# The Innovation Effects of Environmental Policy Instruments

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## 1 Introduction

The importance of the environmental policy framework in bringing about a technological trajectory which is less environmentally damaging has been noted. Indeed, as far back as the mid-1970s it was pointed out that "over the long haul, perhaps the most important single criterion on which to judge environmental policies is the extent to which they spur new technology towards the efficient conservation of environmental quality." (Kneese and Schultz 1975).

In this report some of the theory and evidence about the innovation effects of standard environmental policy prescriptions - whether they be economic instruments (emission taxes, tradable permits), direct forms of regulation (performance standards, emission limits, technology-based standards) or non-mandatory measures (voluntary agreements, information schemes) - will be reviewed.

In particular it will be argued that rather too much attention has been focussed on the effects of different instruments on the rate of innovation and rather too little on the direction of innovation. In particular, the report will review the implications of a number of factors which complicate the assessment of the innovation effects of different instruments: missing markets for certain environmental attributes of innovation; technological market failures; the point of incidence of the environmental policy; and, the existence of joint production of emissions.

The issue of direction is particularly important as it is arguably much easier for a policymaker to increase the rate of innovation, than it is to ensure that it is directed in the socially optimal manner - i.e. in a manner which is cost-minimising with respect to the attainment of a particular environmental objective in the long run. For various reasons government efforts to encourage innovation may succeed in increasing the rate of change, but in a manner which is not optimal with respect to the direction. As recent work on "lock-in" and network externalities has shown, the long-run costs of "misdirection" of the direction of innovation can be considerable.

## 2 The "orthodox" view of the innovation effects of alternative environmental policy instruments

Different policy instruments will affect the incentives for firms and households to develop and adopt environmentally-beneficial technologies in different ways; taxes and permits will affect the relative price of different factor inputs, encouraging firms to save on those factors which are closely linked to environmental damages; performance standards will place binding quantitative limits on the use of particular inputs or generation of particular emissions; technology standards or input bans will directly constrain the choice of technologies which can be used; and, information-based measures will affect the firm or household's perceptions of the relative merits of alternative choices of production processes or product design.

Much of the theoretical literature in this area concerns a comparison of market-based instruments relative to direct forms of regulation. While the case for market-based instruments (taxes, permits, deposit-refund schemes, etc....) relative to direct regulation (technology-based controls, performance standards, input bans, etc.....) has usually been made in static terms, at the theoretical level it is thought that the case is even more convincing when the dynamic effects in terms of technological innovation are examined. In particular, it is argued that the rate of change is more likely to be optimal since a greater proportion of benefits of technological innovation and adoption are realised by the firm itself under market-based instruments than is the case for many direct forms of regulation. Moreover, since market-based instruments are not "prescriptive" they are more likely than many types of direct regulation to ensure that the direction of technological change is cost-minimising with respect to the avoidance of damages (see Downing and White 1986; Milliman and Prince 1989; Nentjes and Wiserman 1987; Jung et al. 1996).

This stark juxtaposition of the technological effects of market-based instruments and more direct forms of regulation is somewhat of a caricature. In the first instance, it is clear that there are important differences between types of direct regulation. For instance, while a technology-based standard will provide little incentive to innovate, a performance-based measure will provide strong incentives for innovation and diffusion of technologies which achieve given environmental standards at lower financial cost[1]. In effect, under a technology-based regime, the potential innovator faces both

1 Although incentives will still be less than under most market-based instruments, since savings will only arise up to the point at which the standard is met.

a commercial risk and a regulatory risk, while under a performance-based regime only the former risk is important. Thus, unless the innovator believes that through innovation it can bring about a change in standards, firms will be less likely to innovate under technology-based systems[2].

However, the difference between the two can be overstated since in practice many performance-based standards are equivalent to technology-based standards, with the regulator only granting permits to particular technologies. Moreover, even if the regulator permits without delay all technologies which meet the performance standard, those technologies which are potentially more efficient (environmentally and financially) in the medium-run or long-run will still have zero share of the market until they meet the prescribed standard. (see Environmental Law Institute (1998) for some American examples). This vastly increases start-up costs and prevents supplier-user interactions which usually cut down development costs overall.

