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SUSTAINABLE DEVELOPMENT

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FOREWORD

Innovation has a crucial role to play in shifting our development path towards environmental sustainability, but this role is not currently fully exploited. Investments in research and innovation for environmental objectives are inadequate in both the public and private sectors. In other cases, such investments are not being used effectively. Public policies need to play a greater role in stimulating innovation for the environment.

To address these issues, in June 2000, the Working Party on Innovation and Technology Policy of the OECD Committee for Scientific and Technological Policy held a workshop on Innovation and the Environment. The workshop was chaired by Sung Chul Chung, Korean Delegate to the Committee and Senior Fellow at the Science and Technology Policy Institute of Korea. This volume contains the papers presented at the workshop and the report by the rapporteur which includes a summary of the panel discussion moderated by Nick Johnstone of the OECD's Environment Directorate. The presentations discuss conceptual aspects and assess recent policy initiatives that better stimulate innovation or the factors that drive firms to innovate for sustainability. The discussion focuses on how to bring about better policy coherence and a policy mix that can harness innovation for environmental sustainability. The insights gained at the workshop will contribute to the OECD Horizontal Programme on Sustainable Development.

This book is published on the responsibility of the Secretary-General of the OECD.

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Chapter 1

WORKSHOP ON INNOVATION AND THE ENVIRONMENT: RAPPORTEUR'S REPORT

by

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Introduction: the workshop focus

The Workshop on Innovation and the Environment pursued two central concerns: how environmental policy can stimulate technological innovation; and how innovation policy can enhance environmentally sustainable economic development. Each of these foci in turn looks to the process of technological innovation – an activity, overwhelmingly, of the private sector – as the generator of new products, processes and systems that can harmonise environmental and economic objectives.

The complementarity between technological change and environmental quality is not newly recognised; nor is the realisation that environmental and innovation policies should work in tandem. But these desiderata are still far from achieved: environmental and technology policies are routinely pursued in separate spheres, and environmental technology is too often lodged outside the mainstream of industrial innovation.

With these concerns in mind, the workshop was structured into three main analytical sessions: *i)* environmental policy designs to stimulate innovation; *ii)* leveraging innovation policies and the innovation process in firms to enhance environmental performance; and *iii)* means to promote coherence between environment and innovation policies. The overall aim was to assemble an information base of "best practice" that would move the mix of public policies and private action towards enhanced innovation and environmental quality.

Framing the issues[1]

Although it is widely accepted that technological innovation offers a crucial contribution to environmentally sustainable growth, the context for innovation in this regard is still poorly delineated. Part of the problem is definitional: virtually any technology can become "environmental" when so applied; and much of today's new technological trajectory – information and computer technology for example – tends to be environmentally positive to the extent that it is less pollution- and resource-intensive. Even within the sphere of the traditional environmental goods and services industry, a shift from end-of-pipe controls to

cleaner technology, coupled with new corporate strategies among polluters, is redefining the boundaries of environmental technology. As these various trends tend to "fall between the cracks" of traditional data-gathering, a better conceptual and statistical knowledge of environmental innovation is urgently needed.

Even if it were well-documented, environmental innovation would still be hampered by factors that do not necessarily pertain in other areas of technology. Since environmental costs are often an externality and environmental quality often a public good, it is clear that market failures and under-investment characterise the private sector technology development process. The complex nature of environmental innovations – often requiring transdisciplinary, cross-sectoral and organisationally complex changes – only exacerbates the difficulties innovators have faced. So, too, has a past pattern of defensive or negative corporate responses, as well as environmental regulations that allowed little room for innovative compliance strategies.

Today, however, there are encouraging signs of attitudinal, design and policy shifts. Corporations have begun to take a proactive stance towards the environment, recognising both the value proposition that this implies and the potential economic reward in efficiencies and new business opportunities – a "double dividend". Public policy has begun to shift towards a new policy mix, combining economic incentives, informational strategies and flexible regulatory regimes. And a fair body of research has documented and evaluated these experiments.

