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Fusing East and West Leads a Way to Global Competitiveness in Emerging Economy: Source of China's Conspicuous Strength in Solar Industry

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Abstract

In light of a conspicuous strength in China's solar industry in recent years this paper analyzes an institutional source of its strength. Empirical analysis was conducted focusing on the interaction between indigenous semiconductor industry ("East") and newly emerging solar industry in absorption of global best practices ("West") thereby fusion between them was demonstrated. Success of this fusion can be attributed to a joint work between industry's intensive effort in learning global best practices for exploring new business and government's catalytic role for the attainment of decarbonisation society for nation's sustainability. This suggests a new insight for growing economy for its development of global competitive industry.

Keywords: *Fusion, learning, global best practices, growing economy, global competitiveness*

INTRODUCTION

China's Conspicuous Strength in Solar Industry

China has demonstrated in the recent years as the world's largest solar cell producer as shown in Fig. 1. In 2001 China produced world's solar cells and today four of the top 5 solar cell producers are from China and 3 of the five module producers are.Significant growth in the Chinese solar energy Industry has caused the prices of solar panels to drop worldwide[1]. Chinese manufacturers' lower prices are being interpreted and complainedto the extent of dumpinginto USA[2] (Melanie Hart (2011)) and in Europe[3] (Reuters (2012)). It is also interesting to note that China with rich solar energy[4] of 5000 mega joules per square meter on at least two-third of its region that spread to a vast land of 9.6 million square kilometre but yet represents a meagre internal PV market. Table 1 and 2 lists the annual and cumulative installations of solar PV installations in different countries which clearly show the West leads significantly than China. The reason being, the highly anticipated national feed in tariff (FIT) was dropped indefinitely until2011 as PV generation cost was deemed too high during 2006.After spiking in 2006, prices of crystalline

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silicon PV cells and modules fell by 70 percent through 2011. Only since 2010 that their installed capacity has seen a recognizable growth moving from off-grid stand alone systems to grid-connected applications such as building integrated PV systems and large scale PV power stations. But what interest the research circleis to understand thateven with poor internal demand, how did China acquire its knowledge to reach the world's largest production capability[5] and thus what other reasons drive such conspicuous growth. The reality has been that China has effectively used its internal know-how with external knowledge to increase production and thus a key role in reducing the cost.

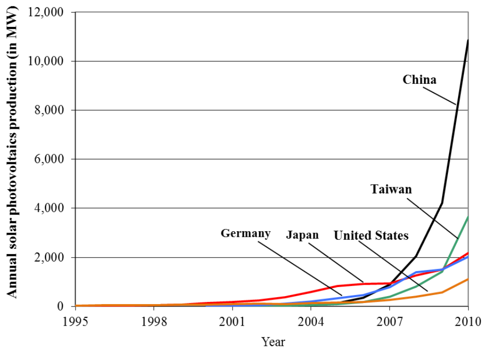

Figure 1: Annual photovoltaic production in different countries (*2000 - 2010*).

Source: Earth Policy Institute (2012).

Table 1: Worldwide annual installation of solar PV installations from (*2000 - 2010*)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
China	0	11	15	10	9	4	12	20	45	228	520	2,200
USA	23	31	46	65	92	117	149	212	349	539	983	2,234
EU	53	94	142	201	708	1,002	987	1,972	5,297	5,803	13,397	21,939
Apac[a]	114	136	186	225	276	296	322	283	563	766	1,618	2,653
ROW[b]	88	56	80	77	29	10	105	42	76	80	284	508
Total	278	328	469	578	1,114	1,429	1,575	2,529	6,330	7,416	16,802	29,534

Source: European Photovoltaic Industry Association (2012).
[a]*Asean and pacific countries.*
[b] *Rest of the world.*

At world level, Solar cell and Solar Module Industry achieved rapid development in 2010, in terms of Global Capacity production growth rate close to 100%, while the Installation statistics shows that the Global Total Installation is about

15.6GW, far more than 6.43GW in 2009. This was achievable due to China contributing to the Global Solar Module output of 43% share in 2010.

Table 2 Worldwide cumulative installation of solar PV (*2000 - 2010*)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
China	19	30	45	55	64	68	80	100	145	373	893	3,003
USA	146	177	222	287	379	496	645	856	1,205	1,744	2,820	5,053
EU	154	248	389	590	1,297	2,299	3,285	5,257	10,554	16,357	20,777	51,716
Apac[a]	355	491	677	902	1,178	1,475	1,797	2,080	2,643	3,409	5,116	7,760
ROW[b]	751	807	887	964	993	1,003	1,108	1,150	1,226	1,306	1,200	1,717
Total	1,425	1,753	2,220	2,798	3,911	5,341	6,915	9,443	15,773	23,189	30,806	69,249

Source: European Photovoltaic Industry Association (2012).
[a]*Asean and pacific countries.*
[b] *Rest of the world.*

Solar cell technologies and value chain

Photovoltaic technology helps convert the solar energy into electrical energy (Chetan (2009)), and China is dominant with the first generation crystalline silicon (C-Si)technology followed by the second popular thin film solar cell (TF-Si) technology which countries such as USA is dominant in terms of cost-competitiveness(Yang Mu et al.(2010)).Fig. 2 describes the various steps of the production chain in China.

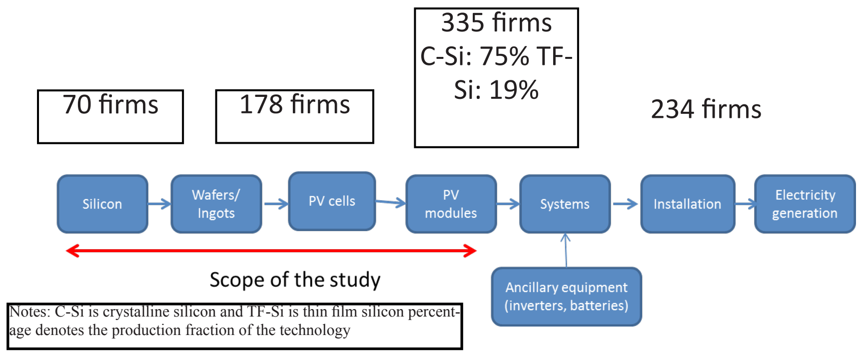

Figure 2.Solar PV production chain with indicative number of firms in China (*2011*).

The solar cell indicated in dotted line in Fig. 2, has few important steps in the manufacturing process that can be depicted as shown in below figure and is mostly similar to the semiconductor manufacturing process which is illustrated in Fig. 3 (Chetan, 2009).

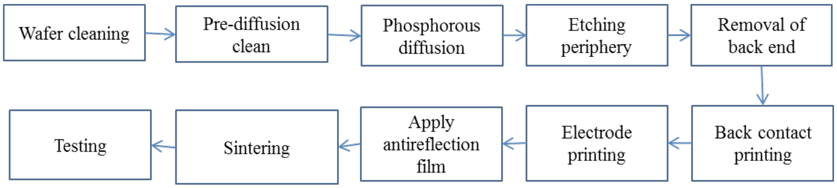

Figure 3.PV solar cell manufacturing process steps.

China Solar Manufacturing Industry

China's foot print in the value chain exhibits an asymmetry in the industrial chain, where it exhibits poor competence in the front end and in the back end of the solar value chain (Yanget al.(2010)). China imported 95 % of its PV raw materials due to lack of advanced technologies to produce crystalline silicon and in the final market of finished solar panels it depends on the foreign markets. Thus both export and import exists in the solar supply chain of China. As pointed out in previous paragraphs, China initially focused its production to the installation needs of USA and Europe.

China today manufactures 18% of global silicon material while it produces 47% and 54% of the global production capacity in the cells and module business. This may arise if it is financed by foreign governments which extended subsidies to China's overseas markets. However this study suspects that there are additional underlying reasons for such results.

Production of high purity polycrystalline silicon has been a bottleneck in the Chinese solar PV industrial chain (Yanget al.(2011)). This being the feedstock of further production steps, it affects the overall production capacity. Since 2009, China's silicon production is seeing serious investments and hence a surge in production, however quality and pollution still persist. As per 2009, still China experienced a shortage of 62.5% raw materials for ingot production, which were covered by imports.

The increase in silicon production resulted in wafer manufacturing growth at an annual increase of 100% between 2004 and 2008. One core technology to such process is wafer slicing (or cutting) which aims to cut a long round bar into thin slices of sheets. One way to produce low cost is through making thinner wafer and thereby producers more wafers from a silicon feedstock. For example a reduction of 0.32 mm to 0.18 mm was achieved by China domestic solar PV cell manufacturing firm that enhanced production. Such know-how comes from the nearby IC manufacturing industry where the art of slicing wafers is being pursued (Arnaud et al.(2011)). Similarly the art of converting monocrystalline silicon to polycrystalline silicon indicates that China's ingot is getting technologically matured.

The next step is the solar cell manufacturing where China leads to be al-most half of the world's producer and has sustained its positions since 2003. For example, as per 2008 the top 10 domestic cell producers accounted for 75% of the national production. Table 3 and 4 lists leading firms and their capacity and country of origin. The leading cell producing firm being Suntech which accounts to 20% of the national production. As we discuss about the first generation solar technology (viz., crystalline silicon), China still lags significantly in second generation solar technology (viz., thin film solar cells) compared to USA and Germany.

Further in the production, the solar cells are converted into solar modules, where China has shown clear domination in its know-how to incorporate clusters of PV cells into a unit namely module encapsulation. In 2009, China's share in the world's module was around 59%. This was possible due to its strength in equipment manufacturing that enhanced from the IC manufacturing industry, due to its relatively lowest technological threshold and demands for unskilled labour and low labour costs, thereby was being handled by small medium sized business, and hence good business growth in the whole PV industry.

According to CASolar[6], the solar panel prices from China have been decreasing significantly[7] as shown in Fig. 4. Similar price reduction is seen at solar cell and module components which form a part of the solar panel system. Accordingly the top ten firms of the global solar cell manufacturers shows that seven out of the ten top positions have been taken up by China domestic solar manufacturers (as per 2011). Similarly in solar module manufacturing among the top ten positions in terms of production capacity (in MW) eight indigenous Chinese firms have overtaken their global coun terparts.

