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產品生命週期與中國政策對太陽能電池產業的影響

The impact of Product Life Cycle and China's Policy on Solar Photovoltaics Cell Industry

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中文摘要

本文探討太陽能電池產業中，先進國家(美國、日本、德國)與後進國家(中國大陸、台灣、韓國)間的生產與專利表現。其中生產量樣本期間為 2001 年至 2011 年，專利樣本期間為 1970 年至 2010 年。

本文引入產品生命週期(product life cycle)與優勢設計(dominant design)以介紹光電科技中，進入產業的時機。並採用 Teece(1986)的研發理論來解釋太陽光電產業中，後進國家產能追趕的行為。

在實證分析上，在 2008 年後中國太陽能光電廠商產能大幅躍進，此可歸因於中國政府供給面補貼政策的介入。最後我們給了太陽能光電後進國家兩個政策上的建議，一、廠商可強化第二代太陽能光電技術的研發投入。二、政府應強化第二代太陽能光電的需求面政策。

關鍵詞: 太陽能光電產業、生命週期、優勢設計、需求面補貼、供給面補貼

Abstract

The thesis analyzes the production and patenting performance among six countries, three forerunners (US, Japan and Germany) and three followers (China, Taiwan and S. Korea) in Solar Photovoltaic Cell industry. We use production data from 2001 to 2011 and patent number data from 1970 to 2010 in the six countries and worldwide.

In this paper, we introduce product life cycle and dominant design to illustrate the importance of timing when the PV technology was introduced into the renewable energy market. In addition, we adopt Teece's theory on innovation (1986) to explain followers' catching up behavior in solar PV production.

Besides, we find out the excellence on Chinese PV production after 2008, which is out of Teece's projection. In our observation, the solar PV market is heavily impacted by Chinese government policies through various supply-side subsidies. The policies also explain the surge of Chinese PV production well. Finally, we give two comments of emphasis on R&D and provision of demand-side policies in 2nd generation of PV industry for follower's firms and governments respectively.

Key Words: solar photovoltaic industry, product life cycle, dominant design,
demand-side subsidy, supply-side subsidy

Context

Table

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Figure

1 Introduction

The importance of renewable energy has risen due to rising of crude oil prices and the concerns about climate change in recent years. Public and private sectors are encouraged to develop renewable energy in hopes of replacing fossil fuel energy. More and more matured technologies and related markets also propel the development of renewable energy.

Solar Photovoltaic (hereafter PV) is one of the potential major technologies as an alternative energy source. Researchers at Bell Labs accidentally produced a 4.5% efficient silicon p-n junction solar cell in 1954. In 1966, the first practical application patent of photovoltaics was applied. It was used to power orbiting satellites and other spacecraft. During the 1960's, the US and the Union of Soviet Socialist Republics (USSR) space programs played an important role in the R&D of solar cells; solar PV cells were the main energy source used to power their satellites. In the 1970's, the energy crisis resulting from the 1973 & 1979 oil crisis resulted in investments in solar PV mainly from the US and Japan. However, due to falling oil prices, solar related developments or policies such as the Sunshine Program in Japan were slowed down.

Not until after the 1990s did concerns about the protection of the environment rise. Restrictions of CO2 emissions imposed by the Kyoto Protocol pushed various governments around the world to promote various projects (ex. feed-in tariffs in Germany) aimed at subsidizing the development of renewable energy, consequently boosting the demand for solar PV products. In the 2000's, development in the PV market accelerated. From 2000 to 2010, annual production increased from 277 to 24,047 MW (EPI,2011). The evolution of global solar PV industry is listed in Table 1 in detail.

Despite the strong demand of renewable energy, there are inconsistencies between innovation and production in the Solar PV industry. For example, the US has obtained more than 43 percent of all PV patents between the years 1996 and 2006, but only accounts for 10 percent of global production (Jang et al., 2011).

In addition, the unit of production is MWp (or simply MW[1]) of PV Cell or Module[2]. Commercial PV modules may be divided into two broad generations: wafer based c-Si and thin films (IEA, 2010). Until 2012, the market share of 1st generation,wafer based c-Si technology, is still over 85 percent. Therefore, we focus on the evolution of innovation[3] and product on 1st generation.

Specifically, the PV Cell or Module is in the midstream of Solar PV industry. Silicon basded PV industry can be separated into upstream, midstream and downstream parts, and the detailed description is list in Table 2. Comparatively, the cell production and module assembling technology is easier accessible (Tour, 2011). Therefore, followers such as China, Taiwan and S. Korea move into the midstream industry. In this paper,

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[1] Megawatt-peak (MWp) is a measure of the nominal power of a photovoltaic solar energy device under laboratory illumination conditions (Source: Wikipedia). In lots of literatures or research paper, Megawatt (MW) refers to Megawatt-peak.

[2] By definition, a solar module is a packaged, connected assembly of photovoltaic cells, so the measure of PV Cell and PV Module are interchangeable. But the companies or productions of PV Cell and Module are not always the same, For simplicity and generality, we adopt PV Cell as the unit of PV product production.

[3] The technology is identified by keywords based upon the Taiwan Institute of Economic Research reports carried out by several experts in Taiwan. And the detailed description is list in Table 3.

product life cycle and dominant design is used to illustrate the importance of timing when the PV technology was introduced into the renewable energy market. We adopt Teece's theory (1986) to explain the inconsistencies between innovation and production in the global Solar Photovoltaic Industry. Fast followers such as China, Taiwan and S. Korea moved into the market in 2000 and saw a sharp increase in production in 2008.

However, China has outperformed S. Korea and Taiwan and even forerunners (i.e., US, Japan and Germany) in production. It also went out of Teece's projection after 2008. In our observation, the solar PV market is heavily impacted by Chinese government policy through various supply-side subsidies to the PV firms.

This study proceeds as follows. Section 2 reviews the related literature on Product life cycle and Teece's theory on innovation. Section 3 analyzes the patenting and production performance of the forerunners and followers in the global solar PV industry and introduces China's associated government policy. Section 4 discusses and arrives at a conclusion based on the empirical results, from which some policy implications are also desired.

2 Literature Review

2.1 Product life cycle

The international product life cycle theory was developed by Raymond Vernon (1966) in response to the failure of the Heckscher-Ohlin model in interpreting the observed pattern of international trade based on the experience of the US market. In the beginning, new products came from the US and then had exported around the world. After a few decades, the US had become a major importer of many goods that they had once developed, produced and exported.