An input ban (or the prospect of such a ban) can provide a very important spur to the development of substitute materials. This case is often made with reference to the ban on CFCs in order to reduce stratospheric ozone depletion (see Ashford et al. 1985 and Kemp 1997 for discussions). It is clear that this did result in innovation. However, it is not clear that either the rate or direction of such innovation was optimal. Firstly, as with technology-based standards – and unlike market-based measures - the effect is a discrete, once-and-for-all event. Further incentives for future innovations which further reduce adverse environmental impacts are only provided if additional input bans or regulations are introduced in due course. With fewer incentives for firms to innovate, the regulatory authorities are less likely to force such a change since the costs will appear to be considerably higher than under a system where continuous incentives for technological development are in place. Secondly, the ban does not provide any incentives for firms to develop and adopt the most environmentally-beneficial substitute technologies, but merely to discontinue using the banned substance. A tax on ozone-depleting potential (ODP) would not have resulted in as much take-up of HCFC's which, while preferable to CFC's, still have a high ODP.

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[2] In fact, under very specific conditions, if rules are technology-based, the incentive for the innovator would be greater if the firm is certain that it will generate a rule change. This arises since the innovator's rents are protected by the patent (as under alternative policies) and the market is guaranteed by the rule (unlike under alternative policies). However, this seems unlikely and the innovating firm would face considerable risk in undertaking the necessary investments.

Analogously, different forms of market-based instrument may have different effects on the technological trajectory of the economy. For equivalent environmental targets, auctioned permits and taxes tend to have comparable effects. However, if policy targets are not adjusted in light of increased information then the effects may differ markedly since one is a price-based measure and the other is a quantity-based measure. Thus, Jung et al. (1996) find that when governments pre-commit to a given tax rate or alternatively pre-commit to a given number of permits, the effect under the two regimes will differ since in the case of taxes the "price" of emissions remains constant even as innovation reduces abatement costs.

More generally, work by Pindyck (2000) and others has shown that uncertainties associated with input costs may reduce or delay rates investment, strengthening the case for taxes relative to permits. As price-based instruments taxes may reduce risk from the investors' perspective relative to a quantity-based instrument such as permits (whether grandfathered or auctioned). With reduced risk the rate of investment (and thus innovation) will tend to be higher. However, evidence on the relative importance of this effect in the environmental area is limited.

Kemp (1997) makes the point that it is unreasonable to assume that the target is exogenous even at the point of introduction of the policy. With taxes or auctioned permits the regulator is less likely to introduce stringent environmental policies than under grandfathered permits. As such, the rate of innovation is likely to be lower. While it is certainly true that issues of political economy and rent seeking have been significant in slowing the take-up of emission taxes and auctioned permits, it is important to remember that under either of these schemes distributional and competitiveness concerns can be addressed much more efficiently through other market-based instruments than under grandfathered permit schemes (see Johnstone 1999).

Moreover, unlike under the other systems, with a grandfathered permit system the innovator will face adverse financial effects from reduced permit prices if it is a net seller of permits. Thus, if the innovating firm is a seller of permits, it will have less incentive to allow for the diffusion to other firms (unless the innovation is patented, in which cases incentives will depend upon relative rates of return for permit and technology sales, (see Milliman and Prince 1989)). Significantly, under these restricted conditions grandfathered permits may perform even worse than direct controls such as mandated emission reductions in terms of incentives to induce diffusion. Under direct controls, the only costs are those associated with abatement, but under grandfathering, permit sellers will lose from increased diffusion[3] (see Albrecht 2001).

Despite these qualifications it is generally recognised that in most instances market-based instruments are effective at inducing environmentally-benign research and development, innovation and diffusion (see Albrecht 2001 and Popp 2000 for further discussions). However, empirical analysis is limited. This can be explained by the fact that the "flexible" nature of responses makes it difficult to identify appropriate dependent variables for such an analysis. However, the American Acid Rain programme which introduced tradable permits as a means of reducing SO2 emissions provides some evidence. Under the previous Clean Air Act's rules, firms effectively only had one option for reducing emissions (i.e. to install scrubbers). The allowance trading programme allowed firms more flexibility in their choice of compliance strategies. Indeed, it is significant that very few firms (approximately 10%) complied with the new programme through the use of the technology which had been mandated under the pre-existing regime (scrubbers)[4].