Perhaps the most striking policy opportunity today is to improve the coherence between environmental and innovation policies. Innovation policy has long underplayed the issue of environmental sustainability, due presumably to its weak link to commercial interests. As the economic value of environmental innovation becomes more obvious, and the centrality of environmental goals to the world's technological future emerges ever more clearly, this policy mismatch must change. The need for more R&D, and for reoriented R&D strategies, is particularly critical. So, too, is the ability to apply R&D to environmental problems through the instruments of technology policy, such as public-private partnerships, technology foresight and others. An active "environmental innovation policy" needs to be crafted.

Previewing the evidence: significant policy studies, industry data gaps

Analysis of the connection between technological innovation and environmental policy has produced a significant body of scholarship that in fact reaches back more than 20 years (see bibliography in Chapter 3 of this volume). Much of this work focuses on policy instruments. It offers a sound theoretical basis to explain which conditions foster innovative, and which non-innovative, responses to public regulation. What may be particularly valuable in this literature is that it exposes the dysfunctionalities of traditional environmental regulation from the point of view of technological innovation and offers lessons of how to avoid them in the future.

Over the last ten years, environmental policy throughout the OECD countries has evolved considerably, prompting experiments with a wide range of alternatives to traditional regulation. Scholarship has kept remarkably abreast of these changes. Indeed, several recent evaluations presented at the workshop provide a substantial record of understanding the consequences – and particularly the successes – of these policy experiments.

The positive, proactive posture towards environmental concerns now adopted by leading firms in the private sector can easily be characterised as a sea-change from the defensive negativity that so characterised corporate behaviour in the past. While anecdotal evidence of this change abounds, systematic data charting what is in fact occurring, and interpretive analysis, are seriously lacking. There are provocative postulates – *e.g.* "the double-dividend hypothesis" – and fascinating case studies of voluntary private sector actions. However, the overall context and motivation for environmental innovation – whether in the environmental goods and services industry or in other firms – is not well understood.

Although the overall coherence between environmental and innovation policies throughout the OECD can only be described as low, this is not to say that there are not encouraging instances in which the instruments of technology policy have been fruitfully applied in the environmental context. A number of such experiments were documented in the workshop, as well as in a recent review by the OECD (*STI Review*, No. 25, Special Issue on "Sustainable Development", 2000)

Reviewing the technology impacts of environmental policy[2]

Reviewing the historical impacts of environmental policy on technological change in industry offers both a useful evaluative yardstick and a springboard from which to prescribe better policies in the future. In evaluating this history, it needs to be recognised that environmental quality – not innovation – is the primary purpose of policy, and that the impacts on technology have mostly been incidental or unintended. Given the wide diversity of environmental problems, available technological cures, industrial contexts and types of regulation, it is to be expected that regulation has elicited the entire range of technological responses: diffusion of existing techniques, incremental process change, product reformulation, product substitution, etc. It is also not surprising that the most stringent regulations have led to the most innovative responses, and that regulations that essentially ratify best practice have only prompted diffusion of the state of the art to technological laggards. It is interesting, and consistent with innovation theory, to observe that much of environmental technology was developed outside of the polluting industries (*e.g.* by the environment industry), and that the most radical technological responses often arose from firms without a vested interest in the technological status quo (*i.e.* new entrants or small firms, as well as firms in the environment industry). It should be noted, however, that this traditional pattern appears to be changing as pollution prevention and product redesign assume greater importance.

Across these diverse contexts, a reasonably strong generalisation emerges: the response to environmental regulation has most frequently been incremental change or diffusion of existing technology – often end-of-pipe process modifications or non-innovative substitutions. This conclusion leads quickly to the questions: why has this been so and what to do about it?

In response to the first question, many analysts have argued that the environmental policy process is easily "captured" by the very interests it seeks to regulate. In consequence, its rules have not greatly threatened the status quo. Others suggest that environmental regulation has been ill-informed about the process of technological change and has in consequence missed opportunities to "tip the balance" towards more innovative responses in specific circumstances.

