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How to judge whether supporting solar PV is justified

EPRG Working Paper 1706

Cambridge Working Paper in Economics 1715

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The Global Apollo Programme (King et al., 2015) calls for a global effort to combat climate change, including support to drive down the cost of zero-carbon generation. Given the range of different zero-carbon options (nuclear, wind, solar PV, etc.) how does one decide when one option merits continued support and when to abandon that technology and concentrate on others? The main case for supporting different renewable energy technologies is that their deployment drives down costs through learning by doing and induced technical progress. If technology developers can see a viable market for their products, they will be encouraged to research, develop, test, and, if the results are promising, scale up production and drive down costs. The resulting cost reductions are typically measured by the learning rate - the proportional drop in cost per unit for a doubling of the installed capacity. While there is uncertainty not only about past learning rates but clearly about future rates and even their attribution to deployment or R&D, the learning rates for some technologies like solar PV seem impressive. Most sources agree on a 20-22% learning rate over long periods for PV modules, up to the 2015 cumulative production of 227 GW_p. The 2015 annual rate of PV installation was 50 GW_p or 28% of the installed base, which alone could cause a current cost reduction of 6%.

These learning benefits are hard for developers to capture (the solar PV and wind turbine markets are intensely competitive) and so they primarily benefit subsequent installations. Even if the improvements could be patented and licensed, there would be a strong case for making these technologies available without a license fee to encourage their take-up and resulting climate change mitigation. The learning externalities require compensation and directly supporting deployment (and R&D) is preferable to license fees. There is an additional case for support that extends to all low or zero-carbon technologies, given the absence of an adequate, durable and credible carbon price. Adequately rewarding any shortfall in the social cost of carbon can be addressed either directly by a carbon price support (as in Britain), somewhat indirectly and more bluntly through emissions performance standards that discourage investment in carbon-intensive generation, or in a second-best world, by subsidizing the output of low-carbon generation by the short-fall in the efficient price set by more carbon-intensive generation.

Grid-scale PV has lower costs than smaller panels, and tracking panels (used in more than half the US larger installations) can have an average capacity factor above 25% in favoured locations like the South-West of the US, or as low as 10% in Northern Europe.

This paper sets out a method for determining the level of support that is justified, taking a global social cost-benefit approach, assuming that some collective funding agreement such as the *Global Apollo Programme* can be implemented. The starting point is to estimate the learning rate, the current installed base and cumulative production, and the current cost level. Evidence is presented that grid-scale systems can be delivered at some US$(2015)1,050/$kW_{p.}$

Investment now lowers future installation costs, and hastens the date at which PV might become cheaper than fossil generation. A trajectory of investment in PV will be justified if it has a positive present discounted value (PDV) when properly accounting for the social cost of the fossil generation displaced, which will include the social cost of CO_2. It will be socially profitable to accelerate this investment if a small increase in investment now has a positive impact on the PDV of the trajectory. This calculation requires a trajectory of the amount of capacity added each year, from which one can estimate the cost of additional units as a function of cumulative gross investment. Note that the installed stock at any moment will be less than cumulative gross investment as PV arrays only have an estimated life of 25-30 years.

The paper develops models to show how these benefits depend on a wide range of parameters and assumptions such as the learning rate, commercial discount rates and market carbon prices, capacity factors and capacity credits and quantifies the value of specific deployment trajectories and the gains from accelerating investment now. It shows that if deployment can be concentrated on high insolation locations (ideally, 2,000 kWh/kW_pyr, as in the South Western US or many developing countries within the tropics), and if carbon is properly priced, then at public sector discount rates of 3% real, even with relatively low (CCGT) displaced fossil fuel benefits of $35/MWh and displaced carbon benefits of $25/tonne CO_2 (rising annually at 1.5%), accelerating investment above 15% per year is socially attractive. Even if the capacity factor and the displaced fuel credits all fall at 1% p.a. this remains true.

The second finding is that the benefit of accelerating investment exceeds the PDV of a constant growth path, as current investment delivers cheaper future cost reductions while cumulative production remains modest. That raises questions about the constraints on the rate of growth of module production consistent with disseminating the relevant learning and research, before the learning rate (rate of cost reduction) is prejudiced.

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Publication March 2017
Financial Support