The programme encouraged innovation. On the one hand, there have been improvements in fuel-mixing technologies, allowing firms to shift toward lower-sulphur mixes in a more cost-effective manner. In the late 1980's the theoretical maximum amount of low-sulphur coal that could be mixed with high-sulphur coal was thought to be in the region of 5%, but by the mid 1990's this had risen to 30%-40% (see Burtraw 2000). On the other hand, since the inauguration of the tradable permit system, technological improvements have allowed the price of scrubbers to drop significantly. In 1995, the capital cost of a scrubber sufficient for a 639 MW plant cost less than a scrubber half this size in 1989 (Bohi and Burtaw 1997). This compares with a situation prior to the introduction of the programme in which there had been no appreciable cost-reducing technological developments in flue-gas desulphurisation for 20 years (see Bellas 1998 for an empirical analysis). This compares with a situation prior to the introduction of the programme in which there had been no appreciable

[3] However, it must again be emphasised that this distinction is not important if innovations are generated by specialist firms which are external to the sector, and thus not themselves involved in the permit market.

[4] Although this is certainly at least partly a reflection of the nature of the existing capital stock.

cost-reducing technological developments in flue-gas desul-phurisation for 20 years[5].

Other more formal empirical evidence on the effectiveness of market-based instruments (or other instruments) in inducing innovation is limited. In a study of German firms, Hemmelskamp (1999) finds some support for the positive innovation effects of market-based instruments, particularly for product innovations. Jaffe et al. (2000) report on a study that found that the tradeable permit program used to reduce lead in fuels was very successful at encouraging efficient technology adoption by firms, although the effects on innovation were not explored. They also review a number of studies which find that energy prices have been significant determinants of increased vehicle fuel efficiency. This would indicate that fuel taxes (or permits) would be effective. However, they also refer to a study by Goldberg (1998) that finds that the American "Corporate Average Fuel Economy Standards" (CAFE) have also had positive effects. While often characterised as direct regulation, the programme is perhaps better described as a performance-based firm-level "bubble", in which manufacturers can trade off fuel efficiency improvements for different models within their fleet.

Using a database of German firms, Cleff and Rennings (2000) is one of the few studies to explore empirically the effects of different policy instruments on different types of environmentally-beneficial innovation, including product and process innovations. While they do not find definitive support for the use of one particular instrument, they do find some support for the use of information-based and "soft" instruments such as eco-audits and voluntary approaches.[6] However, work at the OECD (2000) has reached rather different conclusions on the innovation effects of voluntary approaches.

Given the relatively ambiguous nature of the evidence on the effects of different environmental policy instruments on innovation it is important to examine a number of issues associated with such innovation more closely. Moreover, many of these studies use dependent variables which are more closely related to rates rather than directions of innovation. Four issues which are more closely related to the direction of innovation will be addressed in turn: missing markets for certain environmental attributes of in-

[5] In addition, the costs of transporting low-sulphur coal from the Powder River Basin have fallen, although this is due mainly to institutional, and not technological, factors.

[6] Interestingly, they include liability as a soft instrument, while many would consider it to be an economic instrument, albeit one whose price is determined ex post.

novation; technological market failures; joint production of emissions; and, policy incidence. All of these complicate the design of economically environmental policies, particularly when innovation effects are taken into account.

## 3 Innovation and technological market failures

Environmental market failures are not usually the only failure which affects affect markets in which environmental damages. In the context of this report, there may also be concern about more general innovation-related market failures in environment-intensive sectors. Issues such as capital market failures in research and development, non-excludability and knowledge spillovers, demand-side consumption externalities, credit market failures for potential adopters, and other market failures are pervasive. Thus, with or without the presence of environmental externalities the rate of innovation will be sub-optimal in the absence of government intervention. However, the joint existence of positive technological externalities and negative environmental externalities, may also mean that both the rate and direction of innovation may be inappropriate.

For instance, it is sometimes argued that subsidies should be used to address some of the problems associated with technological market failures. Little work has been undertaken on the evaluation of supply-side environment-related investment subsidies. However, on the demand side, a number of studies have found that subsidies (or tax credits) have been used effectively to support residential energy conservation. Generally such studies find subsidies are very successful in encouraging the rate of diffusion, often much more effective than equivalent tax rates (see Hassett and Metcalf 1995 and Jaffe and Stavins 1995). This might be explained by failures in markets for household credit. However, it is also certainly due in part to the fact that subsidy programmes are not always able to distinguish between households who have been encouraged to undertake the investment because of the subsidy and those who would have undertaken the investment anyway – i.e. there is adverse selection (see Kemp 1997 for a discussion of some of the problems with subsidy programmes).

