Technological and institutional 'lock-in' as a barrier to sustainable innovation

Timothy J. Foxon,
Imperial College Centre for Energy Policy and Technology (ICCEPT),
4th Floor, RSM Building,
Prince Consort Road,
London SW7 2BP, U.K.
e-mail: t.j.foxon@ic.ac.uk
Web site: http://www.iccept.ic.ac.uk

ICCEPT Working Paper, November 2002
available at http://www.iccept.ic.ac.uk/public.html

Abstract

This paper examines the role of technological and institutional 'lock-in' as a barrier to more sustainable innovation, and the implications of this for determining appropriate policy responses. It begins by reviewing the idea of lock-in, and recent work applying this concept to carbon-based energy systems. It then summarises work by the author and colleagues outlining policy instruments to promote more sustainable innovation. Finally, it introduces a new project that will analyse how to determine an appropriate mix of such instruments to overcome the current carbon lock-in.

1. Technological lock-in

Much recent work has begun to investigate 'co-evolutionary' approaches to understanding technological change, in which the development of technologies both influences and is influenced by the social, economic and cultural setting in which they develop (Rip and Kemp, 1998; Kemp, 2000). This leads to the idea that the successful innovation and take up of a new technology depends on the path of its development - so-called 'path dependency' (David, 1985), including the particular characteristics of initial markets, the institutional and regulatory factors governing its introduction and the expectations of consumers. Of particular interest is the extent to which such factors favour incumbent technologies against newcomers. Arthur and others have argued that increasing returns to adoption (positive feedback) lead to 'lock-in' of incumbent technologies, preventing the take up of potentially superior alternatives.

Arthur (1994) identified four major classes of increasing returns: *scale economies, learning effects, adaptive expectations* and *network economies.* The first of these, *scale economies*, is the well-known fact that, when a technology has large set-up or fixed costs, unit production costs decline as these as spread over increasing production volume. Thus, an existing technology often has significant 'sunk costs' from earlier investments, meaning that firms will be reluctant to invest in more sustainable alternatives. *Learning effects* act to improve products or reduce their cost as specialised skills and knowledge accumulate through production and market experience. This idea was first formulated as 'learning-by-doing' (Arrow, 1962), and subsequently, learning curves have been empirically demonstrated for a number of technologies, showing unit costs declining with cumulative production (IEA, 2000). *Adaptive expectations* arise as increasing adoption reduces uncertainty and both users and producers become increasingly confident about quality, performance and longevity of the current technology. This means that there is a lack of 'market pull' for more sustainable alternatives. *Network* or *co-ordination effects* occur when advantages accrue to agents adopting the same technologies as others. This effect is clear, for example, in telecommunications technologies, e.g. the more others that have a mobile phone or fax machine, the more it is in your advantage to have one (which is compatible). Similarly, infrastructures develop based on the attributes of existing technologies, creating a barrier to the adoption of a more sustainable technology with different attributes. Arthur (1989) showed that, in a simple model of two competing technologies, these effects can amplify small, essentially random, initial variations in market share, resulting in one technology achieving complete market dominance at the expense of the other.

It has been argued that similar types of increasing returns, leading to lock-in, apply to large technological systems, such as electricity generation or transportation systems, as well as to individual technologies. This shall be discussed below, after looking at the related issue of institutional lock-in.

2. Institutional lock-in

Institutions may be defined as any form of constraint that human beings devise to shape human interaction. These include formal constraints, such as legislation, economic rules and contracts, and informal constraints, such as social conventions and codes of behaviour. There has been much interest in the study of how institutions evolve over time, and how this creates drivers and barriers for social change, and influences economic performance. North (1990) argues that all the features identified as creating increasing returns for technologies can also be applied to institutions. New institutions often entail high set-up or fixed costs. There are significant learning effects for organisations that arise because of the opportunities provided by the institutional framework. There are co-ordination effects, directly via contracts with other organisations and indirectly by induced investment, and through the informal constraints generated. Adaptive expectations occur because increased prevalence of contracting based on a specific institutional framework reduces uncertainty about the continuation of that framework. In summary, North argues, "the interdependent web of an institutional matrix produces massive increasing returns."