The most fundamental policy conclusion derived from this analysis is that there is no single "magic instrument" to promote innovation. Its policy prescription suggests fine-tuning of multiple instruments: a "modulation view". Based on an appraisal of how policy instruments affect technological change, the analysis argues for policies that move this concern explicitly to the forefront. Doing so requires different roles for policy makers: sponsor, planner, regulator, matchmaker, alignment actor and "creative game regulator". Such approaches are not a substitute, but rather an addendum to those that change the framework conditions; both are needed for ecological modernisation.

Analysis of economic instruments in practice[3]

In 1991, Sweden both introduced a carbon tax and significantly restructured its overall system of energy taxes – most importantly by reducing general energy taxes by 50%. Since then, additional changes have occurred, including regulatory controls on energy efficiency. Currently, industrial consumers pay no energy tax, and only 50% of the general carbon tax. Neither the energy or carbon taxes are applied on electricity production. The current structure of economic incentives is thus radically altered from past decades. Significant changes in energy consumption patterns have followed.

The most obvious effect of the reformed taxation system has been a major expansion of biomass use in the residential heating system (see data in Chapter 5 of this volume). Industry has increased biomass as well, but to a lesser extent. The former effect is easily accounted for by the relative increase in fossil-fuel heat production cost *vis-à-vis* biomass. As to industry, the effect of the carbon tax has been rather small due to the following: the relatively low cost of energy, relatively low reliance on fossil-fuel-based supplies and an overall energy tax decrease for most companies. Given that the carbon tax differentiates among sectors, there has also been some inter-sectoral buying and selling of energy.

Official analysis of CO_2 emissions in 1995 estimates a 15% reduction compared to levels expected without the policy change; by the year 2000, the reduction should be 20-25%. Almost 90% of this results from the reformed tax system, and the remaining 10% from investment grants and official programmes on energy efficiency. The sulphur tax, nitrogen charges and new regulations have also been effective in reducing energy-based emissions.

There are no studies that show the effect of the Swedish economic instruments on technological innovation. Most indications are that only minor changes have occurred in industry. With increased demand for biofuels during the 1990s, several new technical solutions have been introduced in tree harvesting, efficiencies in biomass heating production and flue gas condensation.

The 1990 US Clean Air Act Amendments instituted an emission allowance trading programme to regulate sulphur dioxide (SO_2) from electric generating facilities. The industry is allocated a fixed number of total allowances, and firms are required to hold one allowance for each ton of sulphur dioxide they emit. Allowances may be transferred among facilities or to other firms, or banked for use in the future. A less widely acknowledged but equally important feature is the annual cap on average aggregate emissions by electric generators, set at about one-half of the amount emitted in 1980. The cap accommodates an allowance bank, so that in any one year aggregate industry emissions must be equal to or less than the number of allowances allocated for the year plus the surplus that has accrued from previous years.

The SO_2 allowance market presents the first real test of the wisdom of economists' classic policy prescription, and therefore merits careful evaluation. The conclusion offered, in brief, is that the programme has been a noteworthy success from the standpoint of comparing benefits and costs. It has achieved 100% environmental compliance, and over-compliance in Phase I. Emission allowance trading has not lessened, and may have contributed to, the environmental benefits of SO_2 reduction. Meanwhile, trading has contributed to significant cost reductions compared to original forecasts of cost. An economic assessment of benefits is that they are substantially greater than the costs of the programme.

Innovation accounts for a large portion of these cost reductions, but not in the way that is typically formulated in economic models. More than patentable discoveries, the result has been organisational innovations at the firm, market and regulatory level and process innovation by electricity generators and upstream fuel suppliers. Flexibility in compliance has provided the lion's share of cost savings to date – greater than the exchange of emission allowances through trading. Input markets for electricity generation have redirected investment dollars to take advantage of new opportunities for low sulphur coal. In fact, many of the cost reductions were already in the works, independent of the SO_2 programme. Nonetheless, a

conventional regulatory approach would have failed to capitalise on many of these trends, and arguably would have discouraged them. The SO_2 programme deserves significant credit for providing the incentive and flexibility to accelerate and fully realise exogenous technical changes that were occurring in the industry.