More importantly the innovation and diffusion which is encouraged may be misdirected. Contrary to the arguments of some, in practice subsidy programmes are not analogous to negative taxes, resulting in similar impacts[7]. While the latter can be designed (but are not always designed) in

[7] Except with respect to entry and exit.

such a way as to be "blind" with respect to the technological solutions adopted, this is rarely the case for subsidy programmes. To one extent or another policymakers are required to determine which investments are eligible for support. As with all such programmes, picking winners is a hazardous exercise.

As noted, information failures are thought to be particularly important technological market failures. Thus, while information-based measures are rarely likely to solve environmental problems by themselves, they can complement other policies very effectively, and may encourage environmentally-beneficial technological change. This is strikingly revealed in a study of product innovations for energy-using household appliances. Looking at the energy-efficiency of air conditioners and water heaters offered for sale in the United States, Newell et al. (1998) estimated the responsiveness of manufacturers to rising energy prices, before and after the introduction of an energy labelling scheme in 1975. The results indicate that the effects of energy price changes on the mean efficiency of appliances supplied by manufacturers rose appreciably (and became statistically significant) once appliances were labelled, encouraging innovation.

Why would this be the case? Assuming that manufacturers were responding to household demand, it is clear that households did not have the information necessary to make informed decisions (or information was too costly to acquire) prior to the introduction of the labelling scheme. Significantly, in a study of high-efficiency lighting in commercial buildings – whose owners would be expected to be better informed than households - Morgenstern and Al-Jurf (1999) also find considerable evidence for the complementary effects of information provision and relative price changes. While such programmes are unlikely to be costless, they are perhaps less likely than subsidies or investment credits to result in a misdirection of innovation.

The internalisation of knowledge spillovers through policy initiatives is a challenging policy task for environmental policymakers. Efforts to encourage such internalisation are very common in other aspects of industrial policy but are not yet common in the environmental sphere. However, measures such as support for research and innovation clusters and networks have been advocated. There is little question that such policies can be an effective complement to more generic policies such as effective intellectual property rights regime and support for basic research. Unlike such measures, however, they seek to direct the pattern of technological change – toward environmentally-beneficial innovation (see Honkasalo 2000 for a discussion of the Finnish experience).

Such programmes may not suffer to the same extent from the problems of "picking winners" associated with subsidies since they are institutional rather than specifically technological in nature. However, under certain conditions, encouraging such co-operation may result in delays in the introduction of environmentally beneficial technologies if there is potential for strategic behaviour. For instance, the US Department of Justice successfully brought an antitrust action against the Automobile Manufacturers' Association partly on the basis of collusion in delays of the announcement of process innovations which would have reduced environmental impacts (see Hackett 1995).

## 4 Missing markets for environment-related attributes and product innovation

Closely related to the issue of technological market failures is the issue of missing markets for environmentally-relevant product attributes. Many studies on the innovation effects of environmental policy instruments implicitly assume that the only market which is missing is that for the environmental externality. However, in many cases this is not the case. The example of post-consumption solid household waste is instructive. A study by Eichner and Runkel (2000) shows that if there are not "indirect markets" for product toxicity, then the environmental attributes of products will be sub-optimal - i.e. firms will underinvest in the development of products which are not toxic. Similarly if there are not "indirect markets" for recyclability then firms will underinvest in the development of products with attributes which make this more feasible. Hence, this analysis shows that besides environmental externalities there are further sources for inefficiency, namely missing markets for product design.

The key point is that even if environmental policies - such as technological standards for landfills or incinerators - are targeted at waste at the post-consumption phase, this will not result in improved product design. Under such measures regulators are unable to target products differentially, and thus manufacturers and product designers face little incentive at the individual level to incorporate such elements in their products. Even if such measures are financed through volume-based waste fees – as is increasingly the case – the transmission of signals back to product manufacturers will be blunted by the mixed nature of municipal solid waste streams.

Thus, incentives for firms are often inadequate. Such "technical externalities" are pervasive in the markets for used appliances and parts of appliances, as well as packaging waste. For instance, upstream product designers and manufacturers are not encouraged to design for recycling since downstream users may not face appropriate financial incentives to purchase products which are recyclable. The end result is that the benefits of particular types of design may be less than the costs, but there is no way for this information (and appropriate incentives) to be transmitted to product designers. Technological innovation with respect to product design will be misdirected, even in the presence of measures usually proposed by economists such as volume-based solid waste charges.