Building on this work, Pierson (2000) argues that political institutions are particularly prone to increasing returns, because of four factors: the central role of *collective action*; the *high density* of institutions; the possibilities for using political authority to enhance *asymmetries of power*; and the *complexity and opacity* of politics. Collective action follows for the fact that, in politics, the consequences of an individual or organisation's actions are highly dependent on the actions of others. This means that institutions usually have high start-up costs and are subject to adaptive expectations. Furthermore, because formal institutions and public policies place extensive, legally binding constraints on behaviour, they are subject to learning, co-ordination and expectation effects, and so become difficult to change, once implemented. The allocation of political power to particular actors is also a source of positive feedback. When actors are in a position to impose rules on others, they may use this authority to generate changes in the rules (both formal institutions and public policies) so as to enhance their own power. Finally, the complexity of the goals of politics as well as the loose and diffuse links between actions and outcomes make politics inherently ambiguous and mistakes difficult to rectify. These four factors create path dependency and lock-in of particular political institutions, such as regulatory frameworks. This helps to explain significant features of institutional development: specific patterns of timing and sequence matter; a wide range of social outcomes may be possible; large consequences may result from relatively small or contingent events; particular courses of action, once introduced, can be almost impossible to reverse; and, consequently, political development is punctuated by critical moments or junctures that shape the basic contours of social life.

As modern technological systems are deeply embedded in institutional structures, these factors leading to institutional lock-in can interact with and reinforce the drivers of technological lock-in.

3. Carbon lock-in

These ideas of technological and institutional lock-in have important implications for the understanding of innovation for sustainable development, and the policy framework needed to promote this. Unruh (2000, 2002) has argued that industrial economies are in a state of *carbon lock-in* to current carbon intensive, fossil fuel-based energy systems, resulting from a process of technological and institutional co-evolution, driven by path-dependent increasing returns to scale. He introduces the notion of a *Techno-Institutional Complex* (TIC), to capture the idea that lock-in occurs through combined interactions among technological systems and governing institutions. A technological system is an inter-related set of components connected in a network that includes physical, social and informational elements. For such a system, lock-in is intensified by *network externalities* arising from systemic relations among technologies, infrastructures, interdependent industries and users. These positive externalities, which act to reinforce the dominance of the system, arise because both physical and informational networks grow in value to users as they become larger and more interconnected. In addition, institutions evolve to reinforce the technological system, both in terms of formal rules, such as regulatory structures, and informal constraints, such as codes of behaviour.

Unruh argues that current carbon-based energy and transportation systems in industrialised countries form locked-in techno-institutional complexes, hence the term carbon lock-in. The electricity generation TIC forms an example where institutional factors, driven by the desire to satisfy increasing electricity demand and a regulatory framework based on reducing unit price, feed back into expansion of the technological system, most recently by rapid building of gas-fired power stations. In the UK, regulatory drivers to promote the expansion of renewable energy, including the Non-Fossil Fuel Obligation from 1990 to 1998, and the Renewables Obligation since April 2002, have not so far been strong enough to over come this carbon lock-in (Smith and Watson, 2002). In part, this is because other institutional drivers have acted to reinforce the advantage of current large-scale centralised generators. For example, NETA (the New Electricity Trading Arrangements), introduced in April 2001, designed to correct perceived imperfections in the wholesale electricity market, has reduced prices, but also reduced the output of smaller generators, particularly renewables and CHP (DTI, 2001). In addition, connection charges are higher for decentralised generation technologies, such as micro CHP, which connect to local distribution networks, rather than national transmission systems (Ofgem, 2002). Similarly, hydrogen-based systems, which some have promoted as the long-term alternative to carbon, face regulatory barriers in terms of perceived safety concerns, and lack of incentives for companies to create the large-scale infrastructure which would be needed (Watson, 2002). In such ways, institutional factors act to reinforce the lock-in of the current carbon-based technological system.