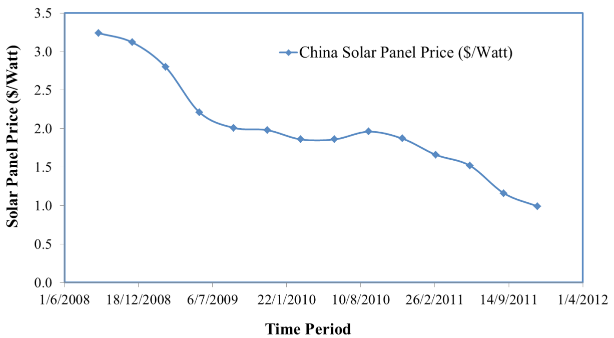

Figure 4: Declining trend in China solar panel prices[a]

[a] *US$/Watt at current prices (2008Q2- 2012Q2).*
Source: CASolar[6] (2012).

Table 3 Top 10 global solar cell manufacturers in China (*2011*)

Firm	Capacity(MW)	Country
Suntech	2400	China
JA Solar	2100	China
Trina	1900	China
Yingli	1700	China
Motech Solar	1500	Taiwan
Gintech	1500	Taiwan
Canadian Solar	1300	China
Neo Solar Power	1300	Taiwan
Hanwha Solar One	1100	China
Jinko Solar	1100	China

Source: Energytrend (2011)[a].
[a] *www.energytrend.com*

Table 4 Top 10 global solar module manufacturers in China (*2011*)

Firm	Capacity (MW)	Country
Suntech	2400	China
LDK	2500	China
Canadian Solar	2000	China
Trina	1900	China
Yingli	1700	China
Hanwha Solar One	1500	China
Solarworld	1400	Germany
Jinko	1100	China
Suneeg	1000	China
Sunpower	1000	USA

Source: Energytrend (2011)[a].
[a] *www.energytrend.com*

Table 5 give a critical analysis of the asymmetry in the value chain of China's PV manufacturing where the bothends have been relatively weak where at one end it imports its raw material and purely depends on exports. This draws clear attention to understand the roots behind the conspicuous strength in cell and module manufacturing.

Table 5 China's manufacturing competitive advantage in Solar PV production chain

Industrial chain	Silicon	Ingot/ Wafer	Cells	Modules	PV arrays
Features[a]	High energy consump-tion; Poisonous emissions	Decrease in the thickness of silicon wafers is an effective way to reduce cost of PV cells	Large scale pro-duction is most important	Fierce com-petition Labour-intensive	Comprehen-sive use of combined technologies is required.
Capital[a]	High investment and long payback	Medium invest-ment	Medium investment	Low Investment & short payback	Low Investment & short payback
Technology barrier	High	Medium	Medium	Low	Low
No. of firms[c]	70	178	335	234	700
Manufacturing in China[a]	Weak	Medium	Strong	Strong	Strong

Sources:
[a] *China Solar PV Industry Report, 2008-2009 All China Marketing Research, ACMR, p. 1.*
[b]*Yang, M., Yu, H., Solar photovoltaic Industry in China, China's Industrial Development in the 21st century, p. 195.*
[c]*No. of firms computed from ENF website (as of 2011).*

China solar manufacturing competitiveness

The five principle reasons for the price reduction in silicon cell and module is generally seen from declining silicon prices, competition from thin film products, government incentives, increasing economies of scale and efficiency, and oversupply. Apart from these factors, yet China shows evidence of lower manufacturers' price compared to their global competitors and hence China's domestic solar PV manufacturers have a cost advantage.

The top tier Chinese cell and module manufacturers have shown a cost advantage of 18 and 30 percent compared to the USA counterparts (Gordon et al. (2012)[8]). According to GTM research analyst Shyam Mehta[9], the cost reduction exhibited by China manufacturers than the USA manufactures is 25 to 30 percent in 2012 and Rob Wanless, Director of Business development, Solon Corporation, mentions China manufacturers' solar panel price is US$1 per watt, while USA manufactures' for similar technical specifications is US$1.20 to US$1.30 per watt. From the view of China manufacturers, China has a cost advantage of US$0.20 per watt on modules and US$0.10 per watt (Gordon Brinser et al.(2012)).

According to Alan Goodrich (Solar PV expert at NREL) comparing the case of manufacturing the solar cells from China such as Suntech and further shipping to USA through sea route and land route to reach the solar farm in arizona, verus purely manufacturing still exhibits a 5 percent advantage(Goodrich et al.(2011)). This success they attribute to purely foreign direct investment in terms of capital investment and knowledge transfer into China. Secondly Gordon Brinser et al.(2012) claims the vertical integration and placing the plants, such as keeping the cell manufacturing in China and placing the module manufacturing (which purely involves assembly) closer to the end user (such as solar farm) turns out to be at best cost advantage. For example, Suntech adopts the above methods to have a cost advantage for its 300 MW solar farm in Arizona. However these two studies fail to tell why the China's advantage arises in the cell and module manufacturing in the China's domestic firm such as Suntech versus that of the US based manufacturer like Solarworld, hence the present research investigates the additional advantages in this research.

Section 2 puts forth the hypothesis and constructs an analytical framework and demonstrates through empirical and qualitative analysis about technology spillover from domestic semiconductor firms and global solar firms to the domestic solar firms of China. Section 3 provides interpretation of the resultsand presents micro evidences of technology spillover at industry level using patent data and supplements with the case of Suntech solar PV manufacturer's evolution and developments.Section 4 briefly summarises the key findings of the analysis and presents policy implications.

ANALYTICAL FRAMEWORK

Hypothesis

Prompted by the foregoing observations, the following hypotheses are postulated:

Conspicuous strength emanates from the institutional sources that arose the China's solar industry in recent years. Interaction between indigenous semiconductor industry ("East") and newly emerging solar industry in absorption of global best practices ("West") thereby fusion between them were the reasons for conspicuous strength.

The fusion can be achieved through joint work between industry's intensive effort in learning global best practices for exploring new business and government's catalytic role for the attainment of decarbonisation society for nation's sustainability.

Analytical Model

Based on the discussion in the preceding section numerical analysis was conducted by utilizing two models, as follows:

(1) Evidence of spillover effects from external knowledge stock of rel evant industries.

It is generally demonstrated that the production prices of the solar cell depends on the actual production and the internal resources of a firm (Labor and capital). In addition, the process innovation that arises from the indigenous efforts along with a capability to assimilate the external knowledge stock enhances the overall production and thereby the production price of the solar cell.

$$P_r=F(Y, L, K,T, T_s) \quad (1)$$

where P_r: solar cell production prices,

Y : actual production of solar cells,

L: number of employees in the solar cell firms,

K: capital stock in solar cell firms,

T: gross technology stock (by terms of TFP) of solar cell firms, and

Ts: technology stock relevant to solar cell production.

Taylor expansion to the secondary termleads to the following analytical model:

$$lnP_r = A + \alpha_1.lnY + \beta_1.lnT + \gamma_1.lnT_s + \delta.lnL + \varepsilon.lnK + \alpha_2.lnY.lnT + \alpha_3.lnY.lnL + \alpha_4.lnY.lnK + \beta_2.lnT.lnT_s + \beta_3.lnT.lnL + \beta_4.lnT.lnK + \gamma_2.lnT_s.lnL + \gamma_4.lnT_s.lnK + \delta_1.lnL.lnK \quad (2)$$

where A: coefficient, α_i , β_i, γ_i and ε_i (i= 1 to 4) coefficient corresponding to the respective explanatory variables.

The evidence of the spillover can be further confirmed by checking the magnitude of the derivative as depicted by equation (3). When the magnitude is negative it demonstrates that the external technology stock relevant to solar cell production provides spillover effects on China solar cell firms' for enhanced production to achieve cost effective prices.

$$\partial lnP_r/\partial lnT_s = \gamma_1 + \beta_2.lnT + \gamma_2.lnL + \gamma_4.lnK \quad (3)$$

(2) Evidence of spillover effects from global solar MNC's knowledge stock.

Solar cells production can be depicted by the following function:

$$Y = F(L, K, T_i, T_g) \quad (4)$$

where T_i: Technology stock of solar cell firms by terms of patents, and

T_g: Technology stock of global solar MNC firmsby terms of patents.

Gross technology stock can be expressed in terms of$T_i$and assimilated spillover technology$z.T_g$ (Watanabe et al.(2000))as follows:

$$T=T_i+z.T_g \quad (5)$$

where z: assimilation capacity.

Thus equation (4) can be depicted by the following Cobb-Douglas type function:

$$Y = A.L^{\alpha}.K^{\beta}(T_i + zT_g)^{\gamma} \quad (6)$$

where A: scale factor and, α , β andγ: elasticitiescorresponding to the respective explanatory variables.

Taking logarithm of equation(6), following linear functioncan be obtained:

$$lnY = lnA + \alpha.lnL + \beta.lnK + \gamma.\ln T_i(1 + z.T_g/T_i) \quad (7)$$

When 1>>$z.(T_g/T_i)$, Y can be approximated as follows (Watanabe et al., 2000):

$$lnY = lnA + \alpha.lnL + \beta.lnK + \gamma.lnT_i + \gamma.z.(T_g/T_i) \quad (8)$$

Assimilation capacity can be identified from equation (8) as

$$z = z.\gamma/\gamma \quad (9)$$

Data Construction

The data of the dominant domestic solar firms of China involved in solar cell and module manufacturing included details on labour, capital, production, prices, registered year and market share as listed in Appendix A1. The firms' technology sources were investigated either from joint ventures or directly funded from foreign funds. Additional information included in looking into their official web links to access their annual reports and obtain product types, models, capacity and yearly growth. Similarly, data was collected for the top ten global solar firms in terms of market share, labour, capital, production, price and other firm details.

Empirical Findings

Facing a paradigm change from a fossil fuel based society towards a decarbonisation society, China's industrial institutions has evolved a conspicuous strength in solar PV manufacturing by producing useful components in the value chain and initially targeting export market and further diffusing into its domestic installation. This approach has aided the evolution and growth of China's leading domestic solar PV firms.