Instead of emphasis on comparative advantage determined by relative endowments of the production factors, such as labor and capital, in Heckscher-Ohlin model, Vernon emphasize on the dynamics of comparative advantage as well as the timing of innovation and the effects of scale economies with product life cycle.

There are four stages in a product life cycle: Introduction, Growths, Maturity, and Decline as shown in Figure 1. At first stage, i.e. the introduction stage, the product has just been introduced to the market after conducting thorough market researches and tests. In this stage, the product is adopted by small portion of people. The market checks the viability of the product and results of the test market are used to make corrections. If corrections cannot be made or are impractical, the product may leave the market. In most cases, producers or firms do not profit during this stage.

After the introduction stage, more customers are aware of the product gradually. Therefore, sales volume increases significantly and economies of scale gradually appear. Producers or firms start to profit. However, competition begins at the same time, decreasing market prices.

At maturity stage, it is a stabilizing stage in which the sales are high but competition is also intensive. Firms struggle to maintain their market shares. However, brand loyalty develops, thereby roping in profits.

Finally, demand for product gradually declines. Sales volume and revenues decrease. Firms with higher cost will leave the market. Eventually, the product will leave the market.

2.2 Teece's Theory on Innovation

Schumpeter (1961, 1964 and 1975) identified innovation as the critical dimension of economic change. He argued that economic change revolves around innovation, entrepreneurial activities, and market power. One of the hypotheses associated with Schumpeter is: There is a positive relationship between innovation and monopoly power with above normal profits. Extraordinary profit is the motive for developing an innovation (Kamien, 1982). However, innovators don't always profit.

Teece (1986) tries to explain why it is common that the fast second or even a slow third player might outperform the innovator, which are first to commercialize a new product or process in the market. Teece developed a framework to explain the distribution of outcomes, which is composed by three basic building blocks, regime of appropriability, the dominant design paradigm and complementary assets.

Regime of appropriability is one of the key insights from Teece. There are two determinants of appropriability, the efficacy of legal instruments (patents, copyrights, trade secrets, trade marks) and the nature of the technology (the degree to which it is tacit).

As for the dominant design paradigm, Utterback and Abernathy (1975) first used the term 'dominant design'. Dominant design is a technology management concept identifying key technological designs that become a standard in their market place. In the early stages of industry development, product designs are flexible, manufacturing processes are loosely defined and adaptive. This is called the preparadigmatic stage of an industry. At some point in time, a dominant design or product begins to emerge. Once a dominant design emerges, process innovation surges in order to lower production costs (Teece, 1986.) Therefore, competition shifts to price and away from design (Teece, 1986).

In order to generate profits, innovators not only need key technology but also some key know-how on how to commercialize, which are called complementary assets. This includes competitive manufacturing, complementary technologies and related services. Specialized (complementary) assets are assets where there is unilateral dependence between the innovation and the asset (Teece, 1986). If the asset is specialized, it is more unlikely to be replicated. This will affect the distribution of returns from innovation (Teece, 2006).

In the paradigmatic stage, once a dominant design emerges, volumes increase and opportunities for economies of scale will induce firms to enter mass production (see Figure 2). With weak appropriability, core technology is easy to imitate, profits are reaped by the firms which are equipped with complementary assets. For instance, the technology of cardiac pacemakers was easy to imitate and so competitive outcomes were determined by the earliest firms which had access to the specialized market (complementary assets) (Teece, 1986).

Specifically, how does a latecomer catch up to a forerunner? Alexander Gerschenkron (1962) created the modern frameworks on the issue with his concept, latecomer development. In addition, Perez and Soete mentioned the leapfrog strategy in 1988. The fast follower aims employs this strategy, moving to mass production as fast as possible for cost deduction through the utilization of existing standards of both product and process.

East Asian firms are typical examples of employing fast-follower strategies, particularly in the heavy engineering and automotive industries (Amsden and Chu, 2003). Successful firms from East Asia choose to enter the flat panel display industry during downturns (Mathew, 2005) and similar strategies are evident in the semiconductor industry (Tan and Mathews, 2010).

3 Empirical Result

3.1 The World Market

In this section, we use the empirical data on global patents and production in the solar PV Cell industry to verify Teece's and fast follower theory. According to Teece's theory, there is a time lag between innovation and production development in industry. The fast follower's strategy will be adopted by newcomers in a matured 1st generation solar PV industry.

After the first solar PV patent was applied in 1966, the newly granted PV patent number increases steadily until 2001 and then started to decline after 2001 as shown in Source: Figure 4 in Teece (1986)

Figure 3The decline can be view as a transition from preparadigmatic design stage to preparadigmatic design stage from Teece's point of view.

Because of advancement and maturation of solar PV technology, Germany's renewables subsidy amount decreased 36% from around 55 to 35.24 €- Cent/kwh between 2004 and 2010 (see Figure 4). However, the global production market still moved in the opposite direction despite weaker incentives.

According to Teece's theory on innovation, there is a time lag between innovation and production in the 1st PV generation of solar PV technology. After initial technology development of solar PV, PV production did not significantly increase until the year 2000 (see Figure 5). Increase in production in 2000 was mainly due to the promotion of renewables subsidy policy, Erneuerbare-Energien-Gesetz (EEG). It was the first effective national renewable policy[4] through feed-in tariffs[5][6](FiT) in the world.

According to Figure 6 and Figure 7, we see further that modules prices decreased around 94 percent, dropping from over 51 USD per Watt (USD/Watt) in 1976 to less than 2 USD/Watt in 2010. Cell prices also dropped about 64 percent between 1989 and 2010. Therefore, from low growth rate of patent numbers and increasing volume of production, we can conclude that the 1st generation solar PV cell technology is matured and in mass production. Finally, cell and module prices decreased as the technology rapidly matured.

Succeeding the 1st generation of PV technology, the second generation technology has grown at a slower pace than 1st generation technology (see

Figure 8). Despite huge development in innovation in the 2nd generation of solar PV techonogy, the productioin volume of 2nd generatioin market share is till less than 20 percent.A time lag also exists between innovation and production similar to that of the 1st generation PV technology.

Overall, the timing of innovation and produciton, as well as the decrease in PV product pries, both the performance of the 1st and 2nd generation in solar PV

[4] There are many other national renewables policies prior to EEG. But EEG is the first one raise the installation in solar PV systems significantly.

[5] A feed-in tarifast follower is a policy mechanism designed to accelerate renewable energy investments. It ofast followerers long-term contracts to renewable energy producers, typically based on the cost of generation of each technology and the price (or tarifast follower) goes down over time

[6] The first form of feed-in tarifast follower was implemented in the US in 1978, which is called Public Utility Regulatory Policies Act (PURPA).

technology globaly fit Teece's and fast follower's theory.

