Discussion of "Relating Product Prices to Long-Run Marginal Cost: Evidence from Solar Photovoltaic Modules"

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1 Introduction

This is an interesting paper on an important topic. The modeling is very well executed. I will organize my comments in three parts. First, what is the context for this work. That is, what are the energy and climate stakes? Second, what does the paper do? I will re-work the equation defining the components of long-run marginal cost to better reflect what is actually estimated and to better highlight some important choices about how the different components are modeled. Third, and most importantly, how do the results inform business decisions and policy choices regarding energy and climate? What more do we need?

2 Context

The dangers of global warming require that we dramatically reduce greenhouse gas (GHG) emissions globally. However, we must also simultaneously meet the needs for global economic development which requires expanded access to affordable energy. Tackling the two is a challenge, but it is also a necessity. If we try to reduce carbon emissions without expanding energy access, we are bound to fail. There is plenty of cheap fossil fuel available, and without viable, inexpensive alternatives, too much of it is likely to be burned.

Solar PV represents an important candidate for meeting that challenge. The solar resource is abundant and distributed broadly across the globe. A basic version of the technology is well understood and used commercially. It is virtually free of GHG emissions. However, solar PV currently accounts for only about 1 percent of global electricity generation. In scenarios developed to help envision the challenge before us, the International Energy Agency (2014) described alternative ways to cut energy-related CO_2 emissions 50 percent between 2011 and 2050, while at the very same time expanding global use of electricity by 79 percent. In one scenario, in which the expansion of nuclear power is constrained, solar power supplies 27 percent of total generation. That requires a near 50-fold expansion of solar generation.

The challenge is that electricity from solar PV is still too expensive. Figure 1 shows a calculation of the levelized cost of electricity (LCOE) from solar PV reported in the MIT study on the *Future of Solar Energy*–Schmalensee et al. (2015). The left pair of columns show the full cost of electricity from utility scale systems, without subsidy, and the right pair the cost from residential systems which are much more expensive per unit of generation. Each pair contains a cost for a system located in southern California and for a system located in central Massachusetts, with the cost difference capturing the value of the stronger insolation in California. The black line across the figure is the average levelized cost of electricity from a natural gas-fired power plant, which is an important cost benchmark. The cost of solar electricity from a utility scale installation in sunny California is within striking distance of being competitive with the natural gas-fired alternative. However, there is still a way to go, and in other regions the challenge is greater still: in Massachusetts we need to nearly halve the cost. In the U.S., we have enjoyed a rapid expansion of solar power despite these cost differentials due to significant subsidies and policy mandates. A global expansion of solar generation on the scale that is required would be more plausible if we can continue to bring the cost of solar power down dramatically. This is especially true if solar power is to be a viable alternative in developing countries where the growth in electricity demand is likely to be the greatest in coming decades.

So, the question arises, what are the future prospects, and what can be done to accelerate the process?

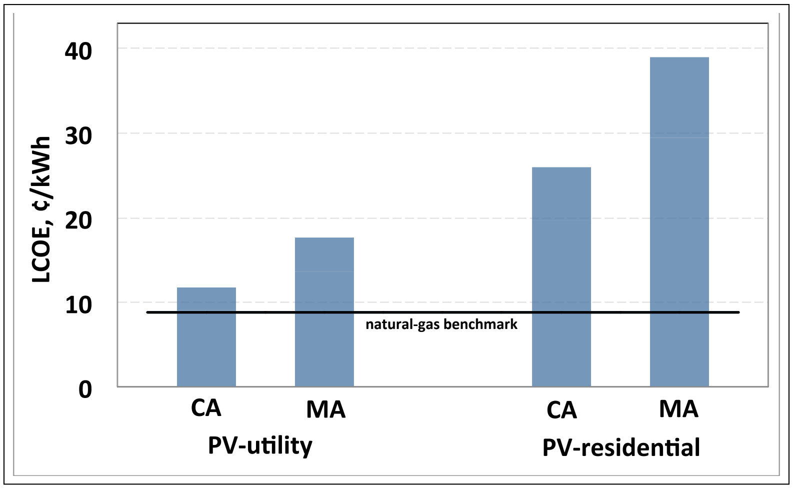

Figure 1: The Levelized Cost of Electricity from Solar PV.