Thus it may be necessary to introduce complementary policies to address the issue of "missing markets", which can encourage the design and development of environmentally-preferable products. In most cases it will not be possible to create the market directly through policy interventions. However, there may be other remedies. For instance, in order to encourage improved product design, measures such as deposit-refund systems or product take-back programmes may be effective since they can "bracket" the missing market and transmit signals back to designers and manufacturers. Directed government support for "Green Design" has also risen up the policy agenda in many OECD countries, and consumer durables have been a primary area of focus. Unfortunately, all such measures impose significant information requirements on policymakers and in some cases administrative costs for public authorities and private firms and households.

## 5 Point of policy incidence and innovation

To a certain extent, the focus on the importance of instrument choice when evaluating the innovation effects of environmental policy may be misplaced. In some senses it might be more important to hit in the right place in the product cycle, rather than to do so with the right stick (or carrot). Indeed, it is frequently assumed that it is possible for the policymaker to target the environmental externality directly. However, this is very rarely the case. Arguably, a $CO_2$ tax is the only existing example. Due to the high administrative costs or even technological infeasibility in other areas, almost all policies are targeted at some proxy for the damage rather than the damage itself.

For instance, taking the example of acidification from $SO_2$ emissions emitted by the electricity supply industry, policies could target any of points listed in table 1. Generally speaking, there is a trade-off between the accuracy of targeting the externality and the administrative costs of doing so as you shift down the list. The administrative savings from not targeting damages are directly are well-understood. However, the cost of shifting away from targeting the externality are not well understood.

**Table 1.** Environmental impacts and policy incidence

| Target | Point of incidence | Example of direct regulation | Example of market-based instrument |
|---|---|---|---|
| Environmental damages | Critical loads | Restricted entry in non-attainment areas | Permits denominated w.r.t. critical loads |
| Environmental pressures | SO2 emissions | Performance standard for emission levels | Emissions permit |
| Material inputs | Coal | Restriction on use of high-sulphur coal | Tax on sulphur content of fuel |
| Production/combustion process | Combustion/abatement technology | Mandated use of scrubbers | Accelerated depreciation for scrubbers |
| Products | Electricity | Restricted access to the electricity grid | "Green" electricity tax exemption |

In the short-run the costs of "missing the target" may be minimal since proxies will always be chosen which are highly correlated with the ultimate damage. However, the long-run effects may be considerable since the policy will, in effect, encourage firms and households to save on the proxy and not on the damage. Moreover, the relationship will necessarily become weaker through time if there is any degree of substitution between the proxy and the ultimate environmental impact.

For instance, in many European countries vehicle ownership taxes are differentiated according to vehicle weight or engine size in an effort to reduce local and global air pollutants. While there is a relatively strong correlation between emission levels and vehicle weight, if the measure is significant enough to encourage vehicle redesign, this relationship becomes weaker through time. By trying to save on the characteristic which is taxed, manufacturers will be unconstrained with respect to emission levels. Similar issues arise in the area of agriculture, where "proxies" are used extensively due to the high administrative costs of target non-point source pollutants directly.

The importance of this issue has not been examined empirically, even though Sandmo (1976) raised the issue three decades ago. However, in recent theoretical papers on the issue of incidence both Schmutzler and Goulder (1997) and Fullerton et al (1999), look at the welfare effects of output taxes relative to emission taxes. Not surprisingly, they find that the welfare costs of the former can be much greater than the latter. Dinan

(1993) looks at the example of the application of a proxy – targeting waste externalities through a virgin materials tax – and reaches similar conclusions. Work on input taxes might be more interesting, given the prevalence of their use as proxies in many elements of environmental policy and given the rather different implications that they have for innovation and factor substitution.

However, what such studies do show is the importance to distinguish between instrument choice and the point of incidence when assessing the innovation effects of environmental policy. The case for economic instruments relative to direct forms of regulation is often made under the assumption that they both target externalities equally accurately. However, two points (point of incidence and instrument choice) are being conflated. For instance, a performance standard based on emission levels is likely to target the externality more directly than a tax in which the tax base is related to an input. While the latter may result in greater static allocation efficiency, it may result in misdirected pattern of innovation. The examples in table 2 make this distinction clear.