Table A1 summarizes the current leading domestic solar firms involved in solar cell and module manufacturing.

The top 74 domestic solar PV cell and module manufacturers form the major share of cell and module manufacturing that amounted to a actual manufacturing capacity of 30325 MW which exceeded world solar panel production in 2011 which amounted to 29534 MW.

(1) Evidence of Technology spillover from Semiconductor industry

Taking the top 74 solar PV cell and module manufacturers production which amounts to a total capacity of 30375 MW in year 2011 which equates closely to the world solar PV installation in 2011 (as per Table1), it shows the accelerated conspicuous indigenous strength building occuring by the extraneous knowledge spillover from the semiconductor industry. Hence their knowledge assimilation aspects from the existing semiconductor industry was determined as per equation (2):

$$\begin{aligned} lnP_r &= -1.016 + 0.281 lnY - 1.499 lnT - 0.180 lnY.lnT_s - 0.048 lnY.lnK \\ &(-2.52)^{***}(2.76)^{***}(-2.88)^{**} \quad (-3.57)^{*}(-3.85)^{*} \\ &+0.209 LnT.LnL + 0.012 LnT_s.LnL + 0.031 LnL.LnK \; adj.R2 = 0.466(10) \\ &(2.83)^{***}(-3.21)^{**} \; (3.89)^{*} \end{aligned} \qquad (10)$$

*, ** and*** indicates significant at the 1%, 3% and 5% level, respectively.

Partial differentiation of P_r with respect to T_s leads to elasticity of spillover technology to production price, as follows:

$$\partial lnP_r / \partial lnT_s = -1.499 \; (\partial lnY / \partial lnT_s) - 0.0148 lnT + 0.012 lnL \qquad (11)$$

Utilizing this relation the sensitivity of price with respect to spilled-over technology stock for the different firms under this study was computed (refer Table A1). Fig. 5 demonstrates the elasticity of spillover of different firms (1 to 74)in the order of increasing market share. Results shows that the negative magnitude of the sensitivity which confirms that the knowledge spillage for each firm from semiconductor industries is positive. Comparing the magnitude between the firms, it is obvious that the first ten firms exhibits increased assimilation capability as compared to the rest of the domestic which implies the importance of spillage to achieve decreased price.

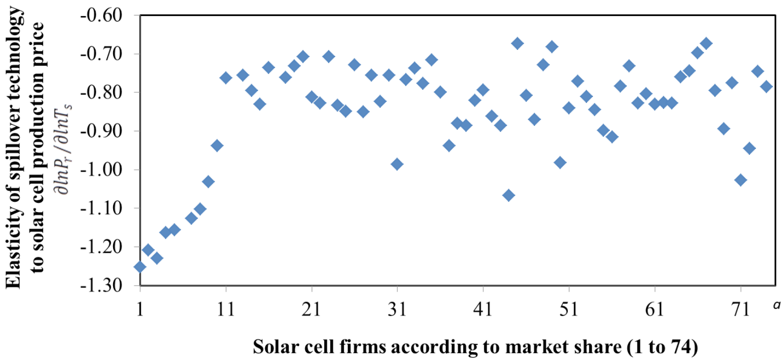

Figure 5: Effects of technology spillover from semiconductor industry to China's Indigenous 74 solar cell firms (2011).

[a]Numbers indicate firms examined in accordance to their market share (No.1 is the largest market share while No.74 is the smallest market share, see Table A1).

Evidence of Technology Spillover from Global Solar Firms

Taking the top 23 solar PV cell and module manufacturers among the 74 domestic China solar cell and module manufacturers, their manufacturing output amounted to 14340 MW which equates to ~ 50% of China's manufacturing output in 2011. Hence their technology stock build-up is of importance from knowledge assimilation aspects from the global solar firms were investigated as per equation (8):

$$lnY = -1.557 + 0.237lnL + 0.023lnK + 0.041lnT_i + 0.010\left(\frac{T_g}{T_i}\right) \quad adj.R^2 = 0.872 \qquad (12)$$
$$(-17.17)^*(2.91)^*(1.02)^{***} \quad (1.48)^*(37.62)^*$$

* and *** indicates significant at the 1%and 5% level, respectively.

By equation (9) assimilation capacity z can be identified as0.24 of spillover technology from global solar firms.

Qualitative Analysis Results: Technology Transfer Modes to China Solar Industry

Technology learning and spillover are key to the evolution of new industry. Technology transfer includes all mechanisms by which a domestic firm can acquire useful knowledge from a foreign firm on the critical aspects of the solar value chain's components and system level (Maskus 2004). Based on the technology literature various knowledge transfer modes could exist and were observed within the Chinese solar industry:

1. Licensing: Codified knowledge and exclusive right to exploit is sold by

one party to another, Example Australia PV Science and Engineering Co., helped transfer solar cell manufacturing technology to Jingao Solar Co., Ltd., in MAY 2005[10].

2. Movement of capital through FDI: Ownership of a productive asset by a foreign entity into the host country. Example, the equipment that is imported is pretty matured for crystalline silicon technology which is a dominant technology when China evolved the solar PV manufacturing industry,
3. Movement of people through migration, travel and foreign education of students and workers. Example: Suntech CEO was educated in New south wales (NSW) and later when he setup this firm in China he setup collaboration with NSW and has taken up as a visiting professor at NSW,
4. Diffusion through media and the internet of disembodied knowledge such as access to international patent database, competitor website and international scientific articles,
5. Integration of benefits into global value chains from foreign technology transferred within the supply chain (Fu, Pietrobelli and Soete 2011), and
6. Knowledge spillover from other domestic related industry through labour mobility.It is empirically proven that in China labour mobility during inter-industry results in salary hike and this is an incentive for such knowledge transferor.

FDI SUPPORTED KNOWLEDGE TRANSFER

Among the various modes, FDI supported knowledge transfer can be expected as a dominant factor. It is widely understood that knowledge from technically advanced countries increasingly transcends national boundaries and contributes to the domestic technological development. FDI plays a significant role in the country's economy and China because of skilled labour availability exhibits a good absorbability and productivity. For example FDI increased from 0.9 billion in 1983 to US$ 74.8 billion in 2007 and have been instrumental in developing healthy electronics industries as listed in Table A4. Productivity spillover is observed as one of the benefits of FDI. However as pointed out in Table 6, the presence of FDI in all the leading Chinese solar firms is minimal.

Among the world's 15 largest solar cell or module producers in 2010, nine firms operate in China and two had foreign direct investment. Canadian Solar was founded in 2001 and has seven wholly-owned manufacturing subsidiaries across China. JA Solar was founded in 2005 as a joint venture between the

JingLong Industry and Commerce Group Co., Ltd., the Australia PV Science & Engineering Company, and the Australia Solar Development Company. Hanwha SolarOne was initiated by Korean Hanwha Group by acquiring in 2010 the China's Solarfun Power that was originated in 2004. The two companies that were either wholly owned subsidiary of a foreign company or as a joint venture with a foreign company was JA Solar and Canadian Solar. JA Solar was a late entrant to the Chinese PV industry, coming well after home-grown firms like Suntech, Yingli, Trina, and Jiawei Solar China. While Canadian Solar was founded in 2001, there is no indication that its foreign counter part helped to drive enough technology transfer to fuel the growth of China's solar industry. Thus FDI in the traditional sense of technology transfer, and knowledge spillover, has not been a significant factor in the development of China's solar cell and module manufacturing industry and has been a predominantly home-grown industry.

Table 6: Technology source of China's top 10 solar PV firms

Chinese Firm	Starting year	FDI-Joint Venture links
Suntech	2001	None
Yingli	1998	None
Jingao	2005	Australia
Solarfun	2004	None
Sunenergy	2004	Australia
Canadian solar	2001	Canada
Ningbo Solar	2003	None
Trina solar	1997	None
Jiangsu Jiaoseng	2004	None

Technology learning, knowledge spillover from previous industries

The dominance of the China's solar power industry is generally being attributed to: (1) the cheap labour availability of skilled members (2) availability of the matured high end equipment which ensures same silicon based solar panels with high quality as that of the international manufacturers. A closer study shows China builds its factories faster in setting up the necessary supply chain. For example, by 2006, Suntech power of China was manufacturing a million solar panels in an annual year. Today China overall manufactures about 50 million solar panels and over half the world capacity in 2010[11] and thus it has exhibited a doubling the production capacity roughly every year. The aggressive scaling of production factories are attributed to the labour availability of other complimentary industries like construction industries. Alongside with its production, it constantly craves for new innovation to enhance its efficiency of the product. Traditionally China set forward to scale their production in standard technology but as supply exceeds demands, to stay afloat globally it has to constantly adopt new innovations to reduce cost and enhance product performance.

To understand the reasons for the availability of skilled labour once needs to look into the possible knowledge spillage. Knowledge is seen as a public good ((Nelson (1959),Balzat et al.(1962)). Spillover is a positive externality due to the public nature of knowledge.Spillovers arise if firm A can benefit from firm's B R&D activity without sharing the R&D costs of B (Branstetter (1998)). For a new industry to tap existing patents from relevant industries may be a good leverage: "By technological (or R&D) spillovers we mean that a firm can acquire information created by others without paying for that in a market transaction" (Grossman & Helpman, (1991)). Many researchers have studied the spillover due to the geographic proximity such as Anselin et al.(2000), Jaffeet al.(1993); while trade related FDI related spillover has been studied by Grossman & Helpman (1991) and Kinoshita (2001).

Assimilation of existing knowledge from relevant know-how along with technology transfer have been key in the indigenous innovation and thereby the world dominance of the solar PV manufacturing in China. Know-how refers to any methods, techniques, processes, discoveries, inventions, innovations, unpatentable processes, technical information, specifications, recipes, formulae, designs, plans, documentation, drawings, data and other technical information and identified in a tangible form.

Among the various institutions private firms have been the major force in pursing R&D and process innovation to become cost-competitive. This has been favoured by the National innovation system (NIS) that is composed of the private firms, government agencies, foreign subsidiaries, their supply chain, academia and research institutions and their actors and various linkages (Balzat et al.(2004)).

