energy systems are coming to be able to compete in the market with conventional energy sources. The importance of these policies lies in their effects on creating market demand for solar PV technologies. These policies provided direct and indirect incentives to firms for investments in solar R&D.

Another factor that could induce the rise in patent activities is related to price declines of solar PV systems. Since solar module prices dramatically declined over the past years, the cost of BOS components came to account for a larger percent of the total system cost. As described in the previous chapter, the BOS now represents approximately 42 percent of the typical PV systems (Kimura and Mano 2013). Therefore, it is rational to target cost reduction in the BOS components next. Based on the induced innovation theory, the potential for cost reduction in the BOS would work as an incentive for engendering additional innovation in BOS components.

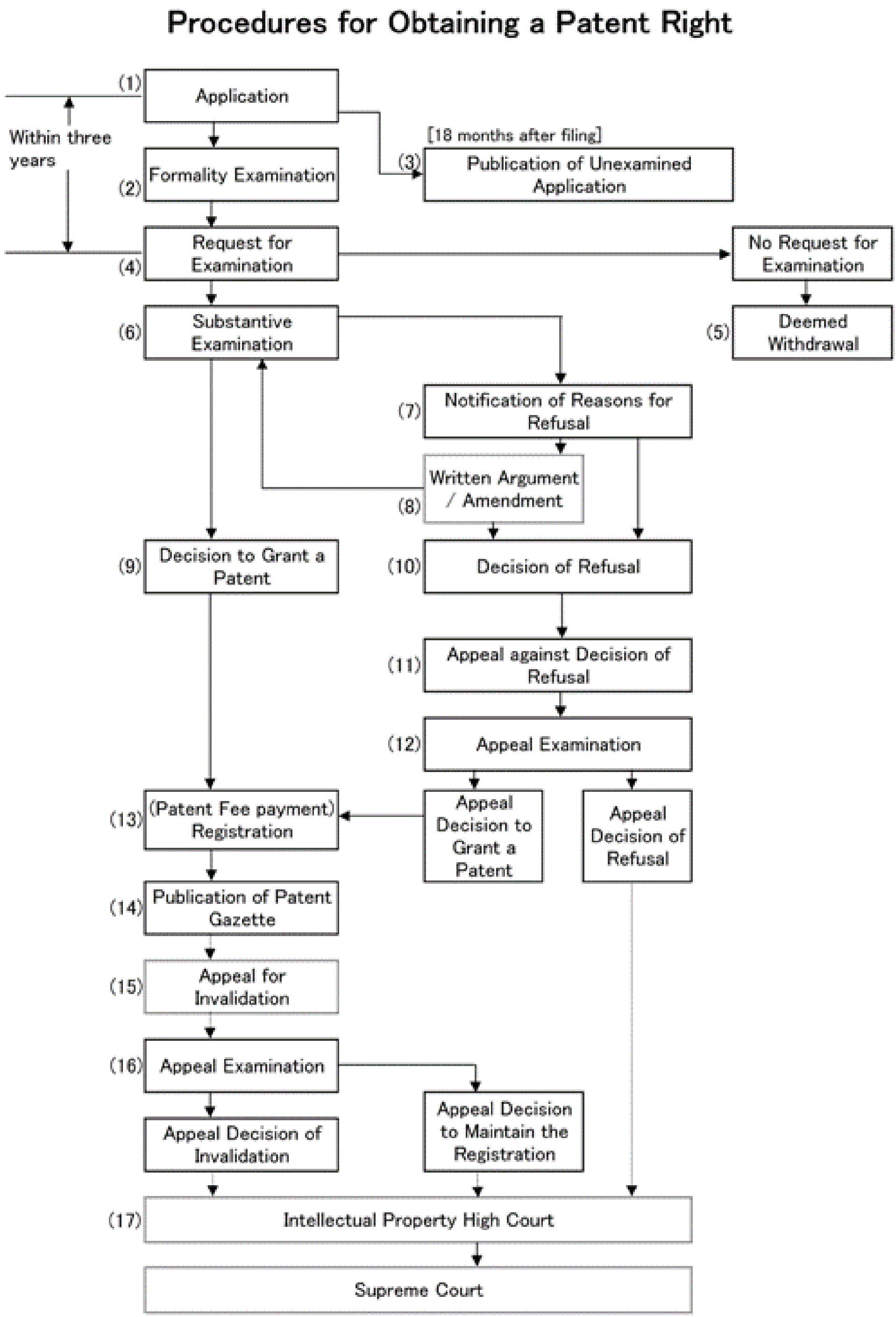
Chapter 5: Methodology

This research tries to understand the drivers of innovation in the balance of system (BOS) technology space in the Japanese solar market. The solar balance of system encompasses all components of a solar PV system other than the photovoltaic cells. To assess the level of innovation activities, this report examines the number of patents and patent applications in four areas of solar photovoltaic BOS (inverters, mounting systems, monitoring equipment, and site assessment). This chapter will discuss the methodology of patent searches in the four BOS technologies.

Overview of Patent System and Search

In Japan, the Japan Patent Office (JPO), an external bureau of the Ministry of Economy, Trade and Industry (METI), is in charge of policy making on the intellectual property right system, as well as the examination, trials, and registration of intellectual property rights. Patent information is available at the Industrial Property Digital Library, JPO's online database. This database offers free online access to the JPO's patent gazette and all published patent documents for the Japanese market. For a new invention to be granted to a patent, it needs to go through a series of steps called examination at the JPO. **Error! Reference source not found.** depicts the whole process of patent examination from filing to issuance of a patent. In order for an invention to become a patent, it needs to meet the general legal criteria: novelty, usefulness, and non-obviousness. Unlike the US patent system, which requires inventors to search out and disclose all "prior art" on their applications, such an inquiry is optional for the Japanese patent system. However, prior art, which refers to previous related inventions, is important in the patent examination because it is used when determining novelty of a patent application.

Illustration 5.1: Procedures for Obtaining a Patent Right



Source: Japan Patent Office. 2007. "Procedures for Obtaining a Patent Right." *Japan Patent Office*. http://www.jpo.go.jp/tetuzuki_e/t_gaiyo_e/pa_right.htm.

Patent documents consist of various components. The most critical component is claims. A claim is a part of the patent that defines the range of legal protection for a given invention. Each patent usually has several claims, which describe specific parts and functions of an invention. The Japanese Patent Law requires an applicant to state "a claim or claims with all matters necessary to specify the invention for which the applicant requests the grant of a patent (*Japanese Patent Law* 1959)." Claims are the legal definition of an invention and form the basis of exclusivity and legal protection for the owner of the patent. A patent application submitted to the JPO will become public within 18 months from the filing date. This process, which is called the publication of an application, is a part of the patent review process and makes the invention available to the public as prior art.

SCOPE OF TARGET AND EXCLUDED TECHNOLOGIES

This patent search focuses on the four BOS technologies used in the residential solar PV systems which are used for the purpose of generating electricity: inverters, mounting equipment, monitoring system, and site assessment. Therefore, inventions mainly related to solar PV cells, panels, and modules or secondary applications for solar panels were excluded. Utility-scale solar technologies and certain types of solar related technologies are excluded from the target of the patent search. Although utility-scale solar systems also contain the balance-of-system, technologies employed in the BOS for utility-scale solar PV systems are different due to their larger size. Also, this study does not include concentrated solar power. Since concentrated solar power does not employ photovoltaic effects, it is technologically different from solar photovoltaic. For this reason, patent documents that included technologies related to parabolic reflectors, mirrors, and other traditional components of concentrated solar systems or BOS components for large-scale solar systems were discarded.

PATENT SEARCH PROCESS

The patent search method employed in this study is based on the methodology of inverters and mounting equipment patent search in the U.S. market conducted by Metteauer (2012). This study uses the JPO's Industrial Property Digital Library database for the patent and patent application searches. The publicly available JPO database contains the data related to all JPO published patents, applications and utility models. For extracting patents and patent applications that reflect the four BOS inventions, this study used specific keywords related to areas of the solar balance of system. The details of four categories of the solar BOS technologies are explained below. Also, patent classification categories used in this study are summarized in Table 5.1[2].

.

1. *Inverters* and their associated components are hardware devices that convert power generated by solar PV cells and modules from direct current (DC) to alternating current (AC). For the purposes of this study, patents and patent applications were defined as "inverter" if they primarily related to power conditioning, power conversion, voltage detection, electrical safety, power optimization and or balancing, or the electrical connection equipment of a PV system.

2. *Mounting equipment* physically supports solar PV modules and/or arrays. An invention is categorized as "mounting related" if it primarily was related to mounting hardware, rails and associated components to physically attach and/or place PV systems

[2] These depictions follow closely Metteauer (2012)

on or near a building. This category also includes the following technologies as mounting innovation: installation methods, solar tracking equipment, rails, or integration of PV components, and building integrated PV systems with functions of residential or small-scale electrical power generation.

3. *PV system monitoring* includes patents and applications for methods and devices that monitor the health, connectivity and output of solar PV systems. This category would include remote tracking of the PV system's hardware performance, remote power management, physical system security (including alerts and safety mechanisms), remote tracking of grid connectivity and weather conditions, and informational mechanisms or methods used to communicate or display operation conditions of PV systems.

4. *Site assessment* encompasses patents or applications that are related to methods or mechanisms of appraising the photovoltaic output potential of a land parcel, determining the ideal placement of PV systems on potential sites. Site assessment technologies determine the extent to which obstructions or shade may impede the outputs of potential of PV sites. Also, they evaluate whether particular sites or land formations are appropriate for the placement of PV modules and systems.

