Cleaner technology and technology transfer: a critique of the linear model

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Abstract

Cleaner technology is central to sustainable development. It has the potential, at least in some industries, to reduce environmental impacts whilst enabling economic growth. Indeed, cleaner technology can be seen as resource efficiency, enabling firms to become both cleaner and more competitive at the same time. In contrast, conventional ('end-of-pipe') treatment imposes costs on society which undermine the goal of sustainability.

To date, too much of the policy agenda on environmental action has been dominated by a linear model of technology transfer which fails to understand how industrial innovation actually occurs. In this model the implementation of cleaner technology is seen as being driven by scientific advances and high technology solutions which are then transferred into firms. In practice, however, most innovation in cleaner technology is not 'high-tech' - it may not even be 'technology' at all, as narrowly defined, when, for example, it involves finding a new market for what was previously considered a waste product. Moreover, much of the innovation required is necessarily specific to the firm and its situation. 'Technology transfer' can be an important source of ideas, techniques and equipment, but rarely can a 'black-boxed' solution be simply adopted from an external source.

In practice, much cleaner technology involves incremental use of existing knowledge rather than new inventions. This means radical social and organisational change, not radical scientific and technical change. How, and why, firms innovate is thus central to improving the adoption of cleaner technology. Firms are typically resistant to change, no matter how beneficial it may be in the longer term, and organisational inertia is a major barrier to the implementation of cleaner technology. Policy measures need to take account of the limits of technology transfer in the industrial application of cleaner technology. This cannot be driven by external R&D; it must instead primarily be stimulated in situ (by the correct mixture of compulsion, encouragement, and expertise provision).

Introduction

Cleaner technology is typically defined by contrasting it to end-of-pipe effluent treatment. Instead of simply adding end-of-pipe treatment to an industrial process, cleaner technology would involve changing the industrial process so as to minimise waste at source. Put simply, cleaner technology means pollution prevention rather than pollution treatment. A broad definition of cleaner technology given by the UK Department of Trade and Industry (DTI) was a technology which 'focuses on reducing demand for raw material and energy and on the <u>prevention</u> as distinct from the treatment or disposal, of pollution and other wastes' (ACOST, 1992).

Cleaner technology is seen as better than end-of-pipe effluent treatment for two main reasons. First, end-of-pipe treatment may often shift the waste from one medium (say, liquid discharges) into another (say, solids which go to landfill). Second, cleaner technology is presumed to involve more efficient use of resources - including energy and water - as well as waste minimisation. It is therefore likely not only to be good for the environment, but also financially advantageous for the firm.

Cleaner Technology as a Technical Fix

To some, cleaner technology has come to mean radical process innovation, whereby the same product can be made, but with less resource use and waste production. According to this definition, cleaner technology is different not just from end-of-pipe treatment, but also from incremental waste minimisation measures. New technology is seen as necessary, and the policy implications are that it is thought that public funded R&D can generate such new technical solutions which will then be adopted in industry.

For example, a 1993 statement of UK policy by the Department of Trade and Industry (DTI), noted the value of waste prevention, but then went on to say that the DTI 'recognises that there is a limit to simple prevention and so, concurrently, it is pushing the need for cleaner technologies'. These cleaner technologies, according to the DTI, take the form of generic technical solutions or 'hub technologies'. Clearly, cleaner technology is seen by the DTI to refer to discrete 'high-tech' approaches - technical fixes which, once developed, can be transferred into industry.

The attraction of this conception of cleaner technology lies in the idea that these cleaner techniques or pieces of hardware can be developed as 'black boxes' and then inserted into existing industrial processes. This focus on applying technical fixes to industrial processes provides a clear model for implementation driven by R&D.

One problem with the emphasis on hub technologies providing generic solutions is the simple model of technology transfer involved. The idea that hub technologies can be developed, and packaged into easily adaptable black boxes, is appealing because it suggests painless integration of these solutions into existing industrial process. However, there has been little evidence to date of the implementation of such cleaner technologies.