3.2 Forerunner vs Follower

The cell production technology is easily accessible. Contrary to upstream segments, turnkey production lines can be bought and run without much prior experience in manufacturing cells (Cerna, 2011). We analyze the differences between forerunners and followers in the solar PV Cell industry. Countries are categorized as forerunners (US, Japan and Germany) and followers (China, Taiwan and S. Korea) by innovation capability (number of patents) in the solar PV industry.

As shown in Figure 9 forerunners perform better than followers in terms of patenting during

And a huge gap between these two groups remains. Despite excellence in innovation, the forerunners' dominance in production only lasts until 2008. After 2008, followers' production significantly increased due to the maturity of the 1st generation solar PV technology (slow growth in patent counts) and the standardization of Si-based PV cell production procedures.

From Teece's point of view, once a dominant design emerges and manufacturing procedure are standardized, competition shifts to price. During this stage, followers who are good at cost control, like China and Taiwan[7], take advantage in the industry.

As shown in Figure 10 & Figure 11, followers' PV production significantly increased since 2008 and specifically for China. Figure 12 to Figure 14 show the

[7] In 2008, the solar PV modules & cell production growth rate is 187% globally, however they are 230 and 210% in China and Taiwan respectively.

comparisons between patenting performance and production performance for the three followers, China, Taiwan and S. Korea. It is obvious that time lags between innovation and production for all three followers.

S. Korean firms have best performance in patenting performance (see Figure 14). Next to S. Korea, Taiwan performs better than in China. However, production performance is inversed among these three followers (see Figure 14). It suggests that there are different determinants in influencing the performance of these three countries.

In Taiwan, the experience and background in semiconductors and flat-panel industries are helpful[8] to her PV production. Fast follower's strategy seen in semiconductors and flat panel display industries is also applied to the solar PV industry. As a follower, Taiwanese firms generally entered the first-generation sector easily, since the associated relatively matured (Wu, 2011). Most of the key patents have expired, which made it accessible to followers such as Taiwan. From Teece's point of view, the technology is in a weak appropriability regime, and low cost imitator-manufacturers may end up capturing all of the profits from innovation. However, the solar PV Cell & Module production in both Korea and Taiwan is far less than China.

Therefore, what causes the discrepancies between the theory's prediction (both Teece's and fast follower Theory) and actual production in followers? We believe Chinese policy in promoting the PV industry is a major factor. We will discuss this issue in the following section.

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[8] In 2006, the Taiwan semiconductor industry generated 60% of worldwide IC revenue (for foundry, packaging and testing) and 25% of worldwide DRAM revenue.

3.3 China's Policy on PV industry

As one of the fast growing economy, China's energy demand has soared in the past 30 years. China has been the country with highest greenhouse gas emission in the world since 2007. Under the pressure of energy supplies and environment issues, China has developed renewables energy eagerly and rapidly with the highest installed power capacity and the highest electricity consumption in the world in the recent years (IEA, 2011).

The rapid development of solar PV industry is caused by low production cost[9] technology transfers[10] and the promotion of government policies. The renewables policies can be categorized as demand-side and supply-side one. The demand-side policy, like FIT policy, were set up since late 1970's and effectively impacted by the EEG in Germany in 2000. Concern about energy sustainability and security, the Chinese Government promoted the development of renewable energy through several Five-Year Plan (from the 7th to the 12th) and 2006 Renewable Energy Law.

More specifically, Chinese government has set up a rural energy special cashing interest loans since 1987 (Zhang, 2009). Recently and more fundamentally, the China Renewables Energy (RE) Law was effected in 2006, to support the RE power supply by way of FIT policy[11]. Besides, China promoted two national solar subsidy programs:

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[9] Consumption of silicon rate has been dropped from average 9g/w to 6g/w, which reduces the manufacturing cost (IEA, 2011).

[10] Tour (2011) claims that there are four main channels of technology transfers, including the markets for manufacturing equipment, labour mobility, foreign direct investment and Licensing, in China.

[11] The surcharge level has been doubled from 0.4 CNY cents/kWh to 0.8 CNY cents/kwh since Dec. 2011 (IEA, 2011).

the BIPV subsidy program[12] and the Golden Sun program[13] in 2009.

The rapid growth of PV production in China is heavily promoted by their government policies. Since 2008, China became the leader in the PV production volume with a annual growth rate over 100%. In 2011, PV production form China accounted for about 56.6% of total PV production worldwide in which more than 90% of PV production was exported[14].

Export-oriented industries are important accelerator for Chinese economic growth (Girma, 2009). Therefore, Chinese authorities have practiced numerous supply side policies in export-oriented industries, including PV industry. For example, the export rebate rate of solar PV product is 17% in China[15].

Specifically, there are four main supply-side policies associated with PV industry promotion such as, low-interest loans & grants, tax incentives, preferential land policy and R&D support. In China, it is reported that China solar companies have benefited from low-interest loans or grants offered by the state-owned banks (see Table 4). A

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[12] On March 2009, China announced its first solar subsidy program, the BIPV (Building-integrated photovoltaics) subsidy program, ofast followerering upfront CNY20 per watt for BIPV systems and CNY15 per watt for rooftop systems. 《财政部等关于加快推进太阳能光电建筑应用的实施意见》(财建 2009，128 号）&《关于印发《太阳能光电建筑应用财政补助资金管理暂行办法》的通知》(财建 2009， 129 号）

[13] In 2009, China's Ministry of Finance, Ministry of Science and Technology and the National Energy Administration of the National Development and Reform Commission, announced the launch of the Golden Sun Demonstration Project, to facilitate the growth and expand the scale of the PV power generation industry. 《财政部科技部国家能源局关于实施金太阳示范工程的通知》（财建〔2009〕397 号）&《金太阳示范工程财政补助资金管理暂行办法》》（财建〔2009〕397 号）&《关于做好金太阳示范工程实施工作的通知》（财建〔2009〕718 号）&金太阳示范工程基本要求》》（财建〔2009〕718 号）

[14] In 2010, the annual PV installation in China is 500 MWp, and the annual production volume is 10,852 MW (IEA, 2011 & EPI, 2011).

[15] After adjustment in 2004, there are five different kind of export rebate rate, 5, 8, 11, 13 and 17%, in China.

budget of 1 billion CNY has been issued by means of grants, and preferential loans from the year 1999 (Cherni, 2007), and a huge loan of around $34-40 billion has been lent from 2010 to 2011 Q1 (GWU Solar Institute, 2011).

