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The effectiveness of domestic content criteria in India's Solar Mission

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H I G H L I G H T S

- Industrial policy for the Indian solar PV sector unlikely to yield competitiveness.
- Developers may be favoring substitute thin-film modules, bypassing the policy.
- The manufacturing base has become less competitive over time.
- Gaps in the innovation system may prevent a return to competitiveness.
- The analysis suggests that the Mission should remove the solar PV DCR.

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A B S T R A C T

Often, a goal of renewable energy policies is the development of domestic renewable energy technology manufacturing capacity. The Jawaharlal Nehru National Solar Mission (NSM) in India is an example; besides targeting an installation of 20 GW of grid-tied solar power capacity, it includes a domestic content requirement (DCR) to strengthen a solar photovoltaic manufacturing base. We ask whether the DCR of the NSM will be effective in ensuring the global competitiveness of the beneficiary sector. Our analysis reveals three observations that indicate this outcome is unlikely: (1) the manufacturing base has become less competitive over time, (2) developers may be favoring thin-film technology, thereby bypassing the DCR, which applies specifically to crystalline silicon cells and modules and (3) gaps in the Indian innovation system are likely to prevent a return to competitiveness by solar photovoltaic manufacturers. In particular, a comparison with the Chinese innovation system indicates shortcomings in the Indian innovation system of R&D capabilities, coordination of resource provision and complementary industrial strengths. Given these observations, we suggest that policymakers remove the solar photovoltaic DCR from the NSM.

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1. Introduction

Renewable energy technology (RET) deployment policies often include support for local manufacturers, and this is usually based on an assumption that it can eventually deliver a globally competitive national industry. A large literature provides a narrative of RET policies and manufacturing growth around the world (Lund, 2009; Fu and Zhang, 2011); given the relatively recent emergence of the RET industry, it focuses on providing ex-post explanations of policy efficacy and industrial competitiveness.¹ In this paper, we

combine the insights of this empirical work with theoretical studies of industrial policy (Lall and Teubal, 1998; Wignaraja, 2003) to answer the following question: will the domestic content requirement (DCR) of India's Jawaharlal Nehru National Solar Mission (NSM) be effective in ensuring the long-term competitiveness of the Indian solar PV sector?² Given the rapid growth of a competitive Chinese solar PV sector, an inherent subsidiary question is the degree to which the Indian innovation system has the enablers of competitiveness present in the Chinese system.

The NSM is an example of an industrial policy intended to promote RET development and deployment. It aspires to both install 20 GW of grid-tied solar capacity by 2022 and establish India as a solar manufacturing hub (MNRE, 2009). The industrial policy elements of the NSM have not yet been formally analyzed,

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¹ An exception is the work by Vidican et al. (2012), which studies the ex-ante likelihood that the United Arab Emirates can build a solar industry. Our focus here differs in several ways: (1) we comment on a specific component of the solar industry, namely, solar photovoltaic manufacturing and (2) our work leverages quantitative data from an existing industrial base.

² Throughout the paper, the term "DCR" refers only to the DCR relevant to the solar photovoltaic sector. The NSM also includes a DCR for the concentrated solar sector.

while its other aspects, such as the impact of both on-grid and off-grid deployment policy, its institutional limitations and its implications for rent capture by solar project developers, have been (Deshmukh et al., 2010; Shrimali and Rohra, 2012; Altenburg and Engelmeier, 2012). This paper is the first to formally analyze the NSM DCR and its likely effectiveness in building a globally competitive solar PV sector.

In answering our motivating question, our paper provides three contributions to the literature. First, we provide a framework with which to assess, ex-ante, the likely effectiveness of a DCR for an existing manufacturing base. To the best of our knowledge, such an assessment has never been conducted. Unlike most effectiveness assessments that rely on qualitative innovation systems perspectives alone, our approach also applies quantitative trade data analyses. The framework can inform the debate over DCRs elsewhere, such as that in Ontario, where 50–60% of all solar PV project costs must be attributed to domestic content (OPA, 2011). Second, we complement existing studies of the NSM by applying our framework to examine the likely effectiveness of its DCR. Third, our analysis of a DCR in the RET context contributes to an understanding of the settings in which this industrial policy instrument could constitute an effective tool to outwardly shift the enacting country's production possibilities frontier; though DCRs have been studied before (Grossman, 1981), they have been empirically examined in only a few industries (Munk, 1969; Takacs, 1994; Veloso, 2001).³

The analysis in this paper is based on three complementary methods and informs our perspective that the NSM DCR is unlikely to ensure the global competitiveness of the Indian solar PV sector or to increase the consumption of its output. In Section 2, we introduce the Indian solar PV sector and industrial policy support for it. Section 3 provides background on industrial policy, especially that targeting the RET industry. Section 4 introduces our framework for analysis of the effectiveness of the DCR. Section 5 diagnoses recent trends in the competitiveness of the Indian solar PV sector. In our first analytical step, we analyze trade data to quantify changes in the sector's international competitiveness, and we find that the existing solar PV manufacturing base has become less competitive over time. We subsequently model the propensity of project developers to source domestic and crystalline solar PV modules; evidence suggests that developers may be favoring thin-film technology, thereby bypassing the crystalline-specific DCR and limiting the dynamic learning gains among domestic crystalline solar PV manufacturers that it could theoretically deliver. Section 6 presents the results of our third analytical step, a comparative national innovation systems analysis. We find that gaps in the Indian innovation system relative to its Chinese counterpart are unlikely to build the technological readiness required to restore the competitiveness of the Indian solar PV sector and realize the NSM industrial policy goals. Section 7 concludes and offers suggestions for further research.

2. The Indian solar PV sector and supporting policies

The NSM DCR is part of a suite of policy tools that seeks to expand an existing Indian solar PV sector. Figs. 1 and 2 compare the scale of the Indian crystalline silicon and thin-film PV sectors with global ones.⁴ The Indian crystalline silicon cell and module capacity of 1.7 GW accounts for about 5% of global capacity, while

the thin-film capacity of 208 MW accounts for less than 2% of global capacity. While the 5% share may appear significant, the cumulative capacity of global tier-1 cell and module manufacturers is greater than India's entire manufacturing base.⁵ In the Online Appendix, we discuss India's virtual absence at the upstream steps, noting that these are less competitive than the downstream ones, require more technological knowledge and are increasingly done by integrated firms.⁶ This absence suggests failures by the Indian PV sector to technologically innovate and expand across the value chain.

Industrial policy support for the sector can be interpreted as an attempt to compensate for these failures, and it includes the development of domestic demand, DCRs and capital subsidies. The three phase NSM deployment policy targets 20 GW of grid-tied solar capacity by 2022 (MNRE, 2009), with goals to deploy 1100 MW of capacity by the end of Phase I in 2013, 4 GW by the end of Phase II in 2017 and 20 GW by the end of Phase III in 2022. Capacity will initially be split equally between solar PV and concentrated solar power. Phase I installation is occurring in two batches; the first in Fiscal Year (FY) 2010–2011 contracted 150 MW of solar PV capacity, and the second over FY2011–2013 seeks to install 350 MW. In its first phase of deployment, the NSM requires first batch solar PV projects using crystalline silicon technology to use modules manufactured domestically and second batch plants to use domestically produced cells and modules (MNRE, 2009). Policy advocates have recommended extending this DCR to include thin-film cells and modules.