Table 5.1: Patent Classification Categories Used in This Study

Broad Category	Subcategories
1) Inverter	*Power conversion or conditioning equipment and methods*
	Voltage detection
	Electrical safety or grounding
	Maximum power point tracking and power optimization
	Electrical connection and management
	Energy Storage
	Mounting hardware
2) Mounting/Rack	*Structural equipment, connections and placement*
	Solar tracking equipment
	Installation methods
	Rails
	Hardware Maintenance/ Repair
3) Monitoring	*Power generation continuity management within PV panels*
	Physical security and maintenance
	Remote diagnostics and alerts
	Remote system operation and control
	Graphical interface
4) Site Assessment	*Shade detection/ estimation*
	Estimation of PV output potential
	Use of satellite imagery for placement
	Remote geographic placement

Source: Metteauer, Maureen. 2012. "Innovation in the U.S. Solar Industry: A Review of Patent Activity in Solar Photovoltaic Inverters and Mounting Systems". Austin, Texas: The University of Texas at Austin. http://repositories.lib.utexas.edu/bitstream/handle/2152/19987/metteauer_report_201291.pdf.

A combination of both Japanese character and English translation of Boolean keywords were used to search the "claims" section of Japanese patent documents. Since the translation of many English terms of art for solar technology differ in Japanese, search terms were expanded in order to obtain the most relevant sample of patents and applications. The keywords used for this patent search are listed in Table 5.2 both in Japanese and English.

Table 5.2: Keywords used for the Patent Search

Inverter	
English	Japanese
CLAIMS ("photovoltaic" and "inverter")	CLAIMS ("太陽電池" and "インバータ")
Monitoring	
CLAIMS("photovoltaic" and "evaluation")	CLAIMS("太陽電池" and "評価")
CLAIMS("photovoltaic" and "diagnosis")	CLAIMS("太陽電池" and "診断")
CLAIMS("photovoltaic" and "maintenance")	CLAIMS("太陽電池" and "メンテナンス")
CLAIMS("photovoltaic" and "monitor")EN	CLAIMS("太陽電池" and "モニタ")
CLAIMS("photovoltaic" and "monitor")	CLAIMS("太陽電池" and "監視")
CLAIMS("photovoltaic" and "repair")	CLAIMS("太陽電池" and "修理")
Mounting/Rack	
CLAIMS("solar" or "photovoltaic" and "bracket")	CLAIMS("太陽電池" or "太陽光発電" and "ブラケット")
CLAIMS("solar" or "photovoltaic" and "frame")	CLAIMS("太陽電池" or "太陽光発電" and "架台")
CLAIMS("solar" or "photovoltaic" and "rack")	CLAIMS("太陽電池" or "太陽光発電" and "ラック")
CLAIMS("solar" or "photovoltaic" and "roof" and "installation")	CLAIMS("太陽電池" or "太陽光発電" and "屋根" and "設置")
CLAIMS("solar" or "photovoltaic" and "rail")	CLAIMS("太陽電池" or "太陽光発電" and "レール")
Site Assessment	
CLAIMS("photovoltaic" or "Solar" and "Satellite")	CLAIMS("太陽電池" or "太陽光発電" or "光起" and "衛星")
CLAIMS("photovoltaic" or "Solar" and "Map")	CLAIMS("太陽電池" or "太陽光発電" or "光起" and "地図")
CLAIMS("photovoltaic" or "Solar" and "Shade")	CLAIMS("太陽電池" or "太陽光発電" or "光起" and "日陰")
CLAIMS("photovoltaic" or "Solar" and "Estimate" or "Estimation")	CLAIMS("太陽電池" or "太陽光発電" or "光起" and "見積もり" or "見積")
CLAIMS("photovoltaic" or "Solar" and "Projection")	CLAIMS("太陽電池" or "太陽光発電" or "光起" and "予測")
CLAIMS("photovoltaic" or "Solar" and "Support" and "installation")	CLAIMS("太陽電池" or "太陽光発電" or "光起" and "支援" and “設置”)

This study excluded utility models from its scope by focusing on patents and patent applications, because only a part of BOS technologies could be protected by utility models. Since the subject of protection of the *Utility Model* Act (Articles 2-3) is a device that is related to the shape or structure of an article or combination of articles, only mounting equipment, whose physical form is the essential part of technology, is relevant to utility models among the four BOS technologies. The characteristic of other BOS technologies is not necessarily related to the shape or structure of an article. Therefore, it is likely that the remaining BOS technologies are not protected by utility models. Another reason is that the number of utility models filed in the Japanese market is negligible compared to patents. Since the mid-1990s, the number of utility model applications has been less than 3% of that of the number of patents.

The patent search period in this study was set from January 1, 2002 to May 31, 2013: any *patents issued* or *applications published* during that time are included in the data set. On the other hand, patents filed or applications published prior to January 1, 2002 or after May 31, 2013 were excluded from the dataset.

One of the benefits of this patent search with the publicly available database is that other researchers could replicate the same search with the specific keywords used in this study. In other words, the same search terms specified in Table 5.2: would yield the same set of patents even if executed by other researchers on different dates.

PATENT SEARCH RESULTS

The patent search results obtained from the Industrial Property Digital Library are summarized in the following Table 5.3:. Table 5.3: shows the number of all patents or applications that fulfill the criteria for each of the four BOS technology categories. The numbers in the parentheses are the number of patents or applications found through the initial keyword search before filtering by reviewing claims. In the review process, patent titles and abstracts provided the first key to check the relevancy of technology. The technological function of all patents and patent applications were assessed based on information in claims. When it was difficult to assess if the claims meet the search criteria, the technological background section was reviewed for additional information. Some patent claims actually included multiple categories such as roof materials with an incorporated inverter. In this case, these patents and patent applications were categorized in all relevant categories.

Table 5.3: Patent Search Results[3]

	Patents	Patent Applications
Inverter	141 (429)	292 (825)
Mounting System	241 (423)	300 (1443)
Monitoring Equipment	22 (245)	117 (1363)
Site Assessment	20 (195)	59 (751)

This categorization method, which employed review of patent claims, enabled this study to deal with only relevant technologies. Unlike previous studies, which mostly relied on the patent classification system, this approach will be more precise in capturing inventions that truly reflect the functions of the four BOS technologies. As mentioned in the previous chapter, the patent classification system could be somewhat arbitrary or contain erroneous information. This study could avoid including irrelevant patents or patent applications that could have been captured by the classification search by actually reviewing the claims.

Based on the U.S. patent search in inverter and mounting by Metteauer, the results of the patent search obtained in this study were recorded in a database with the following information when entering each patent or patent application: Patent Issue Date; Patent Application Publication Number; Patent Application Publication Date; Inventor(s); Patent Assignee; Solar Supply Chain Category; Patent Number or Patent Application Number; Patent Subject; Filing Date; Location of the Assignee; Location of the Inventor(s)); Assignees' (or Inventors') Country of Origin; Patent Cross-reference; Search Terms used

[3] The patent search results show the number of all patents or applications that fulfill the criteria for each of the four BOS technology categories. The numbers in the parentheses are the number of patents or applications found through the initial keyword search before filtering by reviewing claims.

to find the information; and technological categories (2012). The “technological categories” field has two categories based on technological functions of each patent or application. A patent or patent application was categorized into either Category A, which referred to inventions whose key component is mostly relevant to the search term technology or Category B, which contained inventions with the search term technology as well as other innovation related to several areas. For an entry categorized as Category B, a subcategory was added to record that the invention contained multiple technological characteristic in the solar balance of systems.

LIMITATIONS OF THE METHODOLOGY AND DATA

There are several limitations to the search methodology and patent dataset. First, as Metteauer (2012) pointed out, inherent biases in the types and sizes of firms that file patents exist. Typically, larger firms tend to have the capacity to file their inventions to the patent office. Thus, examining patent data could fail to capture inventions made by smaller firms which were not filed as patents. Another weakness of patent data is the accuracy of actual information contained within the patent document. Also, the rates at which patents are granted vary depending on the unique processes and systems of national patent offices.

Second, although this study tries to extract as many patents and applications that are related to the four BOS technologies as possible, there is no way to capture every single patent and application related to a technology subfield. Since different applicants use different words and phrases to describe their inventions, there might be patents and applications related to the four BOS technologies that were not captured by the search keywords employed in this study.

Third, the true origin of invention is difficult to track from the location information specified in patents or applications. This is because firms in general list their headquarters' location for location information in the applications. Therefore, there are cases when actual inventions were made in a different place, but the patent documents show the corporate headquarters. However, this study accepted the location listed on the patent documents as the origin of innovation because it is difficult to determine the true innovation origins within the scope of this study.

Fourth, the JPO employs a different system to record the publication date of patents and applications. There are two major dates for patents after they pass the examination. The date at which a patent is "granted" is called "granted date," whereas the date at which the granted patents are published is "publication date." The granted date comes a little earlier than the publication date. According to the JPO, the time lag between the two dates is typically 10 to 11 weeks on average (Japan Patent Office 2013a).

Finally, administration within the JPO might have an impact on the rate of innovation. Changes in the number and expertise of JPO patent examiners or in policies for administration of the JPO could affect the number of patents granted or their quality. In fact, the JPO added 490 examiners from 2004 and 2008 (Japan Patent Office 2013b). That could have accelerated the speed of the examination process. Also, the JPO established a "fast track" system in particular for "green energy-related technologies" in 2009 (Japan Patent Office 2009). This change in administrative system could partly account for an increase in solar patents over that period.