Tax incentives and Preferential Land Policy are two other common ways of financial support in PV industry. Tax incentives include tax exemption or reduction (see Table 4). Preferential Land Policy offers firms land with price under market level and is mainly authorized by local government (see Table 4).

The last supply-side subsidy is R&D support, which is composed of various projects by different departments (see Table 4). However, the total amount in PV R&D is still far less than other countries (Huo, 2012). In view of public budget for PV R&D, China ranked 12th in th list of 17 countries (IEA, 2009). In addition, due to the difference in goals of R&D support, it is rather difficult to get consistence in the same field and making a long-term and effective system to support RE's sustainable development in China (Zhang et al., 2009).

4 Conclusion

Based on our empirical results, we can observe that there is a time lag between innovation and production in 1st generation of solar PV technology on a global or national scale. Followers entered the market and have grown rapidly since 2000. The result fits Teece's model globally and on national scale. However, the three followers do not fit the model well.

Taiwan and Korea are considered as potential followers because of better performance in innovation and experience in related industries, such as semiconductors and flat panel display industries. In reality, only Taiwan has performed better than forerunners, but is still worse than China. In 2008, China's production significantly increased because of standardized procedure of production and their government policies in the solar PV industry. Obviously, Chinese policy in solar PV industry has dominated the industry.

However, because of policy-dominated export in China, arguments between free trade and trade protectionism were at the center of controversy. The International Trade Administration (ITA) in USA announced affirmative preliminary determination, imposing an anti-subsidy duty in the form of 2-5 percent tariff rates on Chinese solar PV firms on March 20, 2012. Subsequently, it announced antidumping duties with tariff rate over 30 percent on May 17, 2012. In turn, solar imports from China decreased about 45 percent in May from 2011 to 2012[16].

In addition, according to GTM Research, top three thin film PV companies in 2012 in terms of production, are First Solar (US), Solar Frontier (JA) and Sharp (JA). None of

[16] . According to the Department of Commerce's "U.S. Imports of Merchandise" database, Chinese solar imports totaled $124.1 million in May, down about 45 percent from $225.8 million in May 2011.

the above is a Chinese company. This implies that the 2nd generation of solar PV technology has not matured and Chinese polices have not been implemented, which indicates that the 2nd generation of solar PV technology may still fit Teece's model.

Over all, oversupply may not be a long-term phenomenon (see Figure 15), and many measures such as punitive tariffs will be implemented. Therefore, we put forward two comments as policy suggestions for followers. First, followers such as Taiwan and Korea should keep carry on with R&D regarding new generation technologies and process improvements to catch up to forerunners. Second, the government should also provide demand-side policies to stimulate and create a domestic market for 2nd generation of PV technology.

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6 Appendix

Table 1 Evolution of solar PV industry

1960's	NASA deployed solar cells as power generators in space probes.
1970's	After two oil shocks, governments in Europe, Japan and North America started to actively promote solar PV cells as a realistic energy source.
1980's	Slowing down in development such as Sunshine Program in Japan from oil shocks in 1973 &1979.
1990's	Policy instruments—particularly the "feed-in tariffs" utilized in Germany.
2000's	Germany's re-framed Feed-in Law, Renewable Energy Sources (Erneuerbare Energien Gesetz), underwent in 2000. Acceleration in PV market-annual production from 277 to 24,047 MW during 2000-2010.

Source: Green Energy Industry Information Net- Industrial Technology Research Institute (ITRI)

Table 2 Value China in Solar PV industry

Upstream	Midstream	Downstream
Silicon material, Ingot and Wafer	Solar Cell and PV Module	PV System
Source: ITIS IEK, 2008		

Table 3 Keywords of Midstream: Solar Cells and Modules

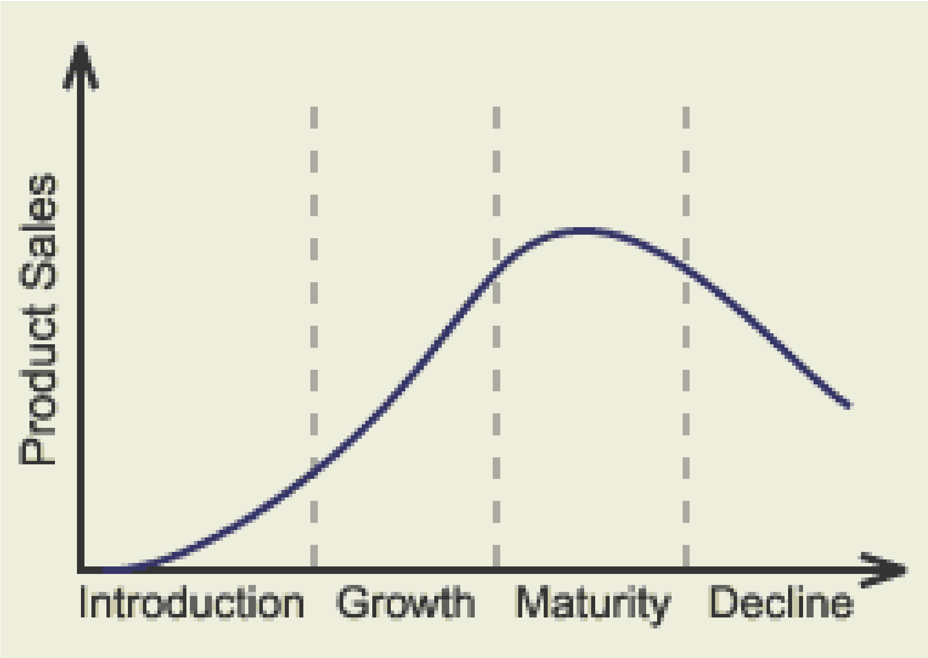
Keywords	("Photo-voltaic",photovoltaic,"solar cell","solar cells","PV cell","PV cells","solar module","PV module","PV modules","solar modules","PV system","solar system","building integration","Building Integrated","solar panel","solar panels","pv panel","pv panels","solar powered","solar array" <IN> ttl,abst)
Source	USPTO granted data from Webpat
Period	1970-2010

