Policy support for innovation to secure improvements in resource productivity

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Abstract: This paper presents the case for direct policy support for environmental innovation, aimed at improving resource productivity, as a complement to standard regulatory or market-based instruments of environmental policy. This case is that investments in environmental innovation create options, reduce uncertainties and give rise to positive externalities, i.e. wider benefits to society and future generations, thus reducing the long-term costs of tackling environmental problems. It is argued that these policy instruments can be classified 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. The paper argues that more widespread adoption of such policy instruments is needed, together with systematic analysis and assessment of their effectiveness in stimulating environmental innovation in different industries and at different stages of the innovation cycle.

Keywords: Environmental innovation; policy instruments; resource productivity; positive externalities.

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1 Introduction

This paper is based on work done by the authors for reports by Imperial College and the Fabian Society on policy support for environmental innovation [1], and by the UK Cabinet Office Performance and Innovation Unit (PIU) on developing a resource productivity framework [2]. It seeks to identify key insights and questions raised by this work for both further research and policy making. Both reports drew on the views of a wide range of stakeholders from the business, policy making and academic communities and mark a growing consensus in the UK on the importance of innovation in working towards environmental and sustainability goals. This is reflected in both positive statements from UK Government Departments [3,4] and in certain areas of policy action, notably the creation of the Carbon Trust in March 2001 with a remit to promote the innovation and take up of low carbon technologies. However, many questions remain about the nature of the innovation process itself and the most effective forms of policy support. This paper explores the basic argument for policy support for environmental innovation and seeks to clarify the key questions for researchers and policy makers.

The paper begins by distinguishing various types of innovation and aspects of the innovation process that may impact upon securing environmental improvement. It goes on to make the argument for the importance of innovation, in particular in securing radical improvements in resource productivity. The drivers and barriers to various stages within the innovation and diffusion process are then examined. Finally, conclusions are drawn on the implications for policy and the need to gain experience in the use of a range of policy instruments.

2 Defining environmental innovation

Schumpeter [5] defined three stages of the process of technological development and acceptance as *invention*, *innovation* and *diffusion*. Invention is the first demonstration of the physical feasibility of a proposed new solution. Innovation is the stage of first developing and bringing a new product or process to market. Diffusion is the stage of replication and standardisation of a technology and its successful widespread adoption. Of course, this should not be viewed as a simple linear process. A systems framework [6] is essential to take into account the social context of the process, including the motivations of the actors involved, the drivers and barriers to change created by current technological systems and regulatory frameworks and the importance of networks and feedbacks within the innovation system. Nevertheless, it is helpful to distinguish the three phases, especially because, as we shall argue, different policy instruments are likely to be important at the different stages of the overall *innovation process* (which includes the three stages of invention, innovation and diffusion.)

How should we define environmental innovation and, indeed, is it useful to classify this as a special category of innovation? It is helpful here to apply the language of resource productivity. Resource productivity is a measure of the efficiency with which the economy generates added value from the use of natural resources. Because most large-scale environmental concerns, such as climate change, focus on the impact of economic activity on environmental systems, rather than primary resource use, it is helpful to take a wide definition of natural resources. In particular, it is important to include the resource provided by the capacity of the environment to absorb waste and pollution [2]. Though it is difficult to produce a single, overarching measure of resource productivity, a number of more or less complex metrics and simple proxies have been developed. These measure economic output or value added per unit of resource use or waste produced, e.g. GDP per tonne of greenhouse gas emissions.

Evidence from the use of a wide range of resources and materials points to a similar conclusion [7]. Whilst the efficiency with which the economy uses resources has been increasing over the last decades, in most cases this rate of increase in efficiency has been less than the rate of economic growth, meaning that absolute levels of resource use and associated environmental impact have been increasing. This implies that the natural 'background' rate of innovation is not sufficient to tackle environmental problems and that incentives are necessary to increase the rate of environmentally beneficial innovation. An environmental innovation may be defined as any innovation that significantly improves resource productivity. However, environmental performance is only one driver of innovation and other drivers, particularly economic performance, may be more important. This suggests that, rather than promoting specific environmental technologies, the role of policy should be to change the framework conditions that influence economic behaviour in a way that promotes more environmentally beneficial innovation. This approach of changing the framework conditions has been referred to as a *modulation* policy [8].