Next absorptive capacity has been addressed on human capital as instrumental in productivity (Griffithet al.(2003) and (2004), Miller et al.(2000)). In the case of China, the absorptive capacity through different channels for knowledge spillovers such as R&D, FDI and exports have been through the right calibre labour intake into firms that they have employed such thattheir interaction effects have resulted in the increased firm production. In such a view, foreign firms have aided as an active player in the NIS through knowledge transfer, knowledge creation and through participation of competition. On an average, foreign invested firms (MNEs) have demonstrated the real manufacturing procedure as a predecessor to the domestic firms, such that it was easy for the domestic firms to mimic and practice. For example, the developments of some industries in China such as integrated circuits, automotive have been fuelled by the foreign invested enterprises. The presence of these MNEs helped to fuel development of indigenization in China through technology transfer and rapid diffusion of know-how. The spillover takes place through (a) inter firm mobility of workers and managers (b) industry supply side and customer side relation (c) exports by multinational affiliates (d) utilization of supply chain actors from other relevant industries. Blakeet al.(2009), study on 998 Chinese manufacturing firms showed labour transfer between foreign invested firms and local firms affect the productivity of local firms positively when they employ foreign trained workers. Their results confirmed absorptive capacity of local firm is important for spill over to occur and to increase productivity.

Productivity spillover takes place when worker or manager in foreign MNC resigns and joins a domestic firm or starts their own firm specific to that industry. Thereby they exert a positive impact in the industry and the foreign firms in terms of productivity. Fosfuriet al.(2001) showed that the multinational had to increase salary to retain worker after they trained him, else a technology spillover may result to a local firm.

One possible knowledge source can be its own domestic know-how by studying the technology similarities between industries which is one observation that can be made between the new solar industry and existing semiconductor industry in China. Their technology similarity can be observed by closely observing the process plan of the silicon material as shown in below figure.

China solar manufacturing has been essentially dominant in C-Si technology compared to TF-Si technology. The dominance in the first generation C-Si silicon technology may be due to rich source of raw materials and technology maturity; however one reason that can be postulated is the history of success in China's semiconductor industry even with complex technological nature. Figure 6 shows how the semiconductor and solar industries are linked through the silicon value chain.

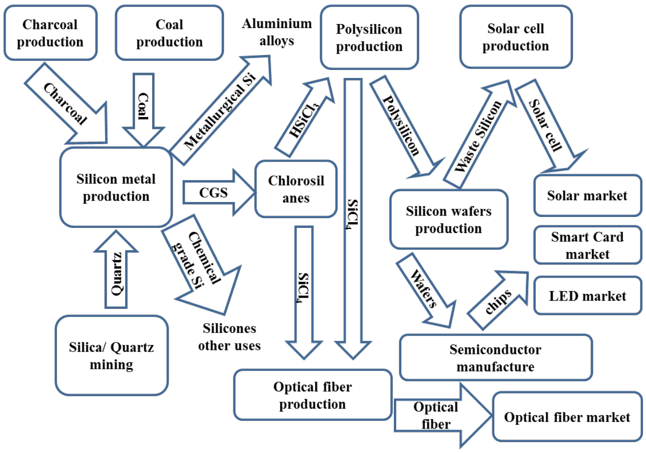

Figure 6.The production chain for high-purity silicon and its use in semiconductor, solar cell, smart card, LED and optical fiber manufacturing.

To understand why China chooses to focus on the first generation Solar PV cell and module manufacturing we could investigate its industrial history. China has been successful in the electronic industry in 1990s and has made significant progress as seen in Fig. 7. Hence there is significant evidence of its knowledge accumulation in the process technologies that are required for electronics manufacture (Tilman et al.(2008) and Liu X., (2001)). Table A4 lists the various electronics industries productivity and capital per capita. The production function of the Chinese electronic industry was studied earlier[12] which shows that the industry has good productivity due to skilled labour. Such healthy presence has exhibited a strong growth in revenue in both semiconductor manufacturingindustry and integrated circuit manufacturingindustry (which is also called semiconductor packaging industry).

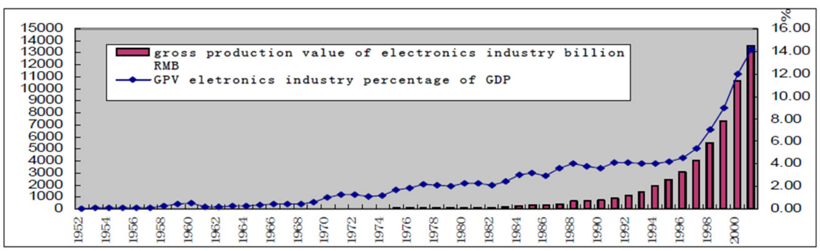

Figure 7.China's 50 year electronics industry growth

Source: Xinxin Kong, National Research Center for Science and Technology for Development (NRCSTD).

Table 7: Annual revenue of semiconductor and IC industries in China (*2000-2010*).

Year	Semiconductors	Integrated circuit (IC)
2000	14.4	11.4
2001	17	13.8
2002	21.4	17.7
2003	30.7	25
2004	43.4	8.3
2005	56.5	46.4
2006	71	59.5
2007	88.9	73.9
2008	103.8	85.9
2009	101.2	18.1
2010	132	108.6

Source: Price Waterhouse[b] (2011).
[a] Billion US$ at current prices.
[b]www.pwc.com

According to NREL analysis US manufacturing facility is automated as compared to China manufacturing facility which is more labour based, yet Chinese products have demonstrated 18 to 30 percentages increases[13.14]. This possibly shows that the inducted skilled force and their internal training can meet the final customers of the solar production value chain. This evidence of quality production that meets the end requirement shows that the technology transfer (1) through equipment manufacturers, (2) through licensing and research collaboration, and (3) know-how from the Chinese diaspora have been well absorbed and assimilated into useful process capability of solar manufacturing. For example, technology transfer from American, German and Swiss equipment makers has allowed Chinese manufacturers to initiate and scale the solar production lines into their factories in a short time span (Gordon Brinser et al.(2012)). Thus it is convincing that China's labour force has acquired skills from other relevant industries and foreign direct invested MNEs.

DISCUSSION

Moving towards a renewable energy adoption, China has coevolved a conspicuous Industrial strength to evolve solar PV manufacturing ability into order the growth and adoption and to evolve a new export market to cater the world needs. In a very short time span as seen in Fig. 1, it exhibited a rampant growth in production capabilities. Table A1 summarizes current state of China's leading solar PV manufacturing by order of real production, market share and price in 2011.

Comparative Advantages

A broad investigation may show that China has the following advantages:

(1) Advantage of scale
(2) Advantage of vertical integration
(3) Availability of cheaper skilled labour.

(1) Scale

China's core advantage in cell manufacturing can be seen to arise from scale and vertical integration. Comparing a 60 MW plant in USA and a 2000 MW plant in China shows that 10 percent reduction in material cost and 50 percent reduction in equipment cost from Chinese equipment vendors, due to supplier leverage and captive production strategies (NREL report, Goodrich et al., 2011).

According to Rob Wanless, Director of Business development, SOLON Corporation, most of the facilities in China of the leading manufacturers have larger facilities than the USA manufacturers (Gordon Brinser et al.(2012)). The typical top tier manufacturing plant in China produces annually about 500 to 1000 MW which is higher than the typical manufacturing plant capacity of USA which ranges between 40 to 100 MW. Thus according to Melaine Hart, Policy analysts for Chinese Energy and Climate policy at the centre of American progress, China gets advantage as being a manufacturing powerhouse (Hart, 2011).

According to Goodrich of NREL[15] cost comparison of cell manufacturers shows:

(i) US 60 MW automated plant shows US$0.89 per watt.
(ii) China 60 MW plant shows US$0.85 per watt.
(iii) China 2000 MW plant shows US$0.82 per watt.
(iv) China 2000 MW plant with discounted equipment US$0.80.
(v) China 2000 MW plant with discounted materials US$0.73.

Thus purely comparing a 60 MW manufacturing plant of China versus USA shows a minimum of 4.5 percent which is primarily due to low cost of relevant skilled labour. Adding the advantage of scale and vertical integration and domestic equipment and materials supply, Chinese cell manufacturers show an 18 to 20 percent manufacturing cost advantage.

(2) Vertical Integration

The top tier Chinese solar manufacturers also aim to benefit from vertical integration. For example, manufacturing both cells and modules helps in manufacturer's economies of scale.

(3) Availability of cheaper skilled labour

Published literature more relates production to the resources availability of a firm (viz., labour, capital and technology stock). For example, as per year 2011, labour rate in China solar work force costs US$2.13 per hour as compared to USA work force where it would be around US$13.33 per hour, similarly a manufacturing engineer annual salary is US$8,171 in China versus a similar capable engineer's annual salary of US$75,110 in USA (Goodrich et al.(2011)). Thus for 500 MW capacity of Cell and Module facility, a China factory has 1492 employees and 508 employees, respectively, as compared to a USA factory where it is 296 and 104 employees, respectively. The difference is attributed mainly to the automation in the manufacturing. Based on the export acceptance record by the West in the recent years, the quality of the Chinese solar panels can be deemed to be acceptable as that of the West's solar products, since they have been swappable in a final solar PV project, and can infer that the labour supply to the China solar factories have met the automated factory quality of USA solar factories, possibility with the necessary job based trainings and equipment and tools. However it interests us that how such apt labour force gets supplied to the China's solar industry is scalable in number in the short time span.