Table 4 China's supply-side policies associated with Solar PV industry

Instrument	**Time**	**Specification**	**Source**
Low-Interest Loans & Grants	1999-	The State Council set up an innovation fund for small and medium sized technical enterprises supporting energy efficiency and renewable energy by means of grants, and preferential loans, and with a budget of CNY 1 billion.	Cherni, 2007
	2010-2011 Q1	The total amount of loans for Chinese solar manufacturers is in the range $34-40 billion.	GWU Solar Institute, 2011
	2010-	Yingli Solar announced that Jiao Tong Bank will provide Yingli CNY 1.5 billion Project loan and CNY 250 million special liquidity loans and will build “Panda” single-crystal integrated production line with capacity of 300MW.	China Policy in Focus
	2011-2015	Suntech and Trina Solar have signed deals with the government-backed China Development Bank that could give them access to a total of CNY 80 billion.	Reuters
Tax Incentives	2000-	Under Renewable Energy Law, eligible PV companies are exempt from value-added taxes and customs duties, and business income tax may be reduced to 15%.	George Washington University Solar Institute
Preferential Land Policy		Yingli Solar’s Haikou Shiziling Industrial Park Project (英利集团海口高新区狮子岭工业园项目), a solar battery integrated production line project with an annual	China Policy in Focus

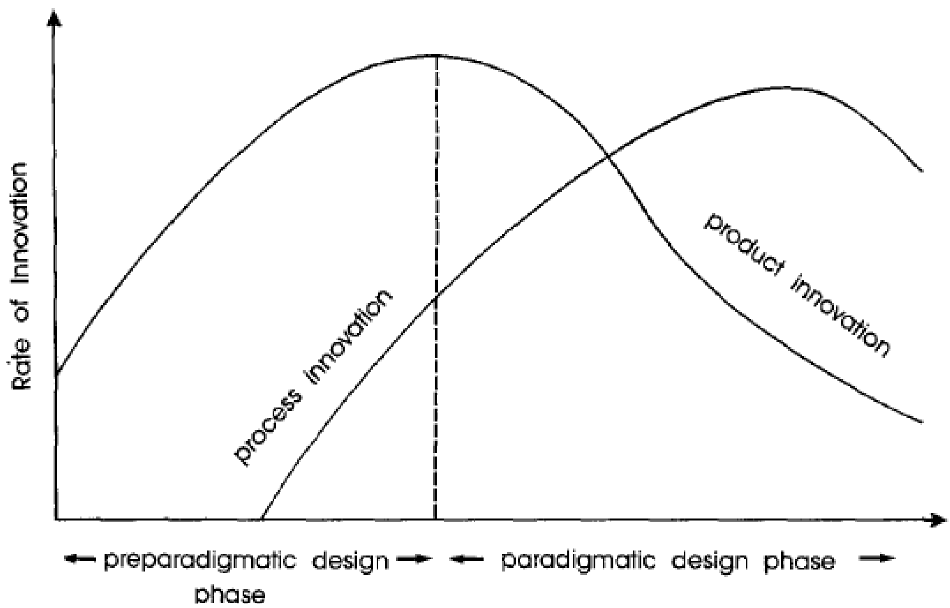
		capacity of 100-300 MW, was awarded 260 acres. Suntech was awarded 3000 acres and Trina Solar was awarded 7000 acres for their respective projects. These beneficial land-use policies help Chinese solar companies to lower their production costs	
R&D Support	2004-2005	The national high-tech industry development program of the National Development and Reform Commission (NDRC) targeted to facilitate R&D and demonstration by supporting manufacturers and R&D institutions. From 2004 to 2005, it provided around 50.2 million CNY to support PV R&D.	Zhao et al., 2006
	1981-	The Key Technologies R&D Program was created in 1981 to support R&D for the current development of economy in China. From 2006 t0 2010, it gave about 20 million CNY to support R&D of equipment manufacturing of crystalline silicon PV.	Huo and Zhang, 2012
	1986-	National High-Tech Development Plan (the 863 Program) was created in 1986 to develop a wide range of technology fields. The program invested $3billion in research from 2001 to 2005, and another $585 million was approved in 2008 jointly.	Campbell, 2010
	1997-	The National Basic Research Program (the 973 Program) was funded in 1997 to support basic scientific research for long-term development. From 2006 to 2010, it gave about 30 million CNY to support R&D of thin-film PV.	Huo and Zhang, 2012

