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Evaluating the case for supporting renewable electricity☆

David Newbery

Energy Policy Research Group, University of Cambridge, Sidgwick Avenue, Cambridge CB3 9DE, UK

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A B S T R A C T

Renewable electricity, particularly solar PV and wind, creates external benefits of learning-by-doing that drive down costs and reduce CO_2 emissions. The *Global Apollo Programme* called for collective action to develop renewable energy. This paper sets out a method for assessing whether a trajectory of investment that involves initial subsidies is justified by the subsequent learning-by-doing spillovers and if so, computes the maximum justifiable additional subsidy to provide, taking account of the special features of renewable electricity – geographically dispersed and variable quality resource base and local saturation. Given current costs and learning rates, accelerating the current rate of investment appears globally socially beneficial for solar PV in most but not all cases, less so for on-shore wind. The optimal trajectory appears to involve a gradually decreasing rate of growth of installed capacity.

1. The case for supporting renewables

The *Global Apollo Programme* called for collective action with "one aim only – to develop renewable energy supplies that are cheaper than those from fossil fuels. …These price trends help to create a *prima facie* case in favour of focussing heavily on solar energy." (King et al., 2015, p15). The case for support is primarily to compensate for the otherwise unremunerated learning spill-overs arising from cumulative production. Each additional installation adds to the cumulative production, which Fig. 1[1] persuasively suggests is the prime driver of cost reductions of solar modules (Fraunhofer, 2016; Rubin et al., 2015a). Renewable electricity technologies, particularly wind and solar PV (hereafter just PV), have been heavily subsidized for many years. Both PV and wind are finally at the point of becoming commercially viable without subsidies in some locations, but new installations continue to enjoy significant, if now much lower, support in many jurisdictions. This paper asks whether past and continued support for such technologies is justified, and, more fundamentally, how to determine the appropriate level of support now and in the future for emerging low-carbon technologies with learning spillovers. While it is easy to present qualitative arguments for such support, the practical question is to quantify the level of justified support, and relate it to observable features of the technology and the location. The strongest case is one in which all countries recognize the social value of supporting immature zero-carbon technologies and collectively fund that support. *Mission Innovation* is a recent example, through which "22 countries and the European Union are taking action to double their public clean energy R&D investment over five years".[2]

This paper provides a method for calculating the justified subsidy to compensate for the learning spillovers. There is typically also a shortfall between the social cost of carbon and its market price to account for in the social cost-benefit analysis. To justify the learning subsidy the investment must be socially profitable – if it never becomes socially profitable there is little point in pursuing these cost reductions. The paper sets out a methodology for a social cost-benefit analysis of a global support programme for low-carbon electricity generation technologies, illustrated for PV and on-shore wind. The electricity supply industry has particular characteristics that need careful modeling if the results are to carry credibility. Consumption is constrained by current available capacity as storage is costly (Newbery, 2016), and

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☆ This paper was prompted by Neuhoff (2008), who was pessimistic about the social profitability of PV when its cost was much higher, but noted that increasing current investment might relax constraints on future investment rates, which conferred an additional and potentially large extra benefit. I am indebted to insightful comments from Rutger-Jan Lange, and very careful checking of the paper and formulae to Linden Ralph and Bowei Guo, as well as to very helpful reviewers.

E-mail address: dmgn@cam.ac.uk.

[1] Source: Delphi234 - Own work, CC0, https://commons.wikimedia.org/w/index.php?curid= 33955173. The straight green line predicts that modules decrease in price by 20% for every doubling of cumulative shipped modules. The other line (with squares) shows world-wide module shipments vs. average module price. The data are from ITRPV 2015 edition and can be updated to 2015 with ITRPV (2016); later updates are available annually at http://www.itrpv.net/Reports/Downloads/.

[2] See http://mission-innovation.net/.

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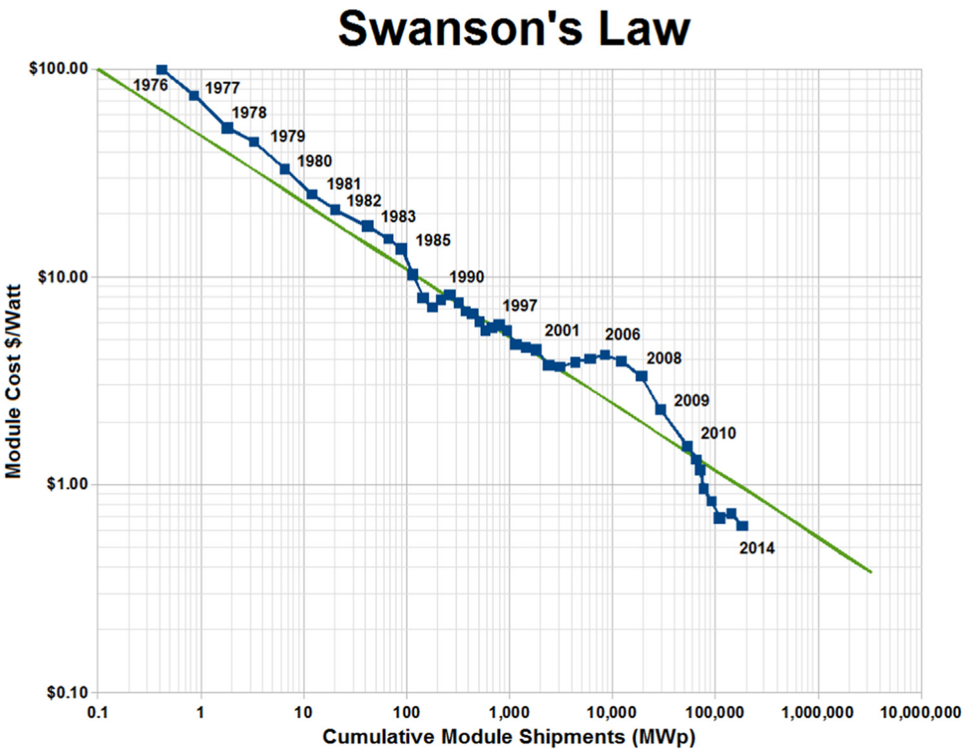