Researchers have identified the importance of tacit knowledge (or personal knowledge) in addition to the explicit form of knowledge that is available in the form of patents and international journal papers.Also literature shows the importance of externalities as a source of increasing returns and productivity growth. Technology spillovers exist and the R&D of nearby firms produce positive effects, so that firms could get large benefits from spillover (Griliches (1998) and Anon (1998)). These could come into a firm in the form of skilled labour hiring and training, use of firms of related industries' supply chain, manufacturing best practices that are borrowed from other related industries, etc. This presence of R&D spillovers result because the technology distance

(Jaffe (1986))between the firms that generates the spillover and the receiver is short. From such a view, we find that semiconductor industry has much technological similarities to solar industry and hence the manufacturing know-how or the personal knowledge of the labour becomes relevant. Such addition of semiconductor manufacturing trained people to a solar PV manufacturing firm enhances the absorption capacity (the capacity of the receiver to absorb technology from the other sector) and the assimilation capacity (the capacity of the receiver to assimilate and then utilize the technology absorbed from the other sector). The assimilation capacity has a direct impact on the speed of technology adoption and thus ramp up the production capacity of a firm. Fig. 8 clearly relates the role of learning to a whole dynamism in assimilation, innovation emergence, production increase and thereby price decrease of the product.

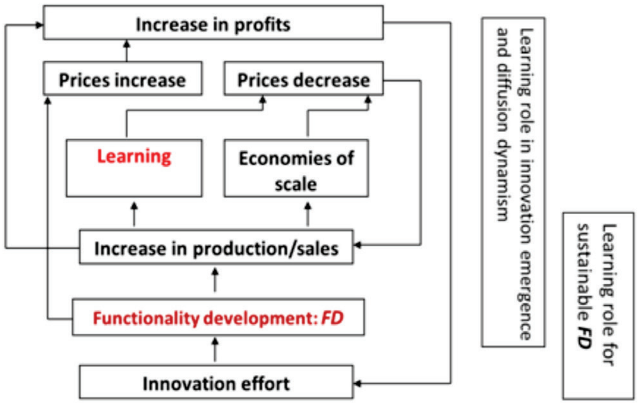

Figure 8.Policy's role in leveraging learning for price decrease

Source: Watanabe et al. (2000).

The empirical findings in this study show that the external knowledge spillovers (FDI and external R&D) have proved elusive. Additionally, this study has pointed out that the domestic industries' know-how interacts with external technology through an integrated learning process and thereby the TFP (total factor productivity). The study elucidated the structural sources of the high level of conspicuous strength building in China's domestic solar firms. Focusing on their exploitation of semiconductor industry by the assimilation of spillover technology, the motivations of private firms and increases in production and price reduction are identified, particularly in domestic originated firms within a short time span.

3.2 Effective Knowledge Spillover Between Industries

(1) Clear Linkage of Semiconductor and Solar Technologies.

In order to show the micro-evidence in the form of clear linkage between semiconductor and solar patent one could resort to compute the backward citations to show the knowledge spillage. However at this point, the China patent database does not have the backward citation and hence a different method was pursued. Technology can be classified by the International patent classification (IPC) code. Accordingly taking the top 100 technologies based on the IPC-4digit classification for semiconductor industry and comparing with solar industry, the numbers of patents in the two different industries were determined using Thomson database.Among these 100 IPC classes, study shows 80 IPC classes are common between semiconductor and solar industries. Table A5 lists the most common technologies between the semiconductor and solar industryand thenumber of patents originated from the solar and semiconductor industries. To propose that relevant knowledge stock from the semiconductor industry (*Pat_IPC_Semicon*) has a direct correlation to the knowledge stock in the solar industry (*Pat_IPC_Solar)*, a linear regression can be shown as follows:

$$\underset{(-3.34)^{**}\ (32.38)^{*}}{Pat\_IPC\_Semicon = -268.291 + 0.898 Pat\_IPC\_Solar} \quad adj.\ R^2 = 0.930 \qquad (13)$$

* and ** indicates significant at the 1% and 3%, respectively.

(2) Evidence of relevant know-how from China's semiconductor industry

Table 8 lists the top technologies (25 technologies) of China solar industry origin.Analysing these patents' IPC codes it is clear that they are common to semiconductor industry. Thus it is convincing that the know-how of the semiconductor industry is relevant to the inception and growth of the China's solar industry. For example, H01L is a focused technology classification in the field of semiconductor process and figure 9 shows how patents have been growing specifically from China solar firms in the recent years. This exhibits the absorption and assimilation trend within the solar industry from the semiconductor manufacturing know-how and further transforming into useful innovations to support solar manufacturing capability.

Table 8: Top 25 technologies of China solar expressed as IPC codes (*2012*)

IPC (4 characters)	Patent Count
H01L	1109
C30B	246
C23C	87
C01B	73
B81C	60
G02B	54
B01J	52
H02N	48
B81B	45
G02F	42
H01M	41
G01N	41
H02J	39
C08L	39
A61K	38
C03C	35
C09K	35
C23F	31
C04B	31
B32B	30
H01J	29
B82B	29
C22C	28
C07C	26

Taking patent count as one good measure to check how China has a good innovation base in semiconductor industry (Price Waterhouse (2012)) the total number of patents of China (*Pat_CS*) was regressed to the global number of semiconductor patents (*Pat_GS*) on a cumulative basis.

$$Pat_{CS} = -817.853 + 0.411 Pat_{GS} \quad \text{adj. } R^2 = 0.980 \qquad (14)$$
$$(-3.05)^{**} \; (20.90)^{*}$$

* and ** indicates significant at the 1% and 3% level, respectively.

Thus equation (14) shows China has a healthy growing stream of patents similar to the global semiconductor patents. This shows there is a growing population of innovators in the semiconductor manufacturing field and thus could directly contribute to the manufacturing of solar industry due to the technical relevance as pointed out in earlier paragraphs. Accordingly we see enough reasons for the solar industry to induct the skilled innovators from the semiconductor industry which would have been a key causal reason for the solar industry growth. For example, Figure 9 shows the conspicuous strength of the H01L technology class from the solar industry since 2005 which possibly would have influenced by the presence of relevant knowledge stock and the people stock in the semiconductor industry, due to the common technology relevance as per equation (13).

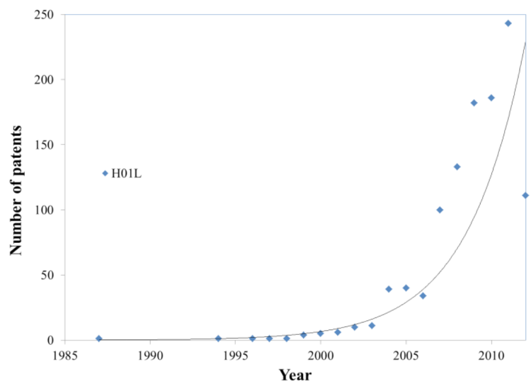

Figure 9: Technology trend in H01L patents from the China solar industry

Also a specific keyword search of China's academic publications specific to solar cells (in Engineering Village Database of international journals) shows the important frequently occurring keywords. These give a clue of their research focus. Fig. 10 shows the technical keywords searched specific to the solar cell technology and specific to China. The keywords signify the semiconductor related and process related keywords and that shows the focus of the academic research which is inline to the industry.

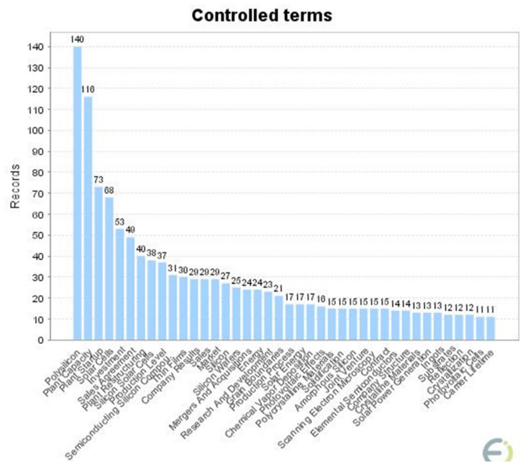

Figure 10: Frequent keywords of China originated solar journal papers.

The other promoting reasons for spillover are due to geographic proximity of placing the solar PV industry in the same industrial clusters of semiconductor industry. For example, one of the key presence of the PV industry cluster is in the pearl river delta (Mark Ng 2011) which is known for the semiconductor industry and this has a strong influence in supporting useful labour mobility, capital resources availability and easy identification of supply chain partners for the newly evolving industry.

China's National Subsidy Program

Subsidies are designed mainly to position China as the global leader in solar manufacturing and essentially not anti-competitive, according to Melaine Hart, Policy analyst for Chinese energy and Climate Policy at the Centre for American Progress. As Robert Petrina, Managing director at Yingli green energy Americas Inc., explained at the ITC conference, "Government incentives for solar projects have been very important in lowering net costs so that the projects can achieve these goals and are implemented. However with incentive levels declining on an unpredictable basis, there has been tremendous pressure to maintain the all in total cost for the projects at levels that continue to be economically viable and drive adoption, preferable, and ultimately without incentive support".

China's government has implemented three important policies to stimulate the solar PV industry; (i) feed in tariffs at national and regional level (ii) the tendering policies (iii) the renewable portfolio standards. The feed in tariffs accelerates development of the renewable energy infrastructure and the tendering policies are helpful to get competitive prices (Zhen et al.(2011) and Wiser et al.(2002)). Table 9 summarizes the various subsidies and benefits provided by the government to its solar PV production chain.

(i) Rural electrification: Launched in 2002, it aimed to provide electricity to rural areas of China that lacked grid support. By the end of 2005, 721 wind-solar PV power stations were accomplished in west part of China and benefited 1.3 million people.

(ii) Feed in tariffs (FIT): Since 2006, the FIT price was determined as per "cost plus reasonable price" to electricity supply to grid system. The national feed in tariff was put on hold "indefinitely" because the cost of solar power was deemed too high in 2006. But in Aug 2011, the government reinstated the FIT for solar PV industry. In addition, favourable regional subsidies in terms FIT were announced in Zhejiang, Shandong and Jiangsu.

(iii) Golden sun: Launched in 2009, helps to cover 50 to 70 percent of costs to cover utility scale solar projects and other infrastructure and targets towards 1000 MW capacity build up.

China uses the national industrial policy[16] which is a very clear and specific strategic national policy that directs (and then promotes) the development of a specific industry. The pinnacle of industrial policy in China is the five year plan. China's 12th five year plan clearly articulates the China's goals for the industry. It identifies the solar PV as one of the seven new strategic industries for development. For example China plans to invest US$100 million to build power projects using Chinese solar panels in 50 African nations(Yang et al.(2010)). In its 11th five year plan it spent US$309 billion on energy efficiency and environmental protection measures and today four of the world's five largest photovoltaic solar cell manufacturers are Chinese domestic firms. Over the next five years, the Chinese central and local governments are expected to focus on resources and potential opportunities to further enhance.