## 6 Innovation when pollutants are joint-products

Pollution emissions are best understood as joint-products, not just with respected to commodities, but also with respect to each other. Firstly, emissions of different pollutants are often highly correlated. table 2 presents correlation coefficients calculated for four different pollutants, based upon almost 3,000 observations from the US EPA's vehicle emissions database.

**Table 2.** Correlation between different vehicle emissions

| | | THC | CO | NOX |
|---|---|---|---|---|
| CO | Pearson Correlation | .828 | | |
| | Sig. (2-tailed) | (.000) | | |
| NOX | Pearson Correlation | .132 | .107 | |
| | Sig. (2-tailed) | (.000) | (.000) | |
| CO2 | Pearson Correlation | .026 | -.002 | .265 |
| | Sig. (2-tailed) | (.171) | (.920) | (.000) |

Correlation is significant at the 0.01 level (2-tailed). 2,851 observations

One pair of pollutants (CO and THC) have particularly a high positive correlation. This can be seen visually in figure 1 which provides a scatter plot for observations between 1990 and 1995. Interestingly only CO2 and CO, have a negative relationship - but it is not significantly different from zero.

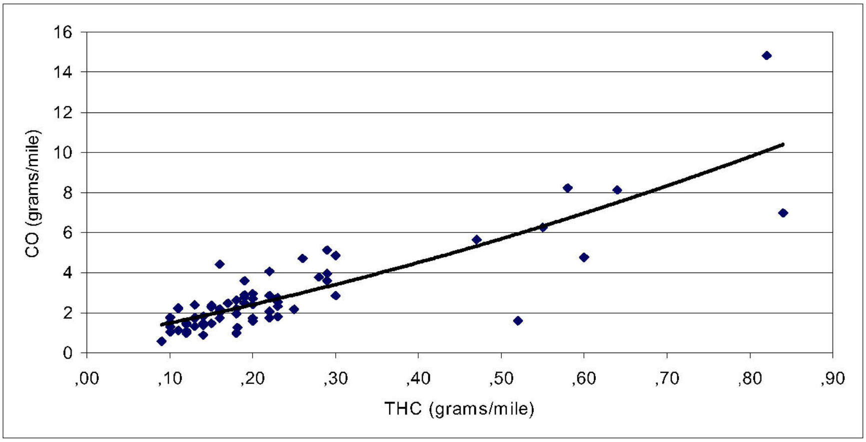


**Fig. 1.** Scatter plot of CO vs. THC emissions

The jointness of emissions is partly a consequence of the nature of the production or combustion process. However, and perhaps more significantly in policy terms, different emissions are often jointly reduced through abatement. The close link between CO and THC emissions illustrated in figure 1 is partly a consequence of the application of end-of-pipe catalytic converters. In effect, the degree of 'jointness' is endogenous to the policy measure.

However, in recent years there has been a marked shift toward the use of changes in production processes rather than end-of-pipe abatement. (See figure 2 for some data derived from the American Census of Manufactures.) Production and abatement are no longer separable. This necessarily results in "bundling" of emissions associated with different technologies. In effect, the shift toward abatement through changes in products and production processes is likely to lead to economies of scope across different types of pollutant. Unfortunately, the importance of this has not yet been explored systematically.

