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Commentary

Commentary on 'the interplay of the innovation cycle, build time, lifetime, and deployment rate of new energy technologies: a case study of nuclear fusion energy' designing innovation strategies for rapid feasible technological change

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Abstract

How fast can new technologies come online and what is the most effective policy strategy to accelerate their growth? A recent article by Lopes Cardozo and Ward contribute to shedding light on this very interesting question particularly tricky to answer for technologies which are not yet commercial. Taking the case of nuclear fusion, the authors aim to identify the best innovation strategy for the technology. They embed this analysis in a useful concept of a 'forced transition' which echoes the general belief that energy transitions will need to be driven by policies rather than pure market forces. Their work introduces two significant theoretical advances: the Fastest Feasible Growth (FFG) model and foregrounding generational changes for analyzing technological deployment. While the authors' insights offer valuable contributions to both growth modeling and experience curve analysis, their work raises important questions for future research. These include the empirically validating of the relationship between technological generations and growth; identifying the conditions under which technological expansion would be faster then their FFG model; the duration of the exponential growth phase; the applicability of the model beyond the global scale; and conceptualising technological generations.

Key words: energy transition; technology change; technological growth; feasibility; clean energy

In a recent article published in Oxford Open Energy [1], Lopes Cardozo and Ward contribute to shedding light on a very interesting question of how fast can the energy transition feasibly unfold, which is particularly tricky to answer for technologies which are not yet commercial. Taking the case of nuclear fusion, a technology which has been said to be close to a breakthrough for almost 50 years now, the authors aim to identify the best innovation strategy for the technology. They embed this analysis in a useful concept of a 'forced transition' which echoes the general belief that energy transitions will need to be driven by policies rather than markets [2] and recent calls for mission-driven innovation [3].

Lopes Cardozo and Ward make two contributions which will be particularly interesting for other scholars of technological change and energy transitions. The first is the thinking around how to model and project technological development. And the second is the authors' proposal of a new way to think about technological learning. Both are rooted in attention to the production and replacement rate of technological artefacts reaching the end of its lifetime, which has so far been neglected in the literature and poses a very interesting connection to designing the most effective innovation strategies.

Scholars have struggled for decades to accurately model the growth of new technologies [4–7] and there are intense debates today about how to most accurately model even near-term technological deployment of solar, wind and other low-carbon technologies [8–13]. Lopez Cardozo and Ward propose a long-term growth model—the fastest feasible growth (FFG) model—with a short acceleration phase marked by exponential growth followed by a longer linear growth phase. This move departs from the two dominant approaches in the literature today: modelling the growth of new technologies as (quasi-)exponential or following a logistic growth function. The Lopez Cardozo and Ward approach echoes recent arguments that technological deployment should be distinguished into what scholars have called an 'acceleration' and a 'stable growth phase' [14–16] and reflected in recent modelling approaches [12, 14–16].

While the FFG model echoes recent insights into distinct phases of technological growth, the authors uniquely position their argument within the dynamics around the production

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of new equipment. The authors argue that it is unlikely for a technology to expand faster than the replacement rate of that technology and also that the saturation of operational capacity occurs once the production rate matches the replacement rate. They explain this with the logic that if a technology expands faster than the replacement rate, it would lead to large swings in production capacity which is unlikely. Take for instance electric vehicles. production will initially ramp up during which time growth accelerates, but once production of electric vehicles matches car purchases which go to replacing an old vehicle, it is likely to saturate. The authors' illustrate their fastest-feasible growth path with the historical deployment of solar PV, onshore wind, LEDs, and smartphones.

Lifting up the role of production in shaping technological deployment also contributes to a better understanding of the mechanisms shaping experience curves. Experience curves are based on the empirical observation that as the cumulative production of a technology rises, costs fall. This pattern is generally explained by technological innovation which occurs from increasing innovation and learning-by-doing; however, there is still a need to unpack how exactly this occurs and estimate how fast it can occur for any given technology. Lopez Cardozo and Ward contribute to this with a novel observation that technological progress is punctuated as a technology proceeds from one generation to the next. Since each generation encapsulates a burst of innovation and learning, the authors argue that the speed of technological innovation can be estimated from the generation time for a given technology.

