An Analysis of Industrial Policy Support for the Indian Solar Photovoltaic Manufacturing Sector

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Abstract
National renewable energy policies often have many goals, and frequently an aspiration is the development of domestic renewable technology manufacturing capacity. The Jawaharlal Nehru National Solar Mission (NSM) in India is an example; besides targeting an installation of 20GW of grid-tied solar power capacity, it includes industrial policy to strengthen a photovoltaic solar manufacturing base. We develop and apply a framework to examine the likely efficiency and equity implications of the policy’s domestic content requirement (DCR), which requires 100% of crystalline silicon cells and modules in NSM plants to be sourced domestically. We suggest that any efficiency improvements would be driven largely by surplus gains by domestic manufacturers at the potentially large expense of electricity consumers. Our analysis reveals three observations that suggest this equity implication is unlikely to change throughout the NSM: (1) developers continue to favor substitute thin-film technology, bypassing the DCR, (2) the manufacturing base has become less competitive over time, and (3) ancillary domestic industries that could provide complementary skills are uncompetitive.

1. Introduction

Over the last few decades, renewable energy technologies (RET) have emerged from the university lab into the generation site. The mass media touts this transition as the cure for a number of social ills, including local and global environmental degradation, unemployment, and the need to publicly support national security forces to ensure the supply of traditional energy sources (cf. Gillingham and Sweeney 2010). This perspective motivates calls for strong policy support for quick and concerted shifts to RETs. In many cases, support for RET manufacturers and upstream components is included as part of such policies. Though a large literature provides a narrative of RET policies and industrial growth around the world (inter alia Lund 2009, Fu and Zhang 2011), industrial policy for the RET industry has mostly received a blank check from normative analysis in the economic policy analysis literature. This gap may be due in part to the existence in the international economics literature of many theoretical analyses of industrial policy (inter alia Brainard and Martimort 1997, Dinopoulos et al 1995, Melitz 2005).

However, theoretically and empirically based analyses of industrial policies for RET industries are useful for at least two reasons. First, many analyses assume that the enacting country is attempting to catch up technologically to a mature efficient producer; in the relatively young RET market, the enacting country may already hold significant strengths in RET technology. Second, competition in the RET markets has prompted the use of policy instruments, such as domestic content requirements (DCRs), that though studied before (inter alia Grossman 1981 and Mussa 1984), have been extensively empirically examined in only a few industries and most thoroughly in the automobile industry (Munk 1967; Takacs 1994; Veloso 2001). Using the particular case of the Jawaharlal Nehru National Solar Mission (NSM) in India, this paper comments on the implications of DCRs for solar PV manufacturer and electricity consumer welfare.

Besides aspiring to install 20GW of grid-tied solar capacity by 2022, the NSM seeks to establish India as a solar manufacturing hub (MNRE 2009). The industrial policy elements of the NSM, which include DCRs and capital incentives, have not yet been formally analyzed; the other aspects of the NSM, including the distributional impact of both on-grid and off-grid deployment policy and its institutional limitations are covered well by previous work (Govindarajalu et al 2010; Shrimali and Rohra 2012). Accordingly, the goals of this paper are twofold: (1) to provide an analytical framework for the study of DCR-based industrial policy
for RET and (2) to apply it to the particular industrial policy of the NSM. Our hope is that such work can also inform the debate over DCRs elsewhere, such as those in Ontario.¹

The remainder of this paper is organized as follows. Section two provides background on industrial policy theory and practice, the global and Indian solar PV industry, and industrial policy support for the Indian solar PV sector. Section three develops our analytical framework. In section four, we apply this framework to the NSM. We begin by exploring whether there is enough domestic manufacturing capacity to supply the NSM, and we diagnose the competitiveness of and potential for learning within the solar industry. Section five concludes and offers suggestions for further research.

2. Background

Industrial policy is a broad term and can be used to describe a range of policy measures. In section 2.1, we offer a general definition and objective of industrial policy. Our subsequent discussion focuses on the externalities that justify such policy and pays particular attention to the implicit goals of DCRs. In section 2.2, we review the record of industrial policy. Following this theoretical and empirical background, section 2.3 provides an overview of the global and Indian solar PV industries, and 2.4 of the current Indian industrial policy measures.

2.1. The objectives and justifications of industrial policy

Industrial policy includes instruments that shift resources towards industrial sectors expected to generate greater economic growth than would the equilibrium allocation of goods (Pack and Saggi 2006). Dynamic efficiency is important in policy analysis, as resource allocation only by current competitive advantage ignores the evolution of competitive advantage over time (Ibid). A traditional justification for industrial policy is that firms cannot fully appropriate dynamic learning and training effects (Ibid). Further, industrial policy could address an informational externality by allowing a country to learn about the potential profitability of an industry (Ibid). In the case of energy generating industries, industrial policy could reduce the external social costs associated with funding militaries to guarantee energy procurement. In this section, we discuss these justifications and highlight the ones we emphasize in our analysis.

2.1.1. Industrial policy is an attempt to trigger external dynamic learning and training effects

Industrial policy has been conceptualized as a response to learning, coordination, and informational externalities. A fundamental assumption is that the domestic industry will learn by doing or that industries will reduce their costs as cumulative output expands.² Industrial policy is justified as a means to align private production decisions with socially optimal ones: if firms are unable to fully appropriate the learning that its production activities generate, they will produce at a suboptimal level. This notion of dynamic learning provided one of the first normative criteria for industrial policy, the Mill-Bastable test, which stipulates that (1) there must exist dynamic learning effects external to firms, (2) that the industry must be able to generate non-negative economic profits after public support is removed, and (3) the net benefits from the protected industry exceed the net costs of protection (Itoh et al 1991). Analogously, firms cannot appropriate the full benefit of training employees on the job; labor that shifts across firms in the same industry will transfer their skills with them, implying a private incentive to under-invest in labor force development (Pack and Saggi 2006).

DCRs are tools to catalyze dynamic learning effects by triggering an expansion in domestic industrial output. Since they are at the heart of Indian solar PV industrial policy efforts, we focus in this paper on DCRs. While most formal models of DCRs conclude that they increase the cost of intermediate goods and thereby the price of the final good, they could also trigger investments by foreign original equipment manufacturers, prompting entry by supporting domestic firms (Veloso 2001). Moreover, by favoring domestic

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¹In 2009, Ontario implemented a feed-in-tariff program for both wind and solar power projects. For solar projects with capacity greater than 10kW and anticipating commercial operation by January 1, 2011, the Ontario program required domestic content to account for 50% of all project costs; this increased to 60% for projects anticipating commercial operation after that date (OPA 2011). While the Ontario DCR differs from the Indian context in that the former stipulates a percent of cost and the latter specific components that must be sourced domestically, the modularity of the crystalline PV value chain will allow readers to draw parallels between the Indian and Canadian case.

²Learning by doing was first formalized by Arrow (1962). A conventional assumption is that costs decrease by a certain percentage for each doubling in cumulative output.
inputs, DCRs can support technological learning processes in the relevant domestic industry (Ibid). The resources employed by newly entering foreign firms and domestic suppliers generate spillover effects that make them more valuable than in alternate uses in the economy (Ibid). DCRs must balance luring foreign investment and strengthening domestic players against introducing price distortions in final goods (Ibid).³

2.1.2. Industrial policy could address informational externalities

Rodrik (2004) suggests that industrial policy could respond to a different type of externality: investment in a new industry generates information about a country’s comparative advantage. Since potential competitors benefit from this, Rodrik argues that the level of experimentation will be lower than the social optimal. We do not consider these externalities in our analysis since India already has a solar manufacturing base.

