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On a wing and hot air: Eco-modernisation, epistemic lock-in, and the barriers to greening aviation and ruminant farming

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A B S T R A C T

The aviation and livestock agriculture sectors are major producers of greenhouse gas emissions, and have been the subject of extensive examination to develop lower impact, more energy and resource efficient technologies. Yet little attention has been paid to the challenges faced in the adoption of these lower impact technologies in these industry sectors. In this paper we seek to understand the interactions between technological innovation and socio-behavioural contexts in the adoption of more environmentally sustainable practices. Focusing on the UK (although recognising the global context of aviation and agriculture) and using a combination of literature analysis and interview data we undertake a detailed examination of these interactions. We examine why the claims of eco-modernisation theory that argue that the drive for economic efficiency will lead also to improved energy and resource efficiency appear unfounded in our cases. We identify lock-in in both sectors, finding that the barriers to greener innovation hinge particularly on the knowledge practices that pertain in the two sectors. This 'epistemic lock-in', rather than simple inertia and resistance to unfamiliarity, appears crucial, and must be overcome to enable adoption of lower impact technologies.

1. Introduction

Towards the end of the twentieth century a scientific consensus emerged pointing towards a strong causal correlation between greenhouse gases (GHGs) and climate change, and in most countries this view is accepted by mainstream political opinion. In the United Kingdom (UK), policy responses to this challenge led to an ambitious target of reducing GHGs emissions by 80% by 2050 as compared to 1990 levels [1].

Achieving such challenging goals will require the transformation of many industrial sectors. Whether it be automobiles running on fossil fuels, poorly insulated houses, fuel-hungry aircraft, or meat consumption based on ruminant farm animals, it is clear that longstanding technological paradigms need to be displaced or drastically altered. Innovation can provide technologies with less climate change impact, but they must also be adopted into practice to produce this effect. Although 'eco-modernisation' has many conceptual strands, one key idea is that businesses seek to be efficient in order to make greater profits, and such efficiency should lead to less wasteful use of resources and greater energy-efficiency. This 'win-win' argument is also central to the claims made for 'clean technology' whereby innovative restructuring of industrial processes can reduce waste production, thus reducing the need for end-of-pipe approaches to ameliorate pollution.

Here we focus specifically on the processes of innovation in two socio-technical systems – civil aviation and ruminant farming – and the barriers to change that need to be overcome to improve energy and resource efficiency to order to achieve substantial GHG reduction. These two sectors are chosen for their distinctive individual significance and the potential they afford for comparative analysis. To what extent, do these cases support or undermine the argument that eco-modernisation can lead to win-win outcomes by stimulating the adoption of more energy efficient processes? What factors limit the adoption of more efficiency due to the 'lock-in' of existing socio-technical systems? How do these factors differ between the two sectors under comparison here, and what policy measures can help overcome this lock-in?

2. Eco-modernisation, environmental transitions, and lock-in

In broad terms eco-modernisation theory (EMT) views 'the constant ecological restructuring of modernity' as sufficient to meet environmental challenges because of the inherent 'ecology-inspired and environment-induced processes of transformation and reform in the

Abbreviations: APD, Air Passenger Duty; EBV, Estimated Breeding Value; EU, European Union; ETS, Emissions Trading Scheme; FAA, Federal Aviation Administration; GHG, greenhouse gas; LFC, laminar flow control; MLP, multi-level perspective; UK, United Kingdom

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central institutions and social practices of modern society' [2,255]. There are a broad range of critiques of EMT (e.g. [3,4]). Here we focus on one particular aspect: the centrality of technological innovation to the achievement of more efficient and thus greener solutions. A core idea of EMT is that 'the only possible way out of the ecological crisis is by going further *into* the process of modernization' [5,42]. At the heart of this optimistic perspective is the belief that technological innovation can, and will, improve resource efficiency, and that in so doing economic gains and corporate profit will be aligned with reductions in environmental impacts. As Welford [6,3] puts it: 'Eco-modernism as a philosophy, with eco-efficiency as its flagship tool, represents a response to concern over the environment by those people and institutions who are committed to the traditional modernist growth trend. The tool of eco-efficiency, a broadly technological tool, sees no alternative to business setting the environmental agenda and business controlling the greening of development.'

Thus, according to EMT, technology is the solution, not the problem, and 'clean(er) technology' offers 'win-win' solutions [7]. In this perspective, so long as environmental costs over the whole life cycle are internalised, the profit maximising nature of capitalist economies will drive down environmental damage whilst increasing profits. EMT thus seeks to 'solve environmental problems by making capitalism less wasteful and thus more sustainable, while retaining the basic system of capitalist production and consumption. The approach to environmental problems is therefore efficiency-oriented' [8,pp. 3–4].