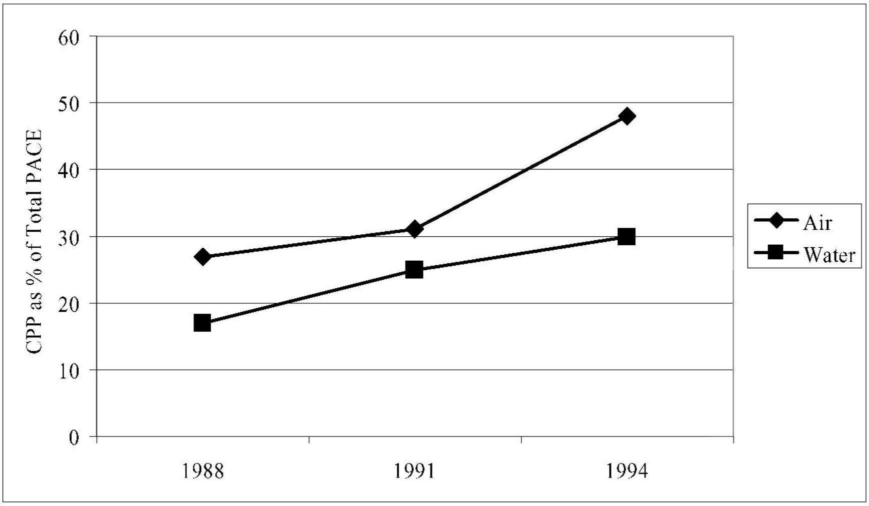


**Fig. 2.** Percentage of total pollution abatement costs attributed

The joint nature of emissions, may appear to simplify the regulator's task when seeking to encourage innovation. Ancillary or complementary benefits will be realised as the overall level of environmental performance rises. However, in some cases they are substitutes. For instance, it has long been recognised there is significant potential for "shifting" of environmental burdens between different types of emissions and even between media. Depending upon substitution possibilities in production and consumption constraining emissions may result in increased emissions of another sort. Grafton and Devlin (1994) explore the effects of regulating one emission when another (substitute) emission is left unconstrained. In the long term as firms will innovate in a manner which results in higher emissions of the latter, potentially resulting in decreases in overall environmental quality[8].

Once again, motor vehicles provide interesting examples of potential substitution. For instance, measures to improve fuel-efficiency (and thus reduce CO2) lead to higher combustion temperatures and thus higher NOx emissions. To find an optimum for controlling pollutants the trade-off between CO2 and NOx controls had to be managed. When catalytic converters were introduced this problem disappeared, as overall reductions of more than 80% of all pollutants and air toxic were achieved. However, there was a slight reduction of fuel-efficiency (and thus increase in CO2

[8] In some cases it is quite likely that emissions will be complements in the short-run, but substitutes in the long-run.

emissions) of a few percentage points. In addition, nitrous oxide (N2O) emissions were 3 to 5 times higher compared to vehicles without catalysts[9]. Khazoom (1996) looked at causality in the opposite direction (i.e. from CO2 to local air pollutants) and pointed out that while the American Corporate Average Fuel Economy standards may have led to fuel-saving (and carbon-saving) technological development, it may have had negative consequences for local environmental quality.

## 7 Implications for the choice of indicators for environmental innovation

Assessing whether or not different environmental policy instruments have positive impacts on technological innovation is dependent upon the existence of appropriate indicators. However, given the discussion above it is clear that the optimal direction of innovation can be complicated by the existence of various factors such as the existence of market failures, the joint production of emissions and abatement, the presence of missing markets, and the targeting of policies at some remove from the externality itself. As such, the choice of indicator is an important but hazardous exercise.

In the OECD framework, indicators have been developed within the 'pressure-state-response' framework (see OECD 2001). Indicators for environmental innovation are, almost by definition, 'response' indicators – reflecting adjustments within the economy to environmental conditions. However, in some cases it may be possible to derive pressure indicators. For instance, much of the work which has been carried out in the context of 'decoupling of environmental pressures from economic growth' (OECD 2002) can be understood as reflecting, at least in part, innovation. However, at the macroeconomic level, they also reflect other factors such as changes in sectoral composition of the economy.

Therefore, it is important to identify what we might consider to be possible indicators specifically for environmental innovation. A partial list might include the following:

- Patents for innovations which result in improved environmental performance;
- Percentage of research and development which is related to environmental matters;

[9] However, it is worth noting that this increase is of minor importance, as transport contributes only 3% to total N2O emissions (primarily from agriculture), and is less than 1% of total greenhouse gas emissions (ECMT, 2001).

- Adoption/diffusion rates for environmentally-benign technologies and product types;
- Normalised emission rates for particular production processes or product types; and,
- Investment in product designs which reduce resource use in production and use.

Assessing such indicators requires careful analysis. According to the OECD (2001), indicators for environmental issues should fulfil the following criteria:

- Policy relevance and utility for users
  - Provide a representative picture of environmental conditions, pressures or responses;
  - Be simple, easy to interpret, and able to show trends over time;
  - Be responsive to changes in the environment and related human activities;
  - Provide a bases for international comparison;
  - Be either national in scope or applicable to regional issues of national significance; and,
  - Have a threshold or reference value to allow for ease of interpretation.
- Analytical soundness
  - Be theoretically well-founded in technical and scientific terms;
  - Be based on international standards and international consensus about its validity; and,
  - Lend itself to being linked to economic models, forecasting and information systems
- Measurability
  - Be readily available or made available at reasonable cost;
  - Be adequately and of known quality; and,
  - Be updated at regularly in accordance with reliable procedures.

