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Systems Innovation, Inertia and Pliability

EPRG Working Paper 1808

Cambridge Working Paper in Economics 1819

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Innovation can reduce the cost of low carbon technologies for emissions mitigation, and there is overwhelming evidence that technology costs generally reduce with deployment. Energy and other emitting systems can also adjust to energy or emission costs and constraints in other ways, such as with structural change and long-lived infrastructure.

This implies that the act of reducing emissions through investment in the deployment of low carbon technologies and systems will, through learning and other effects, tend to reduce the costs involved in subsequent emissions reduction. At the same time, the learning itself involves costs, whilst both the rapid expansion of new technologies and the displacement of existing incumbent technologies involve overcoming many sources of inertia – for example the build-up of new production facilities, supply chains and associated costs for diffusion processes, and the displacement of existing capital potentially before the end of its economic lifetime.

So far these dynamic aspects of learning and inertia have received little attention in the Integrated Assessment Models (IAMs) often used by economists to assess global climate mitigation trajectories; most such models assume technology costs to be exogenous, rather than evolving in response to deployment scale or the depth of emission reductions, and have little or no representation of inertia.

This paper aims to address this important weakness in three stages.

First, we develop a micro-economic framework for representing learning effects and inertial costs, based on a novel approach of integrating investment costs across technology sectors. We demonstrate the influence of learning-by-doing (parametrised through learning rates) in reducing both the magnitude and the non-linearity of marginal abatement investment cost curves. We develop equations to represent various sources of transitional costs associated with early scrapping of existing plant, the development of manufacturing facilities for producing low carbon plant, and the costs associated with development of supply chains and associated infrastructure required for diffusion. In each case, we show a tendency towards quadratic relationships, in both the scale and the rate of emissions mitigation.

Second, we extend from this micro-economic analysis to a wider consideration of cost structures at the level of emitting systems. We argue that the traditional approach, of representing abatement costs solely in relation to the degree of abatement at a given point in time, in reality conflates costs which are enduring with those which are transitional and that these need to be separately represented. Learning, and the development of long-lived low-carbon infrastructure, reduces the scale of enduring abatement costs (associated with a degree of abatement from an assumed baseline). Transitional costs comprise the various sources of inertia that we identified in part 1, plus components associated with the low-carbon learning and infrastructure investments. We introduce the term pliability to express the ratio between these two components: a non-pliable system has no capacity to learn and no transitional costs; a fully pliable system will in time adjust to emission constraints, incurring transitional costs which then leave the system on a fundamentally different trajectory.

Consequently, we argue that the approach of existing IAMs need to be extended with transitional costs. Several high-level IAMs (like the DICE model) assume costs which rise quadratically with abatement, and based on our micro-economic analysis we argue that the transitional component can also be plausibly represented as quadratically increasing, but with the rate of abatement.

Third, we apply this modeling structure in a simple global integrated assessment model, with mostly traditional assumptions around the degree and structure of economic damages associated with climate change related to global temperature increase. We demonstrate that the resulting model is analytically tractable, providing insights also into the fundamental drivers of results and appropriate boundary conditions, and implement both analytic and numeric versions of the model.

We demonstrate that the economically optimal (total-cost-minimising) trajectory with a pliable emitting system is radically different from the conventional case. Conventional IAM models tend to generate trajectories which involve rapid initial abatement, at moderate costs, both of which then escalate over time as the distance from the reference emission trajectory increases and as the scale of climate damages increase - but generally without getting close to stabilising the atmosphere, because of the steadily rising abatement costs, which reflect the marginal damages associated with a tonne of CO2.

A pliable system, in contrast, tends to involve higher initial effort – marginal cost – required to overcome the inertia of the system and facilitate subsequent abatement, but a far steadier rate of increase of abatement over time; the optimal abatement costs tend to stay steady over the first few decades and then decline as the system approaches atmospheric stabilisation, with zero net emissions. With a pliable emitting system – but otherwise relatively conventional assumptions - the system thus reaches outcomes more consistent with scientific thresholds and political goals (such as in the Paris Agreement), but from a cost-benefit standpoint; greater initial effort is required, but the overall costs associated with tackling climate change are substantially reduced.

We conclude that integrated assessment models must pay far more attention to the dynamics of learning and inertia, and that more research would help to test the functional forms we propose, and probe further the parametrisation of such models and results.

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Publication	March 2018
Financial Support	UK Engineering and Physical Sciences Research Council (EPSRC), grant number EP/K007254/1 (JFM)

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