However, such a benign view of market-driven innovation rests on a neo-classical view of economics in which technological substitution relies simply on straightforward cost-benefit analysis, and where new technology can be readily accessed and exploited by companies. In reality, certain aspects of innovation do not follow this idealised model. Rather than constantly seeking to maximise efficiency (and profits), companies instead 'satisfice' by following routines that usually provide adequate financial returns [9,10]. Moreover, technologies are not readily and smoothly substitutable: in some cases because of the high R&D costs needed to develop new technologies to the point where they can out-perform existing technologies that have benefitted from years of incremental improvement, but more generally because technologies are embedded in broader 'socio-technical regimes'. Moreover, as we will outline in both our case studies, environmental impacts can be multiple, complex, and not directly related to energy or resource efficiency.

A particular barrier for efficiency incentives to drive radical improvements in environmental performance is that socio-technical regimes are typically persistent, and characterised by 'technological trajectories' in which paradigmatic technologies are gradually improved. As Dosi [11,153] noted, 'a technological paradigm has a powerful exclusion effect: the efforts and the technological imagination of engineers and of the organisations they are in are focused in rather precise directions while they are, so to speak, "blind" with respect of other technological possibilities.'

Dosi's emphasis on technical exemplars and engineers' practices was too narrow, and later thinking on regimes emphasises 'the embedding of existing technologies in broader technical systems, in production practices and routines, consumption patterns, engineering and management belief systems, and cultural values' [12,182]. In recent years, the dominant framework applied to understanding the persistence of such regimes has focussed on 'technological transitions', typically through application of the multi-level perspective (MLP) approach (e.g. [13,14]).

Many interesting historical case studies have been produced using the MLP framework, but this approach has also attracted a range of critiques (e.g. [15,16]). Our concerns about the MLP approach to transitions centre on two issues. First, many of these studies are limited by a tendency to focus on the development of technology more than on its use, on the supply-side rather than the demand-side [17]. Second, MLP transition case studies are dominated by accounts of successful transitions (for an exception, see [18]). Because MLP accounts of transitions 'have a tendency to focus on "winning" technologies' [15:1444] they suffer from a lack of methodological symmetry as regards explaining success and failure [19].

While the MLP has dominated recent work on transitions, studies of lock-in have been relatively neglected, and yet they offer a useful corrective to this focus on successful transitions. Understanding lock-in is a key step towards overcoming barriers to more sustainable systems [20]. The concept of lock-in theorises two specific mechanisms – 'increasing returns' and 'network externalities' – that account for the persistence of socio-technical regimes.

'Increasing returns' draws on the idea of 'learning by doing' [21] whereby chosen technologies get locked in because 'the more they are adopted, the more experience is gained with them, and the more they are improved' [22,116]. Arthur [22,116] thus argues that 'a technology that by chance gains an early lead in adoption may eventually "corner the market" of potential adopters, with the other technologies becoming locked out.' The significance for environmental transitions is clear, as Unruh [23,817], for example, claims that 'industrial economies have become locked into fossil fuel-based technological systems through a path-dependent process driven by technological and institutional increasing returns to scale.'

The second concept underpinning lock-in hinges on the role of network externalities and has been developed by David – though he did not use this term in his 1985 paper – with his iconic case of the QWERTY keyboard. David [24,334] argues that the history of QWERTY shows that what is now considered an inferior technology remains locked in because of '*technical interrelatedness*, *economies of scale*, and *quasi-irreversibility* of investment' (his italics). In other words, there was a strong linkage between the choice of typewriter keyboard and the expertise to type on it quickly, the more that one keyboard design dominated, the more it paid to be skilful in its use, and once such a large stock of keyboards and of people skilled in their use existed, it became increasingly hard for a competitor to gain traction.

Together, these two concepts provide a framework for understanding path-dependence, explaining how a particular technological approach can be locked-in, and others locked-out. Accounts of lock-in include the light water nuclear reactor [25], the gasoline car [26], and, of particular relevance to our case of ruminant farming, pest control in agriculture [27].

However, the classic economic explanations of lock-in take a blackboxed view of technology, neglecting the specific technological practices of the 'epistemic cultures' [28] involved. In particular, the catch-all term of 'increasing returns' (which [29] later disaggregated into 'scale economies', 'learning effects', and 'adaptive expectations') covers a range of kinds of investment, but does not sufficiently un-pick the crucial role of knowledge in socio-technical lock-in.

Shove and Walker [17] argue that practices play an important role in transitions in creating demand, but our contention is that knowledge practices are also key to the adoption of technology. We therefore propose a category of lock-in focussed on the knowledge involved in the development, diffusion and enactment of the technological practices that constrain innovation. We argue that fully understanding lock-in requires us to look at the socio-technical practices involved in <u>*both*</u> development and implementation. In particular, we will investigate the extent to which knowledge-intensive practices constrain technological choice, producing what we call *epistemic lock-in*.

Our central hypothesis is that lock-in happens in ways that are specific to the knowledge practices that prevail in a particular socio-technical regime. According to Knorr-Cetina [30,362] 'epistemic cultures can be seen as a structural feature of knowledge societies' in which knowledge can develop and be applied in local contexts rather than being universal in nature. This means that there can be 'divides between global knowledge and its expert cultures and social groups, and those areas of practice and mentality that remain local' [30,372]. Although Knorr-Cetina focuses on scientists and their practices (for