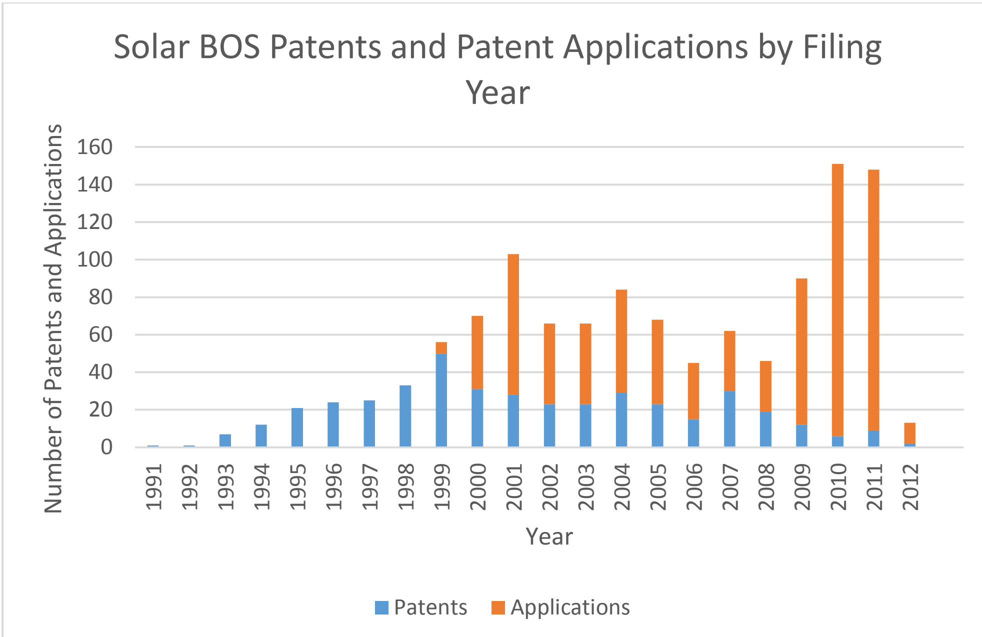
Chapter 6: Patent Data Findings

This chapter introduces details of the results from the patent searches of the solar PV balance-of-system technologies. By counting related patents and patent applications for the past ten years, this chapter observes the trend of innovation activities in four BOS technology categories (inverters, mounting systems, monitoring equipment, and site assessment) in the Japanese market.

PATENT COUNT BY FILING YEAR AND PUBLICATION YEAR

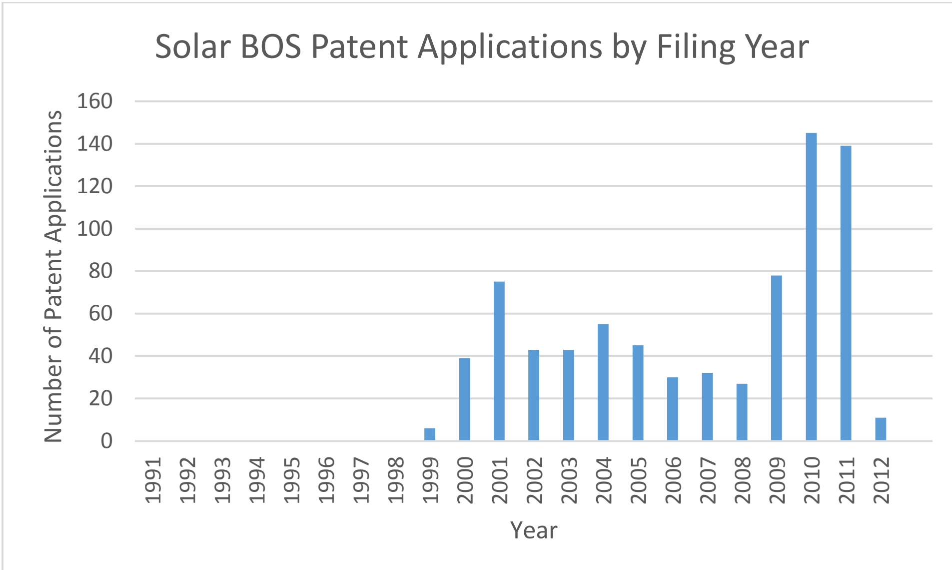
The count of patent and patent applications to the Japan Patent Office (JPO) in the BOS technology areas considered generally increased during the study period, following an upward trend in global counterparts between the late nineties and the early mid-2000s. However, there are some years when the number of patents and patent applications declined. As Figure 6.1 shows, the total number of patents and applications decreased in 2002, 2003, 2005, 2006, and 2008.

Figure 6.1: Patents and Patent Applications of BOS Technology in Japan by Filing Year, 1991-2012



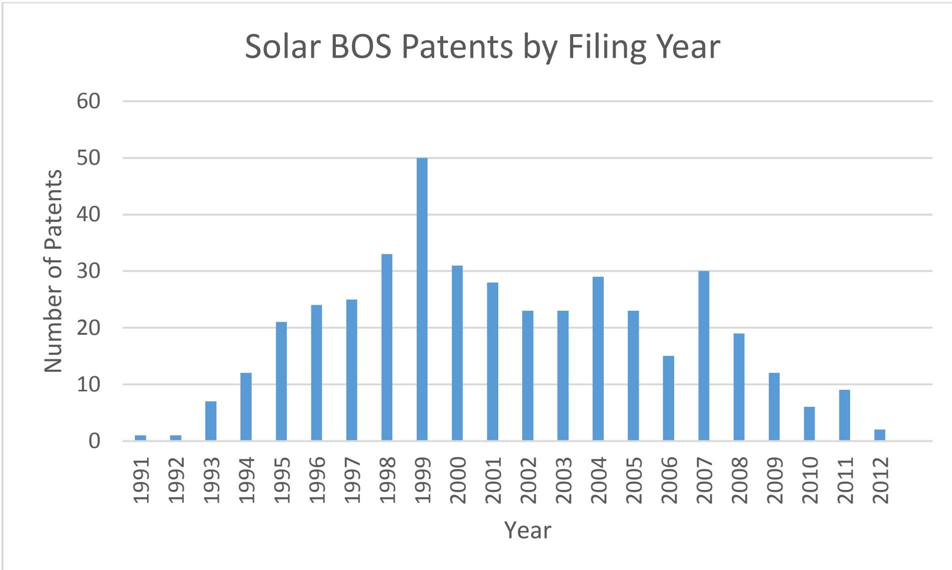
When these numbers were broken into patents and patent applications, different patterns could be discerned. The number of applications dramatically increased from 1999 and peaked in 2001. Then, it showed a declining trend until 2008. In 2009, the number of application began to increase dramatically. Even after 2009, the exponential increase in patent applications continued in 2010 and 2011. The reason why the number of patent applications in 2012 and 2013 is low is the time lag between filing and publication of a patent application. It take 18 months or more for a patent application to be published. In other words, the information of an invention filed as a patent application becomes publicly available at most after 18 months from its filing date. Therefore, there should be more patent applications in 2012 that were filed earlier but have not been published as of the date when this search was conducted.

Figure 6.2: BOS Patent Applications in Japan by Filing Year, 1991-2012



Patent counts, on the other hand, show a different pattern from that of patent applications. The number of patents increased from 1992 and reached a peak in 1999. After that, the figure in general declined except in 2004 and 2009. Here too, the main reason why the recent number of patents filed is small is the time lag between filing and granting. Typically, it takes three years or more for a patent application to be granted when it meets the criteria. Therefore, the patent counts after 2009 could be larger once pending patent applications filed after 2009 pass the examination and become patents.

Figure 6.3: BOS Patents in Japan by Filing Year, 1991-2012



Patent Data by Technology Categories

The next two figures show the annual patent or patent application counts by the four BOS components during the study period. The results show that mounting systems and inverters accounted for the majority of both patents and patent applications. While the number of monitoring equipment patents and applications was initially small, it is increasing over time.

Figure 6.4: Japanese Solar PV Patents by Year Granted and the Four BOS Categories (Inverter, Mounting, Monitoring, and Site Assessment), 2001-2013