2.1.3. Industrial policy for energy industries could address security externalities

Beyond these standard justifications, RET specific support has the potential to reduce social costs, such as energy security externalities. Industrial policy for RET manufacturing may prevent a shift from reliance on foreign supplies of fossil fuels to one on foreign supplies of RET. Though it is difficult to place a monetary valuation on the marginal reduction of security externalities attributable to domestic RET production, the displacement of energy sources that require military forces to ensure their procurement suggest a positive welfare impact. Nonetheless, alternative measures, such as energy efficiency investments, may be a more efficient response.

2.1.4. Industrial policy could coordinate private investment

Apparent coordination failures in industrialization could additionally justify industrial policy. The coordination of investment by complementary firms requires a mechanism to signal entry (cf. Pack and Saggi 2006). In new markets, prices cannot serve as a signal for firms’ intention to enter, so coordination failures almost certainly exist. It is not clear, however, that they justify governmental intervention. Industrial policy based on coordination failures between upstream and downstream industries requires not only an expectation of scale economies, but also imperfect tradability across national borders (Pack and Saggi 2006). Since many RET goods can be traded across borders, there is no a priori reason to require the indigenization of an entire industry. If there are gains from cluster formation, private profit potential should drive, e.g., joint ventures, foreign direct investment or the acquisition of complementary firms by domestic firms.⁴ Of course, if a new industry is emerging, a country could conceivably coordinate the monopoly capture of global market share by its domestic industry. However, industrial policy on this basis would require immense foresight by the policy maker. Moreover, RET industries are not new. Given these perspectives, we do not consider coordination failures a first order justification for industrial policy for RET.

2.2. The record of industrial policy is mixed

Empirical analyses have documented mediocre gains from industrial policy measures. A 1955 - 90 study across 13 sectors failed to find evidence that preferential policies either targeted sectors with increasing returns to scale or contributed to the rate of capital accumulation (Pack and Saggi 2006). A similarly paradoxical finding is that the effective rate of protection was negatively associated with sectoral factor productivity growth; imports were positively associated with factor productivity (Ibid.). Such apparent failures of industrial policy may be explained by the general level of technological absorptive capacity and preparedness of the national systems of innovation in host countries. Both Lall and Teubal (1998) and Wignaraja (2003) stress the importance of these supra-industrial capabilities to achieving dynamic efficiency. Given these preconditions, Pack and Saggi argue for subsidies for marginal R&D and cluster creation as a tool to improve productivity across an industry (Pack and Saggi 2006). Both proposals would ideally help an industry prepare to absorb new technologies and customize constituent firms’ production systems to capture gains from an optimal structure of intra-cluster trade (Ibid.).

³In the particular case of solar DCRs, Huberty and Zachmann (2011) suggest that, given the low shipping cost of solar components, upstream of and including the module, DCRs may not prompt the growth of a supporting industry; they may only distort an efficient allocation of resources in the economy and raise the cost of achieving deployment goals. Low shipping costs and weak pre-existing technological skills are not the only reasons a DCR could fail to achieve its objective. Grossman (1981) models a DCR on an intermediate good with penalties for non-compliance and shows that it may not increase the domestic content in finished goods.

⁴Imperfections in capital markets could justify non-sector specific capitalization policies.
Reviews of RET specific industrial policies agree with the general trend that such instruments work best when they are part of a comprehensive approach combining industrial policy with deployment policy, utilizing pre-existing strengths in the industry, and developing all parts of the national innovation systems (Lewis and Wiser 2007; Lema and Ruby 2007). Using country-level case studies, Lewis and Wiser (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 result in the establishment of an internationally competitive wind industry. Another set of papers extends the complementary policy argument and asserts that industrial policy works best if it capitalizes on pre-existing strengths in ancillary industries. Huberty and Zachmann (2011) test if industrial policy for RETs can improve competitiveness and show that the most competitive industries exist where policies capitalized on pre-existing industrial capabilities rather than attempted to build them anew. They further show that though policy seems to improve the competitiveness of domestic wind manufacturers, there is no evidence that industrial policy works for solar producers.\(^5\) Examining commercialization processes, value chain analyses, and empirical case studies, Lund (2009) comes to similar conclusions in a study of the impacts of policies on renewable energy sector growth: irrespective of the domestic market, investment or R&D support to strong industries in related fields helps with diversification into sustainable energy. Finally, Lema and Lema (2012) extend the complementarity argument to national innovation systems. They show that conventional mechanisms such as trade, foreign direct investments and licensing were important for infant industries but that as these sectors mature, other mechanisms are more important, including endogenous technology creation, connection to global R&D networks, and acquisitions of leading firms. This finding suggests the need for strong local innovation and global technology collaboration capabilities.

2.3. The Indian solar PV industry is small on a global scale

We review the global and Indian solar PV sectors to introduce the production processes, provide a sense of the scale of the Indian industry, and to highlight two observations: (1) the lack of vertical integration among Indian firms, (2) the small capacity and output of the Indian firms within the global solar PV industry, and (3) the concentration of Indian PV industry at the downstream steps. There are two distinct solar PV production processes. The crystalline PV supply chain begins with polysilicon, which consists of small silicon crystals. The polysilicon is molded into ingots, which are then shaped into wafers, the semiconducting materials used as substrates for the microelectronics of the PV cell. Collections of PV cells are assembled into a PV module, which can be installed as part of an on-grid PV power station. Unlike the crystalline PV supply chain, the thin-film PV market is fragmented by different feedstock materials. The thin-film supply chain requires the input of raw material such as amorphous silicon, copper indium gallium diselenide (CIGS) or cadmium telluride (CdTe). These raw components are deposited on a substrate to produce a PV cell; as with crystalline cells, thin-film cells are combined to produce modules. The downstream balance-of-system steps are common to the crystalline and thin film technologies. Crystalline PV technology is more mature and generally yields modules of higher efficiency. In 2011, crystalline PV modules accounted for 77% of all modules produced and thin-film modules for another 21% (Lux 2012).

Figures 1 and 2 compare the scale of the Indian crystalline solar and thin-film PV manufacturing industry with global levels. The 2011 global output depicted in the figures reflects a market that has experienced a compounded annual growth rate of nearly 40%, with a market value that expanded from $2.5 billion in 2000 to $71.2 billion in 2010 (Platzer 2012). The total global module production in 2011 is estimated at 28GW (Lux 2012). Though the aggregate size of the cell and module production capacity in India accounts for just under 5% of global capacity, global tier-1 producers of cells and modules have as much capacity as India’s entire manufacturing base, and we discuss the implications of this scale in Section 4. Also note India’s virtual absence at the upstream steps. The upstream steps are less competitive than the downstream steps, require more technological knowledge and are increasingly done by integrated firms. We examine why Indian firms have not entered these upstream stages in section 4.2.

2.4. Indian industrial policy support for the solar PV industry attempts to grow the sector

Policy support includes the development of domestic demand, domestic content requirements, capital subsidies, and preferential access to power project licenses.

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\(^5\)Huberty and Zachmann (2011) suggest that given the greater tradability of solar cells, an expansion of domestic demand results in more imports rather than greater domestic production.
While not explicitly an industrial policy instrument, NSM deployment policy targets 20GW of grid-tied solar capacity by 2022 (MNRE 2009). NSM capacity will be deployed in three phases. By the end of Phase I in 2013, the NSM targets 1100MW of capacity, by the end of Phase II in 2017, 4000MW, and by the end of Phase III in 2022, 20000MW. 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 will install 150MW of solar PV capacity, and the second over FY2011 - 2012 will install 350MW of the same. A number of mechanisms guarantee the off-take of power generated by solar PV generation. Utilities must meet solar specific Renewable Purchase Obligations (RPO) (Bhargava 2010). Since solar development will occur non-homogeneously across India’s states, a market-based mechanism will ensure all states can meet their solar specific RPOs: utilities unable to buy their share of renewable energy can compensate by buying credits to make up for the shortfall (EAI 2011).6

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). Given the prominence of the DCR, the attention it has attracted from domestic and international manufacturers, and the potential for revision in subsequent phases, it is the focus of our analysis.

