



Renewable electricity generation in India—A learning rate analysis

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HIGHLIGHTS

- The first learning rate analysis of wind generation costs in India.
- Only the second learning rate analysis for wind in any developing country.
- Reviews missing variable and related issues in learning rate analysis.
- Finds a 17.7% learning rate for wind generation costs in India.
- Finds no significant learning effect for small hydro.

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ABSTRACT

The cost of electricity generation using renewable technologies is widely assumed to be higher than the cost for conventional generation technologies, but likely to fall with growing experience of the technologies concerned. This paper tests the second part of that statement using learning rate analysis, based on large samples of wind and small hydro projects in India, and projects likely changes in these costs through 2020. It is the first study of learning rates for renewable generation technologies in India, and only the second in any developing country—it provides valuable input to the development of Indian energy policy and will be relevant to policy makers in other developing countries.

The paper considers some potential problems with learning rate analysis raised by Nordhaus (2009, *The Perils of the Learning Model for Modeling Endogenous Technological Change*, National Bureau of Economic Research Working Paper Series No. 14638). By taking account of these issues, it is possible both to improve the models used for making cost projections and to examine the potential impact of remaining forecasting problems.

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1. Introduction

In 2009, 69% of India's electricity was generated by coal fired power stations: based on current policies, the proportion will fall only to 67% by 2035 (IEA, 2011). The IEA expects coal demand for power generation to increase from 203 Mtoe (million tons oil equivalent) to 578 Mtoe over that period. As India's rate of economic development has outstripped the production capability of its mines,¹ much of that increase would be met by imports, to the detriment of India's energy costs and energy security. Higher coal consumption will increase GHG emissions, putting in question India's commitment to reduce the carbon intensity of its GDP; it could also have serious consequences for human health (Cropper et al., 2012). To avoid – or at least mitigate – these consequences,

there is an urgent need for policies aimed at cutting the proportion of India's generation that is based on coal.

This raises the question: What would such policies cost? Nuclear is expensive and the Indian public is concerned about its risks: Gas in the form of imported LNG is not the cheap option that it has become in the US; renewable generation technologies are also seen as expensive, though the cost is falling as experience of the technologies grows. This paper uses learning rate analysis to estimate the potential for reductions in renewable generation costs in India by 2020.

1.1. Learning rate analysis

Empirical studies of reductions in manufacturing costs as experience of a technology accumulates essentially began with (Wright, 1936).² Wright's paper discussed the relationship between unit costs and the length of production runs for essentially identical items. He was concerned primarily with assembly operations and discusses

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¹ According to an article in *The Economic Times* of Mumbai dated June 6, 2012, the state owned entity Coal India Limited has warned its power sector customers that it can supply only 60% of their requirements: It hopes to be able to increase this to 80% of requirements within a few years.

² Nordhaus refers to studies of speeds achieved by telegraph operators as long ago as 1899 (Nordhaus, 2009).

learning only in the context of labor costs—“the improvement in proficiency of a workman with practice ... is well known”. Learning rate (or experience curve) analysis, as used today, is more concerned with cost reductions achieved through technological improvement. Learning rate studies model the relationship between manufacturing cost and cumulative volume manufactured, but there is no suggestion that the design of the item remains unchanged – quite the contrary, in fact – the assumption is that design changes result from learning. The departure from Wright's focus on labor costs makes the analysis far more complex.

In this paper I apply learning rate analysis to the capital costs of wind and small scale hydro generation plants in India, and to the cost of electricity generated. The results make a significant contribution to debate about India's energy policy: in terms of contribution to the learning rate literature, this appears to be only the second study to apply the methodology to wind generation costs in a developing country (after (Qiu and Anadon, 2012), which looked at China). A recent meta-analysis (Lindman and Soderholm, 2012) uses 113 estimates of learning rates for wind generation obtained from 35 papers—all of which use data from developed countries.

In Sections 2 and 3 I describe the methodologies used for estimation of generation costs and for the learning rate analysis itself; the results, together with discussion and analysis, are in Section 4.

2. Estimation of generation cost

I estimate generation costs for samples of wind and small hydro projects drawn from the database of registered CDM projects maintained by the UNFCCC.³ This contains (as of July 1, 2012) project design documents (PDDs) for 300 wind and 98 small hydro projects in India. In most cases the PDD contains sufficient financial and operating data to enable generation cost to be calculated, using the identity:

$$\begin{aligned} \text{generation cost per MW h} \\ &= \text{operating cost} + \text{capital cost} \\ &+ \text{additional grid costs due to intermittency} \end{aligned}$$

Cash operating costs for renewable projects are relatively small. Capital cost here means investment cost annualized using the annual capital charge (ACC) methodology (Merrett and Sykes, 1973), using a project-specific weighted average cost of capital – see Section 2.1. The output of wind and solar generation varies over short periods due to the intermittency of the resource, imposing additional costs of intermittency on the grid operator due mainly to the need for conventional generation capacity as backup – see Section 2.2. Zero intermittency costs are assumed for small hydro plants—hydro often runs on a seasonal basis depending on rainfall, but output is predictable during the operating period.