Environment and innovation in the private sector[4]

In 1991, the Japanese *Keidanren* (Federation of Economic Organisations) announced its "Global Environmental Charter" as the general commitment of its membership to deal with environmental issues, as well as an umbrella of authority through which to mount more specific voluntary action plans. In 1997, a Voluntary Action Plan on the Environment was created, which in the instance of the "Second Follow-up" has enlisted 31 industrial sectors in a variety of voluntary measures to address global warming. These sectors represent 42% of Japan's total CO_2 emissions and approximately 75% of industrial CO_2 emissions.

In the view of the *Keidanren*, voluntary measures hold most promise for the future as a means of combating long-term global environmental problems that demand widespread changes in business and daily life. "Traditional regulatory measures", applicable to pollution and other problems identified during the 1970s, afford less leeway to business to mount the most effective solutions. Still, however, there is a need for accountability, which in the *Keidanren's* voluntary plans consists of public promises and follow-up monitoring, whose results are widely disseminated. Beyond this, there is close consultation with the government, and the government itself has relied on the *Keidanren* voluntary measures in the 1998 plan to prevent global warming.

The goal of the *Keidanren* global warming measures is to reduce CO_2 emissions in 2010 below their level in 1990. Thus far, CO_2 emissions in FY 1998 were 2.4% below 1990 and 6% less than 1997. For a business-as-usual scenario, CO_2 emissions in 2010 are projected to be approximately 10% above 1990. These trends are highly sensitive to overall economic output. Given recent declines in the Japanese economy and projected increases, it is apparent that further efforts are needed if industry is to achieve the goals of the voluntary measures.

Another aspect of the *Keidanren* Voluntary Action Plan pertains to waste. In this case, the 2010 unified target is to reduce the final disposal of industrial waste to 25% of its 1990 level, a figure that is more ambitious than the overall national target set by the government. By FY 1998, the 26 participating *Keidanren* industries had reduced waste by 42% compared to 1990.

The World Business Council for Sustainable Development (WBCSD) sees the private sector's contribution to sustainable development as its development and use of environmentally better products, services and production processes. Technological innovation is at the essence of its role. A new process of innovation needs to be employed, however; one that represents a step-change in environmental performance – far beyond simply doing better what is already being done – and a far greater degree of integration between corporations and their societal context.

Leading companies have already begun this transition. They have demonstrated the willingness to operationalise a set of common underlying principles that are crucial to the transition to a sustainable society. These include:

- Understanding what society expects.
- Building the capacity to act across the social, environmental and economic pillars of sustainable development.

- Setting targets and the means to measure their achievement.

These principles are both a matter of social responsibility and prudent management. The positive stock market returns achieved by companies included in the recently launched Dow Jones Sustainability Index suggest that investors too are now recognising the management qualities that have made this progress possible.

Surveys conducted by the WBCSD chart a radically altered scenario for technological innovation. Firms are networked as never before – to each other, to the governmental and university sectors, across national boundaries and to stakeholder attitudes towards their operations, products and services. It is well-documented that the public expects and demands the application of radically new technologies – *e.g.* biotechnology – but it also exhibits considerable unease about the consequences of new technology and who will benefit from them. Social expectations – sustainability, overwhelmingly – thus emerge as a powerful new driver of innovation. The leadership task for management is to harness economic and social trends, capture knowledge and experience from worldwide networks, and combine these in ways that command respect and generate value.

While the achievement of a sustainable economy is a never-finished enterprise, there are signs that the corporate population has effected a profound transition. Of senior business managers surveyed by the WBCSD, 88% "agreed" or "strongly agreed" that sustainable development is a key business driver. This, of course, reflects their predictions of the directions in which markets are moving, but it shows as well a new-found sense of the importance of environmental and societal issues to company image and brand values.