Separately, the 2007 Semiconductor Policy (SIPS-1) sought to subsidize capital investments of at least USD 550 million in capital expenditures for semiconductor or solar manufacturing. By the close of applications on March 31, 2010, SIPS-1 had attracted 26 proposals worth USD 51.7 billion (Indian Rs. 2.3 trillion), of which only 6 were deemed financially viable (Panchabuta, 2011a; Singh, 2011). The selection of manufacturers had not been completed as of December 2012 (Frost & Sullivan, 2010).

3. Industrial policy: motivations and performance

Industrial policy attempts to shift resources toward sectors expected to generate greater economic growth than would the equilibrium allocation of goods (Pack and Saggi, 2006); however, industrial policy can not only sub-optimally shift resources but also deprive economies of gains from trade (Frankel and Romer, 1999). Industrial policy tools such as DCRs are intended to address externalities in the relevant industry; for example, if firms are unable to fully appropriate cost reductions from learning-by-doing⁷, a DCR could trigger an expansion in production toward the socially optimal level. In our subsequent analyses, our interest is in examining whether the NSM DCR is more likely to shift resources toward a productive sector by, e.g., triggering dynamic external learning effects, or to deprive the Indian economy of gains from trade.

The record of industrial policy is mixed, and successful policy appears to require technological readiness and, in the case of RETs, a strong base of domestic demand for the target technology. Empirical evidence documents that the effective rate of protection by industrial policy is negatively associated with sectoral factor productivity growth (Pack and Saggi, 2006). This assessment may mask heterogeneity.

³ A country's production possibilities frontier describes the maximum output possible for two or more goods, given a set of inputs.

⁴ Between 2008 and 2011, crystalline PV modules accounted for 80%, 73%, 77%, and 77%, respectively, of global module production; thin-film modules accounted for 18%, 24%, 21%, and 21% of global module production (Lux Research, 2012). Thin-film includes CdTe, CIGS/CIS, and amorphous silicon technologies.

⁵ Different PV manufacturing tiers primarily refer to the bankability of the modules and the degree to which projects using the particular panels are likely to receive non-recourse debt financing.

⁶ The Online Appendix can be accessed at <http://stanford.io/ZdUtvG>.

⁷ Learning-by-doing was first formalized by Arrow (1962). A conventional assumption is that an industry's costs decrease by a certain percentage for each doubling in cumulative output.

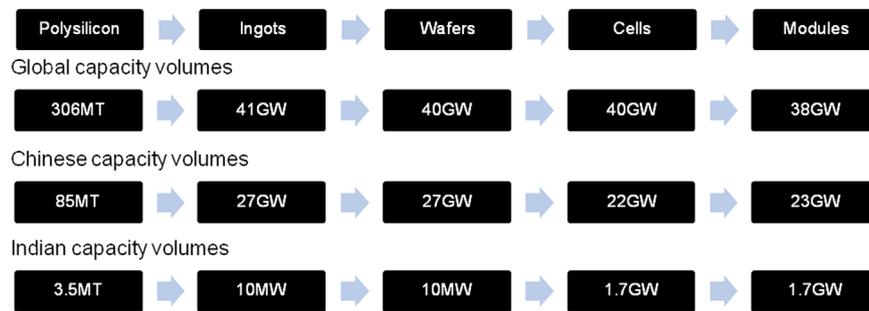


Fig. 1. The crystalline silicon PV supply chain, with global, Chinese and Indian capacity. Capacity figures are for 2011 (Lux Research, 2012). Though India has about 5% of global capacity in both cells and modules, it is virtually absent in the upstream steps of polysilicon, ingot and wafer production.



Fig. 2. A simplified thin-film PV supply chain, with global and Indian capacity. The raw materials above include, respectively, amorphous silicon, copper indium gallium diselenide (CIGS) and cadmium telluride (CdTe). Capacity figures are for 2011 (Lux Research, 2012).

Veloso (2001) suggests that DCRs fail when the scale of the target sector is smaller than optimal, sheltered from competition or offered protection to offset persistently high costs. On the other hand, those that succeed contribute to the realization of economies of scale, eventually expose the target sector to competition, and work in tandem with incentives to trigger sectoral investment (Veloso, 2001). The ability of the sector to scale and absorb additional investment may depend on ex-ante technological readiness; in Section 4, we suggest that a well-functioning innovation system framing the target sector is a pre-condition for the realization of industrial policy goals. In a theoretical analysis, Kwon and Chun (2009) show that DCRs could yield a decision by an international firm to expand manufacturing in the enacting country, but to do so with inferior technology.⁸ However, even if a new technology is superior to domestic technology, it guarantees neither technology transfer to incumbent domestic firms nor the emergence of a globally competitive sector. The limited integration of foreign investment with domestic factors of production beyond labor is neither unusual nor pathological but is a well-documented case in northern Mexico's *maquiladoras* (Brannon et al., 1994). The capture of extensive external dynamic learning effects requires strong backward linkages between new investment and the incumbent domestic industry (Kwon and Chun, 2009).

We thus expect that, all else equal, a greater level of technological readiness will facilitate a more effective industrial policy, generally, and DCR, specifically.⁹ The mechanism through which technological readiness improves the outcome of industrial policy is not well-established, but the former could overcome common challenges identified by Jacobsson and Bergek (2004) to the growth

of high-technology industries. In particular, pre-existing technological strengths could ameliorate technological and market uncertainty and perceptions of technological illegitimacy from the perspective of institutions, networks and institutional agents that would otherwise enable industrial policy.

The requirement of technological readiness is echoed in the RET context by Huberty and Zachmann (2011), who find that advantages in national RET industries are strongly correlated with pre-existing advantages in closely related technologies. Examining commercialization processes, value chain analyses, and empirical case studies, Lund (2009) highlights the role of ancillary technological competence: investment in or R&D support to strong industries in related fields helps with diversification into RET manufacturing. Similarly, Lema and Lema (2012) suggest that though conventional technology transfer, such as trade, foreign direct investment, and licensing helped infant RET industries prosper, the growth of mature RET bases required other mechanisms, such as endogenous technology creation, connection to global R&D networks and the acquisition of leading firms. Alternatively, Vidican et al. (2012) provide a negative example: in a study examining the potential for a solar sector in the United Arab Emirates (UAE), they identify an underdeveloped technical knowledge base as a barrier to industrial development.

In addition to technological readiness, a strong base of domestic demand may at least partially address RET-specific challenges to industrial policy effectiveness. Jacobsson and Bergek (2004) outline three challenges idiosyncratic to RETs: RET industries sometimes fail to establish strong networks that would facilitate, for example, the capture of external learning effects, established energy supply technologies may resist RET development and government policy may “choose winners” or constrain the search for optimal technology by industry agents. A strong base of domestic demand may help address at least the first two idiosyncratic challenges. In her study of Chinese PV manufacturing and deployment, Fischer (2012) alludes to a symbiosis between RET manufacturing and deployment that may not be realized in the absence of policy coordination across both activities; in particular, such synchronization could allow China to not only sustain a lead in PV manufacturing but also to build one in PV deployment and

⁸ We do not discuss the entry of foreign solar PV firms as a result of the DCR because there are at least two arguments countering such entry: domestic capacity can already meet the needs of the DCR, and the infrastructural challenges we highlight in Section 6 are likely to impede efforts by foreign firms to establish globally competitive solar manufacturing plants.