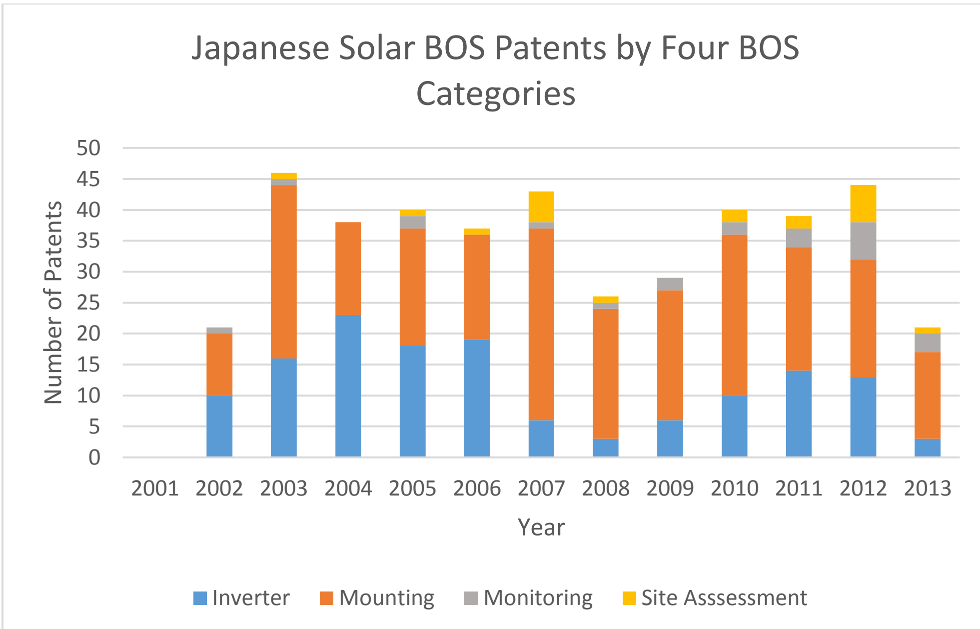
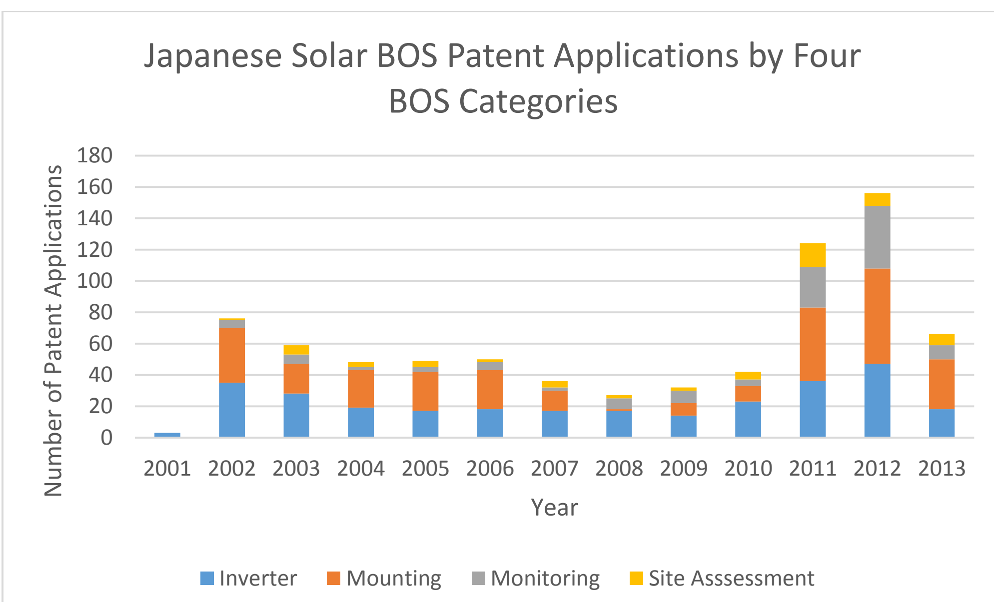


Figure 6.5: Japanese Solar PV Patent Applications by Year Published and the Four BOS Categories (Inverter, Mounting, Monitoring, and Site Assessment), 2001-2013



COUNTRY OF ORIGIN

Location information of patents and patent applications was also tracked in this study. Two kinds of location information was recorded: location of the inventor(s) and/or location of the assignee(s). Not surprisingly, this study found that the Japanese companies dominated the patenting activity in solar PV the four BOS technologies in the Japanese market. The activity level of foreign firms in the four BOS technology categories in the Japanese market was low. In fact, the patents and patent applications combined filed by foreign firms accounted for approximately 5 percent of the entire dataset. Because the scope of this study only covers the Japanese market, it would be reasonable to expect that Japanese firms play a major role in patenting activities.

Table 6.1 provides the number of BOS technology related patents and patent applications in Japan by country of origin. The figures again indicate that there is huge difference between Japanese firms and firms with foreign origin in terms of the number of combined patents and patent applications filed in Japan. Among the foreign firms, though the number of patents and patent applications filed by them were much smaller, firms from the United States and Germany followed the Japanese firms (Table 6.1). Considering the long involvement of firms in both these countries with solar PV technology development, it is understandable that U.S. and German firms have some degree of innovation activity in the Japanese market.

Table 6.1: Solar BOS Patents and Patent Applications by Country

Rank	Country	Number of Patents and Patent Applications Combined
1	Japan	1136
2	The U.S.	19
3	Germany	12
4	France	7

FIRM DATA

According to previous studies, much of the patenting activities in other renewable energy spaces in Japan are from large established companies (Gareth E., Joni, and Govindan 2012). This trend also applied to the patenting activities of solar BOS technology in Japan. Based on the information collected in this study, many firms with longer years in business were found to be active in the solar BOS Japanese market. When tracking firms' business data in this study, firms are categorized into two categories based on their number of years in business: "established" or "start-up." Firms in operation for 10 or more years were defined as established firms, whereas firms in operation for less than 10 years were defined as start-up firms. This study found that 409 patents issued to established firms and 0 patents issued to start-up firms. The remaining 15 patents were either not assigned to firms or firm data was not available. Not all issued patents are assigned and several patents were issued to educational or nonprofit institutions, which were not tabulated. In other words, all of the solar BOS patents issued during the study period were owned by established firms. For patent applications, there were 704 patent applications filed by established firms whereas there were 17 patent applications filed by start-up firms. The remaining 49 patents were either not assigned to firms or firm data was not available.

Table 6.2: Solar BOS Patents and Patent Applications in Japan by firm and the Number of Business

	Patents	Patent Applications
Established	409	0
Start-up	704	17

Another characteristic of firms tracked in this study is their type of ownership. The study found most of the assignees and applicants of BOS technology patents and patent applications were publicly traded companies. Table 6.3 provides the breakdown of ownership types. Only the small number of assignees and applicants were privately owned firms or educational/governmental organizations.

Table 6.3: BOS Patents and Patent Applications by Firm Type

	Patents	Applications
Publicly Traded	407	685
Privately Owned	0	9
Other	17	74

In tracking firm profiles, however, there is another limitation in terms of capturing the actual firms or organizations that created invention(s). Since there is a possibility that patent owners change, the current assignees might not be the initial owner of the invention(s). Some patents could be transferred, usually when another firm bought out a patent holder, or when patents in question were sold under bankruptcy. Despite such a possibility, this study relied on the current patent ownership, as tracking changes in patent ownership is cumbersome.

Chapter 7: Solar Photovoltaic Innovation and Role of Public Policy

Innovation and diffusion of new technologies that suffer from market failures are closely depend on government policies. To spur innovation and diffusion of such technologies, governments typically employ both supply-side and demand-side policy instruments. Supply-side policies are used to encourage firms to directly pursue innovation activities. Supply-side instruments include subsidies for R&D, demonstration, and some times in early stages of commercialization. The main purpose of demand-side policy is to create a new market and develop demand for a new technology. Policy instruments used for the demand-side include, among other instruments, subsidies for purchase of a particular product, tax breaks, and renewable portfolio standards.

In Japan, the national and local governments introduced a number of policy instruments to support innovation and diffusion of solar PV technologies. These policies were the main driver of PV technology development. R&D programs initiated by the government, such as the Sunshine Project, greatly contributed to technological innovation that improved efficiencies of PV technology. Also, policy incentives for the diffusion of PV technology such as the residential subsidy programs accelerated creation and development of the solar PV market. This chapter will introduce the government policies related to solar PV technology and examine how they contributed to PV technology development and PV market growth in Japan.

SOLAR PHOTOVOLTAIC TECHNOLOGY DEVELOPMENT IN JAPAN

Solar PV technology came to the attention of Japanese researchers in the 1950s. Influenced by the United States, which initiated research and development at the time, Japanese firms began their own research and development. NEC Corporation was the first firm to develop p-n junction solar cells in Japan. However, only a few Japanese firms engaged in R&D of solar PV technology at that time. Following NEC Corporation, Sharp Corporation started its research and development of solar cells in 1959. Sharp successfully commercialized its first photovoltaic modules in 1963 (Sharp Corporation 2008). Then, in 1973 Kyocera Corporation also began R&D of solar photovoltaic cells.

In the 1970s, the national government began to be involved in the development of PV technologies. Scarce local fossil fuel reserves and many issues associated with obtaining oil from foreign countries were the major factors motivating the Japanese government to pursue renewable energy sources. In 1974, the government launched the Sunshine Project to develop renewable energy technologies, responding to the oil crisis in the 1970s. Under the Sunshine Project —Japan's first effort to introduce renewable energy— R&D in solar, geothermal, coal, and hydrogen energy was promoted.

GOVERNMENT POLICY FOR INNOVATION AND DIFFUSION OF SOLAR PV TECHNOLOGY

Major Legislation related to Innovation and Diffusion of Solar PV Technology

In 1980, the national government enacted the Act on the Promotion of Development and Introduction of Alternative Energy. This act served as a legal framework for promoting development and introduction of alternative energy. This act also set targets for sustainable and adequate supply of energy alternative sources. In 1997, the Act on Special Measures for the Promotion of New Energy Use was enacted. This act encouraged market formation of renewable energy by specifying roles of the national government, local governments, and utility operators in promotion of renewable energy sources. This act required the government to provide financial support for business operators that employ renewable energy. In addition to previous acts promoting of renewables, the Basic Act of Energy Policy of 2003 went further and required the government to specify the basic direction of the national policy on supply and demand and use of energy every three years. This act also required the government to specify its role in promoting the following measures: market growth, formation of a supply chain, technological development, and promotion of venture businesses.

Supply-Side Policy

Development of solar PV technology gained momentum in the 1970s, when the Japanese national government started the Sunshine Project. The Sunshine Project focused on the development of solar cells and modules. The Sunshine Project opened up an opportunity for most of the Japanese solar manufacturers to become involved in solar photovoltaic R&D. On the launch of the Sunshine Project, Hitachi, Toshiba, and NEC Corporation were selected to conduct R&D projects for the development of crystalline silicon, a key material in the manufacturing of PV cells (Shimamoto 2007). The number of firms which had joined the Sunshine Project increased over time. In 1996, the total number of firms participating in the Sunshine Project amounted to 65. The project encouraged the broad involvement of cross-sectorial firms. The industries to which these firms belonged included textiles, chemicals, petroleum and coal products, ceramics, iron and steel, non-ferrous metals, and electrical machinery (Watanabe, Wakabayashi, and Miyazawa 2000).