There are also indications that the general population holds a new view of the corporate role. A recent WBCSD survey showed 35% of the public looking to corporations for environmental leadership in the future, 25% to governments and 23% to NGOs. However representative these data truly are, it is clear that the challenge for companies is to find new ways to align innovation with public expectations and to establish a management framework that is based on discussing, deciding and delivering sustainable value.

Michael Porter and Claas van der Linde's work crystallised and brought to a larger audience the debate about the relationship between environmental protection and economic performance. For some time, in both industrialised and developing countries, environmental protection has been viewed by many as a brake on economic development. More recently, in both academic and policy circles, doubt has mounted about whether this assumption is true. The so-called "Porter hypothesis" states that environment and competition are not incompatible and that properly designed environmental regulation can act as a trigger to innovation which will in turn make companies more competitive. This ability to simultaneously profit and improve environmental performance has become known as the "double dividend".

Porter and van der Linde identified "innovation offsets". For process innovation, enhanced resource productivity could be achieved through technological changes leading to: higher yields, less downtime, material saving, better use of by-products, lower energy and material consumption, reduced storage and handling costs, and conversion of waste into valuable inputs. For product innovation, innovation offsets could include: higher quality and better performance, increased safety, lower-cost, higher resale or scrap value, and lower disposal costs.

There are many case studies at the industry sector and firm level that demonstrate the potential for the double dividend. There is also evidence that not all investments in environmentally-enhancing technology provide competitive advantage (see discussion of examples in Chapter 8 of this volume). Neither theory, case study or macro-level evidence has answered the question of how large and frequent is the double dividend.

A different body of policy research has identified several characteristics that are important for creating an environment where the private sector will innovate, including stringency, flexibility, adequate timeframe for implementation of innovative solutions, and certainty. Although there is argument by some that economic approaches will be better for innovation, detailed case research suggests that the ability of regulation to capture the full set of characteristics outlined above is the key to creating a policy that stimulates innovation, rather than a preference for any particular mechanisms (see three case studies in Chapter 8 of this volume). In particular, the cases point to the potential synergistic effects of stimulating innovation by investing in R&D and creating markets through environmental regulation.

Promoting the commercialisation of environmental technologies[5]

During the 1990s, "industrial clusters" have proliferated worldwide as a tool of technology policy, based on recognition of the importance of networks, co-operative solutions to common technological problems facing firms, cross-sectoral links and modern information technology. In Finland, cluster programmes were developed by various sectoral ministries during 1997-99.

The Finnish Ministry of Environment is responsible for the administration of the Environmental Cluster, with certain aspects of implementation and funding undertaken by the Ministries of Trade and Industry, Agriculture and Forestry, Labour, TEKES (Technological Development Centre) and the Academy of Finland. Total funding for the first stage of the programme (1997-99) was FIM 80 million. Approximately half was contributed by the research units and other financial institutions.

Funding proposals for individual projects are made by the steering group of the research programme, which consists of representatives of the financing organisation, Ministry of Transport and Communications and industries. About 500 applications have arrived, and 60 of them have so far been allocated funding. The principal aim of the programme is to improve the state of the environment and to create new jobs by enhancing eco-efficiency. It seeks, additionally, to generate environmentally friendly innovations and product ideas. Co-operation among researchers, business people, public authorities and funding organisations in accordance with the cluster approach is expected to integrate environmental matters even more closely with the Finnish system of innovations. The following topic areas will be covered by research projects:

- Material flows and life cycle accountability.
- Eco-efficiency of production processes and products.
- Environmentally friendly infrastructure.
- Management of environmental knowledge and information.
- Promotion of environmental business, ecological exports and marketing.
- Environmental and innovative policies.

Since most of the projects in the first stage will be completed in the spring of 2000, the first formal evaluation will occur during autumn 2000. It is already clear, however, that the goals set by the funding organisations have been attained. Co-operation has been flexible, the number of co-operative projects has increased, and networking among the research institutes is apparent. Although 70 industrial enterprises are participating, most do so through a representative in the steering group, since there appears to be some reluctance to involve R&D projects in a programme whose findings are freely accessible.