Investors typically compare generation projects on the basis of levelized cost of electricity (LCOE). This is the projected generation cost for each period over the project life discounted back to the start date at an appropriate rate (see Section 2.1). LCOE is a flawed metric for comparisons involving renewable technologies as power generated during peak demand periods is worth more than power generated at other times. This can be demonstrated empirically for market based systems that provide realistic price signals (Fripp and Wiser, 2008): In most countries, winds are

stronger at night when demand is low, so the power is worth less and LCOE comparisons overvalue wind generation; conversely, solar generation peaks when demand is close to its daily maximum so tends to be undervalued by traditional methodologies (Borenstein, 2012; Joskow, 2011). As it is impossible to obtain data to adjust for this effect in India, my cost comparisons are based on the traditional LCOE metric.

2.1. The return on capital and the impact of incentives

The annual capital charge (ACC) is calculated using the project's risk adjusted weighted average cost of capital (WACC)—i.e. the weighted average of the interest rate on project debt and the investors' required return on equity invested (RoE). RoE can be estimated using the capital asset pricing model (CAPM) which adjusts the expected return on the stock market by a measure of the project's risk relative to the market known as the project's Beta. Beta is estimated by observing the price movements relative to the market of a portfolio of shares that have a similar risk profile to the proposed investment. An analysis by Donovan and Nunez (2012) found a value of Beta for Indian renewable energy projects close to 1.45.

Using this value for Beta, the CAPM gives a post-tax RoE for the sector of 21%, which is significantly higher than the figure of 15.6% used by the Indian Central Electricity Regulatory Commission (CERC) to set tariffs for renewable generation.⁴ In theory this means that renewable generation projects in India offer returns that are insufficient to attract investors. However this is evidently not the case: Indian investment in clean energy projects in 2011 – essentially all by the private sector – amounted to \$10.3 bn.⁵ A possible explanation is that the actual return to an investor is increased by additional incentives for investments in renewables. A World Bank report notes that these include “feed-in tariffs; generation-based incentives; renewable purchase obligations (RPOs); central, state, and regional capital subsidies; accelerated depreciation; and tax incentives. The lack of coordination between incentives and state programs makes it difficult to adopt an economics-based least-cost development approach to tapping the country's renewable energy potential” (Sargsyan et al., 2010). However the CERC guidelines state that incentives are considered in setting the tariff—i.e. the permitted RoE includes their impact, so they should not affect the average RoE over the project's life.⁶

The most likely explanation for the difference between the CERC allowable return and that estimated using the CAPM is that the portfolio of stocks used by Donovan and Nuñez to estimate Beta does not correctly reflect project risk. Very few renewable generation companies are quoted on the Indian market: Donovan and Nuñez used a portfolio made up of large companies active in thermal generation, manufacturers of renewable generation equipment and a few companies – typically only recently quoted – that make a large part of their income from renewable generation. This explanation is in line with views expressed by CERC that the CAPM approach is inappropriate for their purpose.⁷

⁴ The permitted pre-tax RoE is 20% pre-tax for 10 years then 24% for the remainder of the project life. I adjust this using current tax rules—see http://www.cercind.gov.in/2012/regulation/CERC_RE-Tariff-Regulations_6_2_2012.pdf.

⁵ <http://bnef.com/PressReleases/view/186> (accessed 08/08/2012).

⁶ Since 2011, investors have had the option to accept the CERC RoE or negotiate a tariff with power purchasers and receive renewable energy certificates (RECs) for power generated. RECs may be used by large power purchasers for compliance with renewable purchase obligations (RPOs)—a market for RECs has operated since early 2011.

⁷ <http://cercind.gov.in/2009/February09/SOR-regulation-s-on-T&C-of-tariff-05022009.pdf> (accessed April 27, 2012).

³ <http://cdm.unfccc.int/>. The advantage of the UNFCCC database is that it contains project-specific data on large numbers of actual projects. The main disadvantage is that it contains few or no examples of some project types: For example, at the time of writing there were only two grid-connected solar PV projects registered in India.

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