Outside the big government-led R&D project, firms tried to develop new technologies by conducting their own R&D. Some firms even tried to access new technology developed in foreign countries. In fact, during the early stage of development, Sharp and Kyocera tried to transfer technology from foreign companies to advance their production of photovoltaic silicon. Although these efforts were not fruitful, Japanese firms eventually developed their own original solar PV technologies with their original technologies and products obtained from the national R&D projects. In this sense, the Sunshine Project played a role in building a foundation for the development of Japanese solar PV technology.

The Sunshine Project was later followed by an additional R&D program, which was called the New Sunshine Project, from 1993 to 2000. The New Sunshine Project received funding from the government for development of the BOS technologies (Cabinet Office 2013). Even after the New Sunshine Project, the national government continued to fund solar PV technology R&D on individual basis. The New Energy and Industrial Technology Development Organization (NEDO), which was founded to implement the New Sunshine Project in 1980, selected promising R&D of solar PV technologies conducted by private firms and allocated some part of funding for these projects. These national research projects and funding programs for R&D not only contributed to technological development but also to growth of the solar PV market. Watanabe *et al* studied the effects of the national public R&D funding on innovation in the Japanese solar PV industry with econometirics analysis. They argue that the funding created a "virtuous cycle," which leads innovation, price reduction, market growth and further R&D (2000).

Current Innovation Targets Set by Government Policies

After the termination of the New Sunshine Project, the national government created a guideline for future research and development of solar PV technology. In 2004, NEDO released the Solar Photovoltaic Generation Roadmap 2030. This guideline was amended in 2009 and the Roadmap 2030+ (Roadmap 2030+) was released (New Energy and Industrial Technology Development Organization 2009). The roadmap released in

2009 sets its goal to "make solar photovoltaic energy generation one of the major energy sources by 2030 and contribute to global society with solar photovoltaic technology as a measure to reduce CO2 emissions." To achieve this goal, the Roadmap 2030+ specifies challenges the solar PV industry faces when it accelerates diffusion of solar PV systems and further technological development, and provides scenarios to address these challenges.

The two major challenges specified in the guideline are economic feasibility and low efficiency of solar PV technologies. These two challenges are closely related. Cost reduction in electric generation by improving efficiency of solar PV systems will increase the economic feasibility of solar PV systems. A concrete target to increase economic feasibility is to achieve grid parity. Grid parity is defined as the point when a renewable energy source can generate electricity at a levelized cost that is less than or equal to the price of purchasing power from the electricity grid. In other words, when solar PV energy achieves a grid parity, it becomes competitive with the retail rate of grid power.

In addition to improvement in technological functions of solar cells and modules, the Roadmap 2030+ expects potential of BOS technology to improve efficiency in the entire system. Some of the BOS technologies, such as power storage systems, could contribute to an elimination of a mismatch between demand and supply of electricity generated through solar PV systems. For example, power storage systems would enable PV systems to accumulate excess energy and store it to be used when the systems do not generate enough electricity. Therefore, innovation in the BOS technology space is important to improve the overall economic efficiency of solar PV systems.

In order to achieve grid parity, the Roadmap 2030+ sets target prices of electricity production by solar PV systems. There are three targets within three phases. In the first phase, home electric power generated by solar PV system is expected to achieve grid parity by 2010. The target price in this phase is 23 Yen per kilowatt. In the second phase, commercial power generation is expected to achieve grid parity by 2020. The target price in the second phase is 14 Yen per kilowatt. In the final phase, general solar PV grid prices are expected to become as cheap as the conventional fossil fuel energy by 2030. The target price of this phase is 7 Yen per kilowatt.

In order to reach grid parity, cost reduction targets for BOS components are also specified in the Roadmap 2030+. By 2017, production cost of power conditioners including inverters should be 15,000 Yen per kilowatt with more than 20 years of life span. Also, production cost of battery technology for photovoltaic aims at 10,000 per kilowatt by 2017 with more than 20 years of life span. Since production cost of BOS components accounts for about 40 percent of the entire system cost, an improvement in BOS components could contribute to significant price declines by achieving these production cost targets.

In order to achieve these cost targets, improvements in the durability and efficiency of BOS components are critical. In addition, the Roadmap 2030+ suggests development of new technologies to achieve these cost targets. They include micro-inverters, power conditioners with IT functions, and lighter battery systems.

Demand-Side Policy

Role of Niche Market

Creation of a market is critical for diffusion of a new technology, especially when there are market failures. Market formation usually includes a phase to explore a niche market, a market where the new technology is superior to incumbent technologies in some dimension. Especially in the early stage of diffusion, a niche market is supposed to play an important role in nurturing premature technologies until they demonstrate their usefulness (Weyant 2011). A niche market has additional roles when a new technology develops. First, it could serve as an experimental space for firms to go through a learning process (Jacobsson and Lauber 2006). In a niche market, firms could improve performances of a new technology and reduce prices of a product (Jacobsson and Lauber 2006). Also, a niche market would be a place to learn potential customers' preference. Finally, it could be a place where user-supplier relations develop. Also, in a niche market, firms expand networks such as a supply-chain to generate a "space" for new industry to evolve (Jacobsson and Lauber 2006).

Solar Photovoltaic Technology and Niche Market

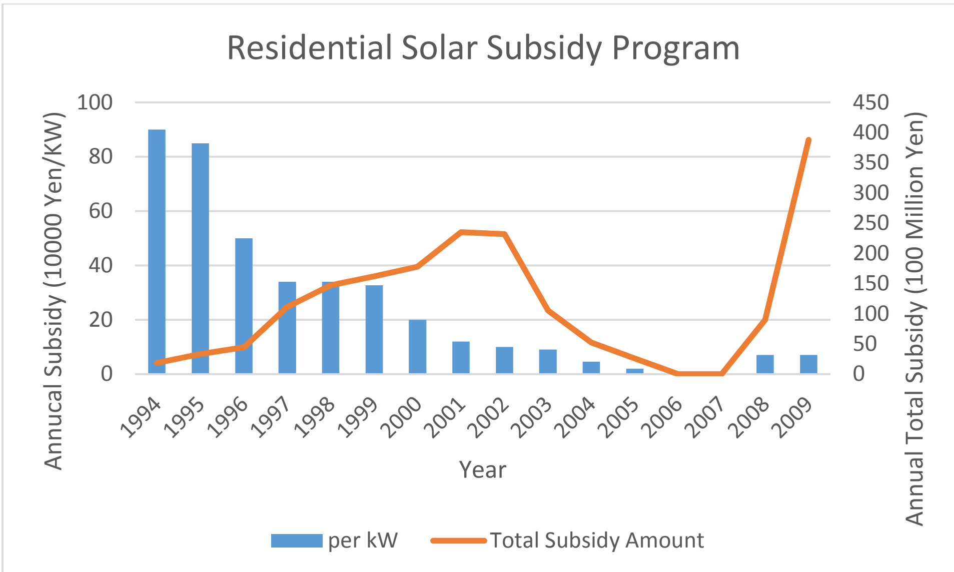
It is typical that the government provides some kinds of support in a form of subsidy with firms in a niche market. In this sense, government interventions, which aim at creation and development of a market for a new technology, are considered to be necessary measures to foster a new technology.

This market formation process also was applied to the solar PV technology in Japan. In the early stage of development, firms tried to find markets for the newly developed solar PV technology. As the early solar PV technology was less efficient, solar PV firms were not be able to compete with fossil fuel energy providers in terms of the cost of production. Therefore, this technology needed a special place in order to fully develop without directly competing with incumbent energy sources. Such niche markets for PV technology included a remote power generation market. Like a typical niche market creation process, the government was involved in the exploration of applications of the solar PV technology. In fact, the very first customers of solar PV systems included government agencies such as the Coast Guard and the Meteorological Agency. The first major niche market for solar PV technology in Japan was the space program initiated by the government. In the 1990s, the government initiated research and development to improve efficiency of solar PV systems in order to utilize them in space. Thanks to this government funding, the Japanese solar PV firms were able to continue the development of new technologies to improve the performance of the technology evolving into other commercial applications.

Solar PV System Subsidy Programs

The Japanese government has focused on the growth of the domestic market by providing significant subsidies for solar PV systems since 1994 (Ministry of Environment 2004). The initial residential solar PV subsidy programs had three phases. The first phase took place between 1994 and 1996. The purpose of the first phase subsidy was to monitor the function of residential PV systems. The subsidy provided in the first phase was to cover 50 percent of the installation costs of residential PV systems (Rogol 2007). The second phase took place between 1997 and 2001. The purpose of the second phase program was to develop the infrastructure for residential PV systems. As Figure 7.1 shows, the amount of government funding available for the PV subsidy increased to more than double during the second phase. By 2002, the Ministry of Economy, Trade and Industry (METI) began reducing the subsidies such that the consumer paid the same net price on residential PV systems. This stable net price and increasing consumer confidence in solar technology encouraged residential PV sales in Japan (Foster 2005). The subsidy programs phased out for the residential market in 2006 after the government concluded it had helped meet the initial goal for installation volume. (Rogol 2007) (Shum and Watanabe 2009).

Figure 7.1: Residential Solar Subsidy Program by kW and Total Subsidy Amount, 1994-2009



Source: Japan Photovoltaic Energy Association. 2010. "Japan Photovoltaic Energy Association and Japanese Market". November 11. http://www.invest-japan.go.jp/pdf/jp/symposium/jpea.pdf.

The important role of PV subsidy programs was not limited to the demand side. By ensuring the demand for PV panels, the PV subsidy programs reduced uncertainty about market demand for suppliers. Rogol points out that on the supply side, executives from the major module manufacturers based their production decisions on the belief that the residential subsidies would continue (2007). Without the residential subsidies, module price expectations would have been much lower and the net present value of cell and module production investments would have been much less attractive (Rogol 2007).