The 2007 Semiconductor Policy (SIPS-1) sought to subsidize capital investments of at least $550M in capital expenditures for semiconductor or solar manufacturing. Investment within Special Economic Zones (SEZ) would receive a subsidy of 20%, while those outside would receive a subsidy of 25% and exemptions on duties on imported capital goods. As in general, firms operating in SEZs would be eligible for a 100% income tax exemption for 10 years and the duty free import of goods to build factories. Finally, the Indian Renewable Energy Development Agency would provide loans of up to 75% of total project costs, at 12.1 - 13.5% interest. The majority of SIPS-1 proposals were for solar PV manufacturing. By the close of applications on March 31, 2010, SIPS-1 had attracted 26 proposals worth $51.7 billion (Rs 2.3 lakh crore), of which only 6 were deemed financially viable (Panchabuta 2011a; Singh 2011). Firms claimed the incentives were too low for

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6These credits are known as Renewable Energy Certificates, and they are described by (EAI 2011).
semiconductor manufacturing and cited support from China and Taiwan, in which up to 50% of capital expenses were subsidized; instead, firms that intended to build semiconductor chip fabrication plants (e.g., SemIndia and India Electronics Manufacturing Corp.) decided to manufacture solar units. The selection of manufacturers had not been completed as of July 2012. (Frost & Sullivan 2010)

Preferential power licensing occurs at the state level; the Rajasthan Renewable Energy Corporation targets the establishment of 200MW of solar PV manufacturing capacity in the state by 2013. Producers that build solar PV manufacturing plants between 25MW and 50MW in capacity will be eligible to establish a 10MW solar PV based power plant, while those who establish larger plants will be eligible for 20MW power plants (Government of Rajasthan 2011).

3. Analytical Framework

Our analysis of NSM industrial policy seeks to (1) examine its likely economic efficiency and equity implications and (2) identify whether it is likely to complement overarching deployment goals. In section 3.1, we develop our framework for economic analysis. Sections 4.2 and 4.3 subsequently apply this framework to comment on the implications of the policy. To examine the complementarity of NSM industrial policy with its deployment policy, we assess in section 4.1 whether the chief actors in the NSM can meet its deployment goals. In this section, we detail the assumptions underpinning our efficiency and equity framework.

3.1. Our efficiency framework considers both static and dynamic efficiency

Our efficiency framework assumes a welfare function that takes as arguments (1) the surplus captured by domestic solar project developers, (2) the surplus captured by domestic solar PV module and cell manufacturers, and (3) the surplus captured by electricity consumers. This decomposition of surplus capture allows us to comment on the equity implications of the DCR.

Our measure of static changes in welfare, \( \Delta W_s \), is given below:

\[
\Delta W_s = \Delta \text{Developer Surplus} + \Delta \text{Manufacturer Surplus} + \Delta \text{Electricity Consumer Surplus}
\] (1)

Industrial policy may be more appropriately evaluated using a dynamic measure of changes in welfare, \( \Delta W_d \). In our subsequent discussions of dynamic efficiency, we will thus refer to equation 2, which provides a stylized two phase model:

\[
\Delta W_d = \Delta \text{Developer Surplus}_0 + \Delta \text{Manufacturer Surplus}_0 + \Delta \text{Electricity Consumer Surplus}_0 + (\Delta \text{Developer Surplus}_t + \Delta \text{Manufacturer Surplus}_t + \Delta \text{Electricity Consumer Surplus}_t)\delta^t
\] (2)

where \( t \) refers to a future time period and \( \delta \) is the social discount factor. This qualitative two phase model suggests necessary conditions for industrial policy support to increase societal welfare: either some cheaper module is sourced in period one or in period two domestic manufacturers have reduced their costs below the globally competitive level, with these lower costs passed on to project developers and electricity consumers. If Indian manufacturers are able to newly produce modules cheaper than foreign alternatives as a result of the DCR, we would expect manufacturer surplus to increase, as these firms sell both in the domestic and global markets, project developer surplus to increase, as these firms would face lower input costs, and electricity consumer surplus to increase, as the implied LCOE of solar projects would decrease. There is no reason to believe that by closing the market to international module producers, Indian project developers could suddenly source a cheaper solar module; industrial policy cannot be statically efficient. Thus, an increase in societal welfare requires that in period two, manufacturers in India have reduced their costs below the globally competitive level. This requires either that domestic firms learn-by-doing or that foreign suppliers enter the market and generate spillovers and learning effects, creating an externality-from-entry (Veloso 2001). Our

\[7\] Alternatively, we could measure the impact on wholesale consumers of electricity, such as the state electricity boards that purchase a bundle of solar generated electric power and thermal generated electric power from NTPC Vidhyut Vyapar Nigam (NVVN), the state owned electricity trading company. Our analysis below would remain the same; however, since retail electricity prices are highly subsidized, the distributional effects may differ. We believe, though, that if state electricity boards face higher wholesale prices, the costs will eventually pass to retail consumers, either in the form of higher retail electricity tariffs or higher probability of power disruptions, as electricity boards are unable to meet their payment obligations.
period two necessary condition would prevent a result analogous to Baldwin’s (1969) discussion of an infant-industry tariff that reduces welfare by its inability to shift the production possibility curve outward, while still causing a consumption loss due to a rise in price of the good above its world level.

Given the small size of the solar market within the Indian economy, we employ a partial equilibrium approach to our analysis of industrial policy. Moreover, we note that our analysis deliberately excludes factors that may be relevant to policy makers. Most notably, our analysis does not consider avoided energy security costs or energy source optionality provided by the development of an indigenous manufacturing base.

Our evaluation of (1) and (2) proceeds in three conceptual stages. We first assess the impact of a particular industrial policy on developers’ module sourcing decisions. We then examine the implications of this choice on module manufacturer, developer and electricity consumer surpluses. The sum of these changes in surplus provides a welfare measure, and we graphically depict this assessment in Figure 3. Critically, for our analysis to suggest a likely consumer welfare improvement, we must see evidence that domestic manufacturers are likely to improve their production technology by learning by doing or even stronger evidence that they are on a path of becoming super-competitive relative to the global PV market. A prognosis of likely super-competitiveness would require a belief that Indian firms can reduce their costs more quickly than their global competitors can; SolarBuzz, a market observer, forecasts module prices will drop 43 - 53% relative to 2011 levels over the next five years (Platzer 2012).

![Figure 3: The welfare impact of the DCR is a combination of its impact in the upstream module market and in the downstream solar power market. In the upstream market, the DCR could grant market power to manufacturers, as depicted in graphs 1 - 2. 2 shows the limit of market power, though full monopoly may not obtain. Alternatively, the DCR could simply shift the marginal cost curve upward, in which case graph 2 would be replaced by a graph that looks like graph 4. The former result is more likely for the thin-film market and the latter for the crystalline market. In either case, the change in manufacturer surplus depends on the elasticity of module demand among developers. In the crystalline only DCR, the potential for substitution by either foreign or domestic thin-film modules limits the surplus gain by manufacturers. Any increase in domestic manufacturer surplus is augmented by new participation of domestic manufacturers. The equilibrium module price will increase, implying higher costs to project developers. We make an assumption that module manufacturers capture fixed relative margins, implying that the higher cost of module procurement is reflected in higher bid levelized costs of electricity (LCOE). The net change is a gain in project developer absolute surplus. The higher bid LCOEs imply a higher price equilibrium in the downstream market. The magnitude of change in downstream consumer surplus (graphs 3 - 6) depends on the elasticity of demand, but the directional impact is the same: higher electricity prices imply a loss in surplus among electricity consumers. The overall impact depends on the relative magnitudes of surplus changes across manufacturers, developers, and consumers.]