3 What This Paper Does

This paper analyzes costs of solar PV modules between 2008 and 2013 and uses this analysis to address two questions. First, do recent prices, which fell dramatically, reflect underlying changes in costs or do they reflect overcapacity? The authors provide evidence that some of the price declines reflected overcapacity, although there had also been a significant fall in cost. Second, what is the estimated rate of decline in costs, and how does this compare to the prior historical rate as well as established targets for future costs?

As shown in their equation (4), the authors decompose long-run marginal cost, LMC_t, into three elements: (i) variable operating costs, w_t, (ii) fixed operating costs, f_t, and (iii) capacity costs, $c_t\Delta$. Section 2 of their paper presents the theory behind this decomposition, along with some detail for moving from the cash flow cost of long-lived capacity to an after-tax rental cost which is what is shown in equation (4). However, the itemization in equation (4) does not match the itemization they estimate.

First, the data does not allow them to separately identify the variable and fixed operating costs. Fortunately, given their definition of long-run marginal cost and assumptions about the equilibrium path, there is no meaningful distinction between variable and fixed operating cost. Therefore, they focus on the portion of the combined operating cost appearing in the cost of goods sold, $w_t^+ + f_t^+$, and the portion appearing in general and administrative expenses, including advertising and R&D, $w_t^- + f_t^-$. They call the former the core manufacturing cost and the latter the period cost. Second, when actually evaluating the cost of capacity, they make much of the distinction between the cost of facilities and the cost of equipment. Since this is the decomposition that is taken to the data, I find it helpful to write the long-run marginal cost accordingly:

$$LMC_t = MC_t + PC_t + CF_t + CE_t.$$

where, (i) MC_t stands for the core manufacturing costs, (ii) PC_t the period costs, (iii) CF_t the rental capacity cost of facilities, and (iv) CE_t the rental capacity cost of equipment. The translation between the variables in this equation and those in the authors' equation (2) is as follows:

$$
\begin{aligned}
MC_t &= w_t^+ + f_t^+ \\
PC_t &= w_t^- + f_t^- \\
CF_t + CE_t &= c_t\Delta.
\end{aligned}
$$

I also prefer to keep this decomposition in mind because the authors make starkly different structural assumptions on the dynamics of each of these components of cost. Their Figure 1 plots prices against cumulative production, which is evocative of a learning curve model in which costs decline with cumulative production. However, the authors only apply the learning curve structure to core manufacturing costs, MC_t, and then only in Section 5 when forecasting futures costs. In Section 4, when testing for a divergence between price and cost, they impose no structural restriction on the dynamics of core manufacturing costs. They impose no structural restrictions whatsoever on the path of period costs, PC_t. Presumably they are held constant when forecasting future costs. For capacity costs, they assume that equipment costs decline with time (not as a function of cumulative production), while factory costs do not decline.[1]

The authors also estimate the first two elements using one dataset and the second two using another. The first two elements, PC_t and MC_t, are estimated from quarterly accounting data on 10 major module manufacturers over 2008-2013, supplemented with industry analyst data on annual production and production capacity at the 10 companies. Estimates are made for individual firms, $PC_{i,t}$ and $MC_{i,t}$, which will be averaged to calculate the industry value. In the process of calculating the quarterly values, some interpolation is required for certain variables that are only available on an annual basis. For the second two elements, CF_t and CE_t, the authors turn to industry analyst estimates of the industry's costs for different pieces of capital reported annually and displayed in Table 2. From this data, they estimate the 76 percent annual rate at which equipment costs fall.[2]

Table 1 here shows the authors' median estimated values for these components at the start and end of their estimation period, Q1 2008 and Q4 2013.[3] Note that the estimates for both core manufacturing and period costs fell. The capacity cost estimates fall, too. The core manufacturing costs start out as nearly 80 percent of the total cost, experience the largest drop, and end as 65 percent of the total cost.

The quarterly estimates of long-run marginal cost throughout this window of time are used to answer the first question about whether overcapacity was a driver of price reductions. The authors find that from Q1 2008 through Q2 2011, prices were close to these estimated long-run cost estimates, while from Q3 2011 through Q3 2013 prices had fallen below these long-run marginal cost estimates. This is evidence that some of the dramatic price drop during this period may have been due to overcapacity. At the same time, the estimated long-run marginal cost also fell, and by Q4 2013 prices and estimated cost were back in alignment.