Renewable Portfolio Standard and Feed-in-Tariff

In addition to residential subsidy programs, there are two major policy instruments that the government employed to develop solar PV market on the demand side: Renewable the Portfolio Standard and the Feed-in-Tariff. The Renewable Portfolio Standard (RPS), which was introduced in 2003, requires electricity retailers to supply a certain amount of electricity from renewable energy sources to grid consumers. The purpose of the RPS legislation was to increase renewable capacity in the electricity market. The RPS is supposed to stimulate competition among different renewable energy sources. As a result of the introduction of the RPS, the most economically efficient energy source that survives the competition would dominate the market. In this sense, the government believed that the RPS was a market oriented policy instrument. Although the government expected the RPS would increase renewable capacity, the Japanese RPS legislation has failed to produce much significant outcome. It did not achieve significant accomplishments either in terms of renewable energy capacity or a price decline in power generated from renewable energy sources (Suwa and Jupesta 2012).

The other policy tool for the development of renewable energy market was the feed-in-tariff (FIT). The FIT imposes an obligation on electric utilities to purchase renewable electricity transmitted through grid at a predetermined price. The last piece of the obligation makes the FIT a price-based approach that establishes a premium per generated kWh. Unlike the RPS, the regulated price (tariff) generally determines the overall volume of renewable energy production in the case of the FIT. The Japanese government enacted the FIT legislation in 2009. The FIT works to provide an incentive for households to install PV systems due to its fixed price for electricity generated by solar PV systems. So far, the impact of the solar PV fixed price system has been contributing to a dramatic increase in installed solar PV system capacity (International Energy Agency 2013)

Table 7.1: Summary of Major Policies related to Solar PV Technology

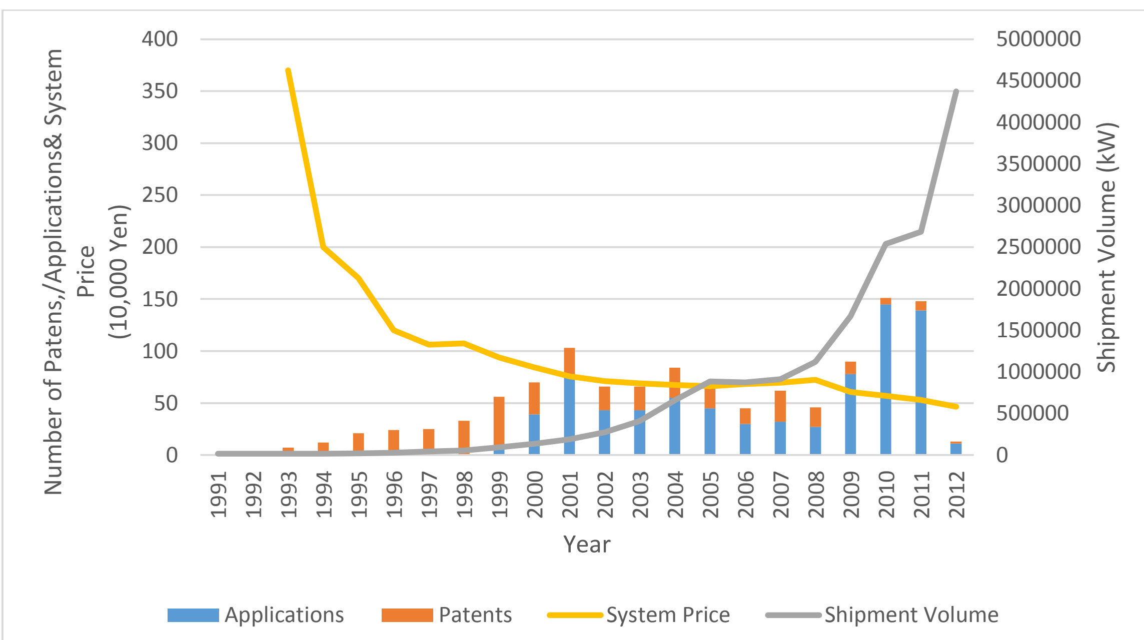
Supply-Side Policies		
Year	Policy	Notes
1974	Sunshine Project	A national R&D project for "new energy" including solar energy
1980	Establishment of the New Energy and Industrial Technology Development Organization (NEDO)	Act on the Promotion of Development and Introduction of Alternative Energy
1993-2000	New Sunshine Project	The successor of the Sunshine Project
2001-2005	NEDO 5-year plan	Development of technology to achieve 482000 kW of installation of PV by 2010
2004	NEDO Roadmap 2030	Direction of photovoltaic technology development toward 2030
2009	NEDO Roadmap 2030+	Update of the Roadmap 2030

Demand-Side Policies		
Year	Policy	Notes
1994-2006	National residential subsidy	First phase:1994-1996 Second phase:1997-2001 Third phase 2002-2006 (March)
1997	Act on Special Measures for the Promotion of New Energy Use	Financial support for the business operators who use the new energy including solar energy
2003	Renewable Portfolio Standard	Requiring electricity retailers to supply a certain amount of renewable electricity to grid consumers
2009	Feed in tariff	Electric utility companies are obligated to purchase excess electricity generated through PV facilities
2009	National residential subsidy resumed	National residential subsidy will end in 2014

GOVERNMENT POLICIES AND BOS INNOVATION ACTIVITIES MEASURED BY PATENTS

This section examines the actual effects of supply and demand side policy instruments on innovation activities in the BOS technology space. The number of patents and patent applications is used to measure innovation activities by firms in the Japanese market in the four BOS technology areas. Figure 7.2 shows the count of patents and patent applications, solar PV system prices, and shipment volume of solar PV cells and modules from Japan. The shipment volumes grew gradually until 2007 and later increased exponentially. This increase in the shipment volume indicates that the solar PV market in Japan developed and expanded for the past 20 years. Also, the prices of solar PV systems dramatically dropped from 1991 to 1997 and gradually declined after 1997. When comparing the trends of increase in shipment volumes and price decline, these graphs show that the growth in shipment volumes responded to the declines in system prices. Responding to the price declines and market growth, the number of patents and patent applications counted by filing year also shows an upward trend. This upward trend indicates that at least some parts of innovation activities that could be measured by patent counts were in general expanding over that period. However, the number of patents and patent applications dropped between 2002 and 2008 despite price declines and growth of shipment volumes.

Figure 7.2: the Number of Patents and Patent Applications by Filing Year, Solar PV System Price, and Shipment Volume by Year, 1991-2012



Source: Ministry of Economy, Trade and Industry. 2012. *Study of Diffusion of Solar Photovoltaic Generation Systems*. http://www.meti.go.jp/meti_lib/report/2013fy/E002502.pdf.

Japan Photovoltaic Energy Association. 2010. “Japan Photovoltaic Energy Association and Japanese Market”. November 11. http://www.invest-japan.go.jp/pdf/jp/symposium/jpea.pdf.

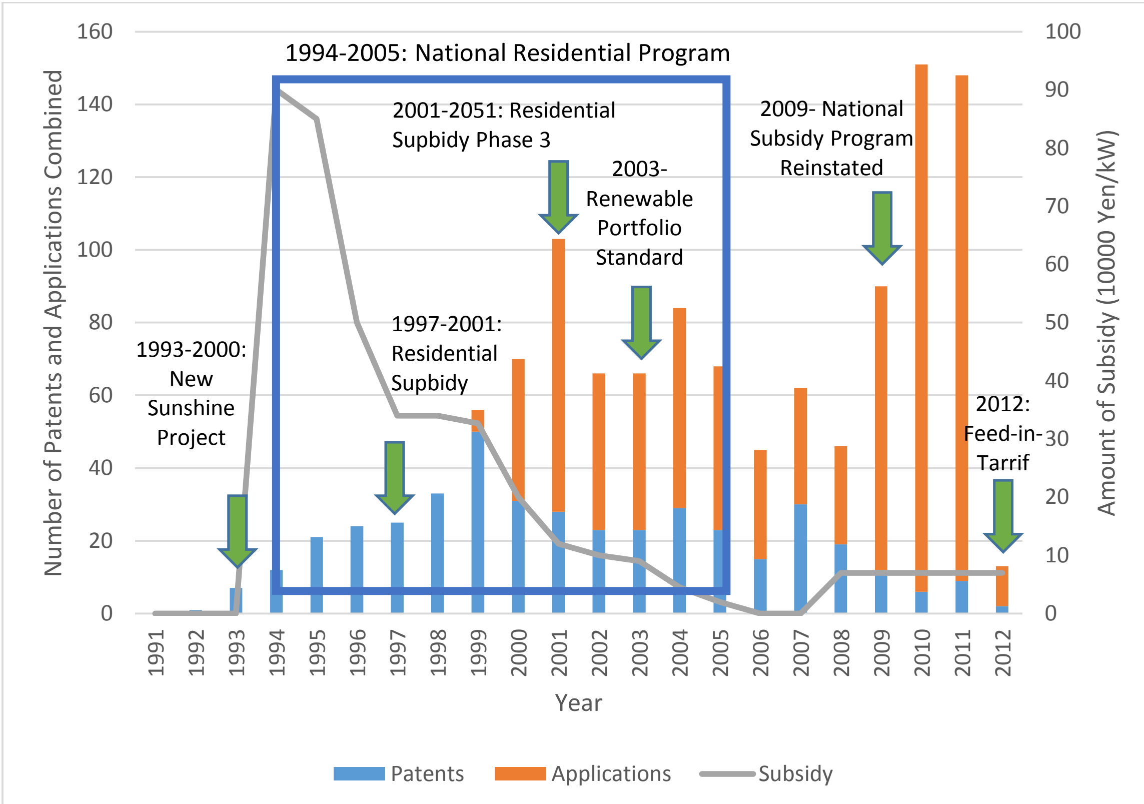
A decline in the number of patents and patent applications in 2002 and 2003 could be explained by the termination of the New Sunshine Project in 2000. Generally, patentable inventions are filed as patent applications in the final year of or after the R&D project. The spike in the count in 2001 could be due to the increased patent applications from the New Sunshine Project. It is also possible that the decline in the government R&D investment triggered after the New Sunshine Project a decline in innovation activities of some the solar firms[4] (Cabinet Office 2013). In this sense, the declining number of patents and patent applications in 2002 and 2003 could be as a result of the change in the supply-side policy. Another decline between 2006 and 2008 could be influenced by a change in the demand-pull policy. During that period, the national government halted its residential subsidy programs. Responding to this change, the rates of price declines and shipment volume increase slowed down. This means that the solar PV market was shrinking during that period. As mentioned earlier, demand-side policy also affected decision making processes in innovation activities. Therefore, the shrinking market triggered by the change in the demand-side policy could have stopped providing

