Energy Economics 40 (2013) 32–39

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

A model of competition in the solar panel industry

Unni Pillai [a,*], Jamison McLaughlin [b]

[a] College of Nanoscale Science and Engineering, University at Albany, SUNY, 257-Fuller Road, Albany, NY-12203, USA
[b] Ross School of Business, University of Michigan, USA

ARTICLE INFO

Article history:
Received 12 June 2012
Received in revised form 14 May 2013
Accepted 20 May 2013
Available online 14 June 2013

JEL classification:
L19
Ł13
O30

Keywords:
Photovoltaics
Competition
Polysilicon

ABSTRACT

We develop a model of competition in the solar panel industry. Solar firms manufacture panels that are differentiated both vertically and horizontally, and compete by setting quantities. The equilibrium of the model is consistent with a set of stylized facts that we document, including variation in prices, markups and market shares across firms. We calibrate the model using a new dataset data on prices, costs and shipments of leading solar companies, as well as solar sales in four leading markets. The calibrated model is applied to evaluate the impact of a decline in the price of polysilicon, a key raw material used in the manufacture of solar panels, on the equilibrium price of solar panels.

1. Introduction

The electricity generation sector is the leading contributor of greenhouse gas emissions. Most plans to stabilize greenhouse gas emissions view solar photovoltaics as an electricity generation technology with potential to replace a sizeable section of fossil fuel generation (see Nakicenovic and Riahi, 2002; Baker and Solak, 2011; Lewis and Nocera, 2006). At present however, electricity from solar photovoltaics constitute a very small fraction of the world electricity production. The cost of generating electricity from solar PV systems has fallen over time. A major factor behind this decline has been the continual decrease in the price of solar panels (also called solar modules), the principal component in PV systems. These declines have brought the price of solar generated electricity closer to the price of electricity generated from conventional sources, but a gap still remains.

There has been an extensive examination in the literature of factors that have contributed to the decline in solar module prices. Most of the existing studies are based on learning curves, which extrapolate past observations about the relationship between the price of solar modules and the volume of production (for example, see Swanson, 2006; Schaeffer, 2004). There have been other studies, for example Nemet (2006) and Bruton (2002), which look at the contribution of various factors like plant size and module efficiency in reducing the price of solar modules. Learning curve models and models like Nemet (2006) are suited to explain how different factors affect the cost of production. The use of these models in predicting changes in price depend entirely on the assumption that changes in cost will translate into identical changes in price. If the solar module industry was perfectly competitive with modules being sold at a price equal to its marginal cost, then any reduction in cost would result in the same reduction in price. The solar module industry, however, is not a perfectly competitive industry. As documented in Section 2, there are differences in prices, markups and market shares of different firms in the industry, all indicative of deviation from the assumption of perfect competition. Under imperfect competition, the effect on price of a change in cost would depend on how firms respond to the change in cost. The use of price instead of cost in learning curve models and in Nemet (2006) provides a useful simplification, but ignoring the role of competition among firms in determining equilibrium prices is not without consequence. For example, Nemet (2006) finds that changes in factors that affect cost can only explain a part of the change in the price of solar modules in some of the years considered in his study. He argues that there was an increase in the extent of competition in the industry in those years, which might partially account for the residual variation in price over and above the variation in cost. A contribution of this paper is to develop a model that explicitly incorporates competition among firms in the industry and can be used to evaluate how changes in costs affect the selling price of solar modules.

In Section 2 we lay down three empirical observations that capture the salient features of competition in the industry. In Section 3, we develop a model that is consistent with these observations. The model derives a demand function for solar modules, taking into account the behavior of electric utility companies, power producers and solar

* Corresponding author.
E-mail address: usadasivanpillai@albany.edu (U. Pillai).

0140-9883/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.eneco.2013.05.017

module manufacturers. Electric utility companies, who deliver electricity to consumers (either directly or through local distribution companies), purchase electricity from solar power producers, who can be individual households, businesses or commercial power producing companies. These solar power producers in turn demand solar modules from module manufacturers. The solar modules made by different firms are differentiated both vertically and horizontally. The module firms compete by setting quantities and we derive a set of equations that can be used to compute the equilibrium prices, markups and market shares in this Cournot model.

The model can be extended to incorporate other features of the solar industry, and Section 4 describes some of the possible extensions. The inclusion of non-module (or balance-of-system) costs does not affect the equilibrium strategies of the module firms but increases the price of solar generated electricity. The effect of differences in *insolation* (the intensity of incident sunlight) can be easily incorporated in the model. Finally, the model can be extended to consider the impact of changes in usage of different factors of production on price of solar modules. These extensions can be used to investigate the impact of decline in balance-of-system costs, the impact of differences in insolation, and the impact of technological improvements like reduction in raw material requirements or plant automation on the equilibrium price of solar modules and of electricity generated from solar modules. The data necessary to calibrate the basic model described in Section 3 can obtained from publicly available sources, as described in Section 5.