One problem is that high-technology solutions emerging from public R&D may be far removed from the current circumstances and requirements of firms. For example they may require substantial investment in replacing equipment or retraining in new operating principles. The evidence from studies of innovation is that such radical new technologies may typically require protracted technological innovation (for example in series of complementary technologies needed to get them to work) as well as institutional change (e.g. acquisition of new bodies of expertise).

Cleaner technology in the real world

In contrast with this R&D driven, science-based view of cleaner technology, most of the cases found in our EC project involved more mundane, local innovation. Where outside expertise was helpful, it was typically in the form of general conceptual suggestions rather than black-boxed technical solutions. By its very nature, cleaner technology depends on process-specific innovation rather than blanket solutions. Although general principles may apply widely, the detailed implementation of these principles will depend on their application by the people (particularly, managers and process engineers) with specific knowledge of a firm's processes.

A broader view of cleaner technology encompasses all potential ways of reducing waste - including not just radical new technologies, but also more modest technological changes. In the short-term at least, the latter may offer most significant sources of environmental improvement.

In practice, implementing a cleaner technology approach need require little more than changes in techniques and working practices. For example, a cheese manufacturer was able to address part of its effluent problems by introducing a number of measures to reduce the amount of cheese wasted throughout the factory. This was being washed into the drains, leading to both high sewage charges and complaints from the regulator (in this case the local Council). What quickly became clear was that the savings in lost product were even greater than reductions in sewage charges. Instead of spending tens of thousands of pounds to build a treatment plant, the company found that a programme of waste minimisation was saving it hundreds of thousands of pounds per year in lost cheese. This involved a variety of relatively modest and localised changes in working practices and adjustments to plant (e.g. fitting sieves to trap waste) rather than a radical change in plant and manufacturing processes. These responses were not 'high-technology', but were very effective as moves to cleaner technology. In many of our case-studies some of the most important environmental improvements have been achieved by this kind of incremental programme of relatively modest changes.

Another limitation of a narrow view of cleaner technology is the focus on improvements <u>within the firm</u>, with the emphasis on reducing waste rather than treating it. However, restricting the search for cleaner technology to process innovation within firms fails to encompass the full range of ways that industrial processes can (and probably need to) be reshaped to improve environmental performance. First, focusing simply on process innovation to improve 'eco-efficiency' ignores the more fundamental issue of changing patterns of consumption and lifestyles in order to move towards a more ecologically sustainable industrial system. Second, and perhaps more pragmatically, such narrow definitions of cleaner technology exclude many important potential sources of environmental improvement which may be available if we address the entire life-cycle of a product, from the extraction of materials, through production to consumption and disposal.

Although valuable, there is a limit to how much reduction in environmental degradation can be gained from cleaner technology which seeks only to improve waste minimisation within the context of making the same products. At the very least, cleaner technology needs to encompass product innovation, asking not just whether the same products can be made with less resource use, but whether products can be modified or substituted for further environmental gain. For example products could be changed to reduce their utilisation of scarce or non-renewable resources, or to allow materials used to be re-cycled.

Further than this, is the possibility that sustainable development may require more profound changes in lifestyles and societal organisation. For example, cleaner technology as now widely defined would seek to reduce the resources used (including through pollution) by introducing process innovations in car manufacturing. A more radical application of the concept might seek instead to change the nature of cars produced, including perhaps a move to electrical power, as well as lightweight materials. However, even a the development of new types of 'cleaner cars' may not by itself be sufficient to address some of the fundamental environmental concerns about the sustainability of transport systems. What might really be needed is to tackle the level of car use, which in turn relates not only to the availability and quality of public transport, but also to work and recreation patterns, urban design, and so on. To simply apply the concept of cleaner technology to production of existing car types might offer some immediate environmental gains, but at the expense of masking the more fundamental issues which will eventually need to be addressed.