3.1.1. The outcome of a no-policy scenario provides a benchmark for welfare analysis

We begin by defining the outcome of a no-policy benchmark scenario. In this case, the project developer is unconstrained in its choice of module technology, and it chooses a module, M, to maximize its expected
profits, $E[\pi^{\text{Developer}}]$:

$$\max_M E[\pi^{\text{Developer}}] = E[q_e](\text{LCOE}(L(M), K(M), M))$$

where $E[q_e]$ is the expected quantity of electricity generated by the project, the LCOE is the levelized cost of electricity, assuming $L$ units of labor, $K$ units of capital and $M$, a particular module. When we subsequently consider developers’ choices over alternate modules, we assume that the developer purchases modules based on a conversion efficiency-adjusted price.

Assuming a competitive module market, the project developers’ module choices imply that those module manufacturers with the lowest marginal cost of production, globally, will be selected. In the course of this selection, we anticipate that only those domestic manufacturers occupying infra-marginal positions on the global module supply curve would be able to sell modules to NSM developers. Since these manufacturers are globally infra-marginal suppliers, they are also infra-marginal on a domestic-only module supply curve.

Finally, the choices of the developers are translated into bids for electricity power production, and we assume, as equation (3) suggests, that developers bid their LCOE, given the incentive of the NSM bidding mechanism for truthful revelation.¹ In particular, plants are selected for participation in the NSM on the basis of discounts to a Central Electricity Regulatory Commission (CERC) sanctioned benchmark tariff rate; those projects bidding the greatest discount to this rate are selected for the NSM, and bids with greater discounts must be accompanied by bonds that increase linearly in the level of discount (MNRE 2011). Projects are selected for the NSM until the desired generating capacity is reached. The truthful revelation result follows from the close relation between this auction mechanism and the ascending bid auction for multiple auctions proposed by Ausubel (2004). Under the no-policy benchmark, we thus expect bid power tariffs to be as low as possible under any alternative policy scenarios, thereby maximizing electricity consumer surplus.

4. Policy Analysis

In section 4.1, we begin by examining NSM industrial policy within the lens of the wider Mission and evaluate its compatibility. Since the current performance of the Indian solar industry provides signals about its competitiveness and potential to learn with DCR protection, section 4.2 diagnoses the sector. In 4.3, we apply our analytic framework from section 3.1 to analyze the efficiency and equity implications. Though we do not identify major capacity incompatibilities between industrial policy and the deployment policy, our results in 4.2 and 4.3 suggest that the domestic industry has become less competitive over time. Although the DCR could improve economic efficiency, these gains would entail potentially large economic costs borne by electricity consumers.

4.1. The DCR does not (yet) place capacity constraints on NSM deployment policy

The DCR implies that a certain supply of domestically manufactured crystalline modules and cells must be available to project developers. From Figure 1, the domestic crystalline cell and module capacity is about 1.7GW, an adequate level for current NSM deployment, with a total Phase I (2009 - 2013) capacity addition target of 500MW. At the time of writing, the first batch of solar PV plants was under construction, with over half using domestic crystalline modules. Similarly, bidding for the second batch of plants had concluded, and the developer with the lowest bid indicated that the eventual plant would use domestic crystalline cells and modules (Ramesh 2011). Capacity thus does not appear to place a binding constraint on the NSM deployment goals. Assuming a continuing 50% split of grid-tied solar capacity between PV and concentrating solar power, crystalline capacity should remain a non-binding constraint, even as annual deployment rates grow. We summarize this observation in proposition 1:

**Proposition 1:** Observed Indian crystalline solar PV manufacturing capacity suggests that the DCR does not and will not place capacity constraints on the NSM deployment policy.

Our concern in sections 4.2 and 4.3 is with the cost of using domestic capacity as the deployment schedule demands increasing amounts of domestic product.

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¹We assume that developers bid so as to capture a fixed rate of return and that their bids thereby reveal their true levelized cost of electricity. We are aware of suspicions that developers in batches I and II of the NSM phase I may have underbid as part of a “gold-rush” mentality towards the NSM, but theory suggests that this will not be representative of equilibrium behavior. Such short-term behavior is peripheral to our central analysis.
4.2. The Indian solar PV industry has become less competitive over time

Social welfare improvements critically depend on whether the potential for dynamic learning-by-doing spillovers exist in the Indian solar PV manufacturing sector. We assume that evidence on past learning in the industry can serve as a signal of future learning potential.

4.2.1. India’s increasing UVR relative to China and the OECD suggests its solar PV industry has become less competitive over time

We begin by calculating the unit value ratio (UVR), as comparisons of unit values with respect to technology leaders have been used to study technology catching-up processes among countries (Brunner and Cali 2006). In our application, we derive UVRs that compare the unit value of Indian solar photovoltaic exports to a particular region with those of other countries. As an illustrative example, the UVR of Indian PV exports relative to OECD PV exports is given by:

\[
UVR_{\text{India/OECD}} = \frac{\text{ValuePV exports}_{\text{India to OECD}}}{\text{QuantityPV exports}_{\text{India to OECD}}} / \frac{\text{ValuePV exports}_{\text{OECD to OECD}}}{\text{QuantityPV exports}_{\text{OECD to OECD}}},
\]

In this specific example, we include only the value of PV exports from India to OECD member countries. Exports from OECD to the OECD include exports from one OECD country to another. The graph in Figure 4 tracks the India-China UVR, the India-OECD UVR and China-OECD UVR from 2003 to 2011. Note that a lower unit value implies greater competitiveness, and a country with a UVR less than one is considered to have a more competitive industry. Figure 4 reveals an Indian solar PV sector that has lost the competitiveness it held before 2007. Between 2003 and 2007, India enjoyed a UVR below that of both China and, for the most part, below that of the OECD countries. Chinese producers were “learning” in this period, as the Indian industry after 2007 is not competitive against either the OECD or China.

Export data reinforce this interpretation, as they suggest that the Indian export market is sensitive to feed-in-tariffs elsewhere and that its products provide high cost marginal supply (Department of Commerce 2012). Figure 5 shows the value of Indian exports between FY 2003 - 04 and FY 2010 - 11 and by destination.

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9The use of the unit value is inspired by Brunner and Cali (2006). They examine UVRs across industries within a particular economy, while we examine the UVR across countries within a particular industry. Thus, while Brunner and Cali interpret higher UVRs to indicate “changes in the export product mix towards relatively high technology goods and in the factor intensities using more capital and skilled labor”, we interpret higher UVRs as an indication of decreasing competitiveness. The assumptions behind our interpretation are (1) that all countries sell modules of equal quality and (2) that all countries theoretically have access to the same production technology and should thus be able to achieve equal unit values.

10Since much of our analysis is based on trade data which does not distinguish between crystalline and thin-film PV, we are unable to separately assess the competitiveness of manufacturers of each technology.