⁹ A consistent definition of technological readiness does not exist, but Lall and Teubal (1998) allude to a working definition in which a “high level of basic knowledge and capabilities exists in most firms...or is easily acquired”, allowing them to “[master] existing technologies”. This paper uses this definition.

possibly balance-of-systems components.¹⁰ The mechanism by which domestic deployment and international competitiveness could be coupled is unclear. In line with [Sung and Song \(2013\)](#), domestic deployment itself is unlikely to be sufficient, but it is possible that a coordinated manufacturing and deployment approach allows a synchronization of national RET sectoral policies and activates learning across the entire sectoral value chain.

The notion that technological readiness, backward linkages and policy coordination affect the effectiveness of industrial policy motivates our use of an innovations systems analysis, which we introduce in [Section 4](#).

4. Analytical framework

Our analysis of the NSM DCR evaluates the likelihood that it will be effective in expanding the output and ensuring the global competitiveness of the Indian solar PV sector. In this section, we develop our analytic framework; [Sections 5 and 6](#) apply it.

The framework involves a two-step process. In the first, we use quantitative trade data and project developer choice analyses to diagnose the sector and derive early indications of the policy's ability to expand capacity utilization; the latter is a pre-condition for the realization of dynamic learning effects. In the second, we apply a qualitative comparative innovation systems perspective to determine whether the factors that functionally supported industrial policy for a solar PV sector elsewhere are sufficiently strong.

4.1. Quantitative trade and developer choice analysis

The establishment of a globally competitive Indian solar PV manufacturing sector depends on its ability to capture external dynamic learning-by-doing spillovers at least as quickly and strongly as its global peers. In the absence of production cost time series for both Indian and global firms, we analyze trade data to examine the sector's competitiveness over time. In particular, we use two metrics with origins in the international economics literature: the unit value ratio (UVR) and revealed competitive advantage (RCA).

Comparisons of unit values have been used to study technology convergence processes among countries ([Brunner and Calí, 2006](#)).¹¹ We derive unit value ratios (UVR) that compare the unit value of Indian solar photovoltaic exports to a particular region with those of other countries. As an example, the UVR of Indian PV exports relative to OECD PV exports is given by

$$UVR_{\text{India/OECD}} = \frac{\text{Value of PV exports}_{\text{India to OECD}} / \text{Quantity of PV exports}_{\text{India to OECD}}}{\text{Value of PV exports}_{\text{OECD to OECD}} / \text{Quantity of PV exports}_{\text{OECD to OECD}}} \quad (1)$$

¹⁰ Domestic demand generation can support the growth of a globally competitive wind energy industry; using country-level case studies, [Lewis and Wisser \(2007\)](#) find that a combination of deployment policies that support a sizable, stable market for wind power and industrial policies that incentivize local wind technology manufacturing are most likely to yield an internationally competitive wind sector. [Lema and Ruby \(2007\)](#) describe a similar process underpinning the development of the Chinese wind energy manufacturing sector. There are important differences in the technologies and structures of the solar and wind industries, and the role of domestic demand generation in wind industry competitiveness does not provide an immediate implication for solar PV industrial development. Nonetheless, these narratives of the wind industry emphasize the general point that domestic demand must be coupled with additional coordinating policies for an internationally competitive sector to emerge.

¹¹ The use of the unit value differs from that in [Brunner and Calí \(2006\)](#). They examine UVRs across industries within a particular economy, while we examine the UVR across economies within a particular industry. While Brunner and Calí interpret higher UVRs to indicate "changes in the export...mix towards...high technology goods", we interpret higher UVRs as an indication of decreasing competitiveness. The assumption behind our interpretation is that all countries have access to the same production technology and should be able to achieve equal unit values.

A lower unit value implies greater competitiveness, and UVRs smaller than one imply that the numerator region has a more competitive sector.¹²

The second metric that we use is the RCA, which is generally used to identify globally (un)competitive industries. This metric compares the ratio of exports of a particular good to exports of all goods from a particular country with the same ratio across all countries. RCAs greater than one indicate that the country of interest has a competitive advantage in the production of the relevant good, and we define the RCA by¹³

$$RCA_{c,i} = \frac{x_{c,i} / \sum_i x_{c,i}}{\sum_c x_{c,i} / \sum_{c,i} x_{c,i}} \quad (2)$$

where x is the value of exported goods, i is a product index and c is a country index. To calculate both the UVR and RCA metrics, we use [UN Comtrade \(2012\)](#) data.

Finally, we corroborate the implications of the trade metrics by examining trends in capacity utilization among Indian solar PV manufacturers, which, when compared with capacity utilization elsewhere, gauges the relative health of the sector. We define capacity utilization as the ratio between output and nameplate capacity. The [Online Appendix](#) presents an additional analysis on the sensitivity of Indian solar PV export volumes to changes in feed-in-tariffs.

4.2. Qualitative innovation system analysis

The quantitative analyses allow one to diagnose the Indian solar PV sector, and we employ a functional national innovation system analysis to explain the diagnostics and form a prognosis about the effectiveness of industrial policy.

Innovation system frameworks assume that relationships between firms in an industry and their suppliers and governmental, financial, educational and infrastructural institutions help explain the record of innovation within an economy ([Godin, 2009](#)). The boundaries of innovation systems can be drawn at national (NIS), regional (RIS), sectoral (SIS) and technological (TIS) scales; analyses at different scales often yield similar conclusions, and all have been applied to energy technologies ([Truffer et al., 2012](#)). Each has provided unique insights; the RIS perspective has confirmed that regional systems can be important in explaining energy innovations, while the SIS frame emphasizes the support or opposition by incumbent actors in the energy system to the development of new technologies ([Truffer et al., 2012](#)). TIS analyses identify the institutional structure needed to support particular technologies and are suited to study emerging industries ([Truffer et al., 2012](#)). [Vidican et al. \(2012\)](#) apply the TIS framework to study the potential emergence of a solar sector in the UAE and identify missing institutional functions that would challenge its formation.

Our analysis is similar to [Vidican et al. \(2012\)](#) in assessing the functional performance of the innovation system but differs in identifying not whether a solar sector can form but whether an existing one can expand its market and innovate across the value chain. We use the distinction between market formation and subsequent expansion to paraphrase our central question: will the

¹² Since trade data do not distinguish between crystalline and thin-film PV, we are unable to separately assess the competitiveness of manufacturers of each technology. Exports from OECD to the OECD include exports from one OECD country to another. Following [Brunner and Calí \(2006\)](#), we exclude the four countries that most recently joined the OECD (Chile, Estonia, Israel and Slovenia). To guarantee a unitless UVR measure, we only include data from countries that report quantities to the United Nations in terms of units of goods instead of in terms of weight. This decision excludes export and import data for the United States, Canada, and Japan.

¹³ We recognize that there are competing definitions for the revealed competitive advantage, and we use this one as it is also used by [Huberty and Zachmann \(2011\)](#).