4. Implications for policy

There appear to be two main implications for policy from the idea of technological and institutional lock-in:

(1). Existing technologies, and particularly technological systems, have benefited from a long period of increasing returns. These are reinforced by the institutional factors, which also benefit from increasing returns. Together, these can create a Techno-Institutional Complex, such as those of fossil fuel based electricity generation and transportation systems. This can act to *lock out* the development of new technologies, particularly more sustainable technologies, which have high unit costs and are yet to benefit from scale economies, learning effects, adaptive expectations and network effects.

(2). Policies that can act to promote those types of increasing returns in more sustainable technologies have the potential to stimulate the development and take up of those technologies much more rapidly than would otherwise be the case.

5. Policies for sustainable innovation

Previous work by the author and colleagues (Anderson *et al.*, 2001), drawing on the views of stakeholders from the business, policy making and academic communities, examined the role of policies in supporting environmental innovation. This outlined the importance of innovation in helping to solve environmental problems, and presented the case for policies to support such innovation. The case is that innovation provides a range of positive externalities, by creating options for substitution, mitigating against uncertainties and enabling environmental problems to be solved sooner than they would otherwise, and that policy measures can stimulate these by accelerating the natural rate of innovation. In this way, innovation can help to overcome lock-in to existing technologies or technological systems and/or lock out of emerging, more resource efficient technologies. A range of policy instruments that can drive environmental innovation were identified, including long-range targets; financial support mechanisms; public procurement; producer responsibility; innovation networks; and modernisation and transformation of infrastructures. Further work (Gross and Foxon, 2002) classified these instruments according to: how they support basic R&D; help to develop markets for innovative new products or processes; or provide financial incentives for the development or deployment of cleaner technologies (cf. papers in Hemmelskamp *et al.* (2000)).

(1). Basic R&D:

The argument for public support of basic R&D for technologies in the early stages of development is well-known, in terms of the wider social benefits that can accrue. For example, there is an accepted case for supporting early developing carbon-free technologies, such as solar photovoltaics (PV), wave energy generators, and hydrogen-powered fuel cells. Carbon-based energy sources, including oil and gas, as well as nuclear power (which is carbon-free, but faces severe waste disposal problems), have benefited from large amounts of publicly-funded R&D and other financial incentives.

(2). Market development policies:

Market development policies can help to create or stimulate markets for low-carbon technologies. 'Strategic niche management' (Rip and Kemp, 1998) involves the creation of specific market niches where new technologies can benefit from learning opportunities. These niches can be in the form of pilot projects in specific, local areas, or in particular sub-markets. For example, niche markets for electric vehicles in cities have been created through public demonstration projects (Hoogma *et al.*, 2002). To avoid the problem of 'picking winners' in advance, support could be offered in the form of prizes or secure niches for innovations that reach specified environmental standards. This type of 'back-loading' support has a long history - the most famous example being the prize offered by the British Admiralty in the 18^{th} Century for a precise way of measuring longitude at sea, which stimulated the development of the world's then most accurate clock (Sobel, 1998).

A complementary approach is to tilt or 'modulate' the market by setting long-term, outcome-based targets or obligations for cleaner technologies to gain a certain proportion of the market. Such targets should be legally or economically enforceable, and need to be set such that they are stringent enough to promote genuine innovation, but realistic enough to be believable by the market players. In order to allow maximum flexibility, it is important to allow sufficient time for innovation to occur, and for the target to classify the outcome in environmental or performance terms, without specifying particular technologies. Furthermore, by providing a clear signal of the direction of environmental policy, targets can also influence wider company expectations and technology, research, investment and marketing policies over the longer term. The most well-known example of an innovation-driving target is the California Zero Emissions Vehicle (ZEV) Mandate. This mandate, initiated in 1990, required 10% of new cars offered for sale in California in 2003 (and beyond) would have to be ZEVs. Because it was based on an environmental outcome, this has stimulated the development of hydrogen fuel cell vehicles, which produce zero emissions in use. Similarly, the UK Renewables Obligation aims to promote the take up of zero carbon electricity generation technologies. However, concerns have been expressed that, in practice, this will favour near-market technologies, such as wind, at the expense of 'next generation' technologies, such as PV (Smith and Watson, 2002). This example shows that an appropriate mix of innovation-driving policies is needed, depending on the state of the industry and the technologies.