The second problem with the tendency to focus on cleaner technology as process innovation is that this narrow vision does not take full account of the potential for recycling and re-use of materials. Definitions of cleaner technology usually encompass recycling/re-use within an industrial process or 'on-site recycling' (see, for example, ACOST, 1992, 36). However, to limit the search for recycling to re-use within a firm is perhaps rather arbitrary; end-of-pipe waste may be unavoidable in some industries, and may not be in conflict with sustainability. Rather than focusing on the firm as the level for environmental control, it is argued, we should take a broader view of 'industrial ecology' (Frosch, 1995) in which one company's waste stream could be another's feed stock.

This view of cleaner technology therefore involves the use of Life-Cycle Analysis to go beyond the level of any particular industrial process and to develop Cleaner Production Systems. For example, what was formerly seen as a waste/by-product could be redesigned to enhance recycling/re-use. A traditional way to do this would be to co-locate another industry which the waste would feed into. One traditional example is the use of spent hops and barley from brewing as animal feedstock (this dates back to the 19th century when brewing wastes were used to feed urban dairy herds, before transport systems were sufficiently developed to remove these wastes from the city - and bring in milk from the country).

This example forces us to reconsider what counts as 'waste'. In economic terms any process streams which produce something that cannot be sold are waste streams. For example, oil refining involves splitting the crude oil into a range of products, and it makes both financial and environmental sense to do this as efficiently as possible. The exact range of products produced varies from one refinery to another, depending not just on the composition of the crude oil, but also on the technology used to convert low value hydrocarbons into higher value ones. However, crude oil also contains sulphur which must be removed from these products (because of environmental legislation of the products). Whether this sulphur then constitutes a waste product or a by-product depends entirely on its market price or on the proximity of another industrial process to which it could be fed.

Consideration of industrial ecology and the potential value of waste can thus blur the distinction made at the outset between end-of-pipe and cleaner technologies. Many end-of-pipe treatment plants produce biomass in one form or another: sometimes simply settled out from a waste stream; more typically in the form of a sludge from biological treatment. Where there is no viable alternative but to pay to send this biomass to landfill then it must be considered waste. However, in many instances it may be possible to recycle the biomass as animal feed or agricultural fertiliser. Whether such recycling is financially viable or environmentally desirable will depend in large part on the potential to avoid significant transport costs by co-location of complementary industries.

Clean equals efficient?

At the heart of the 'pollution prevention pays' axiom is the potential for financial savings through the use of cleaner technology. These savings can arise in two main ways. First, the cost of waste treatment can be eliminated or reduced if less or no waste is produced. Often, the cost of implementing waste minimisation at source will be exceeded by the savings in treatment costs, thus producing an overall financial benefit to the firm. Second, in many instances at least part of the waste which requires treatment will consist of lost product or other valuable process materials. Less product or process materials lost into the waste stream not only means less need for treatment, but also more product that can be sold, or less materials that need to be purchased.

Many cleaner technology developments may thus occur as a result of attempts to improve process efficiency rather because of environmental concerns. A survey of cleaner technology in the UK noted that:

> Where activity in cleaner approaches has been found, the environmental benefits are rarely either the motivating force *or recognised* by the developer. The aim is usually to reduce the costs associated with energy and raw materials use and the disposal or treatment of wastes (PA Consulting Group, 1991, p. 5).

To a large extent, then, cleaner technology can be equated with the efficiency of industrial processes. For example, putting aside broader doubts about the long-term sustainability of petrochemical use, much of the potential for cleaner refineries relies on use of the most efficient plant and practices to split the crude oil into saleable products with the least losses to the environment. Eliminating hydrocarbon losses means more product, as well as reducing the need for end-of-pipe treatment of oil-contaminated waste streams.

Not all environmental improvements offer such savings, but many do, and yet go untapped. If helping the environment can also be good for 'the bottom line', why do firms fail to achieve such efficiency gains? Mostly, it seems, the problem lies in organisational inertia which ensures that firms tend to carry on what they have done before unless subjected to a sudden shock.