Figure 1: Product life cycle



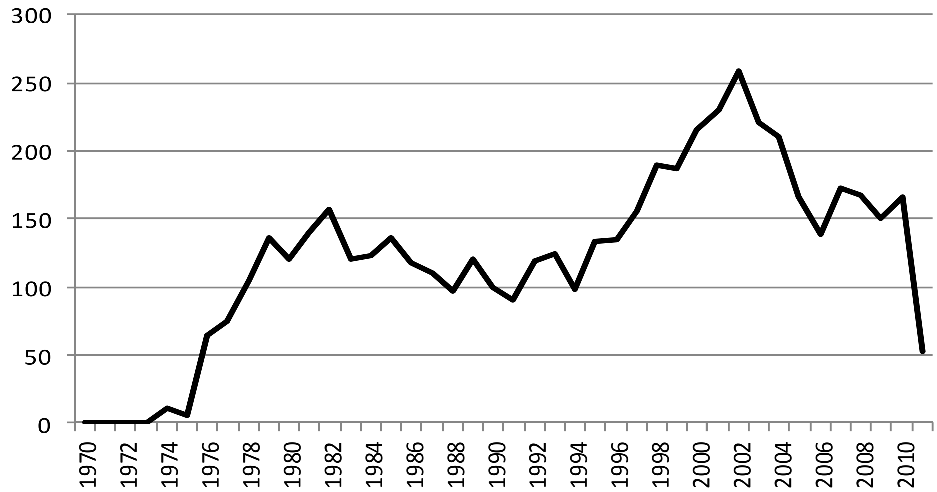
Source: QuickMBA.com

Figure 2: Innovation over the product/process life cycle



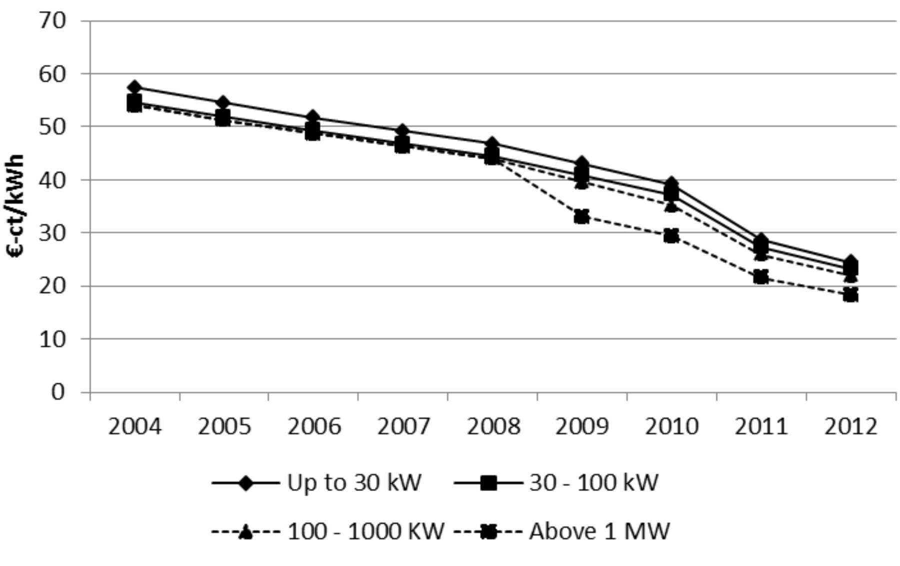
Source: Figure 4 in Teece (1986)

Figure 3: Global Patenting Performance on 1st generation of Solar PV technology



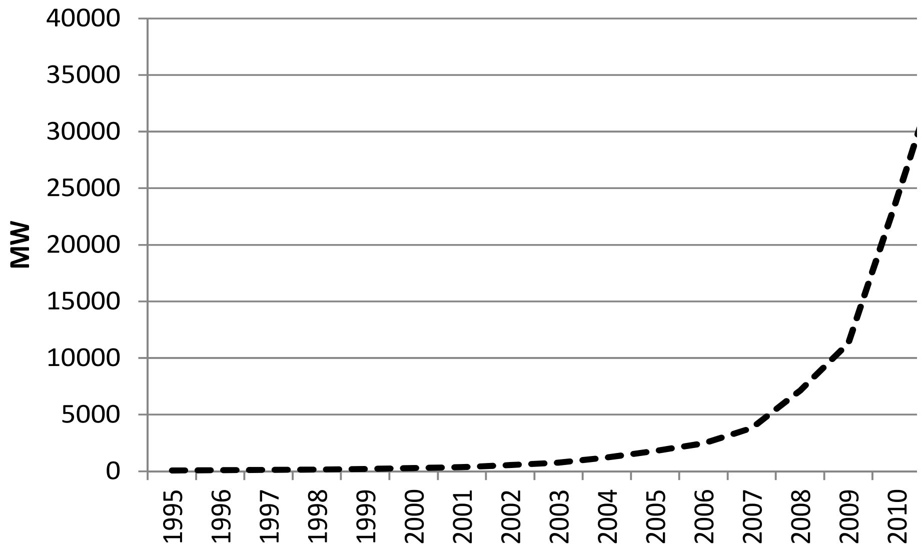
Source: USPTO patent data collected by author

Figure 4: Feed-in-tariff in Germany during 2004-2012



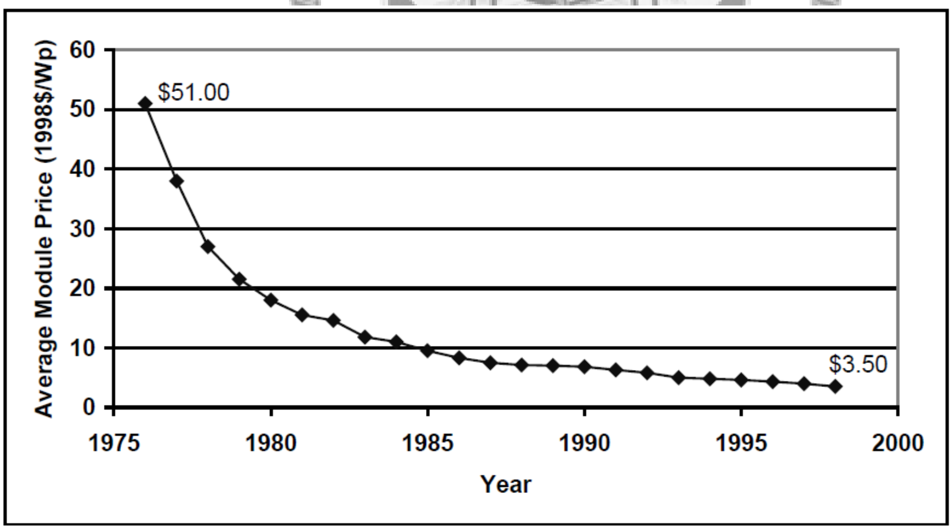
Source: German Energy Blog

Figure 5: Global Production of 1st generation of Solar PV technology



Source: Earth Policy Institute (EPI)

Figure 6: The average selling price of PV modules



Source: Figure 5-1 in Harmon (2000)

Figure 7: Solar Cells & Modules Prices of 1st generation of Solar PV technology

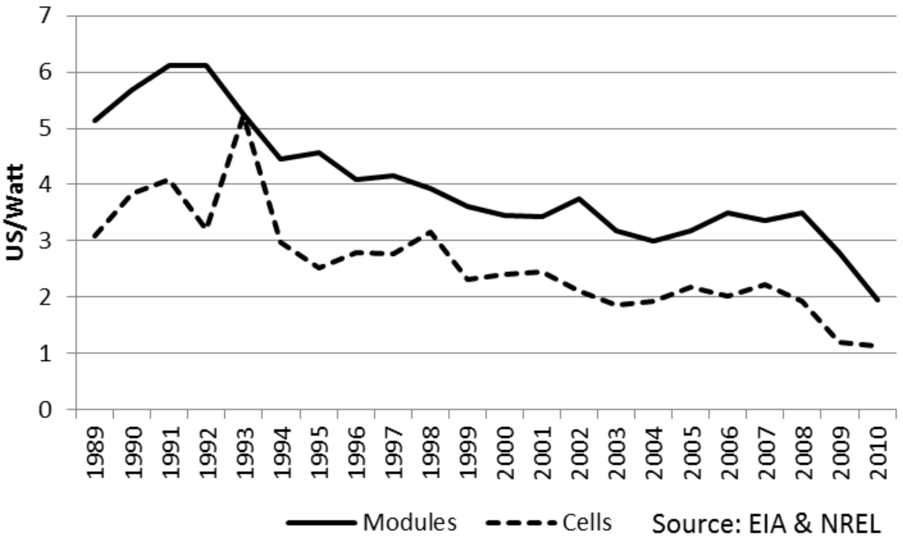
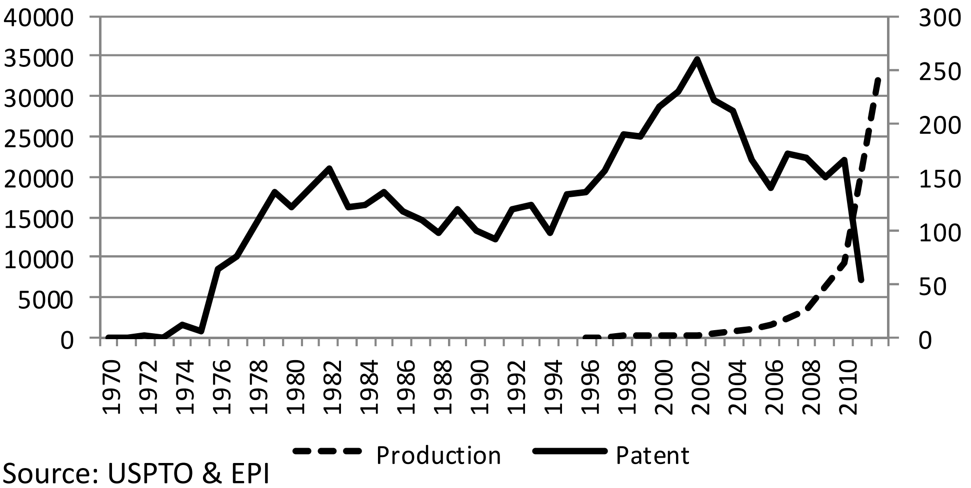