The five year plan (2011-2015) developed by Ministry of Industry and Information Technology for solar industry was released in Feb 2012:

(a) Reduce the cost of domestic solar power to 0.8 Yuan (about US $0.13) per kwh by 2015 and 0.6 Yuan (about US $0.10) by 2020.

(b) The cost of solar panels in China will drop to 7000 Yuan (about US$1100) per kw by 2015 and 5000 Yuan (about US $800) per kw by 2020.

(c) The plan requires China's leading polysilicon manufacturers to reach a

50000ton annual production capacity (per firm) and leading solar panel makers to reach 5 gigawatts (annually per firm) by 2015.

(d) China will further help solar companiesincrease their annual sales, with atleast one firm reaching 100 billion Yuan (about US$16 billion) in sales and 3 to 5 firms reaching 50 billion Yuan (about US$8 billion) in sales by 2015.

(e) Increase the conversion efficiency of monocrystalline silicon solar cell to 21 percent, polysilicon cell to 19 percent and amorphous silicon cell to 12 percent by 2015.

(f) Eighty percent of solar equipment and auxiliary materials will be produced domestically.

(g) Thereby it aims to have a minimum installed capacity target of 5 GW by 2015 and 20-30 GW by 2020 such that these large scale capacities is being planned to be placed in deserts.

Such plans that treated solar industry as its strategic focus are the key reasons for the China's solar manufacturers to conspicuously grow from just 2 percent of the market in 2003 to 45 percent in 2010. Other countries such as Germany and Japan have industrial policies too. China support has been on direct manufacturing policies including preferential loans, tax incentives (including sales/value added tax waivers, preferential tax rates, income tax credits, property tax credits, income tax credits, property tax credits, research and development support, central government planning, local and provincial policies, domestic proprietorship requirements and facilities, land and training grants. The other is indirect deployment policies designed to promote demand for photovoltaic solar, direct subsidies, feed in tariff and local and provincial policies.

In 2006, China made key solar PV technologies part of the pillar R&D support scheme which provided funding for the commercialization of solar technologies by Chinese manufacturers. Recipients include solar PV manufacturers, including Wuxi Suntech, Baoding Yingli green energy, Changzhou Trina Solar ad Xinjiang new energy, and silicon manufacturers including Sichuan Xinguang Silicon and Luoyang Silicon Technologies. The local government provides loans to solar PV manufacturers and not grants that need to be payable. According to Shah (Gordon Brinser et al.(2012)), the Chinese government gave US$30 billion to its solar firms by opening a line of credit to aid manufacturing cells and modules. According to online investment magazine Motley Fool, LDK solar has a credit line of US$8.97 billion, JA solar has credit of up to US$.4.42 billion, Suntech has upto US$7.29 billion,, and Trina solar another US$4.3 billion. Such financing is difficult to obtain in open market due to least competitive advantage. Thus it is convincing that China government focused between 2006 to 2011 mainly manufacturing and due to evidence of poor domestic installation, it mainly targeted the export market (West) and thereby diffused useful technologies and evolved a new industry in its soil. The economic literature is full of evidence that international trade is an important channel for technology diffusion (Bin Xu, (2007)).

Table 9: Credits, guarantees, subsidies and grants for solar manufacturers in China[a]

Features	**National Provincial and Local**
Domestic Proprietorship required	Yes
Sales/value added tax waiver	Yes
Property tax credits	Not applicable
Subsidized cost of debt	3-4.5%
Subsidized debt limit	80%
Features	**National Provincial and Local**
Delay in processing subsidized debt	<1 year
Facilities grant	100%
Land grant	Discount purchase (land use right)
Training grant (millions USD)	Yes
Effective corporate income tax rate	21%
Income tax credits	20 year holiday
Loans/ Loan guarantees	$30 billion total credit line from China development bank.

Sources: Alan Goodrich, Ted James and Michael Woodhouse, Solar PV manufacturing cost analysis: US competitiveness in a global industry, Stanford University, Precourt institute for energy, 10 Oct 2011.

[a]Chinese Renewables Status Report October 2009, The Renewable Energy Policy Network for the 21st century.

Microanalysis: The case of Suntech Solar PV manufacturing capabilities

Suntech[17] was one of the earlyfirms engaged in solar manufacturing and is now the leading firms in the world's silicon solar panel manufacturers. The firm started since 2001 and has become global, spreading to 80 countries. Its founder Dr. Shi Zhengrong graduated from Changchun University of science and technology in China in 1983 and received masters in laser physics from Shanghai Institute of optics and fine mechanics in 1986 before entering University of New South Wales in Australia. He believed in research and development and had close cooperation with academia such as University of south wales (Australia) specifically in new generation technologies.

Suntech started production since 2002, and by 2005 it was ranked by Photon International magazine as the world's top 10 PV cell makers in 2004. In 2005, with the support of Wuxi government it was listed in New York stock exchange and later released into a fully-fledged private enterprise. It proved its technology to the nation by winning the contract to supply the solar panels for the revolutionary Bird's Nest of 2008 Olympics which was a 130 Kilo watt solar installation. Suntech technology delivers a 19 % for monocrystalline solar 17% conversion efficiency and for second generation (polycrystalline PV cells in 2009) it showed 17% efficiency. In 2011 it crossed the mark of 2 GW annual production capacity.

For example, the Suntech researchers brought in a complicated technology of the 1990s, that depended on sophisticated processes like photolithography and vacuum deposition from the labs of the University of South Wales, Australia, and showed a clever way of incorporating to a production assembly line with reducing cost with improvement of performance of 10% from the initial 205 watts range. They setup a pilot line in 2009 and faced challenges during production scaling.

A patent search of Suntech shows it has utility and application patents of 291in China patent office and in outside China it has submitted 1551 patents.

In 2010, the US secretary of state confirmed from his visit to Suntech Power that he observed the automation with advanced high efficiency product technology was a key in its success. Indigenously they have shown indigenous process innovations to reduce silicon consumption, for example Suntech's annual report says the production team has found ways to use thinner silicon wafers to enhance production by reducing the silicon wafer thickness (180 micron range)[18]. The manufacturing processes have been constantly revised to show that their learning process is enhancing. For example, the conductive metal lines that collect electric charge from the silicon aren't created with standard methods like screen-printing process; instead, Suntech uses a proprietary process to deposit much thinner, more closely spaced lines that are more efficient at extracting electricity from the cells. The changes have allowed the firm to reach efficiency levels and cost reductions that an industry road map released in 2011 had set as targets for 2020. As Stuart Wenham the chief technology officer at Suntech puts it, "When you put all those things together, we are not only doing better than what people are doing now, We are also doing better than what they think they could be doing in 10 years." This year Suntech is poised to increase production of the new generation cells, and annually generate 500 megawatts of power—roughly 2.5 million solar panels.

In 2010, when US secretary of Energy Steven Chu gave a speech to the National press club, he pointed out that he was impressed with Suntech manufacturing competence when he toured the factory and found it to be "high-tech automated factory" and mentioned that "it's not succeeding because of cheap labour" and it had developed a type of solar cell with world record efficiencies. This convinces us the state of indigenization of China is internationally good.

CONCLUSION

In light of a conspicuous strength in solar PV cell and module manufacturing in recent years this study investigated the institutional sources of its strength. Empirical analysis was conducted focusing on the interaction between indigenous semiconductor manufacturing industry and newly emerging solar PV manufacturing industry in absorption of global best practices thereby fusion between them was demonstrated.

Noteworthy findings obtained include:

(i) Success of the fusion can be attributed to a joint work between industry's intensive effort in learning global best practices and existing know-how for exploring new business,

(ii) Technology contributes significantly to production increase in solar industry and thus an increase in technology stock by assimilation capability,

(iii) A set of 74 leading domestic solar PV manufacturing firms shows the evidence of positive knowledge spillage from the existing semiconductor industry,

(iv) The top 23 leading domestic solar PV manufacturing firms exhibits an assimilation capacity of 0.24 in learning the global best practices from global MNE solar firms,

(v) Improvement of assimilation capacity is essential for effective utilization of spillover technology, and this depends on the level of technology stock and skilled labour in the host,

(vi) A new way of identifying the technology spillover and competence growth using patent technology class has been demonstrated,

(vii) Government's catalytic role insupporting the solar manufacturing industry has aided the attainment of decarbonisation society for nation's sustainability, and

(viii) The evidence demonstrates the possibility that developing countries can take an alternative path of development with green technology industries growing by its conspicuous strength and leapfrogging into global low carbon economy.

These findings provide important policy implications suggestive to growing economies for their advancement of competitive industries:

(i) From the success of China's solar industry evolution and growth, growing economies such as India can evaluate their own conspicuous strengths based on their technology stock, exports, productivity, etc., as measures and devise roadmaps for possible inception of new industry by exploitingtheir intrinsic know-how.

(ii) The present study showed convincing facts that the global MNEs knowledge spillover to the domestic firms helped to acquire global best practices and thereby reached export quality. Thus growing economies should promote the co-existence of foreign direct invested MNEs with domestic firm evolution to promote knowledge spillover, labour mobility and supply chain evolution.

(iii) It is appealing to find that China even with initial meagre domestic installations has demonstrated its conspicuous strength through enormous production capability to become the world leading manufacturer and exporter of solar PV cells and modules. However,the West (USA and Europe) presently views China's price reduction capability as an act of dumping of the solar PV products below the manufacturing price. If proven, this may affect the China's exports.Secondly, China's energy mix presently shows solar PV sources constitutes not even 1 %. Hence it is recommended that China can develop the domestic market to sufficient level such that it meets their growing energy needs, ensure a sustainable growth for its solar PV manufacturing industry, and ensure the country to become a decarbonized region.