Contrary to classical economic theory firms do not maximise their profits; instead they 'satisfice' - content to follow a routine set of practices so long as profits are satisfactory. The various local actors within firms are subject to 'bounded rationality' with only partial knowledge and limited perspectives of the world they operate in. Decision-making is thus rooted in the firm's traditional culture, which will have evolved along with the industrial processes - typically dating from a time when environmental concerns and regulatory pressures were not significant.

Wasteful practices have often become a way of life, not simply because the environmental and resource costs were not significant, but because firm culture and management focus were directed to other goals. For example, if no-one in a firm has specific responsibility to reduce energy costs or minimise waste than nothing may be done despite the obvious gains in profitability which are being missed. Economic rationality would point to the need for action, but the reality is that, although the firm's profit would benefit, no individual or group within the firm has any particular reason to act.

What is often required is not technical innovation as such, but rather organisational and managerial innovation. In itself, increased environmental responsibility within a firm does not guarantee the implementation of cleaner technology. In particular, where a firm has already invested in end-of-pipe solutions (for example a waste-water treatment plant) this may act as a disincentive for the search for cleaner solutions. It provides a predictable way of dealing with environmental emissions. Moreover it provides a solution which can be implemented without transforming existing production processes and methods of operation. End-of-pipe solutions are both technologically and organisationally easier in that they constitute 'add-ons', both to the firm's existing industrial plant and to the firm's existing organisational culture. A new piece of hardware - a treatment plant - is added, and with it, a new, or up-graded, organisational unit is charged with environmental responsibility. Fundamental change of the industrial process and of the firm organisation is thus avoided. Having once invested in acquiring the expertise for end-of-pipe treatment a firm is more likely to look to the specialist group responsible for future environmental solutions - and this group may (depending on its internal expertise resources, its culture and links to other players) may be satisfied to restrict the scope of its search for solutions to the established end-of-pipe approaches that it is expert in.

Even where firms do recognise that they could conduct their operations in a more efficient (and cleaner) manner there may be limits to how easily or quickly change can be implemented. In some cases there is a limit to how much cleaner the process can be made without replacing the whole of the plant from scratch. In practice, of course, there is a limit to how much capital a firm can invest in new plant at any one time, investment will typically occur in long time cycles, and fluctuations in profitability will influence the exact timing of capital spend.[1] This concern was noted in the ACOST report (ACOST, 1992, p. 11):

> end-of-pipe solutions are likely to be preferred by companies required to upgrade the environmental performance of existing plant before it had reached the end of its economic life. The lifetime which companies require of their plant investment will therefore be crucial in determining whether they opt for end-of-pipe or cleaner technology.

The organisational culture of firms will tend to reflect their traditional practices, practices which have developed to match the particular needs of a firm, and in turn will pattern approaches to future innovation. These practices will be focused on the core business of the firm, reflecting both its size and the nature of its industrial endeavour. Traditionally, however, environmental impacts could usually be externalised, and thus would not be amongst the central practices of a firm.

Technology transfer and the fallacy of the linear model

Simply put, 'the linear model' suggests a one-way flow from science to technology, and from basic R&D to exploitation. In this model, knowledge developed by scientists would lead to new advances in technology which would then be exploited commercially, all of this with a certain inevitability. In fact, science and technology studies have shown that although science and technology are related activities, and each draws on the other in many instances, neither is totally dependent on the other. Much new technology actually precedes scientific

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[1]. However, in other cases lack of capital may force companies to address environmental concerns by more innovative means than simply adding an end-of-pipe treatment plant to the existing process. If the company cannot afford a waste treatment plant or if increased production threatens to exceed the capacity of an existing plant, then the attention may shift to ways of reducing waste production.

knowledge, depending more on the experience and skills of the practitioners, on 'tacit' rather than explicit knowledge.

Moreover, just as not all science leads to technology, so not all new technology leads to commercial exploitation. Some inventions are exploited very successfully, but many other - apparently equally good - inventions remain footnotes in history. Technological success depends not on the inherent quality of the invention, but on how that invention is taken up and developed.