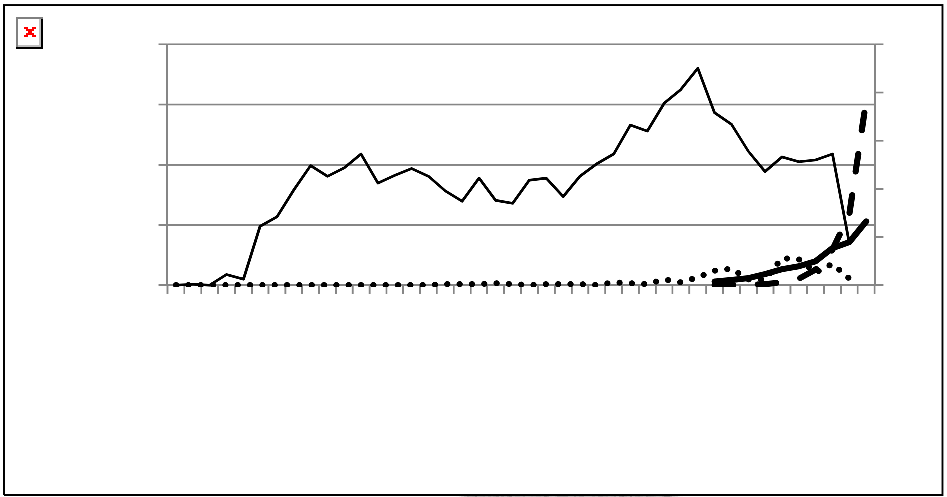
Figure 8: Global Production & Patent number of 1st generations of Solar PV technology



Source: USPTO & EPI

Figure 9: Solar PV Production & Patent number:

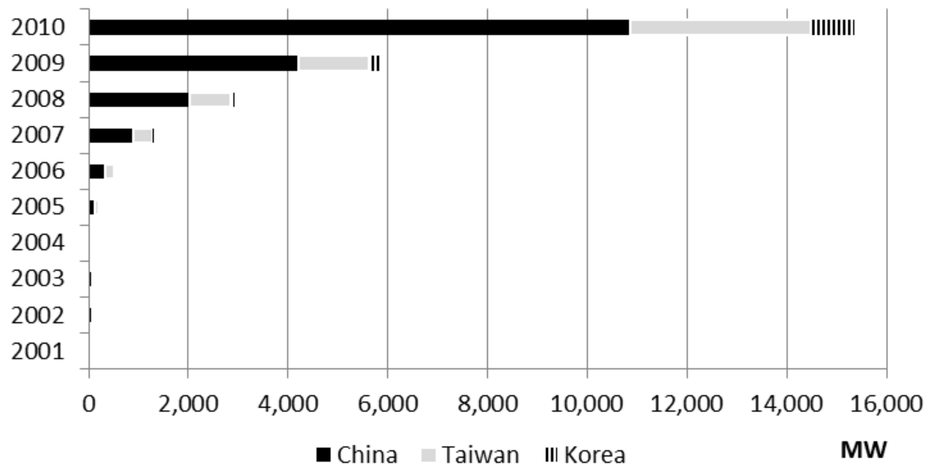
Forerunners vs Followers



Source: USPTO & EPI

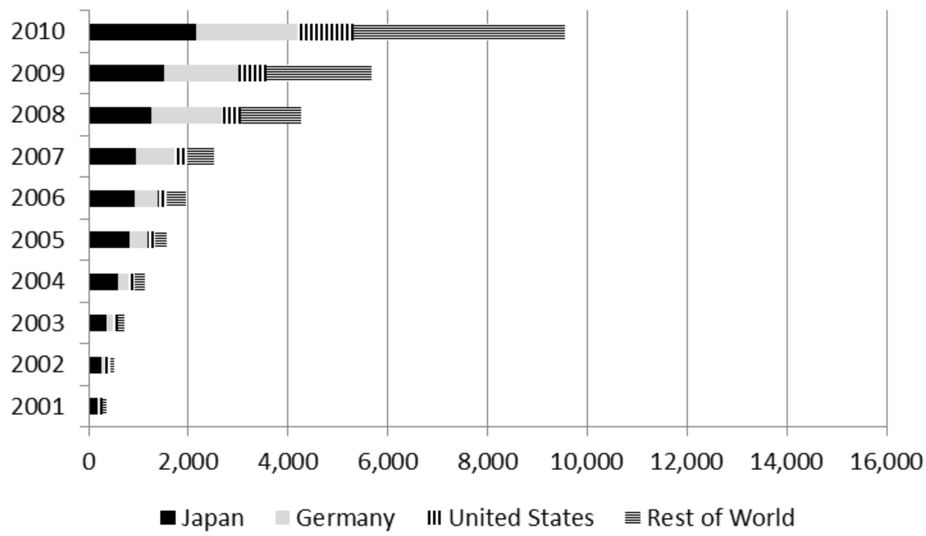
Figure 10: Solar PV Production Performance in three