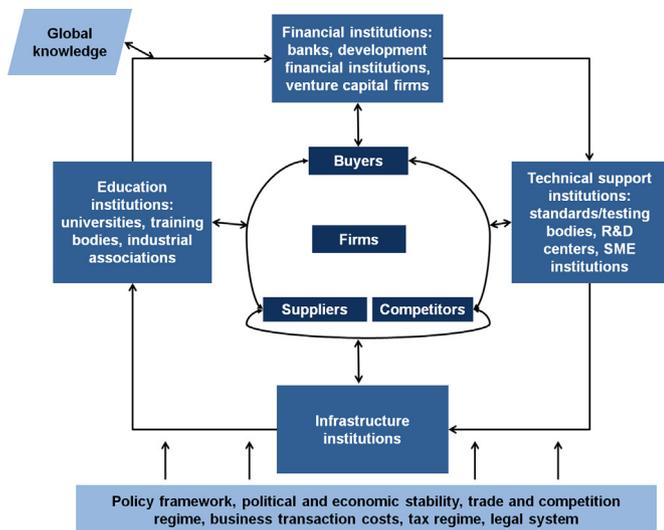


Fig. 3. The national innovation system framework; adapted from Wignaraja (2003) with permission from the author.

NSM DCR be effective at facilitating an expansion of the Indian solar PV sector? As in Vidican et al. (2012), we assume that the innovation system must serve five functions to do so; it must create and diffuse knowledge, guide technological search, supply resources, including capital and competencies, create positive external economies, and form markets (Jacobsson and Bergek, 2004).

While our framework is open to any scale of innovation system, we analyze the NIS because the DCR operates at a national level and there are institutional, economic and network dynamics that may affect the efficacy of the DCR but are not limited to either the RET industry or solar PV sector. In particular, the success of national industrial policy will likely depend on the level of technological absorptive capacity (Lall and Teubal, 1998). Indeed, Oughton et al. (2002) suggest an integration of innovation policy and industrial policy, as the former would enable the absorptive capacity and cost reductions that would facilitate the goals of the latter. A major focus of our NIS analysis will be to determine the degree to which the Indian innovation system provides the absorptive capacity and incentives for innovation necessary to achieve the goals of industrial policy. Fig. 3 illustrates the NIS, which emphasizes interactions across a system of national policy, institutions, actors and networks. For example, the link between global knowledge and the domestic system captures the importance of national technological readiness and backward linkages in allowing an integration of and contribution to the global knowledge base.

Since it is difficult to attribute competitiveness outcomes and prognoses to the absolute performance of particular functions of innovation systems, we compare national innovation systems to identify gaps and explain quantitative competitiveness measures. In this comparative application, we follow Marinova and Balaguer (2009), who compare innovation systems in Germany, Japan and Australia to identify relative strengths and weaknesses of the Australian system.

5. Diagnostic analysis

In this section, we present our assessment of trade data and infer that the Indian solar PV sector has become less competitive over time (Section 5.1). We also examine module choice data and find that the NSM has not triggered additional production that could prompt renewed competitiveness (Section 5.2).

5.1. The Indian solar PV sector has become less competitive

Both the UVR and RCA analyses imply that India's competitiveness in solar PV has declined, implying that the sector has not dynamically learned as quickly or extensively as have competitors in other countries.

5.1.1. Increasing UVRs reveal a decreasingly competitive sector

Using trade data spanning 2003–2012 from the UN Comtrade (2012) database, we calculated the UVRs as illustrated by Eq. 1.¹⁴ Fig. 4 plots the UVRs for India relative to China, India relative to the OECD and China relative to the OECD; it reveals an Indian solar PV sector that has lost the competitiveness it held before 2007. The India/China UVR may merely reflect the impact of Chinese industrial policy rather than the decreasing competitiveness of Indian manufacturers. However, OECD manufacturers did not benefit from Chinese policy, so the latter cannot account for the decreasing competitiveness of Indian firms relative to their OECD counterparts.

5.1.2. Revealed competitive advantage metrics also indicate an uncompetitive solar PV sector

Since strengths in adjacent industries help explain competitiveness in RET manufacturing (Huberty and Zachmann, 2011), we compute recent RCAs for the solar PV sector and ancillary industries (e.g., chemicals and electronic transformers). The RCA metrics in Fig. 5 corroborate the UVR analysis: the Indian solar PV sector has demonstrated only occasional global competitiveness (see Section 6 for an analogous assessment of Chinese industries).

Importantly, our analysis suggests weaknesses in the electronic machinery industry that could otherwise help solar PV manufacturers improve their technological efficiency. Indian manufacturers are unusually reliant on turnkey manufacturing lines: 77% of Indian capacity uses turnkey lines, as opposed to 15% of global capacity (Colville, 2010). The uncompetitive electronic machinery industry and reluctance to modify turnkey lines indicates that the sector lacks the capacity to innovate in production technologies and helps explain the inability of the sector to transition from market formation to expansion.

5.1.3. Low competitiveness is also implied by low capacity utilization

Though Indian module capacity utilization is only slightly below global figures, cell capacity utilization has sharply underperformed relative to the global average since 2010 (see Figs. 6 and 7). While the drop in cell capacity utilization reflects an expansion from 545 MW in 2009 to 1.9 GW in 2011, expansions in Japan (2.0 GW in 2009 to 3.9 GW in 2011) were not met by a concomitant drop in utilization. These observations corroborate our export metric based analyses.

Our national capacity utilization analysis masks heterogeneity across different tiers of manufacturers and does not differentiate by thin-film and crystalline technology. About 85% of Indian manufacturing capacity is of tier 2 (Colville, 2010). Between 2005 and 2010, the capacity utilization of all tier 2 producers was about 60%. Though utilization of Indian capacity was about equal through 2009, it has recently fallen to approximately 45%; this may be due to the smaller scale and lack of vertical integration relative to international counterparts. Indian producers have not achieved the economies of scale that major solar PV manufacturers have realized with capacity in the 1–2 GW range. Solar Semiconductor, the largest Indian producer by capacity, has an installed capacity of 195 MW per annum. Indian capacity utilization is unlikely to increase simply with integration, with competitive advantages accruing to manufacturers that can

¹⁴ In particular, we used harmonized system industry codes, as reported by the reporting nation. We used code 854140, which labels photosensitive semiconductor devices.

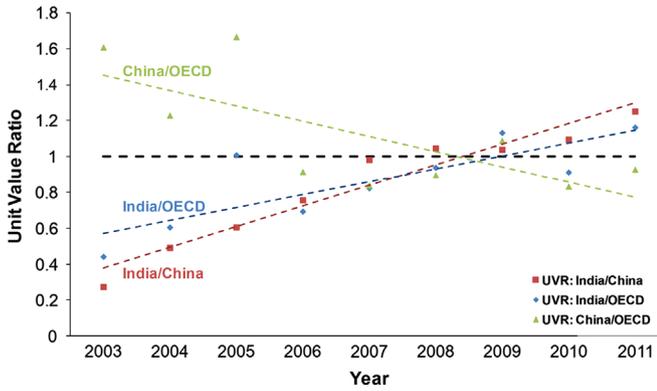


Fig. 4. India's UVR relative to China and the OECD has worsened. Linear trend lines are superimposed. The upward India/China and India/OECD UVR drifts are consistent with an Indian solar PV sector that has become less globally competitive. Data are from UN Comtrade (2012).