Before turning to answer the second question, the authors now impose a learning curve structure on the

[1] Despite the significant space given over to the distinction between the capacity cost of facilities and of equipment and their separate dynamics, the cost of facilities is always less than 3 percent of the combined cost of capacity, so any significant cost changes are coming from the cost of equipment.

[2] A separate estimate of company specific capacity cost values made using the data on the 10 major module manufacturers is discussed in the Appendix, but is not used in the results shown in the main body of the paper.

[3] The values for the period costs, PC_t, core manufacturing costs, MC_t, and the total long-run marginal cost, LMC_t are taken from the authors' Tables 6 and 7. The value shown for the total capacity costs, $CF_t + CE_t$, is a residual, calculated to make the numbers fit the definition of long-run marginal costs. Since medians do not necessarily add, this is just an approximate figure. Checks against other estimated parameters elsewhere confirm the approximation.

Table 1: Estimated Cost Components at the Start and End of the Data ($/W).

	Core Manuf. Cost MC	Period Cost PC	Capacity Cost CF+CE	Long-Run Marginal Cost LMC
Q1-2008	3.13	0.27	0.58	3.98
% LMC	79%	7%	15%	
Q4-2013	0.52	0.08	0.20	0.80
% LMC	65%	10%	25%	
Change	-2.61	-0.19	-0.38	-3.18
% change LMC	82%	6%	12%	
% Q1-2008	83%	70%	66%	

pattern of core manufacturing cost through time, making MC_t a function of cumulative production as shown in equation (23), or, using a different specification, in equation (24). They then project costs going forward in time, conditional on an annual rate of production as shown in their Table 4. It is worth noting that these projections embody different assumptions about how each of the cost elements evolves going forward:

- core manufacturing costs, MC_t, decline with cumulative production as described by the estimated learning curve,
- period costs, PC_t, remain constant,
- the rental capacity cost of facilities, CF_t, remains constant, and
- the rental capacity cost of equipment, CE_t, falls with time, not with cumulative production, at the estimated rate.

For the core manufacturing costs and the cost of equipment capacity, this is a forecast based on tomorrow being like yesterday: that is, they will fall tomorrow according to the pattern they fell in our recent data. Oddly, for period costs, this is a forecast that disregards past price declines. Nevertheless, the combined estimated rate of decline in long-run marginal cost going forward is fast. It is a faster decline than what has been estimated from the much longer historical price trend. Assuming prices match this estimated long-run marginal cost going forward, then prices will easily reach the targets established at the U.S. Department of Energy.

4 What We Still Need

This is a very interesting documentation and analysis of recent price and cost trends. I will make three very different points about the larger context within which I read these results and what I think are the unanswered questions highlighted by this larger context.

The first point is narrowly about the documented fall in costs. What is still missing is an understanding of the 'why' behind the data analysis:

- Why was there an overcapacity in the industry, so that for a period of time prices fell below long-run marginal cost? Was it a response to the policies in various countries encouraging investments in capacity?
- Why has the rate of decline in costs accelerated recently in comparison to the much longer historical trend? Was it a response to the policies in various countries funding R&D and/or deployment?

Remember, one of the main reasons we care about these price and cost trends is because we imagine we might be able to influence them with policies. That is not the only reason, but it is certainly one of the main reasons. So, we would like to understand if policies played a role in shaping these recent trends. In fact, in order to properly answer the second question about the price trend going forward, we need to know whether it makes sense to assume that tomorrow will be like yesterday. If policies drove the pace of recent price declines, then whether prices will continue to decline depends on whether those policies are likely to remain in place. The future decline also depends upon whether the policies can be expected to have the same effect as we move out further on the learning curve. These authors documented that the recent trend has seen a faster decline in long-run marginal cost than the longer historical trend, and these authors project this recent trend forward. But maybe the recent trend was just a temporary aberration from the longer historical trend, so that instead of projecting the recent pace forward, we should expect a return to the older pace. Or, since we now see that the pace has been unstable, maybe we realize that we have no sound basis for assuming that tomorrow will be like yesterday. The paper gives us little in the way of a foundation tying the estimated results for the past to a prediction about the future.