The Environmental Cluster Research Programme will continue with public funding of at least FIM 30 million for 2000-01. A special emphasis will be placed on the sub-programme dealing with sustainable development and the information society. Dematerialisation, and even more, immaterialisation (replacing material products with non-material ones), will be major emphases.

The UK Foresight programme aims to link the research base and the market by stimulating private sector innovation and business activity in the environmental sector. Foresight is a process involving business, academe, government, NGOs and consumers in articulating scenarios for 10, 20 and 30 years hence. It is an attempt to change culture, both in firms and in the larger society, so as to come to terms with the sweeping modifications in lifestyle, production and consumption patterns that are foreseen by the year 2025.

The programme has proceeded in three stages: *i)* establishing broad priorities; *ii)* detailed work on specific projects; and *iii)* the institution of a new round of panels. "Consultation papers" are to be published in July 2000, detailed reports and plans by the end of 2000, and actions undertaken in 2000 and 2001. Government funding of GBP 30 million is supplemented by matching funds from the private sector. Approximately GBP 20 million of the total is devoted to sustainable technology.

Although Foresight is a major future-envisioning process, the presentation of projects at the workshop focused largely on energy, transport and environmental initiatives (see cases in Chapter 10 of this volume). The overall programme fits with the larger "modernisation policy" of the United Kingdom. It postulates that radical shifts will be occurring within the foreseeable future. Its challenge is thus leviathan: the enlistment of many, diverse stakeholders in an interdisciplinary, inter-professional and inter-sectoral process for the restructuring of industry.

Linking environment and innovation policy[6]

One of the biggest policy challenges facing governments is how to co-ordinate the dynamic technological effects of environmental policy with the environmental effects of innovation policy. Both environmental policy and innovation policy are designed to deal with externalities – on the one hand, those arising from the physical externalities associated with the environmental impacts of economic systems and, on the other hand, the economic externalities arising from the inevitable "leakage" associated with research, development, innovation and diffusion. The issue, therefore is how to co-ordinate policy efforts to internalise these "dual" externalities.

Three general prescriptions hold significant potential:

- Combine a flexible, incentive-based environmental policy – which focuses on the direction of technological change – with a technology policy designed to increase the rate of innovation.

- Embed innovation policy in environmental policy, by targeting policy instruments towards technologies that will offer a source of potential environmental prevention and remediation.

- Embed environmental policy in innovation policy, by increasing the saliency of environmental criteria in policies and programmes that support technology development.

Conclusions: knowledge and action imperatives

The Workshop on the Environment and Innovation brought into relief a significant body of scholarship and experience that has already mined the relationship between environmental policy and technological change. Particularly in the context of regulation, but more recently as well with respect to a

wide range of new, experimental policy initiatives, much is known about the technology impacts of environmental policy. In summary of the consensus judgement, one can be confident that there is no "magic instrument" of environmental policy that can produce innovation, and that the only sensible approach is to tailor and fine-tune policy instruments to fit the context. To accomplish this will require consistently better information, an improved policy mix, and better judgement in implementation.

Much less attention has focused on the relationship between innovation policy and environmental policy. While some encouraging examples of policy coherence were discussed at the workshop, they are the exception rather than the rule. It seems fair to say as well that the conceptual and research base for policy coherence in this regard is no more advanced than concrete policy action.

Perhaps the greatest lacuna in the knowledge base for sensible policies is the lack of any current map of the process of environmental innovation in the private sector. Data on the environment industry – the traditional source of technology – are still fragmentary. Even more seriously deficient is an understanding of the modalities of innovation in firms and other institutions outside this industry. In short, little is known – although much is speculated – about what motivates companies to move towards an environmentally sustainable future, or how they will do so.

The complexity of today's innovation scenario also suggests that there is a wide range of actors who are not adequately being enlisted in the policy process for environmental sustainability. Leading individual firms, co-operative ventures in the private sector, financial institutions, NGOs, academic and research institutes, new firms and entrepreneurs and consumers can all contribute to a climate of policy experimentation. If a radically new technological trajectory is necessary to produce a sustainable future, then new policy pathways must be forged as well.