This innovation is useful for both anticipating the pace of technological learning and also potentially for formulating policy advice to support rapid innovations. With respect to the former, the authors illustrate their argument by alluding to the long generation time of nuclear fission which inhibits the frequent and large bursts of learning associated with the switch from one generation to the next. This insight underpins the authors' policy advice that for nuclear fusion policymakers and industries should support a number of different designs in parallel—essentially speeding up learning.

As any scientific contribution, Lopes Cardozo and Ward's piece raises a number of scientific questions—related to both growth models for low-carbon technologies and experience curves.

First, highlighting the role that the production of technologies may play in shaping their growth rates is a welcome innovation. This novel argument is ripe for being empirically tested and interrogated. The authors offer a number of illustrative examples, but the empirical evidence for this mechanistic explanation should be further tested and interrogated.

Second, in terms of growth models, it is an open question to what extent is the authors' FFG curve actually feasible and what conditions would enable departing from this curve? The authors's logic for the FFG is based purely on the replacement rate of a technology. How do other mechanisms influence the shape of the growth curve and speed of growth? Many technologies, including energy technologies, face public opposition and grid integration issues. How do these issues affect the FFG? And finally what mechanisms would cause a technology to significantly depart from the FFG? It is tempting to simply call for stronger policies and stronger investments. But are there cases where a technology grew faster than the FFG? And if so, what were the conditions which enabled such expansion? Furthermore, the FFG is based on a stagnant market. Yet a number of countries are planning to significantly expand electricity consumption to meet climate targets. How would large demand growth change the results for the FFG?

Third, in terms of growth phases which the authors use, there are large questions as to how long the exponential growth can last. This is a key uncertainty because as the authors point out, the length of the exponential growth phase is the key factor shaping cost declines for a new technology. Lopes Cardozo and Ward's piece say that energy technologies typically experience 'decades of exponential growth'. But when should we start counting this 'decades' and is it possible to predict when the decades of exponential growth gives way to a linear growth regime? The authors do not answer this question but their results provide some interesting paths to follow. Analysing recent deployment data of solar and wind, the authors show that wind power and most likely solar power as well have switched from the early exponential growth regime to a linear one. For wind, they identify the switch in 2012 and for solar 2016. This is surprisingly close to the take-off year for each technology (2008 for wind power and 2015 for solar power) [9]. Future research should investigate if technology take-off predicts when the switch from exponential to linear growth occurs. This finding also suggests that the use of the exponential model to approximate near-term solar PV and wind growth will lead us astray. The authors argue that exponential growth should resume to meet the IEA net zero emission (NZE) scenario but they do not evaluate the feasibility of this assumption or its logical consistency with their other findings.

Fourth, related to the FFG, to what extent can it be scaled to the regional or national level? The authors' growth model is parameterized based on global data. Yet technologies are fragmented by national and regional markets which significantly shapes their deployment [17]. So there is a methodological question as to what extent the FFG curve can be applied to the national and regional level. And what insights this might yield.

And fifth, Lopez Cardozo and Ward's contribution raises a number of methodological avenues related to analysing experience curves and the cost decline of technologies. The authors' explicit treatment of generations of a given technology and its relationship to the experience curve is a welcome contribution to the literature. However, more work needs to be done to investigate what constitutes a new generation. The authors' examples of generations—iPhones and nuclear power plants have clear generational labels. But what constitutes a new generation for wind turbines? How does this relate to technological upscaling [18] and other incremental improvements such as siting? The 'generation' research agenda marks an interesting lens for technology and policy advice and now we need to understand how to delineate generations in a diversity of technologies.

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Jessica Jewell (Conceptualization [lead], Writing—original draft [lead], Writing—review & editing [lead]).

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