(3). Financial incentives:
As discussed above, there is much evidence that the costs of new technologies decline over time as investment and operating experience is accumulated. This implies that, especially in the earliest phases of technology development, when the 'learning curves' are steep, each investment has two kinds of benefits:

- the direct economic and environment benefits of deploying the technology itself;
- a contribution to cost reductions and improvements in efficiency, which are felt in future investments. These are the positive externalities of 'learning-by-doing'. They reflect the contribution of each investment to future reductions in costs and the volume of future use, plus the environmental benefits arising from improvements in abatement efficiencies and cost reductions.

Financial incentives can take the form of capital subsidies, tax credits or hypothecated revenues. Capital subsidies are more appropriate for technologies that are still at the demonstration stage. For example, the UK government is providing capital subsidies for early commercial demonstration projects of offshore wind and biomass energy crops.

Tax credits, on the other hand, may be more appropriate to help overcome the barriers that prevent the take up of cost effective technology improvements. These barriers include split incentives, limited access to capital and lack or time or incentives for change, for decision-makers acting under bounded rationality (Sorrell *et al.*, 2000). Tax credits provide both a direct financial incentive and a signal to look for other cost savings. In the UK, an Enhanced Capital Allowances scheme has been set up to provide a tax credit for firms investing in specified energy efficiency technologies. Such a scheme could be widened to include a wider range of low carbon technologies.

Hypothecation involves directing some or all the revenues from standard environmental policy instruments - taxes, tradable permits and regulation - to support environmental innovation. This not only provides an additional source of revenue for innovative projects, it is also likely to increase the political acceptability of the tax or other instrument. For example, some of the revenue raised by the UK Climate Change

Levy on the business use of energy has been recycled to fund the Carbon Trust, which supports the innovation of low carbon technologies by businesses.

6. Policies to escape carbon lock-in

As described above, the UK, along with most industrialised countries, has adopted policy measures to promote the development of renewable energy and low carbon technologies, driven by concern over climate change (PIU, 2002). However, it has been argued that current carbon-based energy systems form a techno-institutional complex which is locked in, by mutually reinforcing technological and institutional factors. Current measures are not enough to put industrialised economies on the path to achieve deep cuts in carbon emissions, of the order of 60% reductions, which many argue will be necessary to achieve stabilisation of atmospheric greenhouse gas concentrations (RCEP, 2000). Thus, it is necessary to investigate how a better mix of policy instruments to promote low carbon innovation, alongside other environmental policy measures, could overcome this carbon lock-in and facilitate the path to a low carbon economy.

A project, co-ordinated by the author, under the UK ESRC Sustainable Technologies Programme (ESRC, 2002), will investigate policy drivers and barriers to the innovation of more sustainable technologies in the low carbon and waste minimisation/product policy areas. This will address five research questions, analysing and assessing the past and likely future effectiveness of UK and EU policy measures on sustainable innovation in these areas:

- How can improved theoretical understanding of the co-evolution of technologies and socio-economic systems be applied to the policy making process?
- What is the evidence for how policies in these areas have previously interacted to create drivers or barriers for the innovation of more sustainable technologies?
- What can the UK learn from the experience of other European countries in these areas?
- How can a more integrated mix of policies be developed?
- How would a more integrated policy mix promote the development and take up of more sustainable technologies?