NOTES

1. See Chapter 2 of this volume.

2. See Chapter 3 of this volume.

3. See Chapters 4 and 5 of this volume.

4. See Chapters 6, 7 and 8 of this volume.

5. See Chapters 9 and 10 of this volume.

6. This is based on the panel discussion and remarks by its moderator, Nick Johnstone, OECD Environment Directorate.

Chapter 2

INNOVATION FOR ENVIRONMENTAL SUSTAINABILITY: A BACKGROUND

by

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Summary

Innovation can play a crucial role in contributing to the environmental sustainability of growth. This is because environmental sustainability requires radical changes in the nature of goods and services that are produced as well as the way they are produced, distributed and used. Because of the externalities involved in their development and diffusion, it is clear that environmental innovations suffer from market failure. Also, because of the complex nature of environmental innovations that require a transdisciplinary and intersectoral approach, innovations for environmental sustainability suffer from systemic failure.

There are a number of obstacles in formulating effective policies to address these market and systemic failures. One is the diffuse nature that characterises environmental technology or innovation. Any technology can become environmental technology when applied with the objective of enhancing environmental performance. Many innovations in other areas such as energy, for example, have significant environmental impacts. Structural changes in the economy resulting from the diffusion of ICTs also have environmental impacts by reducing the demand and production of polluting goods and services. Also, the ongoing shift from the predominance of end-of-pipe techniques to cleaner technologies further adds to the diffuse nature of environmental innovations and the consequent difficulty in defining the boundaries of both environmental R&D and the environmental goods and services industry.

These characteristics of environmental innovation make it difficult for firms to formulate corporate strategies to enhance environmental performance. For some time, corporate responses have been defensive and reactive but, more recently, corporate attitudes have become more proactive and positive with the realisation that enhancing environmental performance presents business opportunities, through the shift to cleaner technologies that enhance firm-level resource efficiency. This trend has given rise to the double-dividend argument that environmental regulations can induce dynamic efficiency gains by the firm through innovation, although this has met with criticisms about the level of actual cost as well as the nature of the benefits gained. Lack of indicators and disaggregated data hinder drawing satisfactory lessons from this debate. It is now widely viewed that the factors that drive firms to innovate environmentally make up a

* Some parts of this chapter draw on the recent paper by Fukasaku (2000).

complex incentive structure which encompasses regulatory, commercial as well as social awareness factors. Organisational innovations within the firm, including re-orientation of R&D, play an important part, and co-operative forms of action through networks of collaboration and learning both within and extending beyond the boundaries of the firm play a crucial role.

Because of the characteristics of environmental innovation and the complexity of the incentive structure that drives firms to innovate for environmental sustainability, it is not easy to design effective public policies to address the market and systemic failures involved. So far, there has been a lack of coherence between environmental policies and innovation policies. The former had long been largely based on technology specification and performance standards of the command and control type that stifled innovation or ignored cost effectiveness. This is giving way to the integration of more incentive-based tools such as economic instruments and voluntary agreements that give more flexibility to firms. The transformation in the regulatory regime is facilitating the shift to cleaner technologies. In addition, experiences with some economic instruments, such as the tradable sulphur dioxide permits programme in the United States, indicate that this can induce cost-effective innovations on the part of the firms concerned.

The importance of R&D itself and the need to re-orient R&D strategies, as well as the systemic failures involved, point to the crucial role of research and innovation policy in stimulating environmental innovations. Innovation policies had long ignored environmental sustainability because of its vague link to commercial interests. However, as the commercial value of environmental innovations is becoming clear, this trend is changing. The issues involved are leveraging R&D funding, promoting co-operative approaches, identifying potential future technologies and linking the research base with the market, and exploring the commercialisation of relevant technologies. These are being pursued through such instruments as public/private partnerships, technology foresight, promotion of innovative clusters, and strategic niche management. Such active innovation policy instruments are necessary to overcome the systemic barriers to enhancing relevant research and innovation for environmental sustainability.