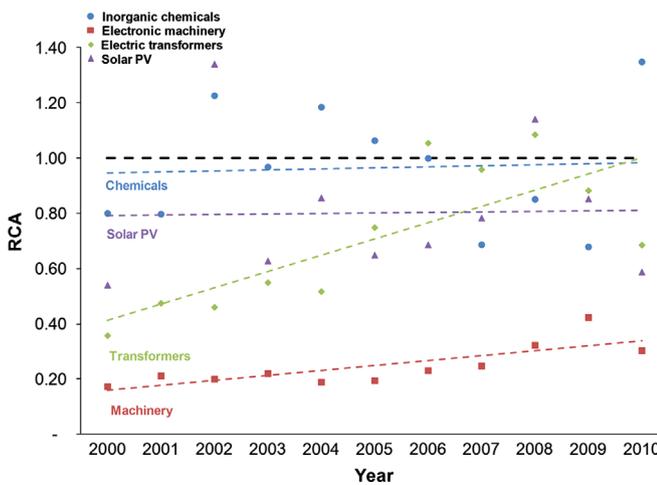


Fig. 5. The revealed competitive advantage of selected industries in India. We exclude 2011 data because all trade flows had not yet been reported to the UN. Note: We use harmonized system industry codes, as reported by the reporting nation. The harmonized system codes are as follows: chemicals: 28 (we use a two digit code because we could not find a closer match to polysilicon), electronic machinery: 85, electric transformers: 8504, solar PV: 854140. Linear trend lines are superimposed. Data are from UN Comtrade (2012).

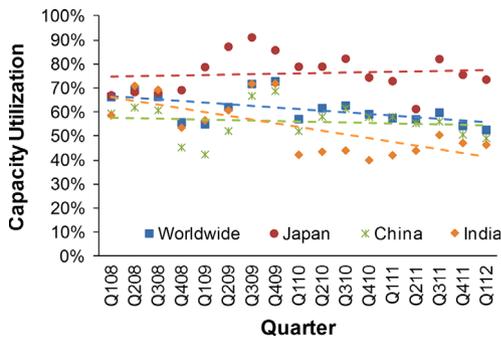


Fig. 6. Module capacity utilization (Q1 2008–Q1 2012). Data are from Lux Research (2012). Linear trend lines are superimposed on the utilization data.

deliver efficiency gains. Such gains could be in the form of higher module or balance-of-system efficiency. Instead of backward integrating into polysilicon, firms (e.g., Trina Solar, Yingli and DeSolar) have elected to enter long-term contracts for the commodity (Photon, 2010). Moreover, while solar PV manufacturing was previously done by many small firms, it is now dominated by a smaller number of large producers; this may be accelerated by a deliberate

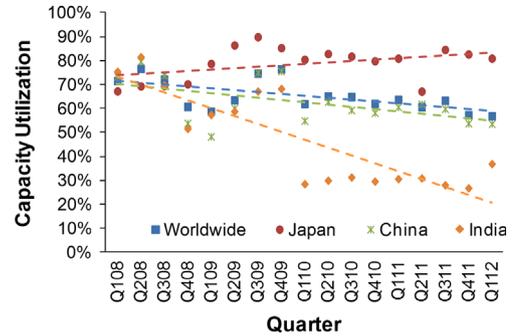


Fig. 7. Cell capacity utilization (Q1 2008–Q1 2012). Data are from Lux Research (2012). Indian cell manufacturers have had low capacity utilization rates, especially since 2010. Linear trend lines are superimposed on the utilization data.

consolidation led by the Chinese government (Platzer, 2012; Bayaliyev et al., 2011).

We summarize our analyses in Proposition 1:

Proposition 1. Capacity utilization trends and competitiveness metrics, including the UVR and RCA, imply that the Indian solar PV sector has become less competitive over time.

5.2. Developers continue to deploy substitute thin-film technology, bypassing the DCR

To examine whether the NSM is expanding domestic production, we assess module sourcing choices across Indian solar PV plants. Our analysis of plants uses records from the Alternative Energy eTrack (2012) and Bloomberg New Energy Finance (2012) databases, with supplementary press release data.¹⁵ We included plants under construction or active by September 2012 and excluded plants under 5 MW in capacity to ensure projects were at least as large as those in the NSM.¹⁶

We sought to test four hypotheses:

Hypothesis 1 (3). The proportion of crystalline silicon modules in NSM Phase I, Batch I (II) plants is statistically equal to the proportion in non-NSM plants.

Hypothesis 2 (4). The proportion of domestically manufactured crystalline silicon modules in NSM Phase I, Batch I (II) plants is statistically equal to the proportion in non-NSM plants.

We were unable to test Hypotheses 3 and 4, and they should be tested when full data are available; though we had aggregate data about 53% of Phase I, Batch II target capacity, we had plant-level data for only five projects that constituted 27% of the 350 MW to be added.

Our specifications of logit models of technology choice (see Table 1 in the Online Appendix) do not reveal a statistically significant coefficient on an NSM Phase I, Batch I (NSM_I) dummy variable.¹⁷ Upon not rejecting Hypothesis 1, we do not find evidence that the NSM Phase 1, Batch 1 encouraged the use of crystalline silicon

¹⁵ Explanatory notes on our database are included in the Online Appendix.

¹⁶ This exclusion was also driven by data availability. A full set would require press release based records of module choice for approximately 155 of 187 solar plants with capacities lower than 5 MW. Details of the solar plants used in the analysis are available from the authors.

¹⁷ We may be missing critical explanatory variables, such as solar insolation, temperature and air quality, but the relative geographical proximity of plants within a particular state should allow the state variable to capture these attributes. Moreover, we did not have data on when module choices were made and the efficiency adjusted crystalline/thin-film price differentials at that time. Our expectation is that the year variable is at least partially correlated with crystalline/thin-film price differentials at the time of module choice. Finally, the statistical insignificance of the NSM dummy may be due to our use of models without adequate sample sizes.

modules.¹⁸ This is supported by the aggregate data: the proportion of crystalline silicon modules is virtually equal between non-NSM (49%, or 40 of 82) and NSM Phase I, Batch I (50%, or 15 of 30) plants.

Our specifications of logit models of domestic sourcing of crystalline silicon modules (see Table 2 in the Online Appendix) do not reveal a statistically significant coefficient on the NSM_I dummy variable.¹⁹ Upon not rejecting Hypothesis 2, we do not find evidence that the NSM Phase I, Batch I shifted the odds of a developer using domestic, rather than foreign, crystalline silicon technology.

In NSM Phase I, Batch II plants, however, only 41% of plants employ crystalline silicon modules. While we cannot make definitive statements, this indicates that the current DCR may decrease the use of domestic crystalline silicon modules in solar PV plants. The difference between batches suggests that the inclusion of cells prompted a greater use of thin-film technology. The DCR may thus strengthen an idiosyncratic preference among Indian project developers for thin-film modules, and it may be unable to trigger the increase in domestic cell and module production necessary to enhance external dynamic learning effects and facilitate market expansion.