In seeking to develop such a policy, it is useful to draw a distinction between *incremental* and *radical* innovation. Incremental innovation takes place within the context of a particular technological system or regime and consists mainly of improvement or redesign of current products or processes. In environmental terms, this frequently, but not necessarily, leads to relatively modest improvements in resource productivity. Radical innovation develops a new technological system or regime that performs the same function better, or performs a wider range of functions than the previous system. This has the potential to produce large improvements in resource productivity, but may not, either because the new system has similar levels of environmental impact, or because it encourages greater levels of consumption.

3 The need for environmental innovation policy

Over the last hundred years, when serious efforts have been made to address environmental problems, such as local air or water pollution, the challenge of doing so has been met. In many cases, environmental damage per unit of output has been cut dramatically through new processes and products and new ways of providing services and managing resources - that is, through innovation. In many, if not most, cases, this innovation has been stimulated by regulations, such as various Clean Air Acts, which have specified reductions in levels of pollution [9].

However, in the UK at least, a fundamental inconsistency has been identified in the current policy regime [9]. UK government policy, notably through its 1998 Competitiveness White Paper [10], recognises the importance of business and government working together to promote investment and technological innovation. At the same time, the UK government is playing a leading role, both nationally and internationally, in promoting environmental protection and sustainable development [3].

However, until very recently, these two policy areas have shown little evidence of being 'joined-up':

- *innovation policies* have placed little priority on the environment, whilst
- *environmental policies* have focussed on near-term, near-commercial 'solutions' and have neglected the development of technologies and practices of considerable economic and environmental promise in the longer term.

We are of course living in a highly innovative period of history, with rapid technological development occurring alongside profound changes relating to the liberalisation of markets and the globalisation of economic and cultural interactions. Innovative use of knowledge to create high value products and services will be central to competitive advantage and future prosperity in this new economy. However, as pointed out above, it cannot be assumed that innovation, even radical innovation, will necessarily lead to environmental improvement. Even technological systems that clearly have the potential to give rise to dramatic improvements in resource productivity, such as information and communication technology (ICT), will not necessarily do so in the absence of measures to promote such improvements [11].

Historical analysis [9] shows that there have been very considerable time lags in achieving major environmental improvements after a policy has first been announced. There are a number of reasons for this. Firstly, policies themselves are often gradualist, being constrained by the technologies available at the time. Secondly, the technologies themselves take time to develop, e.g. 25 years in the case of flue gas desulphurisation. Thirdly, even when developed, the rate at which the new technology can be substituted is limited by the turnover rate of old, polluting capital stock – which may be ten to 30 years. Fourthly, technology infrastructures, such as for transport systems and fuel supply, may shape the range and potential of individual technology options for decades – the phenomenon of 'lock-in', discussed in more detail below. Thus, although environmental regulations and taxes have in the past given rise to major innovations in pollution prevention and control, given the scale and seriousness of current environmental problems, it is arguable that the historical timescales needed for such innovation are no longer adequate.

4 Understanding environmental innovation

We shall not attempt to review the extensive literature on the causes and processes of environmental innovation (see e.g. [12–14]). However, three key aspects are important to our argument: learning or experience curves; 'induced technical change'; and path dependency or 'lock-in'.

Learning or experience curves are an expression of the empirical relationship between cumulative production levels and costs [15]. They show that the unit costs of a new technology fall with the cumulative level of production, though at a decreasing rate. Thus, in the early stages of production, unit costs fall rapidly as experience is gained. When plotted on a logarithmic scale, this relation gives the familiar straight line of the learning curve. Typical learning rates, defined as the reduction in costs for a doubling of cumulative production, are found to be between 10% and 30% for technologies in the early stages of development. However, a good theoretical explanation of the form and rate of the learning curve is still lacking.

As has been noted by many authors, technological change depends on the social, economic and policy conditions in which it occurs [16]. Conventional neo-classical economic theory has often ignored this complexity and assumed technical change to be exogenous and to occur at a constant rate. More recently, approaches to endogenise technological change are starting to be developed. For example, Grubb, Kohler and Anderson [17] have developed and analysed the concept of 'induced technical change', which depends mostly on corporate investment (R&D and learning-by-doing) in response to market conditions. This is claimed to offer a partial explanation and economic formalisation of the 'Porter Hypothesis', that environmental regulation can improve economic competitiveness by stimulating innovation that is both environmentally and economically beneficial [18]. This type of analysis suggests that the framework created by policy decisions, together with corporate expectations and actions, helps to determine the direction and rate of technological innovation.