(iv) Having understood the technology relevance between any two different industries, growing economies should promote geographic proximity in accordance to the technology distance between two industries. This will aid knowledge spillover through labour mobility and easy supply chain formation. For example, the upcoming LED factories and sensor manufacturing industries of China can benefit from similar knowledge spillage of semiconductor industry.

(v) In order to promote more tacit knowledge spillover between industries and their firms, labour mobility should be promoted through incentives. It is risky for employees to move to other industries at elderly age, but if incentivized, they can be carriers of knowledge and induce new innovations and help emerge new industries and create conspicuous strength for the nation.

Similar investigations taking a conspicuous development of China's wind power development advancement is strongly recommended as a next step together with further analysis of learning processes as well as investigate its roots of knowledge sources.

FOOTNOTE

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APPENDIX

Table A1: List of China solar firms (*2011*)

	Registered Name	Capacity (in MW)	Employees	Registered Year
1	Suntech Power Holdings	2400	8000	2001
2	Yingli Green Energy	2000	6000	1998
3	JA Solar Holdings, Co., Ltd.	3000	5458	2005
4	Motech Industries Inc	2000	1386	1981
5	Trina Solar Limited	1900	4600	1997
7	Hanwha SolarOne (formerly Solar-fun)	1300	3989	2004
8	Neo Solar Power (NSP)	1300	500	2009
9	E-Ton Solar Tech. Co., Ltd	700	900	2001
10	China Sunergy Co., Ltd.	400	1800	2004
11	SHENZHEN TOPRAYSOLAR Co.,Ltd.(TOPRAYSOLAR)	190	848	2002
	Eging Technology Co., Ltd. Chang-zhou	250	800	2003
14	JETION SOLAR HOLDINGS LIMITED	250	900	2007
15	Anhui Tianyi Solar Energy Co., LTD	300	700	2010
16	Zhengrong Solar Company	170	600	2010
17	Bright solar energy Co, Ltd	400	500	2008
18	Best Solar Co., LTD	250	800	2007
19	BOMEX SOLAR NEW ENERGY CO.,LTD	150	600	2008
20	Nesl Solar Company	400	900	2006
21	UE Solar Co.,ltd	300	900	2007
22	Daqo New Energy Co.,Ltd	200	610	2006
23	Aode New Energy Co., Ltd	300	1200	2007
24	Risen Energy Co.,Ltd	300	1000	2002
25	Dongguan Quoncion Solar Energy Co.,Ltd	150	1000	2003
26	Jiangsu Jiao Sheng Photovoltaic Technology Co. Ltd	300	1300	2004
27	DongyingFuda Solar Power Co.,Ltd	200	800	2007

	Registered Name	Capacity (in MW)	Employees	Registered Year
28	Konca Solar (Wuxi) Co., Ltd.	100	1300	2005
29	JiangyinHareon Solar Technology Co., Ltd.	250	1500	2004
30	Hangzhou Blue Sun Solar Energy Technology Co.,Ltd	600	1500	2007
31	Chinaland Solar Company	200	1000	2007
32	Hebei JG Solar Energy Technology Co., Ltd.	200	1000	2007
33	Huayu electro-optic science and technology Limited	200	800	2009
34	GrandPower Solar INC	300	1500	2010
35	Hengji PV-Tech Energy Co.,ltd	250	1500	2007
36	Jiawei Solar China Co.,Ltd	500	800	1993
37	WinSun New Energy Co.,Ltd	350	1500	2008
38	Jiangsu Runda PV Co., Ltd.	200	1000	2009
39	Jiangsu Runner PV Technology Co., Ltd	300	1500	2009
40	Eoplly New Energy Technology Co.,Ltd	300	1500	2006
41	Sun Earth Solar Co.,Ltd	420	2000	1999
42	Realforce Power Co., Ltd	1250	1000	1999
43	Shandong Sunneeg Solar Power Co. Ltd	1100	900	2008
44	Shandong Thai haidai photovoltaic technology Co., LTD	200	700	1999
45	Shanxi Rishengda Solar Company	500	800	1999
46	Shanghai Alex Solar Industry	400	500	2007
47	SHANGHAI PUBSOLAR CO., LTD	150	1000	2005
48	Foxconn Technology Group	150	50000	1974
49	Shanghai Prairiesun Solar Technology Co., Ltd	700	350	2009
50	Winchance Solar (Fujian) Technology Co., Ltd	300	700	2007
51	Wuhu MingyuanNewEnergy Technology Co., Ltd	200	700	2005

	Registered Name	Capacity (in MW)	Employees	Registered Year
52	Jolar Technology Corporation	280	1000	2008
53	Upsolar Co. Ltd	300	1000	2006
54	Yunnan Tianda Photovoltaic Co., Ltd	400	1000	1975
55	Perfect Energy Technology Exhibition (Shanghai) Co., Ltd	400	1300	1994
56	Perlight Solar Co., Ltd	200	1300	2006
57	Zhejiang BLD Solar Technology Co.,LTD	150	800	2008
58	ZheJiangBeyondsun PV Co., Ltd	250	900	2009
59	CN Solar Technology Co., LTD	215	700	2007
60	Zhejiang Guangyi Optical Energy Technologies Co., Ltd	250	700	2007
61	Zhejiang Hengsheng Photovoltaic Technology Co., Ltd	250	1000	2007
62	Zhejiang Topoint Photovoltaic Co.,Ltd.	300	2000	2007
63	Leye Photovoltaic Co.,Ltd	200	1000	2009
64	Zhejiang Riyuewang Solar Technology Co., Ltd.	150	600	2004
65	ZHEJIANG RDM TECHNOLOGY CO.,LTD	120	600	2010
66	Longbai Group Zhejiang Co., Ltd	100	700	2007
67	Zhejiang ShinewPhotoelectronic Technology Co.,Ltd.	200	900	2008
68	ZG-Cells Group (Hong Kong) Limited	400	900	2008
69	Zhejiang Aurora PV Solar Co., Ltd	200	900	2008
70	The 48th Research Institute	1000	1000	1964
71	CNPV Dongying Solar Power Co., Ltd	600	1000	2006
72	Zhongheng Technology (Tangshan) Caofeidian Co., Ltd	150	1000	2009
73	Chinalight Solar Co. Ltd	200	400	2005
74	ET Solar Group	250	3000	2007

Table A2: List of Foreign solar firms (*2011*)

Firm	Registered Name	Employees	Capacity (in MW)	Registered Year
1	First Solar, Inc.	4700	4000	1999
2	Q-Cells Associate Companies	2750	150	1999
3	Sharp Corporation	54000	1100	1963
4	KYOCERA Solar, part of KYOCERA Corporation.	66,496	1000	1996
5	SunPower Corporation.	5400	1300	1985
6	Sanyo solar	230	1000	1975
7	REC Solar	3400	400	1996
8	SolarWorld AG	2000	1250	1998
9	Isofoton	800	550	1981

Source: QResearch (2012).

Table A3: Major PV companies' knowledge sources in China (*2007*)

Firm Name	Wafer and Ingot	PV module cell/module	PV system assembly	Notes on collaboration
Beijing Corona Technology Company ltd.			Yes	Controlled by chinese academy of sciences
Beijing new energy Technology Development Co.			Yes	Controlled by the Energy Research Institute, National development and Reform Commision
Soltech Corp		Yes		A chinese US Taiwan joint venture
Beijing YiweiFengla Electronic Technology Co.			Yes	
HebeiJinglong Group	Yes	Yes		A JA Solar Shareholder
Baoding TianweiYingli New Energy Resources co.	Yes	Yes	Yes	Working with Yingli
HebeiNingjinSonggong Semiconductor Co.	Yes			A HebeiJinglong group member
Tianjin Jinneng Solar cell co.		Yes		A pilot enterprise approved by the state development planning commisisionto produce thin film non siliccon PV cells.

Firm Name	Wafer and Ingot	PV module cell/module	PV system assembly	Notes on collaboration
Jinzhou Xinri Silicon Materials Co.	Yes			Working with Monosilicon/ ingot
JA solar Co.		Yes		JA Solar
LDK Solar Energy High-Tech co.	Yes		Yes	
Jingxing Electronic Material	Yes			A HebeiJinglong group member
Linuo PV High Tech Co. (Shandong)		Yes		
Suntech Power Co.		Yes	Yes	Working with Suntech
Trina Solar Energy Co. (Changzhou)		Yes		
Nanjing China Power PV Ltd.		Yes		
Solarfun Co. (Jiangsu)		Yes		Working with Solarfun
Shanghai Solar Energy Science and Tec		Yes		
Shanghai Chaori Energy Science and Technology Co.		Yes		
Shanghai Linyang Solar energy Science and Technology Co.		Yes		Working with Solarfun
ZhengjiangRenesola Co.	Yes			Renesolar Ltd.
Ningbo Solar electric Power Co.		Yes		
Shenzhen topray Solar Co.		Yes		Products include solar water heaters as well.
Shenzhen Chuangyi Science and Technology Development co.		Yes		Thin film non-silicon cells, BIPV
Shenzhen Jiawei Industries Co.		Yes		Products include solar lamps as well.
YunanTianda Photovoltaic Co.		Yes		
China Xinjiang SunOasis Co.		Yes	Yes	Cooperating with Tsing Hua University

Source: The Renewable Energy Industry Development Report 2008.