Fig. 1. PV Module price reductions.

transmission constraints limit the size of the market that can be supplied from local capacity. As a result the value of electricity can vary strongly over time and space in ways that make the concept of a global market inappropriate. Local saturation is an important element, while the value of any one low-carbon option depends on what others are available and when they become competitive. A key issue is whether to accelerate deployment to reap earlier learning, or delay until the technology becomes more competitive against rising fossil energy costs.[3]

1.1. Literature review

The idea of including learning-by-doing as a general driver of technical progress dates back at least to Arrow (1962), and has spawned an extensive literature.[4] Two immediately relevant strands are the extent to which cost falls can be reliably estimated and attributed to cumulative deployment (Rubin et al., 2015a) or R&D (Jamasb, 2007; Nordhaus, 2014),[5] and the policy implications of the market failure of unremunerated spillovers. The focus here is on low-carbon technologies, which, because of heavy subsidies, have attracted particular attention. Most papers study how specific subsidy policies have worked and whether they were justified (e.g. Bollinger and Gillingham, 2014; Rasmussen, 2001 for wind in Denmark; van Benthem et al., 2008 for Californian PV; Andresen, 2012 for offshore Norwegian wind). Others address how to design policy (Bardhan, 1971; Lehmann, 2013; Mazzola and McCardle, 1997), and what is the right instrument – whether to subsidize capacity (Andor and Voss, 2016) or support the production of the technology (Reichenbach and Requate, 2012). Few if any papers attempt to estimate the justified subsidy for specific technologies with their own characteristics.[6] An earlier working paper (Newbery, 2017, a shortened version of which appeared as an appendix in Newbery, 2018) took a similar but simpler approach, but ignored future competition from other low-carbon options, and future post-saturation growth. The present paper points out the sensitivity of results to the details of the modeling assumptions.

Goulder and Mathei (2000) build an elegant but highly simplified global optimal abatement model in which abatement reduces CO_2 emissions, whose cumulative stock must be kept below some critical level. Investment in R&D generates knowledge, as does cumulative abatement effort (learning-by-doing, LbD). If cost reductions come from R&D alone, the optimal choice of abatement will be later when costs are lower, but if it comes from LbD, the impact on timing is ambiguous, although Grubb et al. (2002), in reviewing their model, note “their specific examples do yield stronger early mitigation with LbD”. The model developed here is very partial (just the electricity sector) and ignores any impact on the carbon price (central to global energy-environment models), but it asks whether it is desirable to accelerate or delay deployment in the presence of LbD, and what might influence that choice.

1.2. Relevant technology characteristics

PV is a key low-carbon[7] generation technology as it enjoys the

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[3] Grubb et al. (2002) review the implications of induced technical change for energy modeling. They note the contrast between learning, which argues for earlier support for climate mitigation, while autonomous technical change argues for later support when more knowledge has accumulated, making action later cheaper. Our emphasis is on changing relative costs rather than autonomous technical change.

[4] The concept has been influential in both policy design (e.g. Succar, 1978) oligopoly pricing policy (e.g. Spence, 1981), and industrial and trade strategy (e.g. Ghemawat and Spence, 1985; Dasgupta and Stiglitz, 1988).

[5] Grubb et al. (2002) and Gambhir et al. (2014) note the complex interactions between R&D and deployment, with increased deployment stimulating more R&D and vice versa, supporting the view that increments in cumulative capacity are the main factor driving down costs in later near-market stages. Papineau (2006) cautions that adding time and R &D makes cumulative production statistically insignificant; a reflection of the often high collinearity between time and log cumulative output.

[6] Kalkuhl et al. (2012) presents a calibrated general equilibrium global model and gives graphs of optimal learning subsidies (fig. 5) for generic technologies.

[7] Although PV generation is zero-carbon making the modules is quite energy and potentially carbon intensive. Wider decarbonization would reduce its manufacturing carbon footprint.