Technological lock-in is the name given to the phenomenon in which advantages accruing to incumbent technologies act to prevent the adoption of other technologies, even if the new technology has potentially superior attributes [19]. The barriers created by the incumbent technology are often a combination of economic, technical, social and institutional factors. For example, existing technologies often have significant 'sunk costs' from earlier investments, infrastructures develop based on the attributes of existing technologies, people become familiar with known technologies and technical and environmental regulations tend to favour existing technologies against others with a different set of attributes. This concept can apply to individual technologies or to socio-technical systems, such as the current system of large, centralised electricity generation, which may be acting to lock out the development of smaller, more flexible decentralised generation.

5 The economic arguments for innovation policy

The orthodox economic case for policy intervention to tackle environmental problems rests largely on the negative externalities associated with the over-utilisation of resources (sources or sinks) that are not priced. This is right, of course, but a simplistic response that focuses only on 'getting the prices right' fails to understand the role of innovation in environmental improvement and the inherent uncertainties that surround both cost and benefit curves. In practice, particularly for long-term, scientifically uncertain, global issues such as climate change, the assumptions that the marginal cost and benefit curves are well-known and well-defined and that the 'end-point' of policy can be clearly identified, is simply wrong:

1 *The marginal benefit curves are not well known or well defined*. These curves are very difficult to estimate and the uncertainties are appreciable for most forms of pollution. For example, the EU ExternE project [20] showed large uncertainties in the estimates of the external costs relating to local and regional air pollution from electricity generation in 15 European countries. This creates great difficulty in setting the level of any environmental tax that is designed to internalise such externalities.

In practice, however, an environmental tax is usually set at a lower level, one that is judged to be politically acceptable, since the introduction of any new economic or regulatory instrument is likely to be opposed by those current actors who feel they will suffer because of it. This provides another argument for the use of instruments that directly stimulate innovation because these can provide an economic incentive for those who innovate most successfully.

2 *The marginal cost curves for future abatement are similarly uncertain*. For example, estimates of the costs of responding to climate change show a large range, depending greatly on uncertainties in the costs of technology [21]. Such research shows that the key variable for reducing costs is the rate of technology development and innovation. Thus a key policy issue is to influence the technology *pathway*, rather than attempting to assess in advance end-point abatement costs.

None of this undermines the general economic principle that unpriced resources, in particular environmental 'sinks', are a source of market failure that needs to be rectified by a tax, market-based instrument or a regulation. However, there are appreciable benefits from policies that create options and enable environmental problems to be solved sooner rather than later. Given the uncertainties and the high economic burden of 'getting the price right' at today's costs, such policies are also likely to be more politically acceptable than taxes alone. Because they accelerate the development of key technologies they also augment and complement tradable permit schemes, facilitating more ambitious targets within such schemes.

The case being made is that an appropriate policy mix should use a combination of standard instruments of regulation or market-based instruments to internalise costs, together with instruments to support innovation directly. The case is three-fold:

1 *The positive externalities of innovation*. Innovations are successfully taken up only if they reduce costs or raise productivity or create possibilities that did not previously exist. In doing so, they also provide opportunities and sources of productivity gain to future generations and so have a positive externality. In these respects, environmental innovations are no different to other innovations. The additional feature of environmental innovation is that, by creating options and reducing costs, it also enables environmental problems to be solved sooner and thus increases the environmental benefits.

2 *Uncertainty and risk and the need to explore options*. Because uncertainties and risks associated with environmental problems are large, there is a value to policies that create or bring forward options that would not otherwise exist, so helping to overcome 'lock in' to existing technologies and/or 'lock out' of emerging, more resource efficient techniques. This is called the option value of a policy, which can only be realised through investment and operating experience.

3 *The high costs of abatement and inelasticities of demand and supply response in the absence of alternatives*. In many instances, short-term abatement costs can be extremely high. Carbon taxes, for example, would have to rise to politically unacceptable and possibly economically damaging level before having a significant impact on carbon emissions. This is because near term energy demands and supply responses are inelastic. This means that, whilst in the short term, environmental taxes raise revenues and often create resentment in the process, they may have limited

immediate impact on environmental problems. Over the longer term, products and infrastructures do change in response to price signals. Accelerating the development of environmentally improved technologies will enable substitution to take place earlier and at lower cost.

The argument for direct support for environmental and resource productive innovation is thus that it complements the standard instruments of environmental policy: by giving rise to positive externalities, which lower the long-term costs for substituting less environmentally damaging alternatives and by reducing uncertainties and creating options.