Follower Countries



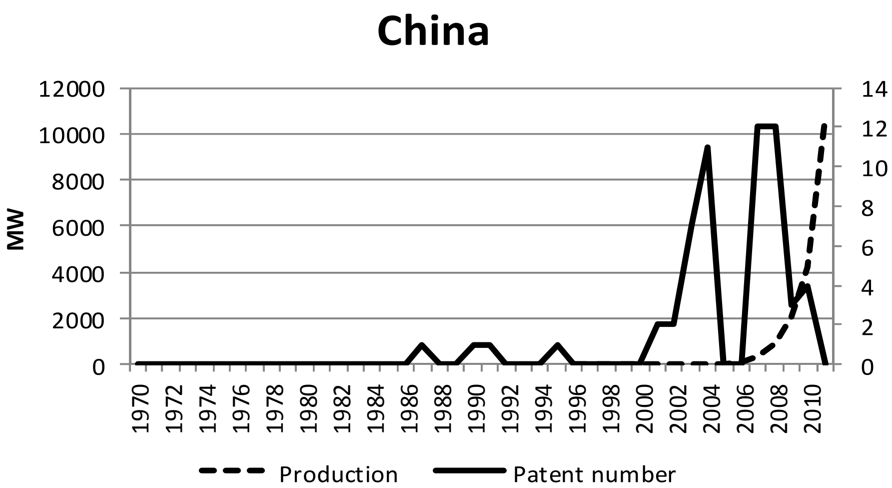
Source: EPI

Figure 11: Solar PV Production Performance in three Forerunner Countries



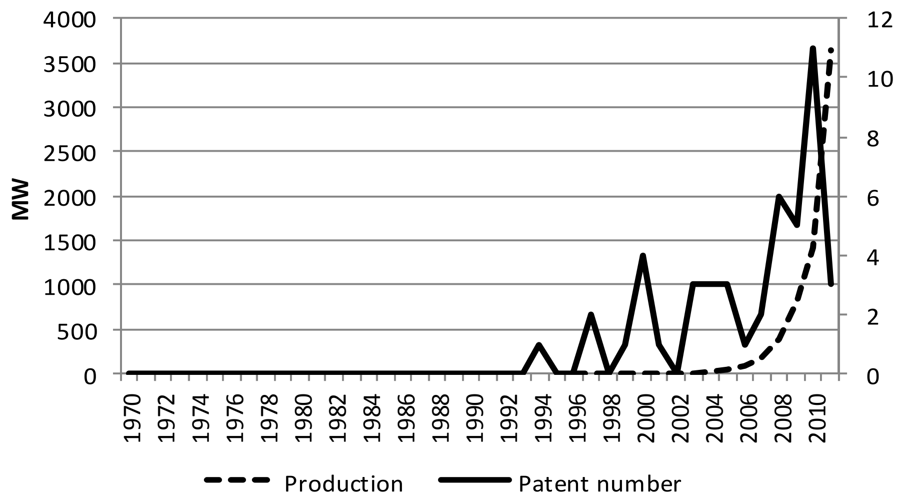
Source: EPI

Figure 12 China Production & Patent number of 1st generation of Solar PV technology



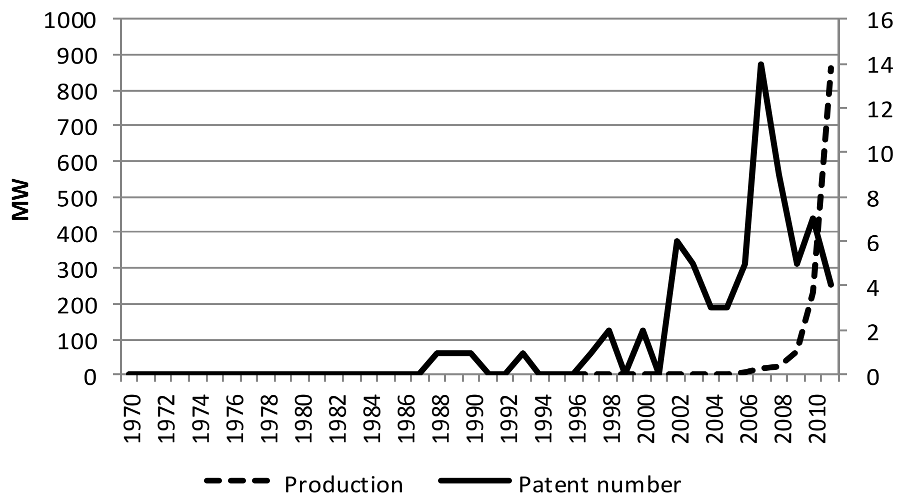
Source: USPTO & EPI

Figure 13 Taiwan Production & Patent number of 1st generation of Solar PV technology



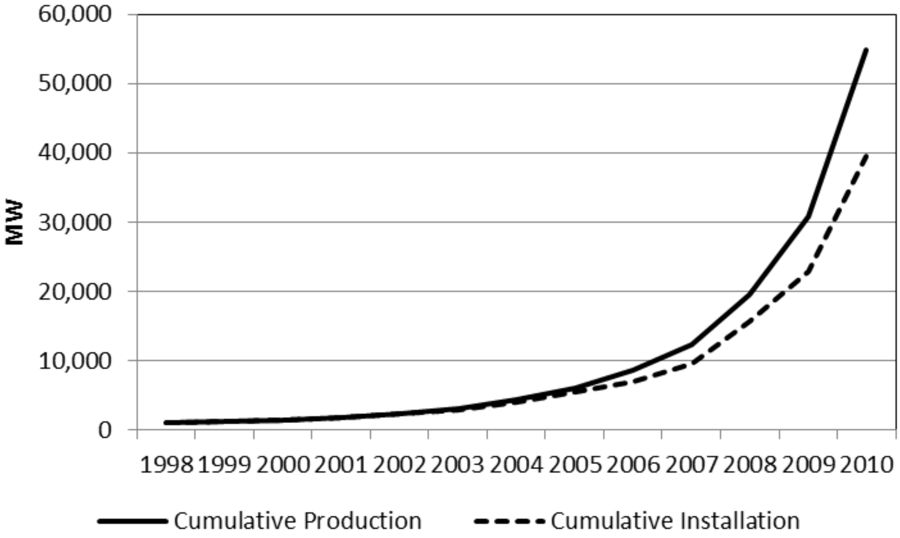
Source: USPTO & EPI

Figure 14 Korea Production & Patent number of 1st generation of Solar PV technology



Source: USPTO & EPI

Figure 15: Solar PV Cumulative Production vs Installation



Source: EPI

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