11Following Brunner and Cali (2006), we exclude the four countries that most recently joined the OECD. These countries are Chile, Estonia, Israel and Slovenia, all of which joined in 2010. To guarantee a unitless UVR measure, note that 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 OECD export and import data for the United States, Canada, and Japan.
Note that the values of exports to a particular country follow trends in feed-in-tariffs in that particular country. For example, the pattern of export to Germany, Spain, and Italy reflect movements in the feed-in-tariff rates provided by those governments. We take this as a signal that India’s capacity provides high marginal cost capacity to the global market. Had India’s capacity provided infra-marginal capacity, the value of PV products exported to these European markets would not display such sensitivity to the feed-in-tariff magnitude. The German market in FY 2009-10, for example, could have again imported from India a value equal to the value of its imports from India in FY 2008-09, even with its lower feed-in-tariff levels. It could be argued that solar PV modules were decreasing in cost over time. If the decrease in value is solely attributable to this, we would still expect India to maintain a constant share of the global solar photovoltaic production market. However, as shown in Figure 6, India’s share has fallen from 4.1% in 2002 to 2.0% in 2010 (Earth Policy Institute 2011). The erosion of market share corroborates both our export value and unit value ratio data analyses; the Indian PV sector has become less competitive over time.

Figure 5: India’s PV capacity utilization appears at least partly driven by feed-in-tariffs. In FY 2007-09, both France and Spain introduced feed-in-tariffs, but Spain’s support dropped after FY 2008-09, and Germany has been ratcheting down its tariff level. The spike in exports to Italy in FY 2010-11 is likely due to the introduction of feed-in-tariffs in that market. Markets shown account for ~80% of exports by value, and data is for harmonized system commodity number 854140. Source: Department of Commerce (2012).

Figure 6: China’s share of PV production increased from lower than 2% in 2002 to 45.1% in 2010, while India’s has fallen from 4.1% to 2.0%. Since ISA data was only available from India’s fiscal year 2001-02 to FY 2008-09, we used numbers from Lux Research to fill in missing data for calendar years 2008, 2009, 2010. Indian calendar year data for 2002 through 2007 are derived from FY level data. We allocated 3 of 4 quarters of a given fiscal year (e.g., 2002-03) to the first calendar year (e.g., 2002) and 1 of 4 quarters to the second calendar year (e.g., 2003). Over the same time frame, India’s share has remained roughly constant; between 2002 and 2010, its share fell from 4.1% to 2.0%, with a peak of 4.4% in 2003. The erosion of market share corroborates unit value ratio data examined in this paper. Sources: Earth Policy Institute (2011), Lux Research (2012) and ISA (2010).

4.2.2. Though the Revealed Competitive Advantage metric similarly suggests an uncompetitive solar PV and electronic machinery industry, upstream and downstream opportunities may exist.

We use UN Comtrade data to calculate revealed competitive advantage (RCA) metrics; this compares the ratio of exports of a particular good to exports of all goods in a country with the same ratio across all countries (2012). The intuition is that if this ratio is greater than one for this good, the country of interest has
a competitive advantage in its production, as it is exporting in a higher ratio than other nations. Formally, we define $RCA_{country,tech}$ by: \[ RCA_{c,t} = \frac{\sum x_{c,i}}{\sum_{i} x_{c,i}} \] \[ (5) \]

In equation 5, $x$ is the value of exported goods, $i$ is a product index, and $c$ is a country index.

Since strengths in closely related industries are prerequisite for competitiveness in renewable energy manufacturing (Huberty and Zachmann 2011), we compute the Revealed Competitive Advantage (RCA) over the past decade for the solar PV industry and sectors ancillary to the crystalline silicon module value chain (e.g., chemicals and electronic transformers). The results of our analysis are shown in Figure 7. The RCA metrics for solar PV corroborate our other analyses: we observe a sector that has demonstrated only occasional global competitiveness.

Figure 7: The RCA of selected industrial sectors in India. None of the tracked industries has a revealed competitive advantage over all years. We exclude 2011 data because all trade flows had not yet been reported to the UN at time of writing. We use harmonized system industry codes, as reported by the reporting nation. Linear trend lines are superimposed on the RCA data. On average, the chemicals industry appears close to globally competitive, while the solar PV industry does not. The fit to data is better for electronic transformers and machinery, and the trend lines suggest improving competitiveness in both. Nonetheless, the electronic machinery sector begins from an apparently severely uncompetitive base. Source: UN Comtrade (2012)

Our analysis suggests that there may exist opportunities for the development of competitive sectors upstream and downstream in the value chain. We measure the RCA of the chemicals industry to gauge the competitiveness of sectors that could contribute to establishing a polysilicon manufacturing base, and we find that over the last decade, this industry has occasionally been characterized by an RCA greater than 1. We believe other factors, such as poor electricity infrastructure, explain why a polysilicon base nonetheless does not exist in India. Relevant to steps downstream of modules, the electronic transformer sector has been competitive in the past, and a linear trend fit to the data suggests that the RCA of this industry has improved notably over the past decade. Balance-of-systems for solar power plants include power inverters, transformers, module support, and the nearly competitive nature of the electronic transformer sector suggests an opportunity for India to focus on achieving reductions in the balance-of-system costs associated with solar power project development. This would, of course, depend on the reestablishment of a competitive transformer sector in the first place.

However, our analysis suggests weaknesses in electronic machinery; domestic advances in solar ingot, wafer, cell, and module manufacturing could be more easily made with a well developed machinery industry that could help solar PV manufacturers understand what product specifications are technologically feasible. Observed RCA metrics for electronic machinery suggest that India does not have strengths in this sector, and this likely helps explain trends in the indigenization of turnkey lines in India (see the next section, 4.2.3,

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12 We recognize that there are competing definitions for the revealed competitive advantage (see, for example, Vollrath 1991). We defined the metric in this manner because it is the one used by Huberty and Zachmann (2011).

13 The harmonized system codes used 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.
for a discussion). Though the industry appears to be becoming more competitive over time, it is doing so from an apparently severely uncompetitive position.

4.2.3. Low competitiveness is also suggested by low capacity utilization and limited upgrades of turnkey production lines among Indian manufacturers

Capacity utilization and turnkey production line upgrades are signals of, respectively, the health of and innovation within the Indian solar PV industry. Neither metric provides a positive assessment. Figures 8 and 9 plot solar PV module and cell capacity utilization, respectively, from Q1 2008 to Q1 2012. While Indian module capacity utilization has recently been relatively close to the worldwide figure, cell capacity has sharply underperformed relative to the global average. The figures reveal that both Indian module and cell capacity utilization fell sharply in Q1 2010. Though this coincides with a global decrease in module and cell production, Indian utilization dropped more sharply than that in other countries and has settled below the worldwide average. These observations suggest a loss in competitiveness after 2010 and corroborate our export metric based analyses.

![Figure 8: Module capacity utilization (Q1 2008 – Q1 2012). Source: Lux Research 2012](image)

![Figure 9: Cell capacity utilization (Q1 2008 – Q1 2012). Indian module and cell manufacturers have had low capacity utilization rates in both module and cell markets, especially since 2010. Linear trend lines are superimposed on the utilization data. Source: Lux Research 2012](image)

Our national level utilization analysis masks heterogeneity across different tiers of manufacturers and does not differentiate by thin-film and crystalline technology. While we do not know production and capacity by tier in India, 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 ~60%, and Indian utilization was about equal through 2009.