Very few, if any, of the general environmental indicators listed in the report, satisfy all of these criteria. Applying these same criteria for the specific case of innovation-related indicators in the environmental is likely to be even more problematic. However, rather than seeking to identify the extent to which individual indicators satisfy all criteria, particular attention will be paid to those criteria which relate specifically to analytical soundness.

In particular, it is important to recognise the implications of the discussion above, which highlighted the distinction between measures of the 'rate' of innovation, and 'direction' of innovation. Since all response and pressure indicators of the sort enumerated above are at least one step removed from the ultimate policy objective (the state of environmental conditions), it is important that the indicators seek to reflect the 'direction' of innovation in a manner which is useful for assessment. There can be many slips 'twixt the cup and the lip'.

Therefore, a successful indicator must reflect not only the rate of innovation but also the direction of innovation. How well do the possible indicators listed above capture these two effects? Problems in accurately measuring 'rate' of innovation are inherent in any measure which does not reflect the efficacy of measures of the sort discussed above. There is, for instance, a lively debate as to whether public investment in research and development 'crowds in' or 'crowds' out private investment in research development.

Thus, indicators such as the percentage of research and development or levels of investment in 'environmental' areas (whether defined by sectoral or commodity classification) are only useful insofar as they are examined jointly with other indicators which reflect the efficacy of such expenditures. However, perhaps even more fundamental is the assessment of the analytical soundness of different indicators with respect to the direction of innovation.

For example, if we take the case of patents for innovations which result in improved environmental performance, the direction of innovation is dependent upon the choice of technologies which are considered 'environmental' in nature. Arguably, such technologies are easier to identify for technologies related to 'end-of-pipe' abatement than changes in production processes, and as such are likely to be disproportionately reflected in the measurement of the indicator. However, since changes in production processes are often more economic in the longer-run, an increase in the indicator might not reflect improved environmental innovation.

Similarly, if we take the case of waste-related innovations in the area of product design as another example, it might well be easier to develop indicators which relate to ease of recycling than those which relate to waste prevention. Since some innovations which result in improved recycling rates for material inputs may substitute for overall waste prevention, an increase in particular indicator may not reflect an optimal direction of innovation.

It is, therefore, quite possible to develop indicators which appear to reflect environmental innovation, but the distance between such indicators and ultimate environmental conditions is such that the relationship between the two can not be taken as given. Such problems are likely to be particularly problematic for indicators at the macroeconomic or sectoral level. Assessing environmental 'innovativeness' at such an aggregate level is an exercise which needs to be undertaken with great care, for all of the reasons discussed above.

## 8 Conclusion

The first lesson to be drawn from this study is the importance of not confusing the optimal rate of innovation with the optimal direction of innovation. Given that the latter may be more difficult to achieve than the former, this point is far from trivial. Ascertaining what direction is optimal is, of course, endlessly problematic. However, in abstract terms it should be that path which is cost-minimising in the long-run with respect to the realisation of the given environmental objective.

The second lesson is that in order to ensure that there is no misdirection of innovation, policies should be targeted at the ultimate environmental damage as closely as is administratively feasible. This is easier said than done, and direct targeting is rarely possible - except with the notable exception of carbon dioxide. However, the costs of mistargeting, particularly in the long-run, need to be more widely-recognised than is usually the case at present.

Moreover, targeting must be undertaken in an "integrated" manner. If different environmental objectives are narrowly defined in terms of objectives and targeted sequentially (as is usually the case) then economies may be pushed onto a technological trajectory which is relatively inefficient, and potentially environmentally perverse. Realisation of one environmental objective today may come at the expense of the realisation of other objectives in future years.

The third lesson is that it is important to look at the structure of markets, technological factors associated with production and abatement, and the precise nature of the environmental damage to be mitigated, when designing policies to encourage environmentally-beneficial innovation. Blanket prescriptions in favour of one instrument over another are not reliable. However, those instruments which allow for flexibility in implementation and provide continuous incentives for innovation should be used wherever possible.

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