We summarize our findings in Proposition 2:

Proposition 2. Module technology choice data do not reveal a statistically significant difference in the proportion of crystalline silicon modules deployed in Phase I, Batch I NSM and non-NSM solar PV plants. The data also indicate that there are no statistically significant differences between the proportion of domestic crystalline silicon modules in Phase I, Batch I NSM and non-NSM plants. We conclude that there is no evidence that the NSM has contributed to increased output or consumption of domestic crystalline silicon modules.

6. National innovation system analysis

To examine whether the Indian innovation system can functionally support the re-emergence of a competitive solar PV sector, we study how components of the Chinese innovation system allowed its solar PV sector to assume a globally dominant position. We find that the Chinese innovation system was capable of performing the five functions identified in Section 4.2. Early rural electrification primed a small domestic market for the solar PV sector, and recent deployment policies bolster it as demand from importing countries decreases. In line with Sung and Song (2013), deployment support was not itself sufficient to trigger a competitive solar photovoltaic sector; instead, it was part of a broader package of industrial support. Competitiveness in related industries allowed positive external economies to develop; prominently, experience with the semiconductor value chain allowed the development of a

domestic polysilicon sector. Public and private R&D facilitated knowledge creation, and public funding linked to national innovation goals allowed the government to guide technological search. Finally, the innovation system supplied resources through a coordinated implementation of supporting policy and provision of financing.

In Section 6.1, we detail the components of the Chinese innovation system that performed these functions. Section 6.2 presents our assessment that the Indian innovation system appears primed to form a domestic market but not to perform the other four functions. Each of the four subsections within Sections 6.1 and 6.2 discusses how the relevant national innovation system successfully or unsuccessfully performs the five functions identified in Section 4.2; note that we discuss jointly the technological innovation and technological search functions. Section 6.3 offers conclusions from the comparison. As a caution, though we use Chinese policy as a benchmark, policymakers there and in India must design policies to incent cost reductions among their manufacturers. As Huo and Zhang (2012) suggest, the longer-term prospects for Chinese manufacturers are clouded by the lack of a long-term plan for the cessation of public subsidies. The similar lack of details in the NSM about the duration of industrial policy support introduces uncertainty in incentives for the domestic sector to pursue cost reductions.

6.1. China provides a benchmark for solar PV industrial policy

6.1.1. Market formation: domestic demand seeded and helps sustain the Chinese solar PV sector

China's solar PV production share jumped from virtually 0% in 2000 to about 45% in 2010. While rural electrification formed a demand base to trigger Chinese production, growth in European demand between 2003 and 2006 allowed firms to expand (Li and Wang, 2007; Campillo and Foster, 2008). Chinese producers had a cost advantage and were both unburdened by Kyoto Protocol greenhouse gas commitments and able to access cheap debt (Zhou, 2011). In 2010, Chinese producers had estimated production costs about USD 0.60/W lower than OECD peers (BCG, 2010). As major module importing countries began to reduce their feed-in-tariffs, the Chinese government codified in its 13th Five Year Plan an aspiration to build strong domestic demand, and its plans target a cumulative installed capacity of 20 GW by 2015 and 48 GW by 2020 (Sicheng, 2012).²⁰ These installations would augment a 2011 capacity of 2.6 GW (Alternative Energy eTrack, 2012).

6.1.2. Positive external economies: complementary strengths helped the Chinese PV sector expand upstream

Fig. 8 demonstrates that, over the period examined, China had competitive advantages in the solar PV and ancillary industries in which India is uncompetitive (see Fig. 5). Strengths in ancillary industries may have helped Chinese solar PV manufacturers gain the absorptive capacity to create and diffuse innovations. Since it created a stock of knowledge in ingot and wafer production, the Chinese semiconductor industry may have played a singularly important role in allowing firms to virtually integrate. As a specific example, Chinese knowledge of monosilicon ingot growth furnace manufacturing allowed it to cooperate with Russia and develop indigenous polysilicon cast furnaces (Zhao et al., 2008; Fischer, 2012). The indigenization of polysilicon production by 2008 allowed Chinese manufacturers at downstream steps to limit their exposure to high global polysilicon spot prices and is an example of the growth of a positive external economy (Fischer, 2012).

¹⁸ See Table 1 in the Online Appendix. Our specifications model the log odds that a plant developer will choose crystalline module technology. Specification 1 examines whether developers in Phase I, Batch I of the NSM had statistically significantly different odds of choosing crystalline technology. Specification 2 expands on Specification 1 by controlling for effects of the Gujarat Solar Policy on technology choice within non-NSM plants. Specification 3 further controls for the capacity of the plant. Specification 4 uses robust standard errors to account for possible heteroskedasticity in the data. Specification 5 introduces a state fixed effect to Specification 4, while Specification 6 adds both state and time fixed effects.

¹⁹ See Table 2 in the Online Appendix. Specification 1 examines, contingent on a choice of crystalline technology, whether developers in Phase I, Batch I of the NSM had statistically significantly different odds of choosing domestically manufactured modules, while controlling for the capacity of plants and the participation of non-NSM plants in the Gujarat State Solar Policy. The model uses robust standard errors to account for possible heteroskedasticity in the data. Specification 2 adds state and time fixed effects. Specifications (3–4) and (5–6) in Table 2 examine the implications of coding our 30 observations of crystalline modules of unknown origin as foreign and domestic, respectively. This allowed us to examine the sensitivity of our results to the missing data. Since we observe that the significance of the NSM_I coefficient does not change based on our treatment of the missing data, we conclude that the NSM Batch I, Phase I did not have a significant impact on the sourcing of crystalline modules.

²⁰ The target may be raised to 100 GW, of which at most 5% will be from concentrated solar power (Sicheng 2012).

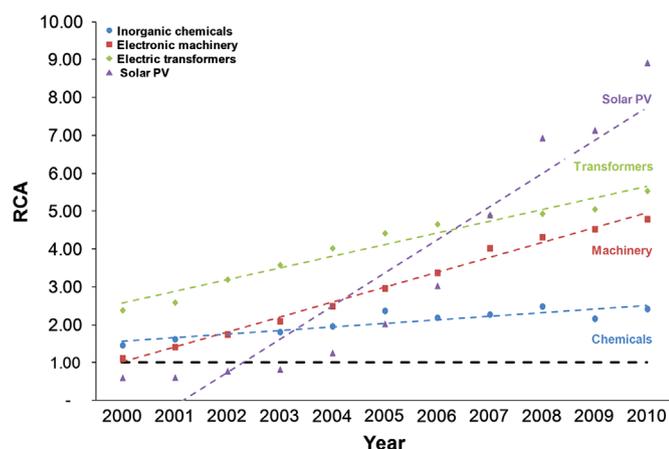


Fig. 8. The revealed competitive advantage of selected industries in China. China has a revealed competitive advantage in all of the tracked industries. We exclude 2011 data because all trade flows had not yet been reported to the U.N. at time of writing. We use harmonized system industry codes, as reported by the reporting nation. Note: The codes are as follows: chemicals: 28 (we use a two digit code because we could not find a close match to polysilicon), electronic machinery: 85, electric transformers: 8504, Solar PV: 854140. Linear trend lines are superimposed on the RCA data. Data are from UN Comtrade (2012).