[4] The budget for the Sunshine Project was 107.4 billion Yen. The budget for the New Sunshine Project was 57.2 billion Yen. From 1993 to 2000, the government spent 58.6 billion Yen for solar Photovoltaic technology R&D projects. During that period, average R&D spending for solar photovoltaic by year was 8.3 billion Yen. After the termination of the New Sunshine Project in 2000, the government supported five solar PV R&D project by funding 28.1 billion Yen in total between 2000 and 2005. The average solar PV R&D funding by the government during that period became 5.62 billion Yen.

incentives for solar PV firms and discouraged them from pursuing innovation activities of solar BOS technologies.

Figure 7.3 shows major government policies with the number of patents and applications. The first increase in the patent counts happened in the beginning of the New Sunshine Projects. Then, with the introduction of the residential solar subsidy programs in 1994, the patent counts gradually increased over time. As described earlier, the patent counts declined responding to the end of the supply-side policy and demand-pull policy between 2000 and 2008. However, once the residential solar PV subsidy programs resumed and the Feed-in-Tariff program began in 2009, the patent counts dramatically increased.

Figure 7.3: Patents and Patent Applications by Filing Year and Major Policies



As shown here, the level of innovation activities generally responds to government policies. However, in some years like 2007, when the patent counts could be expected to decline due to the change in demand-side policy (the termination of the residential subsidy program), the increase in the number of patents and patent applications was seemingly unrelated to the policy changes. In this sense, although price reduction and market growth are critical factors that influence the level of innovation activities, there might be other factors affecting innovation activities not observed here. However, the overall level of increase in 2007 is not too great, and it could just be related to the timing of patent filings related to R&D efforts in the immediately preceding years.

Chapter 8: Regression analysis of BOS Innovation activities

This chapter will empirically study the drivers of innovation activities in the four balance-of-system technology areas for the past ten years in Japan. By using the results of the patent search and a complementary dataset that contains various economic characteristics, two regression models are built to examine factors influencing the innovation activities of the Japanese solar firms.

HYPOTHESIS

As described in Chapter 4, the literature points out that the demand-pull theory provides one of the backbones that explain stimuli of innovation activities. In fact, most of the relevant literature recognizes the impact of domestic policies on domestic innovation. These previous studies assert that domestic innovation activities are driven by the domestic demand-side policies. Statistical analyses support this assertion in some technology areas. For example, Peters *et al* (2012) found that the scale of domestic innovation was positively associated with the strength of the domestic demand-pull policies. Accordingly, this study will examine the relationship between the scale of domestic innovation of solar balance of system (BOS) in the Japanese market and the domestic demand-side policies employed by the Japanese government with statistics analysis. The hypothesis that this study employed is based on the one used by Peters (2012): the bigger the size of the local market created by demand-pull policies, the higher is the scale of innovation in a region.

Data and Models

This study examines effects of selected independent variables on the number of patents and patent applications filed between 2002 and 2011. This model employed the ordinary least squares (OLS) regression model. The response variable in this study is the patent count sorted by filing year and region. Although the initial dataset was based on 47 prefectures, for this analysis I divided these prefectures into 3 regions: Tokyo, Osaka and "Other", which aggregated the remaining 45 prefectures. The decision to aggregate the prefectures in this way was based on the nature of the distribution of patents issuance and applications. While approximately 70 percent of the patents and patent applications found in this study are concentrated in Tokyo and Osaka, smaller values are much more common across other prefectures, with zero being the most commonly observed value. Such a skewed distribution violates the assumption of the OLS regression, the normal distribution of the residual of the response variable. After aggregating the 45 prefectures, this issue was alleviated, which allows this study to use the OLS model.

The dataset that this study uses is panel data, in which the behavior of entities are observed across time. To analyze the panel data, this OLS regression study used a fixed-effects model to measure unique differences among Tokyo, Osaka, and the other region.

Supply-Side Policy Effects

A factor of supply-side policies was not included in this model. This is mainly because the timing and focus of government funding for BOS technology did not coincide with the study period. The major supply-side policies were the consolidated national R&D projects, which ended in 2000. After the termination of the New Sunshine Project in 2000, there did not exist major funding for research and development of BOS technologies by the government. In fact, there is only one R&D project for BOS technology which obtained funding from the government from 2005 to 2007. Also, the amount of funding for that R&D project was not large —600 million Yen (Cabinet Office 2013). Thus, this study concluded that the direct impacts of government funding on innovation activities in the four BOS areas between 2002 and 2011 were relatively small and therefore not included in the model.

Variables

This study used five factors to predict the number of patents and patent applications filed between 2002 and 2011. The explanatory variables are displayed in Table 8.1.

Table 8.1: Factors Used to Predict the Patent and Patent Application Counts

Variable	Definition
Local Annual Installed Capacity	Installed solar Photovoltaic System Capacity by Year and Region
Non-Local Annual Installed Capacity	Difference between the National Total Installed Capacity and Local Installed Capacity
House Price Index	House Price Index by Year and Region
Average Income	Average Income by Year and Region
Residential Utility Rates	Residential Utility Rates by Year and Region

Local Annual Installed Capacity was included in the model as an indicator of the size of the local solar PV market. In line with Peters *et al* (2012), this study assumes that the installed PV capacity reflects the strength of the local demand-pull policies. This is a robust assumption, considering that electricity prices of solar energy without subsidy were generally higher than average grid electricity prices in Japan during the study period. Non-local Annual Installed Capacity measures the demand-pull policies of the other local governments. House Price Index and average income are included to control for a human capital factor reflected by the wealth of a household. Finally, Residential Utility Rates are included to account for the cost of the default option – the cost of electricity from the grid. The cost of the default electricity supply can be an important determinant for the diffusion of solar energy.

In addition to these five explanatory variables, this OLS regression model included an interaction term of the Local PV Installed Capacity variable and the Tokyo dummy variable. Since there are many solar PV firms which have their headquarters in Tokyo, Tokyo seems to have unique characteristic that affect PV installed capacity. This interaction variable tries to measure the effect of an interaction between the local PV installed capacity and a unique characteristic of Tokyo on the number of patents and patent applications.

Table 8.2: Descriptive Statistics

Variable	Mean	Standard Deviation
Local Installed Capacity (1,000 kW)	120.2387	228.0074
Non-Local Installed Capacity (1,000 kW)	5,530.982	11,034.9
House Price Index (Yen/m^2)	176,055.8	112,198.5
Average Income (1,000 Yen)	3,477.647	985.384
Residential Utility Rates (Yen)	7,627.012	417.4381

Issues in the Model

Multicollinearity

The initial model was found to have a multicollinearity issue. If there is multicollinearity, reliability of a model would be reduced because coefficients estimates of the explanatory variables have larger standard errors, so less precise. In this model, since the Local PV Installed Capacity variable and the Non-Local PV Installed Capacity variable are highly correlated, the standard errors of their coefficients were inflated. In order to solve this problem, this study dropped the Non-Local PV Installed Capacity variable because the major interest of this study is to examine an effect of demand-pull policies of a particular region, which is measured by the Local PV installed Capacity variable. Similarly, there is another high correlation between the House Price Index variable and the Average Income variable. Therefore, the Average Income variable was dropped to avoid the multicollinearity issue because the change rate of the Average Income variable is smaller than that of the House Price Index variable during the study period.

Over-specification

The initial result of the OLS regression model found that a p-value of the coefficient on the Residential Utility Rates variable was really large (0.981). This high p-value indicates potential for over-specification of the model. In other words, the model contains an irrelevant explanatory variable. One issue of over-specification is that including an explanatory variable which does not belong in a model increases the variance of the estimates of the coefficients on other explanatory variables which actually belong to the model. In this case, therefore, it is likely that the coefficients of other variables (the Local PV Installed Capacity, the House Price Index, and the interaction) were inflated. In order to avoid this problem, the Residential Utility Rates variable was dropped from the model.

RESULTS

Overall Impacts

The results of the OLS regression estimates for the model are shown in Table 8.3. The coefficients on all variables except the House Price Index variable are statistically significant. The coefficient on the Local Installed Capacity indicates that 1 MW of PV installed in Japan induces 0.02 BOS innovations (i.e., patent or patent application). As this result shows a positive association between the size of the local market and the BOS innovations, it supports the initial hypothesis: the bigger the size of the local market created by demand-pull policies, the higher is the scale of innovation in a region. However, the impact which the size of the local market has on the BOS innovation activity remained small (0.02). This finding is generally consistent with the findings in Peters *et al* (2012).