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14 Different PV manufacturing tiers refer to the reputation of manufacturers and the efficiency of the outputted cells and modules.
The decrease in Indian utilization may be due to the smaller scale and lack of vertical integration relative to international counterparts. Producers in India have not been able to achieve the economies of scale that major solar PV manufacturers have realized upon expansion into the 1 - 2 GW range. Solar Semiconductor, the largest Indian producer by capacity, has an installed capacity of 195MW per annum.\textsuperscript{15} Moreover, even before a peak in polysilicon prices incented many players to integrate into polysilicon production, leading solar firms had proceeded with an integration of other steps in the production process. Trina Solar, for example, had integrated its ingot, wafer, cell and module manufacturing lines in one manufacturing site prior to a 2008 polysilicon price peak (Power & Energy). This vertical integration has insulated major producers at times of shortages of polysilicon or wafers.

Indian capacity utilization is unlikely to increase simply with integration, as the technological and cost frontier is shifting again, with competitive advantages now accruing to manufacturers that can deliver efficiency gains. Such gains could be in the form of higher module efficiency, but also in the efficiency of balance-of-system work and installation costs. Instead of backward integrating into polysilicon production, firms are now electing to enter long-term contracts for the commodity. For example, in 2010, Suntech signed four deals for solar panel efficiency improvement, including one that explores the installation of microinverters on modules to simplify solar system installation (Photon 2010).

Note moreover that the character of the global solar PV industry has begun to shift. While solar PV manufacturing was previously done by many small firms, the industry is now dominated by a smaller number of large producers, and this may be accelerated by a deliberate rationalization by the Chinese government, which is promoting the consolidation of its PV industry (Platzer 2012; Bayaliyev et al 2011). Product differentiation cannot make up for a lack of scale and integration; PV systems do not offer opportunities for customized, higher-value products to meet unique needs (Platzer 2012).

Finally, Indian manufacturers rely on turnkey manufacturing lines to an unusual degree: 77\% of Indian capacity uses turnkey lines, while only 15\% of global capacity uses turnkey lines; elsewhere, firms have modified turnkey lines by adding indigenous process units (Colville 2010). This dependence suggests that Indian firms may lack the absorptive capacity to innovate in production technologies and process engineering. We summarize our analyses of trends in Indian solar PV manufacturing in proposition 2:

**Proposition 2:** Competitiveness metrics, including the UVR, RCA, capacity utilization and feed-in-tariff sensitivity suggest the Indian solar PV industry has become less competitive over time.

4.2.4. **Developers continue to favor substitute thin-film technology, bypassing the DCR**

Our fourth perspective examines the choices of solar project developers in India, and we do so within three classes of solar PV plants: (1) those constructed outside of the NSM and constituent DCRs, (2) those included in the NSM Phase I, Batch I, with its crystalline module DCR, and (3) those included in the NSM Phase I, Batch II, with its crystalline cell and module DCR. Our interest in analyzing these data is to identify any shifts in module technology choice across these three classes. Our data were from the Alternative Energy eTrack (2012) database, from which we retrieved a listing of all solar PV plants currently active, partially active, under construction or planned in India. These records include details on the solar PV module manufacturer at the plant level; when this field was empty for a given plant, we searched press releases to identify the module manufacturer. This process allowed us to capture the module technology for 24 of the 29 Phase I, Batch I NSM solar PV plants currently active or under construction. Our set of comparable non-NSM PV plants included only those either under construction or active as of May 2012. Since we wanted to include only those projects at least as large as those in the NSM, we excluded all projects with a capacity lower than 5MW.\textsuperscript{16} Finally, though full module technology choice data was not available for NSM Phase I, Batch II plants, we received secondary data on a subset of plants to be built (Ghosh and Jaiswal 2012).

The proportion of crystalline modules differs across the three classes of plants. In particular, 48\% (25 of 52) of non-NSM plants employ crystalline module technologies, while 57\% (16 of 28) of NSM Phase I, 15Despite the plans by Indosolar to expand to 260MWpa by the end of 2011, the firm still reports a 160MW capacity on its website.
16The decision to restrict to plants of at least 5MW of capacity was also driven by data availability. A full set would have required us to find press release based records of module choice for approximately 155 of 187 solar plants with capacities lower than 5MW.
Batch I and 41% of NSM Phase I, Batch II plants do so.\textsuperscript{17} The initial increase in Phase I, Batch I of the proportion of crystalline modules used and subsequent decrease in Phase I, Batch II suggests that the NSM has not had a straightforward impact on module technology choice. While we cannot make any definitive statements about the historical or future impact of the NSM on module technology choice, this first sign of a shift to thin-film modules may suggest that the DCR could have the opposite of its intended intent, as the share of domestic crystalline modules in domestic solar PV plants may actually decrease over time. In fact, a preference for foreign thin-film modules may simply be continuing: India is expected to become the largest market for the U.S. Export-Import Bank, given the number of projects sourcing U.S. modules and financed by the institution (Jaiswal 2011). By August 2011, the Bank had guaranteed loans of $75 million for four solar projects, with another $500 million pending (Ibid.). The apparent shift between Phase I batches could also suggest that the marginal strengthening of the DCR to include cells, and not just modules, in the second batch drove substitution toward thin-film cells and modules.

Since the proportion of crystalline modules in the two NSM Phase I batches are both within 10% of that in non-NSM plants, we tested a hypothesis that the proportion of crystalline modules is statistically equal across non-NSM and Phase I, Batch I NSM plants. To do so, we fit logit and probit models to module technology choice. We examined a number of alternative formulations and examined the impact of (1) inclusion of a plant in the NSM, (2) state, (3) capacity, (4) inclusion of a plant in the Gujarat Solar Policy and (5) year on module technology choice.\textsuperscript{18} Across our alternative formulations, we do not observe a significant coefficient on our dummy coding for inclusion in the NSM, and we summarize this finding in proposition 3:\textsuperscript{19}

**Proposition 3:** Module technology choice data do not reveal a statistically significant difference in the proportion of crystalline modules deployed in Phase I, Batch I NSM and non-NSM solar PV plants.

The statistical insignificance of the NSM dummy may be due to our use of models without adequate sample sizes. A logit model including year, dummies for the NSM Phase I, Batch I, the Gujarat Solar Policy, plant capacity, and state yielded the greatest log likelihood among specifications; though the NSM dummy coefficient was insignificant, the model provided a positive point estimate of an increase of 0.66 in log odds for crystalline modules in Phase I, Batch I NSM plants. Since our Phase I, Batch II data were limited, we do not attempt to make any claims about the statistical significance of the observed differences in module technology share; this is an area for future research, especially when full Phase I, Batch II data become available.

Interestingly, bid data suggests that the DCR has not disrupted the downward progression of solar PV tariffs in the NSM. While the batch I benchmark was Rs. 17.91/kWh, with developers offering substantial discounts, the batch II benchmark tariff was Rs. 15.39/kWh.\textsuperscript{20} Developers again offered steep discounts, with a lowest bid of Rs. 7.49/kWh by Solairedirect (Ramesh 2011). Solairedirect plans to use domestic crystalline module capacity, suggesting that some domestic capacity may occupy the lowest portions of the global module supply curve. The story that emerges from observable module choice appears to be that bid prices continue to proceed downwards in the NSM, despite a stricter DCR. However, some evidence exists that the DCR restriction on foreign crystalline cells and modules has prompted a shift towards foreign thin-film capacity. It may thus be that, without the DCR, cheap foreign crystalline capacity could have further decreased tariffs bid by developers in batch II.

\textsuperscript{17}The NSM Phase I, Batch II data includes 185MW, or about 53%, of the planned 350MW of capacity additions.

\textsuperscript{18}We may be missing critical explanatory variables, such as solar insolation, temperature and air quality, but we anticipate that the relative geographical proximity of plants within a particular state will allow the state variable to capture these attributes. Moreover, we did not have data on when module choices were made and what the efficiency adjusted crystalline/thin-film price differentials were 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.