6 The role for environmental innovation policy

The importance of business and government working together to promote investment and technological innovation was recognised in the UK in the 1998 Competitiveness White Paper [10], which defined government's role to be:

- to invest in capabilities to promote enterprise and stimulate innovation
- to catalyse collaboration to help business win competitive advantage
- to promote competition by opening and modernising markets

However, the role of innovation in stimulating environmental improvement was not given priority. Similarly, the 2000 UK Science and Innovation White Paper [22] provided generous support for research in key new areas "that will shape life in the 21st century: genomics, e-science and basic technology such as nanotechnology, quantum computing and bio-engineering", whilst largely ignoring the potential and importance of environmental technology.

More recently, UK policy has begun to provide explicit support for environmental and resource productive innovation in the energy sector [23]. In April 2001, a Climate Change Levy was introduced on the business use of energy and roughly 10% of the funds raised are being directed to support the development and take-up of low carbon technologies through a new Carbon Trust (the remainder going to reduce labour taxes.) In addition, capital grants are being made available to support development of particular technologies, notably offshore wind and biomass energy crops and a tax credit introduced in the form of Enhanced Capital Allowances for investments in specified energy saving technologies and practices. Furthermore, the Renewables Obligation, introduced in April 2002, imposing annually increasing requirements on electricity suppliers to purchase a set percentage of electricity from renewably generated sources, subject to a price cap, aims to stimulate the deployment of renewable generation by creating a guaranteed market.

However, such support still focuses primarily on near-commercial technologies most readily applicable in the near-term. While such support is a necessary aspect of innovation policy, it has three limitations:

- in the absence of other measures, technologies and equipment may be imported from other countries that provide incentives for earlier phases of the technology development cycle

- technologies of much promise in the long term, but which are still high on the learning (cost) curve, may be neglected
- some technologies with large potential may be neglected, because the complexity of the innovation process and the network of actors and agents involved are not taken into account

The problem of innovation policy neglecting environmental issues and environmental policy neglecting the potential for innovation has resulted in a 'missing middle' in UK policy. The science base has given rise to much innovation within the public R&D phase, for example, on thin-film photovoltaics, wave energy and fuel cell materials technologies. However, such projects often founder at the pre-commercial stage because deployment and development policy has been either too small in scale, or oriented to the very near commercial. Potential for public/private collaboration, publicly supported technology clusters and 'spin outs' has so far been less utilised for environmental technologies than in other technology areas. This has resulted in UK innovations being exploited more successfully in other countries and cleaner technologies developed overseas being imported into the UK.

7 Future policies and assessment

We are thus arguing for the application of a wider range of policy instruments to support environmental innovation. No single instrument will provide 'the answer' and finding the right mix of policies is the key. This will require a willingness to test different instruments, for example with pilot projects and research to assess the individual and cumulative success of instruments. Different instruments are better suited to different aspects of the innovation process and perform different roles. There are three basic types of instrument:

1. *Basic R&D* – this is crucial to support the earliest phase of the development of a technology from an idea to a physically feasible solution.
2. *Market development policies* – these aim to create markets for innovative new products or processes.
3. *Financial incentives* – these provide 'carrots' for firms investing in the development or deployment of cleaner technologies.

We examine each in turn.

7.1 Basic R&D

The argument for public support of basic R&D is well known, in terms of the wider social benefits that can accrue. Applying an evolutionary metaphor [24,25], R&D helps to create the variation in new technological options, providing the raw material from which successful technologies can be selected. In particular, it has been argued that the UK is likely to suffer economically due to its relatively low level of support for energy R&D [26].

7.2 Market development policies

7.2.1 Strategic niche management

Policies can either aim to create specific market niches where new technologies can benefit from learning opportunities, so-called ‘strategic niche management’ [16], or to tilt an existing market in favour of cleaner technology options. Strategic market niches can either be in the form of pilot projects in specific, local areas, or in particular sub-markets. One way of doing the latter is through public procurement programmes, which may be used in several ways. The most familiar one is the purchase of ‘best-practice’ technologies or their outputs, perhaps with a small premium for near commercial solutions. Public procurement may also be used to support a number of small-scale demonstration projects, for example in schools or public bodies. In each case, this helps to provide a secure niche and gain the benefits of ‘learning-by-doing’.