Table A4: List of electronics industries in China (2005)

Category	**Kf/K[a]**	**K/L[b]**	**K/Y[c]**	**Revenue/ Firm[d] (RMB 10K)**
Complete Radar manufacture	1.2311	1.9147	0.3122	59177
Special equipment and parts for Radar	1.7437	0.8224	1.5431	2321
Wireless transmission equipment manufacture	21.8544	5.1273	2.1657	30878
Exchange equipment manufacture	30.4337	8.4946	0.8575	24173
Wire communication terminal equipment	38.1237	3.113	1.1884	5812
wireless communication terminal equipment	32.8871	5.9971	0.2986	54825
Other communicable equipment	16.2522	3.6114	1.4	6457
Broadcast and TV equipment manufacture	2.9027	2.3128	2.5941	1705
TV set manufacture	28.4263	5.249	1.1604	30985
Radio and recorder manufacture	36.7231	2.9793	1.2106	10011
Video manufacture	47.223	17.3272	2.6633	42123
Other Broadcast equipment	21.777	4.1677	2.5588	2030
Complete computer manufacture	15.1064	5.0432	0.9118	24025
Computer exterior equipment manufacture	46.144	5.7214	0.9432	21388
Computer necessary accessories manufacture	16.1847	5.5873	1.0484	4654
Software manufacture	15.3015	7.5641	0.7766	5254
Calculator manufacture	45.7108	2.0051	1.2017	15477
Other computer accessories	69.5599	10.2727	2.1352	10099
Electronic micro-electrical machine	29.059	2.8293	2.668	3635
Electronic electrical wire and cable manufacture	12.0793	4.0294	0.9969	8008
Electronic storage battery	20.7358	1.6611	1.6275	5480
Electronic dry battery	78.8808	9.3314	1.5183	9131
Electronic component manufacture	29.4864	2.7553	1.3959	2821
Electronic component special material	39.4012	4.0928	2.5573	1872
Other electronic components	33.3621	2.1594	1.2209	1998

Category	Kf/K[a]	K/L[b]	K/Y[c]	Revenue/ Firm[d] (RMB 10K)
Electronic measuring instrument manufacture	6.0632	2.41	1.9358	1246
Others electronic measuring equipment accessories	23.0276	3.2736	1.4003	1848
Electronic special equipment manufacture	29.7506	2.6823	1.9611	2160
Electronic industrial mould and gear manufacture	24.1003	2.1395	2.1287	470
Others electronics special equipment accessories	19.352	2.4677	1.0885	2232
Refrigerator manufacture	24.9129	8.2622	1.7204	42421
Electric heating equipment	64.6789	3.9024	2.0183	8964
Electronic toy manufacture	28.8084	1.3434	1.5915	1669
Other household electronic appliance	42.9226	6.3778	1.3706	12547
Other household accessories	35.7514	3.739	1.5036	1692
Bulb manufacture	42.4407	4.0576	1.5461	2215
Electrical vacuum valve device manufacture	33.0177	9.7229	1.8327	39140
Semiconductor device manufacture	30.4874	2.3629	2.0408	1447
Integrated circuit manufacture	42.9847	11.1162	3.182	8984
Electronic device material manufacture	34.8098	5.7394	1.5287	6042
Other electronic device accessories	50.9389	8.3568	1.9293	7197

Source: Yingqi Wei, Xiaming Liu, Page 97, Foreign direct investment in China, Edward Elgar, USA, 2001

[a]Kf/K is the share of foreign capital (%),[b]K/L is the capital to labour ratio,[c]K/Y is the capital to output ratio, [d]firm size is measured by the industrial sales revenue (RMB 10000) divided by the number of firms in each sub-sector.

Table A5: Dominant technologies Common to both global Semiconductor & Solar industries' patents (*2012*)

	Semiconductor Industry		Solar Industry	
Technology (IPC code)	**Patent count**	**Patent share (out of top 100 technologies)**	**Patent Count**	**Patent share (out of top 100 technologies)**
A01N	638	0.59%	169	0.23%
A61B	506	0.47%	172	0.24%
A61F	495	0.46%	188	0.26%
A61K	5412	5.04%	2364	3.26%
A61L	496	0.46%	177	0.24%
A61N	167	0.16%	99	0.14%
A61P	1399	1.30%	1174	1.62%
A61Q	656	0.61%	702	0.97%
B01D	895	0.83%	385	0.53%
B01J	3038	2.83%	998	1.38%
B05D	714	0.66%	933	1.29%
B22F	289	0.27%	183	0.25%
B23K	513	0.48%	258	0.36%
B24B	312	0.29%	80	0.11%
B24D	267	0.25%	82	0.11%
B29C	801	0.75%	471	0.65%
B29D	181	0.17%	87	0.12%
B32B	2048	1.91%	2593	3.58%
B41J	686	0.64%	92	0.13%
B41M	396	0.37%	140	0.19%
B65D	229	0.21%	97	0.13%
B81C	331	0.31%	87	0.12%
B82B	212	0.20%	556	0.77%
C01B	1615	1.50%	1610	2.22%
C01F	207	0.19%	122	0.17%
C01G	465	0.43%	681	0.94%
C02F	135	0.13%	234	0.32%
C03B	256	0.24%	130	0.18%

	Semiconductor Industry		Solar Industry	
Technology (IPC code)	**Patent count**	**Patent share (out of top 100 technologies)**	**Patent Count**	**Patent share (out of top 100 technologies)**
C03C	844	0.79%	893	1.23%
C04B	1425	1.33%	453	0.62%
C07C	2885	2.69%	753	1.04%
C07D	4310	4.01%	1529	2.11%
C07F	1270	1.18%	562	0.78%
C07H	562	0.52%	151	0.21%
C07K	629	0.59%	256	0.35%
C08F	2322	2.16%	698	0.96%
C08G	1408	1.31%	1052	1.45%
C08J	1022	0.95%	844	1.16%
C08K	1318	1.23%	1355	1.87%
C08L	2288	2.13%	1820	2.51%
C09B	210	0.20%	373	0.51%
C09C	299	0.28%	179	0.25%
C09D	793	0.74%	817	1.13%
C09J	274	0.26%	366	0.50%
C09K	1651	1.54%	1797	2.48%
C11D	670	0.62%	130	0.18%
C12N	780	0.73%	268	0.37%
C12P	216	0.20%	136	0.19%
C12Q	637	0.59%	145	0.20%
C22C	547	0.51%	198	0.27%
C23C	2557	2.38%	2768	3.82%
C23F	193	0.18%	117	0.16%
C25D	157	0.15%	206	0.28%
C30B	2088	1.94%	2008	2.77%
D01F	330	0.31%	194	0.27%
E21B	277	0.26%	426	0.59%
G01J	405	0.38%	177	0.24%
G01N	2005	1.87%	543	0.75%
G01R	486	0.45%	157	0.22%

	Semiconductor Industry		Solar Industry	
Technology (IPC code)	**Patent count**	**Patent share (out of top 100 technologies)**	**Patent Count**	**Patent share (out of top 100 technologies)**
G02B	2496	2.32%	1407	1.94%
G02F	2971	2.77%	1373	1.89%
G03C	680	0.63%	112	0.15%
G03F	1033	0.96%	210	0.29%
G03G	1298	1.21%	322	0.44%
G06F	428	0.40%	247	0.34%
G06K	261	0.24%	178	0.25%
G09F	384	0.36%	223	0.31%
G09G	1030	0.96%	229	0.32%
G11B	1555	1.45%	305	0.42%
G11C	1705	1.59%	224	0.31%
H01B	548	0.51%	1405	1.94%
H01G	284	0.26%	691	0.95%
H01J	1482	1.38%	548	0.76%
H01L	22732	21.16%	21627	29.84%
H01M	861	0.80%	1867	2.58%
H01S	921	0.86%	449	0.62%
H02N	212	0.20%	360	0.50%
H04N	502	0.47%	110	0.15%
H05B	782	0.73%	750	1.03%
H05K	678	0.63%	390	0.54%

Source: Computed from Thomson Database (2012)

Table A6: Cronology of significant PV policies in China

Year	Organization	Policy	Key Points
2005	Renewable energy law	Renewable energy law	The NPC passed the law in 2005 for its implementation in 2006.
2005	National Development and Reform Commision	Renewable energy industry development instruction list	The list spells out 88 renewable energy areas including 35 PV areas subject to support.
2006	National Development and Reform Commision	Provisional administrative measures on pricing and cost sharing for renewable energy power generation.	The document covers how to calculate feed in tariff for renewable energy and the feed in tariff system.
2006	National Development and Reform Commision	Adminstrative provisions for renewable energy power generation.	The document specifies the scope of management responsibility for the central and local goverments, the scope of responsibility for central government organizations, and the responsibilities and obligations of electric power generation and transmission companies.
2006	Ministry of finance	Provisional administrative measures on the renewable energy development fund.	the document specifies the scope for support from the Renewable energy development fund and explains the procedures for applications for financial support and their acceptance. It also clarifies financial support methods and the scope of their applications and specifies the responsibility for monitoring and reporting uses of the fund.
2006	Ministry of finance and ministry of construction	Provisional adminstrative measures on the fund for renewable energy applications for buildings.	The document specifies how local government regulatory organizations should consider applications for subsidies for projects to use renewable energy in buildings and how they should appropriate those subsidies.
2006	Ministry of finance and ministry of construction	Instructions on deliberation process of pilot projects for renewable energy applications for buildings	The document specifies how local government regulatory organizations should deliberate pilot projects. Approved projects will announced annually.
2007	Ministry of science and technology, national development and reform commision.	Renewable energy and new energy international cooperation plan.	The plan promotes international cooperation in research on renewable energy and new energy priorities.

Year	Organization	Policy	Key Points
2007	National Development and Reform Commision	Temporary measures of regulation on renewable energy surcharge.	The document provides for how electric power transmission companies should collect and use renewable energy surcharges.
2007	National Development and Reform Commision	Medium to long term renewable energy development plan.	The plan sets renewable energy development goals for 2010 and 2020.
2008	National Development and Reform Commision	11th five year development plan for renewable energy.	Based on the medium to long term renewable energy development plan, the document sets renewable energy development goals (including modified ones) for 2010 and provides for specific action plans.
2009	Ministry of finance and ministry of construction.	Building PV subsidy policy	A subsidy of 2.90 US dollar per watt (in 2009) is provided for large scale (50 KW or larger) PV panels that meet minimum conditions (energy conversion efficiency at 16% for monosilicon PV cells , 14% for polysilicon PV cells and 6% for non silicon PV cells.
2009	Ministry of finance	Golden sun pilot project	The document provides for subsidies to be given to 500 MW or larger PV plant projects in the coming two or three years. A subsidy will cover 50% of a total project investment amount in principle. The percentage may be raised to 70% for some unelectrified regions.
2009	National People's congress	Revision of the renewable energy law.	The revised law was passed on December 26, 2009.

Source: "China energy development report 2009" and KanSichao, Chinese photovoltaic market and industry outlook, IEEJ April 2010