In Section 6, we put the calibrated model to use for one application. The price of polysilicon, a key raw material used in the manufacture of solar modules, has declined in the last few years and analysts expect further reductions in the price of polysilicon. We use the model to evaluate the impact of decline in polysilicon price on the price of solar modules. Alternative simulations are performed to evaluate the impact of decline in polysilicon price if competition among firms intensifies because of standardization of modules, or if solar generated electricity becomes more differentiated from electricity generated from other sources.

We begin by giving a brief description of the solar module industry in the next section.

2. The solar module industry

The solar module industry consists of a number of firms located in many countries. The output of the firms is usually measured in watts of solar modules.[1] In 2011, the solar module industry shipped around 28,000 MW of solar modules.[2] Contrary to the casual observation that solar modules are standardized homogenous products, solar modules sold by different companies differ in many ways. The most significant of these differences is in the *efficiency* with which they convert sunlight to electricity. The more efficient the solar modules are, the smaller is the size of the module required to produce a unit of electricity. Small module size (or fewer modules) translates to lower expenses on the accessories required to mount the module on a rooftop or ground. Thus higher efficiency is valued in a quantifiable way, and we capture this by treating solar modules as being vertically differentiated with regard to efficiency. Even after adjusting for the efficiency of the modules, there is a dispersion in the price charged per watt by different firms in the industry (see Fig. 1).

In addition to efficiency, the modules sold by different companies differ in other technical attributes as well in commercial attributes, like the offered warranty period. Further, firms also differ in their access to distribution and marketing channels, which are important in the sales of solar modules. These differences in product characteristics,

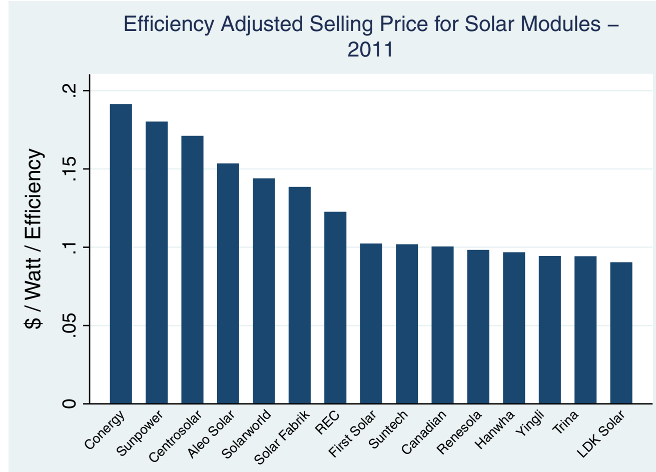

Fig. 1. Efficiency adjusted price of solar modules in 2011. Notes: the prices were calculated by dividing the annual revenues of the companies by their annual shipments. The variable on the y-axis is price divided by efficiency of the modules. See Section 5 for the sources of data.

together with the dispersion in efficiency-adjusted prices seen in Fig. 1, suggest that a differentiated goods model with firms engaging in monopolistic competition would be appropriate for the industry. However, in contrast to the popular Dixit and Stiglitz (1977) monopolistic competition model, there is also a dispersion in the markups charged by the firms in the industry. Fig. 2 plots the markups (gross margins) of companies against their market shares. As can be seen from the figure, bigger firms tend to have bigger markups as would be implied by a Cournot model, although there are deviations from a simple linear relationship. The observations above can be summarized in three stylized facts,

1. There is a dispersion in efficiency adjusted prices across firms.
2. There is a dispersion in markups across firms.
3. Larger firms tend to have bigger markups.

The next section develops a model of the solar module industry that is consistent with the three observations above.

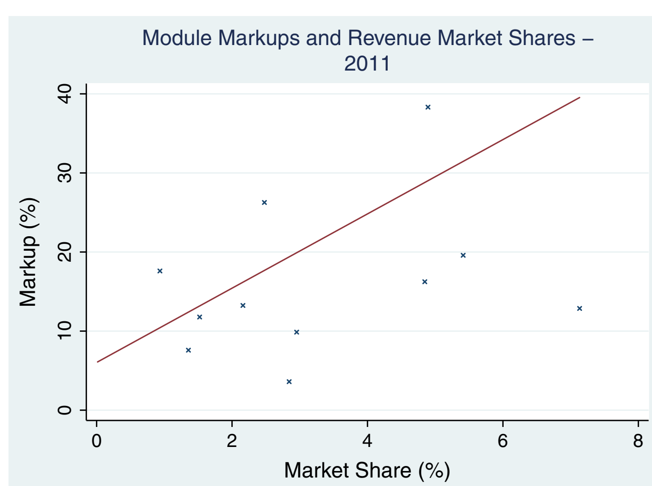

Fig. 2. Bigger firms tend to have higher markups. Notes: each point in the graph corresponds to a firm. The market shares were obtained by dividing the annual revenue of the firm by an estimate of the total sales of solar modules. The estimate of total sales was obtained by multiplying the average price of firms in the dataset by the total shipment of solar modules in 2011.

[1] Ideally, a solar module rated at 1 W when exposed to sunlight for 1 h would generate 1 W-h of electricity. In practice however, the amount of electricity generated depends on the intensity of sunlight, the angle at which the modules are mounted, etc.

[2] A megawatt is a million watts.