The second point looks to where these cost dynamics fit into the overall competitiveness of solar power. This analysis has all been focused on the cost of solar PV modules. But the cost of modules is only a portion of the total cost of a solar PV installation. The rest is the racking, wiring, inverter and other balance-of-system (BOS) equipment that places the module where it needs to be and connects up the electronics so that the system feeds electricity into the grid. Figure 2 graphs module and system prices over time, using estimates produced for the MIT study on the *Future of Solar Energy*–Schmalensee et al. (2015). The bottom line shows an estimate of the unit cost of a solar PV module between 2008 and 2014 like those used by these authors. The module cost falls 85 percent. The middle line shows the unit cost of a utility scale system fully installed, including both the cost of the module and the balance-of-system cost. The difference between the middle and bottom lines is the balance-of-system cost. As the cost of modules has fallen, the fully installed system cost has fallen, too. However, the balance-of-system costs have fallen much less over this period, and they now represent the overwhelming majority of the total system cost–approximately 2/3. If we are to continue to bring down the total cost of electricity from solar systems, we need to find a way to reduce the balance-of-system costs. These may not be subject to the same learning curve forces driving the Swanson plot shown in the authors' Figure 1.

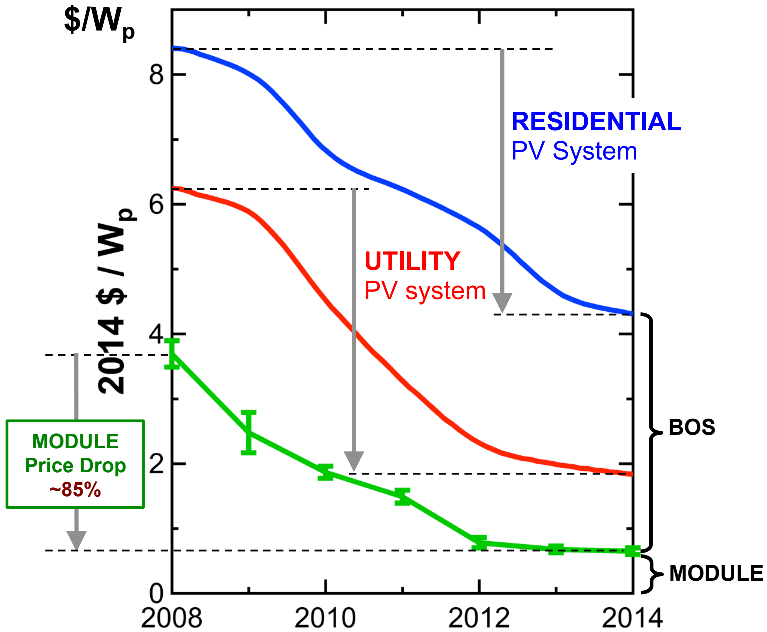

Figure 2: Evolution of Solar PV Module & System Prices.

Finally, I want to make a general point about maximizing the usefulness of high quality applied research like this for potential users in industry and government. In order to assure the reliability of estimates like these, it is necessary to make many considered judgments. That should already be suggested by the use of different datasets to estimate different elements of long-run marginal cost, and by the decision to apply different structural assumptions on the dynamics of each of these components of cost. Think, too, about the fact that the documented fall in costs probably reflects underlying technological change which we must appreciate are likely to bring with them organizational and competitive changes. Global supply chains shifted radically over this time period: final assembly of modules became concentrated in China, but fed from an increasingly internationalized supply chain of materials and parts–see Deutch and Steinfeld (2013). More than ever, how we read the data depends on the model we bring to it. This paper presents an excellent analysis of the data, and I am prepared to believe its conclusions are plausible. However, I am also confident that the authors know a great deal about where certain bodies are buried, and I think everyone would profit from a more open discussion of hidden issues. During my reading, I noticed a few piles of dirt lying around about which I was curious; but the paper kept insisting that we keep moving along to the conclusion. This is symptomatic of our academic culture which requires that we *sell* our work. We must demonstrate and insist that we have found the right combination of assumptions, the right specification and so on. However, for our work to be most successfully taken up by others outside our circle, by potential users in industry and government, those users must be able to take ownership of the conclusions. That means they need to be made more fully aware of the full spectrum of alternative assumptions that could also fit the data. Instead of arguing in favor of what we believe to be the best model and interpretation, it would be better if we were illustrating a range of plausible models. It would be better if we confessed to the full range of reasonable data specifications and possible model parameterizations, and we acknowledge the best cases for alternative interpretations of the data. That is, we need to do some more active pointing to where the bodies are buried. Should I need to utilize the results in my own work, I will be sure to double back and check out some of those piles I had noticed along the way.

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