\textsuperscript{19}In the specification yielding the highest log likelihood, the confidence interval for the estimate of the log odds coefficient for the NSM Phase I, Batch I dummy includes 0, and is insignificant (p = .372).

\textsuperscript{20}Bid data is available from NTPC Vidyut Vyapar Nigam Ltd.
4.3. An evaluation of likely efficiency and equity implications of industrial policy support for the Indian solar PV sector

4.3.1. The Phase I, Batch I DCR could yield an increase in economic efficiency, but it would reduce the surplus of electricity consumers

We apply our framework from section 3.1 to the Phase I, Batch I 100% crystalline module DCR. Proposition 2 implies that module manufacturers are unlikely to capture the dynamic learning effects required for unambiguous improvements in economic efficiency. Though we do not have the data to quantify the efficiency effects, we highlight below the very likely equity implication that any increase in social welfare would come at a cost of reduced surplus to electricity consumers. Throughout this analysis, we assume that developers bid an LCOE so as to maintain a fixed relative margin.21

Project developers who would have selected thin-film technologies in the no-policy benchmark are unaffected by the DCR. However, those developers who would have selected crystalline modules will take one of two options: (1) if a developer would have sourced domestic crystalline modules in the no-policy scenario, it continues to do so here, (2) otherwise, the developer either switches from sourcing foreign crystalline modules to procuring domestic crystalline modules or switches to domestic or foreign thin-film capacity. The first option does not yield any change in welfare, so we explore switching behavior from foreign crystalline to domestic crystalline and from foreign crystalline to thin-film modules.

When a project developer is forced to newly source domestic crystalline capacity, it sources from domestic module manufacturers whose marginal cost exceeds the no-policy market clearing crystalline module price. This implies an increase in cost to the project developer. Our assumption that developers would bid for solar tariffs in the downstream market so as to capture the same relative margin as under the no-policy scenario implies a higher absolute developer surplus.

Since about 45 crystalline module manufacturers exist in India, the close of the crystalline module market to foreign firms is unlikely to endow suppliers with market power but will push the marginal cost curve upwards (Sahoo 2011). The change in manufacturer surplus depends on the elasticity of module demand among project developers, and the potential for substitution with either foreign or domestic thin-film modules limits the surplus gain by manufacturers. If module demand is sufficiently inelastic that some domestic crystalline module manufacturers newly sell their modules under the DCR, there will be a gain in domestic crystalline manufacturer welfare. We comment on the implication of greater elasticity in the module demand curve below.

If domestic crystalline module manufacturing output increases, we would expect any dynamic learning effects to be greater under the DCR. Our analysis in 4.2 suggests that these learning effects will be, at best, small in magnitude. Further, since DCRs close the market to foreign competition, there is no reason to believe that costs will necessarily go down, even if the potential for learning exists. Absent a threat of DCR removal, manufacturers do not have strong incentives to pursue costly reductions in production cost.

Given the higher solar tariffs bid by developers, electricity consumers would face a higher price of electricity, and we expect these higher prices to remain for at least 25 years, the length of power purchase agreements (PPA) in the NSM. Proposition 2 suggests that domestic suppliers will remain globally non-competitive, implying that this consumer surplus loss will not be reversed. Together with our realization that any learning that occurs may not translate into lower prices, we believe consumers would face a loss in both static and dynamic surplus.

The above discussion partially anticipates the implications of the scenario in which developers shift to thin-film technology. Since developers would have chosen foreign crystalline modules in the no-policy scenario, this switch implies an increase in development costs but also an increase in developer surplus. The gain in thin-film manufacturer surplus is ambiguous, as it depends on the distribution of newly sourced domestically and internationally produced thin-film modules. Given the open thin-film module market and our analysis of India’s solar PV competitiveness, however, our assessment is that the gain in manufacturer surplus will be insignificant. Note that at least 10 of 12 project developers sourcing thin-film modules as part of batch I of phase I of the NSM sourced from foreign manufacturers (e.g., Solar Frontier K.K., First Solar, DuPont/NexPower, Abound Solar, MiaSole, Q-Cells) (Alternative Energy eTrack 2012). These choices

21 The developer margin implication of DCRs is an open empirical question that we hope to study in subsequent research. Since the NSM bidding mechanism stipulates a benchmark tariff rate, it is possible that this LCOE ceiling, combined with higher module prices, would lead to decreased developer margins. On the other hand, the Gujarat and Rajasthan solar policies provided developers with an alternative to the NSM; the decision by developers to nonetheless bid and participate in the NSM suggests that its DCR had a nonnegative impact on developer margins.
suggest that developers who newly elect thin-film modules would switch from foreign crystalline to foreign thin-film modules, thereby bypassing domestic crystalline firms. Domestic manufacturers would thus not gain any of the increase in surplus they would have captured had their products been purchased. Here, the welfare loss among electricity consumers will almost certainly outweigh the gain among manufacturers.

Overall, our assumptions of a fixed developer relative margin and a sufficiently inelastic module demand curve imply that the 100% crystalline module DCR could yield a dynamic efficiency gain, but it would do so at a cost to electricity consumers; our expectation of an inelastic electricity demand curve implies a large loss in consumer surplus. A reversal of this equity implication is possible, but only if dynamic learning effects can reduce the price of solar electricity beyond what it would have been absent the DCR. Proposition 2 suggests this outcome is unlikely.

A loss in consumer surplus could be tolerated if an efficiency gain were guaranteed from the DCR. However, there is a non-zero probability that the overall efficiency will not improve. This result would obtain if project developer module demand elasticity was sufficiently high. In the limit, the quantity and price of domestic crystalline modules sold would remain the same before and after the DCR, and the domestic crystalline manufacturer surplus would remain the same. If developers moreover continue their apparent preference for foreign thin-film modules relative to domestic ones, domestic thin-film manufacturers would also face an unchanged equilibrium surplus in the limit. Though our assumption of a fixed developer relative margin implies that developers would gain in absolute surplus from their switch to thin-film, a net loss in economic efficiency could obtain if consumers have a sufficiently inelastic electricity demand curve.

4.3.2. The Phase I, Batch II DCR has the same qualitative implications as the Phase I, Batch I DCR

The analysis for the current DCR that requires 100% crystalline cells and modules proceeds in the same manner as the 100% crystalline module case. Since current domestic capacity for crystalline cells and modules is 1.7GW, capacity constraints should not bind. However, the new participation of previously uncompetitive domestic cell manufacturers would imply an even higher upward shift in the module marginal cost curve, implying that project developers would be more inclined to switch to thin-film modules. Again, our expectation is that this switch would benefit foreign thin-film manufacturers more than domestic ones. The ultimate welfare implication depends on the crystalline module demand elasticity among project developers, and the gain in cell and module manufacturer surplus could be either smaller or larger with the 100% cell and module DCR than with the 100% module DCR. As in the previous case, we expect the project developer surplus to increase, given our assumption of a fixed relative margin, and the consumer surplus to decrease, relative to the no-policy benchmark. In this expanded DCR, the reversal of consumer surplus loss hinges not only on dynamic learning effects among crystalline module manufacturers but also among cell manufacturers.

4.3.3. Though a thin-film DCR would guarantee surplus gains among manufacturers, it would also guarantee potentially large surplus losses among electricity consumers

Finally, we examine proposals to expand the DCR to require 100% of thin-film cells and modules to be sourced domestically. Here, we discuss changes in addition to those anticipated from the current crystalline DCR. Under this all-inclusive DCR, developers which under the 100% crystalline cell and module DCR sourced foreign thin-film capacity would have to either source domestic thin-film modules or domestic crystalline modules.