This research will draw on and involve a network of stakeholders from the business, policy-making and academic communities. It aims to provide a framework of process guidelines to aid policy-makers to develop a more integrated mix of policy instruments to promote sustainable innovation, in order to overcome technological and institutional lock-in in the low carbon and product policy areas.

Acknowledgements

This paper is based on a paper presented at International Summer School on 'Innovation for Sustainable Development: Institutions, Incentives and Economic Policy', Seeon Monastery, Germany, 7-11 September 2002. The author would like to thank the organisers and participants of that conference for their helpful comments and suggestions.

References

Anderson, D, Clark, C, Foxon, T J, Gross, R, Jacobs, M (2001), *Innovation and the Environment: Challenges and Policy Options for the UK*, Imperial College Centre for Energy Policy and Technology & the Fabian Society, London

Arrow K (1962), The economic implications of learning by doing, *Review of Economic Studies* **29**, 155-173

Arthur, W B (1989), 'Competing technologies, increasing returns, and lock-in by historical events', *The Economic Journal* **99**, 116-131

Arthur, W B (1994), *Increasing Returns and Path Dependence in the Economy*, University of Michigan Press

David, P (1985), 'Clio and the economics of QWERTY', *American Economic Review*, 75, 332-337

Department of Trade and Industry (DTI) (2001), 'Government response to Ofgem's reports on NETA', DTI, 1 November 2001

Economic and Social Research Council (ESRC) (2002), *Sustainable Technologies Programme*, see http://www.sustainabletechnologies.ac.uk

Gross, R and Foxon, T J (2002), 'Policy support for innovation to secure improvements in resource productivity', submitted to *International Journal of Environment and Pollution*

Hemmelskamp, J., Rennings, K, and Leone, F. (eds.) (2000), *Innovation-oriented Environmental Regulation: Theoretical Approaches and Empirical Analysis*, ZEW Economic Studies 10, Physica-Verlag, Heidelberg

Hoogma, R, Kemp, R, Schot, J and Truffer, B (2002), *Experimenting for Sustainable Transport: The approach of strategic niche management*, Spon Press, London

International Energy Agency (IEA) (2000), *Experience Curves for Energy Technology Policy*, OECD, Paris

Kemp, R (2000), 'Technology and Environmental Policy: Innovation effects of past policies and suggestions for improvement', Paper presented at OECD Workshop on Innovation and Environment, Paris, June 2000 (available at http://meritbbs.unimaas.nl/rkemp/)

North, D C (1990), *Institutions, Institutional Change and Economic Performance*, Cambridge University Press

Office of Gas and Electricity Markets (Ofgem) (2002), 'Distributed generation: price controls, incentives and connection charging', Ofgem, March 2002

Performance and Innovation Unit (PIU), (2002), *The Energy Review*, UK Cabinet Office, February 2002

Pierson, P (2000), 'Increasing returns, path dependence, and the study of politics', *American Political Science Review*, Vol. 94, No.2, pp. 251- 267

Rip, A and Kemp, R (1998), 'Technological change', in *Human Choices and Climate Change, Vol. 2*, ed. S. Rayner and E.L. Malone, Battelle Press, Columbus, Ohio

Royal Commission on Environmental Pollution (RCEP) (2000), *Energy - The Changing Climate*, The Stationery Office, June 2000

Smith, A and Watson, J (2002), 'The Renewables Obligation: Can it deliver?', *Tyndall Briefing Note No. 4*, Tyndall Centre for Climate Change Research, University of East Anglia

Sobel, D (1998), *Longitude*, Fourth Estate, London

Sorrell, S *et al.* (2000), *Barriers to energy efficiency in public and private organisations*, Final Report from EC funded project, SPRU, University of Sussex

Unruh, G C (2000), 'Understanding carbon lock in', *Energy Policy* **28**, 817-830

Unruh, G C (2002), 'Escaping carbon lock in', *Energy Policy* **30**, 317-325

Watson, J (2002), 'The development of large technical systems: Implications for hydrogen', *Working paper* for hydrogen energy economy project, Tyndall Centre for Climate Change Research