6.1.3. Knowledge creation and technological search: Chinese PV producers are R&D intensive, and they are guided by the innovation system

Chinese firms have built R&D technology absorption capabilities through gradual upstream and downstream expansion, and integration has allowed firms to understand R&D needs across the manufacturing value chain. While Suntech began as an innovative company with strengths in R&D, other firms have built this competence through deliberate partnerships and acquisitions; as an example, Trina has built a State Key Laboratory in collaboration with China's Ministry of Science and Technology. Similarly, Yingli gained upstream R&D strength by acquiring upstream producers such as Cyber Power Group and Fine Silicon (Lema and Lema, 2012).

Though both Liu and Goldstein (2012) and Huang et al. (2012) contend that China's solar PV sector developed without a coordinated national policy or adequate publicly funded R&D in the early 2000s, the story changed markedly by the late 2000s and early 2010s. As Liu and Goldstein (2012) document, and as we discuss in Section 6.1.2, a focus on the early years of the Chinese solar PV sector misses important dynamics in the years surrounding the 2008 surge in polysilicon prices. The ability of Chinese firms to partially insulate themselves from the impact of these price dynamics (Section 6.1.2) was coupled with a decision by the Chinese state to prioritize the sector's development. Public R&D programs now complement private efforts. Nearly commercialized technologies are supported by the 500 million Yuan/year (USD 78.6 M/year) 863 program administered by the Ministry of Science and Technology. The 863 program focuses on lowering module production costs and increasing the efficiency of Chinese products. Less mature technology is supported by the 973 program, and the Ministry sets various technological targets to guide the evolution of the sector (Sicheng, 2012).

6.1.4. An institutionally coordinated policy supplies capital and competency

China's solar manufacturers have been supported by an industrial policy endorsed at the highest levels of the national and provincial governments; the powerful National Development and Reform Commission (NDRC) established the 2006 Renewable Development Fund that issues grants and subsidizes debt and R&D for PV projects (Hart, 2012; Platzer, 2012; Rethinking, 2011). Governmental provision of capital and resources spans up to 200 subsidies, including

subsidized credit, tax incentives, low rates for land and raw materials and rebates on tax and interest. With access to cheaper debt and a capital structure with limited dependence on equity, Chinese firms may be willing to tolerate lower margins than their counterparts. Importantly, policy oversight is matched to institutional abilities; for example, the government's 10 billion Yuan (USD 1.6 billion) Renewable Energy Fund is directed by the Ministry of Finance, while the New Energy Administration is responsible for ensuring the realization of deployment goals set in five year plans (Bayaliyev et al., 2011).

6.2. Several functions are absent from the Indian innovation system

Though the NSM will form a large domestic market, gaps within the Indian innovation system will challenge the emergence of a globally competitive solar PV sector.

6.2.1. Market formation: the NSM provides a domestic demand base

The NSM has already triggered 500 MW of additional solar capacity, and this central directive is joined by additional state level deployment strategies (e.g., in Gujarat and Rajasthan). The national and state level deployment targets have supported an expansion in installed capacity from 17.8 MW in early 2010 to a projected 506.9 MW by the end of March 2012 (NRDC, 2012). However, while China's solar PV deployment policies will likely benefit Chinese manufacturers, the Indian DCR allows project developers to employ foreign thin-film cells and modules.

6.2.2. Positive external economies: infrastructural gaps prevent vertical integration and skill development

Infrastructural gaps have blocked the development of complementary and upstream manufacturing bases. Following economic reforms in the 1990s, infrastructure intensive industries in India had growth rates 10% smaller than less intensive ones (Gupta et al., 2008). Although India has strengths in semiconductor design, unreliable electricity supply, limited access to clean water, poor waste management and the absence of a skilled workforce have stunted Indian attempts to build a semiconductor industry (Jacob, 2011; Krishnadas and Clarke, 2011). Infrastructural constraints may similarly limit upstream solar PV expansion in India. The aspiration of the NSM to build polysilicon production capacity equivalent of 2 GW of solar PV cells by 2020 will be challenged by India's variable power supply; power cuts and fluctuations in voltage and frequency risk entire batches of polysilicon. The installation and maintenance of standby power supply could render Indian projects uncompetitive in the international market.²¹

Labor constraints have limited infrastructural development in India: during India's 11th Fifth Year Plan, only 1/9th of the planned power capacity expansion of 90 GW was realized (Gupta et al., 2008). This outcome was partly attributable to a shortage of skilled labor, which India seeks to ease through a National Policy on Skill Development that aims to train half a billion people by 2022. Since the policy's end date coincides with that of the NSM, the gains to solar manufacturing development may be limited.

²¹ Electricity infrastructure is one of a few challenges confronting potential polysilicon producers. Recently built polysilicon plants have capacities between 3000 and 10000 t/annum. Indian manufacturers may find it difficult to accept the risk of such large plants. While polysilicon capacity has historically remained close to total demand, capacity growth has exceeded demand growth since 2008; specifically, total polysilicon capacity in 2012 is about 5 times total polysilicon demand (GTM Research, 2012). New polysilicon capacity in any context thus bears inherent marketability risks. Proposed Indian polysilicon capacity additions are of modest scale; Lanco Solar has proposed a polysilicon plant with a capacity of 120 t/annum, a level far below what appears necessary to achieve economies of scale (WCN, 2010).

6.2.3. Knowledge creation and technological search: India's solar R&D is public sector driven, without links to or a guide for the private sector

The absence of a coordinated R&D thrust among either private or public agents may complicate India's mission to build a competitive solar PV sector. While China's 2007 R&D spend of 1.5% of its GDP has doubled since 1999, India's has stagnated and accounts for 0.7% (Gilman, 2010). With the exception of HHV Solar and Moser Baer, which pursue in-house R&D, most Indian firms rely on licensing or use external, expired patents for their manufacturing technologies, a trend that may help explain their decreasing competitiveness (Lema and Lema, 2012). Aside from mentioning a new Center for Photovoltaic Research and Education at IIT Mumbai and an International Center for Application of Solar Energy Technologies at IIT Rajasthan, the NSM neither presents an integrated vision for engaging existing knowledge at India's leading engineering institutes nor specifies mechanisms by which such skills can be imported. Like India's broader record, most of the fundamental research is planned at the university level with little participation from the corporate sector (Shrimali and Sonderegger, 2012). Even if university researchers were to correctly appraise industrial needs, India lacks a clear commercialization pathway such as the United States' Bayh-Dole Act (U.S. Congress, 1980). In articulating a clearer roadmap for deployment than for innovation or R&D, the NSM adheres to a general trend in solar policy (Grau et al., 2012); since a broader objective of the NSM is the development of a globally competitive manufacturing sector, it must deliver a clearer framework for the support of innovation and R&D within the solar PV sector than it currently details.

6.2.4. Uncoordinated policies with contradictory national goals challenge the provision of capital and competencies to the sector

NSM industrial policy, which was set by the Ministry of New and Renewable Energy (MNRE), conflicts with India's broader policy agenda to pursue increasing liberalization. The Department of Industrial Policy and Promotion (DIPP) of the Ministry of Commerce and Industry (MCI) is responsible for "generic" industrial policy in India and has consistently pushed to liberalize Indian industrial policy. Similarly, the Planning Commission (PC) formulates India's five year plans and coordinates with the MCI to drive an industrial policy stressing liberalization (Suryanarayana). The inability of the Indian government to disburse SIPS-I subsidies suggests that this uncoordinated policy approach is a weakness of the Indian innovation system and compromises the ability of the latter to provide capital and competencies to a sector of apparent national interest. Further, the oversight of the SIPS-I subsidies by the Department of Electronics and Information Technology (DEIT), under the Ministry of Communications and Information Technology (MCIT), instead of by the DIPP, testifies to the piecemeal approach to institutional support for the solar PV sector. We are unable to find evidence of coordination by the MCI of the NSM industrial policy, and it is unclear how this dissonance has been or will be resolved. The MNRE may need to justify the DCR as improving the competitiveness of the solar PV sector, but Propositions 1 and 2 imply that this is unlikely.