We first consider the impact of developers shifting from sourcing foreign thin-film modules to sourcing domestic ones. Since there are only four Indian thin-film manufacturers, they would gain a degree of supplier power. Higher output and supplier power among domestic thin-film producers would yield a higher thin-film manufacturer surplus. The switch to domestic thin-film manufacturers suggests that any potential dynamic learning effects among domestic thin-film manufacturers would be higher under the thin-film DCR. A caveat similar to that given in our crystalline DCR analysis applies here, too: since the thin-film market will be closed to international competition, the pressure to actually reduce costs is low, and there is no a priori reason to believe that either costs or module prices will go down; indeed, the degree of market power that firms would gain could yield an even lower incentive to decrease their production costs and pass through these cost savings as lower module prices.

Moreover, our partial equilibrium analysis did not consider inefficiencies in the allocation of factors of production. Even if domestic crystalline output increased, it could do so at the cost of large resource inefficiencies across the economy, which could themselves yield a reduction in economic efficiency.

The four thin-film manufacturers of which we are aware are HHV Solar, Moser Baer, Novergy, and Shurjo Energy.
In reality, domestic thin-film module prices that are higher due to both manufacturer technology inefficiency and market power could encourage developers to source domestic crystalline modules. In particular, since almost half of solar project developers currently prefer thin-film modules, a tightening of the DCR to include thin-film technology could place a binding constraint on thin-film capacity and reverse proposition 1. These constraints, in addition to market power, would imply an increase in domestic thin-film module prices and encourage switching to domestic crystalline modules. Moreover, the removal of the foreign thin-film module option would decrease the elasticity of demand for crystalline modules. The movement of formerly thin-film sourcing developers into the domestic crystalline module market implies that higher marginal cost crystalline modules would be employed by solar power developers in India. Together, these predictions suggest that domestic crystalline manufacturers would experience a greater surplus gain under the 100% thin-film DCR than under the DCRs previously assessed, and a greater number of them would potentially benefit from dynamic learning effects.

Whether developers switch to sourcing domestic thin-film or crystalline modules, their costs of project development would increase. Since these modules were not sourced without the thin-film DCR, we assume that they are of higher cost than the modules purchased in the absence of any of the versions of the DCR. Our assumption of a fixed developer relative margin implies that these increased costs would be reflected in higher tariff bids, a higher absolute developer surplus, and a lower electricity consumer surplus. A non-negative manufacturer surplus gain is guaranteed. The corollary, however, is the expectation of a correspondingly larger electricity consumer surplus loss as (1) the choice set no longer includes substitute foreign technologies and (2) domestic thin-film manufacturers gain upstream market power. These imply that the LCOEs bid would be higher than in the crystalline DCRs; combined with our expectations of a relatively inelastic electricity demand curve, the consumer surplus loss could be quite large under a thin-film DCR. As before, a reversal of this loss would require the realization of dynamic learning effects among domestic manufacturers, and proposition 2 suggests these are unlikely. The net welfare implication will depend on the magnitudes of surplus lost by electricity consumers and gained by manufacturers and developers. We summarize our efficiency and equity analysis in proposition 4:

**Proposition 4:** Given proposition 2, any welfare improvements from the DCR would impose a static and dynamic loss of welfare among electricity consumers.

In our analysis of module sourcing implications and description of equation (3), we made an implicit assumption that the project development costs would solely reflect the increased costs of modules. However, a critical driver of module sourcing decisions is the bankability of the product. If financiers put a penalty on domestic modules that lack recognizable international brand names, the technological risk they assign them would increase project developers’ cost of capital. This financial penalty can be substantial, and we subsequently realize that the bid tariffs may be even higher than our analysis above suggests. These higher bids would imply an even lower electricity consumer surplus.

5. Discussion and Conclusion

The DCR based PV solar industrial policy of the NSM is a prominent example of a national renewable energy policy that attempts to bolster a domestic manufacturing base. We have provided a framework for policymakers to examine the efficiency and equity implications of the DCR. In particular, for DCRs to yield positive welfare outcomes for all domestic economic agents, the target sector must eventually become globally competitive; however, our review of trade data from the solar PV sector suggests that Indian solar PV manufacturers have lost a previous competitive advantage. Correspondingly, capacity utilization has decreased dramatically from 2000 to 2010. This may be due to the proclivity of Indian manufacturers not

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24 We do not imply here that all thin-film manufacturers are technologically inefficient; rather, those thin-film suppliers who newly sell modules under the DCR are inefficient relative to producers on the global market, since developers were sourcing from the latter firms in the absence of the DCR. While we do not have access to thin-film prices in the Indian market, our observation that at least 10 of 12 project developers sourcing thin-film modules as part of batch I of phase I of the NSM sourced from foreign manufacturers suggests uncompetitive pricing by domestic thin-film manufacturers (Alternative Energy eTrack 2012).

25 This could happen, for example, if the thin-film module capacity remained the same through the NSM phases. If in the third phase, the goal of adding 16GW of grid-tied solar capacity is split evenly between solar PV and concentrated solar, developers demand thin-film modules for 50% of projects, and capacity is added linearly, then the annual thin-film demand of 800MW would outstrip Indian manufacturing capacity.
to upgrade their turnkey production lines, a phenomenon that may stem from the noncompetitive nature of ancillary industries, such as electric machinery, or the non-existence of complementary ones, such as semiconductor manufacturing. Capacity utilization is unlikely to increase simply with vertical integration, as the global technological and cost frontier is shifting to other drivers of competitiveness. Overall, these trends suggest that the dynamic learning critical to welfare improving DCRs may not occur. Moreover, the choice by developers to continue to favor the substitute thin-film technology suggests that they are bypassing the DCR and that the potential for learning is limited by developers’ preferences.

Our framework for efficiency and equity analyses suggested that though the DCR could yield dynamic efficiency improvements, they would be inequitable in their imposition of large welfare costs on electricity consumers. The likely lack of adequately beneficial dynamic learning effects indicates that this equity result is unlikely to reverse over the course of the NSM DCR. Since recent proposals have suggested a DCR for thin-film technology, we examined its likely efficiency implications. While it would guarantee an increase in manufacturer surplus, it would yield a stream of even larger costs borne by electricity consumers. Our assessment is thus that all three DCRs (100% crystalline modules, 100% crystalline cells and modules, and 100% thin-film cells and modules) will likely yield serious negative surplus losses among electricity consumers.

While we believe the equity concerns raised by the DCR are sufficiently serious to warrant a re-examination of their use, there are welfare components that we did not incorporate in our analysis. Their inclusion would suggest greater efficiency improvements than we describe, and these may justify the equity costs we highlight. For example, an inclusion of energy security externalities could imply a dynamic welfare improvement, if their social costs are adequately high. Moreover, constraints in the political system may provide an alternative non-dynamic efficiency justification for the DCR based policy: the asymmetric appropriability of rents implies that firms struggling to achieve international competitiveness lobby harder and are more likely to receive subsidies than are those firms already succeeding in competitive markets (Baldwin and Robert-Nicoud 2007). Tellingly, crystalline solar manufacturers in India have formed the Indian Solar (PV) Manufacturers Association and among the group’s goals are to manage the thin-film “threat” and to support DCRs in state level solar policies (Panchabuta 2011b). Our analysis suggests that state policymakers should proceed with caution with respect to such DCRs.

Nonetheless, industrial policy has helped build RET industries elsewhere, and we suggest that future research should (1) refine our efficiency analysis by further studying module technology choice and developers’ margins in the NSM and (2) study the evolution of China’s solar PV industrial policy and identify gaps in India’s national systems of innovation that, if closed, could support learning by the domestic RET sector.

References