There may be important advances in cleaner technology originating in R&D in universities and research establishments, but most firms will be unaware of such advances, and probably unable to implement them practically in their own production processes. Many firms (especially SMEs) do not have enough time and expertise to access such outside sources of knowledge. Moreover, unless the new inventions are further developed commercially (by a supplier of production equipment) they may require too much further work to be implemented. Most firms could instead gain improvements in efficiency and environmental performance through the application of existing knowledge.

Rather than focusing on 'high-tech' solutions to environmental problems, the policy agenda should address the ways in which firms can be jolted out the organisational inertia which prevents them from realising broader types of cleaner technology. Innovation needs to be stimulated in firms by use of pragmatic tools which combine compulsion, persuasion and advice.

Regulation obviously remains an important method of effecting environmental improvements, although care needs to be taken to ensure that it does not favour end-of-pipe solutions. Because cleaner technology approaches are more novel, and typically specific to particular production processes, they may be seen as unable to guarantee a particular reduction in effluent within a short time. Where possible, therefore, regulators need to allow some flexibility, especially if costly replacement of plant is needed for a cleaner solution. One such flexible regulatory approach is to impose waste charges which thus make the costs of inefficient production processes more obvious to the firm.

Improving knowledge flows is also important and regulators can be a very important source of advice, especially for small firms. General campaigns to alert industry to cleaner technology seem to have had only limited success, but so long as the relationship is not too confrontational regulators can play a more specific role. Industry bodies can also be important conduits for knowledge flows because they are seen as closer to the firms' interests and more trustworthy than environmental consultants or university-based programmes.

Implementation of cleaner technology depends on the firm's capacity for innovation; at the same time, the ability to innovate is central to the firm's competitiveness. As discussed above, cleaner innovation can encompass a range of solutions, including small changes in working practices, the introduction of radically different process technologies, and redesign of wider production systems. The common thread linking all these cleaner solutions is not just that they improve environmental impacts, but also that they are more efficient in the use of resources, and will therefore (although perhaps not immediately) be financially beneficial to the firm. Better coupling between environmental protection and resource use can, as argued by Porter and van der Linde (1995), stimulate innovation and result in improved industrial competitiveness:

> Properly designed environmental standards can trigger innovations that lower the total cost of a product or improve its value. Such innovations allow companies to use a range of inputs more productively - from raw materials to energy to labor - thus offsetting the costs of improving environmental impact and ending the stalemate. Ultimately, this enhanced *resource productivity* makes companies more competitive, not less.

Conclusion

Cleaner technology can be understood as an alternative paradigm to end-of-pipe waste treatment. Cleaner technology seeks ways of reducing the overall environmental impact, and in the context of an industrial process, this can often be done by reducing the need for waste treatment. In some cases, 'waste' can be redefined as a useful by-product, but more typically cleaner technology involves changes in production processes so as to produce less waste.

It is a mistake, however, to view cleaner technology as comprising discrete alternative technical solutions to end-of-pipe waste treatment plants. Typically, cleaner technology cannot be simply slotted into an existing production process in the way that a waste treatment plant can. Instead, cleaner technology requires a fundamental reappraisal of the production process. Sometimes new 'state-of-the-art' hardware will be an important element of this process redesign, but more often than not cleaner technology can be implemented by innovative use of existing knowledge.

The barriers to cleaner technology are thus usually 'social', rather than 'technical'. Organisational inertia means that firms continue to ignore wasteful practices, even when this means lost product or higher waste disposal charges. Government can thus play a role in stimulating cleaner technology, but not, at least not primarily, by supporting public sector R&D. Much more important, at least in the short term, is the role of regulatory agencies and industry bodies in alerting firms to their own potential for production process innovation. Although R&D in universities and research establishments should continue to receive support, it should not be expected that promising inventions will inevitably 'diffuse' into industry, or that such inventions constitute the main way of achieving cleaner technology.

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