On the other hand, the interaction term of the Local Installed Capacity variable with the Tokyo dummy variable shows a robust result. The coefficient on the interaction term indicates that 1 MW of PV installed in Japan induces 1.138 BOS innovations. This result implies Tokyo's unique characteristic is a factor that positively affects the level of innovation of BOS technologies. Such characteristic includes being the center of business where many major firms in the Japanese solar PV industry set their headquarters. The results thus indicate that corporate practices and routines – such as standard practice of filing patents via headquarter offices – turn out to be important. This may also be partly a reason for the relatively lower coefficient obtained for the local demand pull effect. This suggests that a more robust estimation of the nexus between local demand pull and local innovation requires a better resolution of the true origin of the patenting activity.

The tracking method of the location of invention in the patent search remains an unresolved issue with the results. As described in Chapter 5, some firms do not specify the actual places where their inventions were made when filing patent documents. Instead, they sometimes report the location of their headquarters as the origin of inventions. Since the majority of applicants and patent owners found in this study are large established firms with their headquarters in Tokyo, the number of patents and patent applications claimed to be made in Tokyo could be inflated. This reporting error could have caused an overestimation of the impact of Tokyo and an underestimation of the impact of the effects of the local demand-pull policies, which is measured by the size of local market.

Table 8.3: Effect of Selected Variables on Patent and Patent Application Count

Explanatory Variable	β	Standard Error
Local Installed Capacity	0.0202**	0.0098
House Price Index	-0.0002†	0.0001
Interaction of Local Installed Capacity with Tokyo Dummy	1.138***	0.2018
Intercept	53.44**	20.49
Note: P-values noted by asterisk. Significance Levels: † $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$		

Impacts of Demand-pull Policies by Year

While the first model captured the average impacts of the explanatory factors on the patenting activities, the next model then included another factor to capture impacts of demand-pull policies of each year. As mentioned in Chapter 7, the patent count decreased between 2006 and 2008 presumably because of the termination of the residential subsidy programs. The second model tried to capture the impacts of the termination of the subsidy program on the innovation activities. Accordingly, the second model included a dummy variable of year 2006, 2007, and 2008 in addition to the explanatory variables used in the first model. The results are summarized in Table 8.4.

Table 8.4: Effect of Selected Variables on Patent and Patent Application Count with Year Dummy

Explanatory Variable	β	Standard Error
Local Installed Capacity	0.015**	0.0083
House Price Index	-0.00008**	0.0001
Interaction of Local Installed Capacity with Tokyo Dummy	1.062***	0.1711
Year Dummy 2006	-12.64**	3.686
Year Dummy 2007	-7.44	5.01
Intercept	36.42*	18.31

Note: P-values noted by asterisk.

Significance Levels: † $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

As anticipated, the coefficients of the year dummy variable are negative. The coefficient of the year dummy variable for 2006 was -12.64 ($p = 0.002$). This result indicates that there indeed was decrease in the number of patents and patent applications in 2006; the termination of the residential subsidy programs was like a major factor in influencing this outcome. However, this model did not yield a robust result for the year dummy variable for 2007 and 2008. The coefficient on the year dummy variable for 2007 was not statistically significant. Also, the year dummy variable for 2008 was automatically dropped from the model due to a collinearity issue.

CONCLUSION OF THE REGRESSION STUDY

The results of this regression study empirically confirmed the assertion made by previous literature that the demand-side policies affect the innovation activities. The demand-pull policies employed by the government in general positively affected the level of innovation activities in the Japanese BOS market between 2002 and 2011. Also, this study found that the demand-pull policies in 2006, when the national residential subsidy programs were halted, had a negative impact on the innovation activities.

Although the positive effects of demand-pull policies on the innovation activities were confirmed, its impacts were found to be weak. In other words, while the local demand-pull policies increased the level of innovation activities in the local market, the magnitude of increase remained small. In this sense, there seem to be several reasons why the impact of the local policies remained small in the Japanese BOS technology case.

First, there is a geographical factor associated with places of innovation activities. Unlike other countries which observed a strong relationship between local demand-pull policies and local innovation activities such as U.S. (Metteauer 2012), Japan does not have large land mass. In fact, the size of Japan is slightly smaller than the state of California. Therefore, it is easier for firms to engage in R&D in one place and commercialize their inventions where the market exists. In fact, there are many large firms that conduct R&D activities in the neighboring prefectures and sell their products in big cities. Therefore, the local demand-pull policies could have had influence on innovation activities not only in the local market, but also in other regions in which solar PV firms already located and are close enough to the region where the demand-pull policies were implemented.

Second, the owners of patent applications and patents found in this study are mostly large established firms. As these firms tend to have the established nation-wide sales channels, they do not necessarily have to locate their R&D venues close to the market. Such firms are less likely to respond to local demand-pull policies and start their R&D activities in the region where demand-pull policies exists. Instead, they could continue their innovation activities in a place where they have a R&D venue and ship their products through the sales channels.

Third, assuming that local demand-pull policies could give incentives to local entrepreneurs to engage in innovation activities in the local market, such entrepreneurs could have started new R&D and businesses in the solar PV market in the local government responding to local demand-pull policies. New innovation by such entrepreneurs could have contributed to an increase in the level of local innovation activities. However, the patent search did not find many start-up companies which held patents and patent applications in the four BOS technology areas. Better tracking method for the innovation activities of smaller companies may be needed.

Further, whereas larger firms tend to file patents, smaller companies do not necessarily have ability to cope with patenting processes. In this sense, there could be inventions made by smaller firms but not filed as patents. In other words, patent data as a proxy for innovation activities could have failed to capture inventions made by smaller local firms.

On the other hand, it could be true that there were not many local entrepreneurs who engage in innovation activities in the local market. In this case, there could be a cultural barrier that prevented new businesses from emerging in the Japanese solar market. Factors such as the prominence of large organizations in key areas of Japan's economy and the emphasis its society places on lifetime employment relationships are known to be the socio-economic barrier for nurturing entrepreneurship in Japan (Daly 2013) In this sense, the Japanese culture emphasizes entrepreneurship less compared to U.S. Considering another study of the U.S. solar PV market (Metteauer 2012) that found demand-side policies encouraged start-ups to engage in R&D activities in the local markets, these factors could have prevented innovation activities of start-ups from happening in the Japanese solar PV market.

Chapter 9: Conclusion

This Professional Report studied the innovation activities in four solar balance-of-system (BOS) technology categories (inverters, mounting equipment, monitoring systems, and site assessment) in the Japanese market. This study used patent data as proxy to measure the level of innovation activities.

The patent search results found that the number of patents and patent applications in the four BOS areas increased over time. Looking at patents in the three groups — 1991 to 2001, 2002 to 2008, and 2009 to 2011 — the data in the first and the third periods show significant rise in the number of patents and patent applications. The search results found that these patents and patent applications were mostly owned by the Japanese firms. Also, the majority of firms that filed patents in the four BOS areas were established firms with long business history.

Behind the increase in the innovation activities in solar BOS, government policies played an important role to create markets for solar products. The government employed various demand-side policy instruments including subsidy programs for market development. Also, the government took supply-side approaches to foster technologies by initiating national R&D projects and funding firms' R&D projects. These supply-side policies were particularly effective in supporting cost reduction in the solar PV systems. These demand and supply policies together triggered growth within the solar industry. Increased demand for solar PV systems and the potential for revenue from cost reduction provided an incentive for firms to invest in R&D and increase their intensive activity as reflected in the rising level of patenting.

The impacts of government policies on the innovation activities in the four BOS technology areas were empirically confirmed by this study. An ordinary linear square regression analysis found that the size of local market, which measures the impact of the local demand-pull policies, was positively associated with the number of patents and patent applications. Also, this regression study found that the termination of the residential subsidy program had a negative effect on the patenting activities at least in 2006.

FUTURE OF THE JAPANESE SOLAR INDUSTRY

Considering the exponential growth in the installation capacity of solar PV systems after 2009 when the government launched the feed-in-tariff program, the demand-side policies employed by the Japanese government in general has been successful in spurring demand. With the growing public interest in renewable energy after the nuclear incident in Fukushima in 2011, demand for solar energy is expected to continuously grow. However, in order for solar energy to be able to fully compete with conventional energy sources in terms of price, further cost reduction in the solar PV systems is necessary. Under the current situation where the room for a price reduction in solar cells and modules is shrinking, technological innovation in solar balance of system are likely to contribute to firms' cost reduction efforts in the entire solar PV systems.

Historically, large established firms have led innovation activities in the Japanese solar industry. This trend was actually confirmed in the patent study of this report. The patent search result found that established firms dominated the patents and patent applications in the four BOS technology areas. However, innovation activities of local, smaller firms seem to be emerging in the some areas of solar BOS technologies. This study also found that local roofing companies in prefectures with the high installed capacity such as Aichi prefecture filed many inventions related to mounting equipment and new ways for installation in recent years. This new trend indicates potential for spurring locally initiated technological innovation and knowledge spillover.

Government policies also need to shift from the centralized one by the national government to the decentralized one by local governments. More local governments are expected to take initiatives to induce innovation activities by local firms in the future. Such policy instruments do not limited to traditional demand-side and supply-side policies, which provide financial incentives. New policy instruments which support innovation and diffusion of new technologies could be provided by local governments in various forms. These policy instruments include providing a common ground for local solar firms to share their knowledge, building a network of local solar firms and facilitating collaboration among them, including supporting training programs of local workforce (Porter 2007). Such local initiatives are emerging in some regions such as Kyushu (Tanaka 2011). Building upon the research conducted in this study, a deeper analysis of local initiatives, policies, and how they impact innovation and economic activity offer fertile ground for further research.

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