7.2.2 Back-loading support

Public procurement may also be used as a form of ‘back-loading’ support for innovation. This would aim to avoid the problem of ‘picking winners’, by offering prizes for innovative technologies that secure particular environmental objectives. Though a prize could be financial, the reward could be in the form of a guaranteed niche market for the technology. Such a policy would provide a high profile launch pad for innovation. This type of prize has a long history - the most famous example being the prize offered by the British Admiralty in the 18th Century for a precise way of measuring longitude at sea, which stimulated the development of the world’s then most accurate clock [27].

7.2.3 Long-range targets and obligations

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. (An unrealistic target is likely to be ignored by market players, in the belief that regulators will change it if it is not going to be met.) In order to allow maximum flexibility, it is important to allow sufficient time for innovation to come on stream 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 development, 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 Mandate. This was initiated by the California Air Resources Board (CARB) in 1990 to stimulate the development of zero emissions vehicles (ZEVs): cars, trucks and buses that produce no tailpipe or evaporative emissions. The Board adopted a requirement that 10% of the new cars offered for sale in California in 2003 (and beyond) would have to be ZEVs. It is significant that, because the mandate was based on an environmental outcome, it has succeeded in stimulating the development of hydrogen fuel cell powered vehicles, because these have better performance characteristics than battery-powered vehicles (the original target of the mandate).

In April 2002, the UK introduced the Renewables Obligation, designed to stimulate the development and take-up of zero carbon technologies. This is an obligation on electricity suppliers to supply an annually increasing proportion of their electricity from renewable sources, subject to a maximum price excess over other sources, reaching 10% of renewably sourced electricity by 2010. This aims to create a market for renewable sources such as onshore and offshore wind and biomass energy crops. One of the advantages of such an obligation is that it minimises administrative costs, compared, for example, to the costs of collection of a tax. However, concerns have been expressed that, because the Obligation creates a single market in renewables, it may fail to stimulate innovation in 'next generation' technologies, such as wave power and photovoltaics [28]. The aim of such long-term obligations is always to bring the cost of the cleaner technologies down so that they become competitive in self-sustaining markets.

7.3 Financial incentives

As discussed in Section 4, 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 environmental 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.

7.3.1 Capital subsidies

Such incentives can either be in the form of direct subsidies, or as tax credits. Capital subsidies are more appropriate for technologies that are still at the demonstration phase. For example, the UK Government is providing capital subsidies for early commercial demonstration projects of offshore wind and biomass energy crops. Again, these aim to provide a learning experience that will improve confidence and help reduce future costs towards the point where projects can proceed without additional financial support, in the market modulated by the Renewables Obligation.

7.3.2 Tax credits

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 of time or incentives for change [29]. Split incentives, the generalisation of the tenant/landlord problem, occur whenever the actor responsible for investment (for example, the landlord of a property) is different from the actor who would gain the cost-saving resulting from the investment (for example, the tenant). Lack of time or incentives for change typically occur when resource costs are a small proportion of total costs and so decision makers, acting under bounded rationality, ignore potential cost savings in this area. 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.

7.3.3 Hypothecation of revenues

As described above, financial measures to support innovation should be used alongside the standard instruments of environmental policy – taxes, tradable permits and regulation. In addition, some or all of the revenues raised from standard instruments can be directed to support environmental innovation – so-called 'hypothecation'. This not only provides an additional source of revenue for environmental innovation projects, it is also likely to increase the political acceptability of the tax or other instrument – for example, the recycling of funding raised by the UK Climate Change Levy back to businesses to support innovation of low carbon technologies, via the Carbon Trust.

7.3.4 New financing institutions

Another aspect of financial incentives is the institutional structures by which these are delivered. A single national environmental facility, modelled on the Global Environmental Facility (GEF, the financing arm of the UN Framework Convention on Climate Change), could provide a central mechanism for managing public support for environmental innovation and a means of levering matching or greater private investment.

8 Conclusions

This paper has set out the case for policy support for environmental innovation, aiming to stimulate the development of technologies and practices that have the potential for radical improvements in resource productivity. A large array of policy instruments is available and, as we have seen, some of these are beginning to be adopted in the UK, as in other countries.

We argue that what is needed now is more widespread adoption of such policy instruments, together with systematic analysis and assessment of their effectiveness in stimulating innovation in different industries and at different stages of the innovation cycle. This would apply the principle of 'learning-by-doing' to the policy instruments themselves, as well as to the technologies and practices that they are helping to stimulate. In this way, an appropriate mix of policy instruments may be developed which could accelerate improvements in resource productivity, so as to help reduce environmental impacts to more sustainable levels.

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