6.3. The analysis reveals functional gaps in the Indian innovation system

Though the NSM is forming markets for the Indian solar PV sector, the innovation system is not creating positive external economies, diffusing or guiding knowledge creation and technological search or supplying resources such as capital, labor, infrastructure and competencies. While the DCR could drive hitherto unobserved increases in capacity utilization, the innovation system appears unable to support an expansion of the Indian solar PV sector into a globally competitive one. The comparison of the Chinese and Indian innovation systems

and solar PV development pathways identifies specific functional gaps in the Indian innovation system that, if closed, could theoretically allow the Indian solar PV sector to regain competitiveness. If policy analysis implies that policies to address these gaps are socially beneficial, the economics literature provides guidelines by which industrial policy can assist the subsequent growth of competitive sectors. As an example Pack and Saggi (2006) recommend subsidies for marginal R&D and cluster creation as tools to improve productivity across an industry. These subsidies could enhance the ability of the Indian innovation system to both generate and diffuse knowledge and trigger positive external economies.

Alternatively, more liberal industrial policy measures could synchronize MNRE and MCI/PC perspectives. For example, a shift from a component-specific DCR to one that requires some percent of total installed value to be sourced domestically would direct solar developers to reward those sectors of the Indian economy whose growth could yield dynamic efficiency improvements. Nonetheless, as we discuss below, it may be better for Indian policy to focus on balance-of-systems components than on cell and module manufacturing. Of course, these options should be interpreted only as starting points for further analysis.

7. Conclusion

The NSM is a prominent example of a renewable energy policy that attempts to bolster a domestic manufacturing base. The goal of this paper was to examine whether the domestic content requirement of the NSM is likely to ensure the global competitiveness of the Indian solar PV sector. A subsidiary aim was to understand the degree to which the Indian innovation system has the enablers of competitiveness present in the Chinese system. In this section, we summarize our findings and contributions, discuss implications for policymakers and suggest next steps for research.

This paper has contributed an analytical framework with which one can form an ex-ante assessment of the likelihood with which an industrial policy will facilitate the global competitiveness of its target sector. The innovation, development and industrial policy literatures do not provide a standard method by which to assess the likely impact of an industrial policy, and virtually all previous studies of RET industrial policy and technological development have focused on ex-post explanations. Our framework employs three methods: (1) it analyzes export data to quantify trends in the competitiveness of the target and ancillary industries, (2) it studies choice data to examine whether industrial policy has had a significant impact on the degree to which industrial output is employed domestically, and (3) it compares national innovation systems to determine whether the domestic innovation system can provide the technological readiness needed to build a globally competitive sector. By applying this framework to the NSM DCR, we have analyzed a component of the NSM that had not been formally studied.

Our analysis implies that the NSM DCR is unlikely to yield a globally competitive Indian solar PV sector. The export data analysis implies that Indian solar PV manufacturers have become less competitive. Solar project developer technology choice data do not suggest that the NSM has triggered the uptake of domestic crystalline silicon modules; indeed, developers may be increasingly opting to use foreign thin-film substitutes. Indian solar PV manufacturers are unlikely to capture external dynamic learning effects of the magnitude needed to achieve global competitiveness. Finally, a comparative analysis of the Indian innovation system with its Chinese counterpart reveals that though the former is forming a domestic solar PV market through the NSM, there are apparent gaps. These include knowledge creation and technological search, as R&D is not directed by the needs of the private sector, positive

external economy formation, with unfruitful efforts to build a semiconductor manufacturing base, and resource provision, which is complicated by an uncoordinated implementation of industrial policy. While an analysis of the marginal and joint impacts of closing these gaps is beyond the scope of the current paper, a rigorous analysis of these options is a natural next step if competitiveness in solar PV manufacturing is a national priority for India in the long-term.

Our ex-ante prognosis is in line with ex-post evidence that DCRs tend to fail when the target is of sub-optimal scale and sheltered from competition. It is additionally rooted in a wider understanding about DCRs in developing countries that emphasizes the need for strong complementary technological skills. Our studies of the Chinese and Indian innovation systems imply a possible extension to the narrative: divergent outcomes from DCR implementation are attributable not only to technological readiness but also to the functionality of the upstream innovation system that should provide it. With further examination in other contexts, this extension could bridge the DCR and innovation systems literatures.

Since the NSM DCR introduces the risk of distorting project developers' module technology choices with a low probability of encouraging a globally competitive solar PV sector, we recommend that Indian policymakers remove the DCR.²² We realize that the DCR could be a response to Chinese industrial policy. If it is, our ex-ante effectiveness assessment suggests that it could impose unnecessary costs on the Indian economy while providing a false sense that the competitiveness problem has been addressed. Our recommendation also applies to state-level policies: crystalline silicon solar manufacturers in India have formed the Indian Solar (PV) Manufacturers Association, with goals of managing the thin-film "threat" and supporting DCRs in state-level solar policies (Panchabuta, 2011b). State policymakers should resist the inclusion of such DCRs.

However, the NSM and state solar policies provide a sizable market, and there are other strategies through which the Indian government may be able to facilitate a globally competitive solar PV sector. The bulk of installed solar PV costs are now attributable to downstream balance-of-systems components. Fig. 5 implies that India is nearly globally competitive in the electronic transformers industry, and this indicates that components of the innovation system relevant to balance-of-systems components may be stronger than those to solar cell and module manufacturing. Moreover, since China's solar PV sector has traditionally been export-focused, it does not yet have a globally competitive power inverter sector (Fischer, 2012). The selection of this strategy would require additional due diligence, and our framework from Section 4 could be applied to balance-of-systems components to determine if industrial policy support could eventually yield globally competitive sectors.

The additional due diligence would benefit from the development and application of general equilibrium models capable of estimating the economic welfare impacts of industrial policy for these sectors. Such models could also quantify the impacts of the NSM DCR, though standard partial equilibrium analyses imply a weakly negative welfare outcome (see Online Appendix). Finally, as technology choice data become available for more plants within and outside of the NSM, an empirical analysis of the impact of the DCR on technology sourcing by project developers would allow a better estimate of the short-term implications of the DCR and an opportunity to confirm our expectation that the DCR will not trigger the expansions in domestic output necessary, albeit not sufficient, for global competitiveness.

²² Others, such as Ghosh and Jaiswal (2012) and PWC (2012), have provided policy recommendations to fix NSM industrial policy, but our analysis cautions against certain suggestions. The NRDC, for example, suggests a technology neutral DCR, but that would yield a partial equilibrium outcome analogous to that depicted in Fig. A3b in the Online Appendix.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at <http://dx.doi.org/10.1016/j.enpol.2013.06.090>.

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