Introduction

It is now widely accepted that innovation plays a crucial role in placing our development path on a trajectory of environmental sustainability. This is because environmental sustainability requires radical changes in the goods and services we produce and the ways in which we produce, distribute and use them, while sustaining economic growth. This piece of common sense took sometime to penetrate our way of thinking since during most of the course of industrial development, economic growth entailed parallel growth both in resource consumption and environmental degradation. However, experience in the last few decades indicates that economic growth and growth in resource consumption and environmental degradation can to a considerable extent be de-linked. The path to environmental sustainability lies in maximising this de-linking process.

Despite its crucial role, it is not clear under what conditions innovations for environmental sustainability are stimulated. In order to understand the relationship between environment and innovation, it is first necessary to understand the nature of the externalities involved. It is pointed out that this is dual in nature in that, on the one hand, technology can generate negative environmental externalities and, on the other, technological innovation can generate positive economic externalities (OECD, 2000a). Technology after all, is a double-edged sword, and in fact, for a long time, as far as environmental sustainability was concerned, technology was held responsible for generating mainly the negative externalities. This perception impeded the pursuit of the use of the other edge, the exploitation of the positive economic externalities of innovation for environmental sustainability.

Even if the positive economic externalities of environmental innovation are recognised, compared to innovations that are directly linked to profit increase, innovations for environmental sustainability are far

more difficult to stimulate, since the profit motive often is not the direct driving force. The benefits of environmental improvement are largely public, but this public benefit is gained through investments for environmental amelioration by the private sector. This incongruity of the public and private benefits results in private investments which are sub-optimal in addressing the longer-term costs of environmental degradation and reducing the gap between the positive externalities related to innovation and the negative externalities associated with economic growth, thus making environmental innovations a typical case of market failure.

It is clear that the factors that constitute the driving force for environmental innovations are necessarily more complex than for innovations driven directly by the profit motive. This stems not only from the externalities involved but also from the complexity and diffuseness of environmental innovations. In public policy, formulating coherent policy measures is hampered by the fact that environmental innovations are influenced by measures taken in several policy domains, for many of which stimulating innovation has not been a major consideration. There is a need for greater policy coherence, with a particular requirement for environmental policy measures to be designed in such a way as to stimulate innovation and dynamic efficiency, and for innovation policy to explicitly address environmental sustainability. What is innovation for the environment?

Until recently, the term environmental technology was more often used to describe pollution control or end-of-pipe technology and equipment such as de-sulphurisation plants, that were developed to comply with regulations to improve air, water and other pollution problems introduced several decades ago. Since then, however, technology to counteract pollution and improve the environment has considerably diversified. To a large extent, this is due to the shift in emphasis on cleaner technologies which, in turn, is a result of the shift in focus towards more flexible and incentive-based regulatory tools such as economic instruments and voluntary agreements. Any technology can become environmental technology when applied with the objective of improving the environment, and this extends from technology embodied in tangible equipment to a broad range of innovations including organisational and systemic innovations.

This changing characteristic of environmental technology or innovation is reflected in the increasing difficulty of defining and measuring the environmental goods and services industry. This sector covers a heterogeneous set of goods and services and has as its core a group of firms that supply technology or equipment for "end-of-pipe" clean-up, water and effluent treatment, and air pollution and noise control.[1] However, there is no agreement on criteria to establish the boundaries of the industry, which in turn is due to the growing importance of cleaner technologies. These are difficult to measure, because improvements which are less polluting cannot be separated from general improvements which are more efficient, use less resources and produce less waste or harmful by-products. Despite these difficulties, available evidence based on the "core" activities of the industry, indicates its market size in the OECD area in the order of USD 250 billion in the mid-1990s (comparable to the pharmaceutical and computer industries) and growing at about 5% a year. These figures are based on national statistics that normally exclude cleaner technologies, but with the general shift in innovative response from end-of-pipe technologies to cleaner ones, there is little doubt that these are growing rapidly. In the long run, cleaner production processes and products will reduce the need for "end-of-pipe" solutions, thus changing the structure of the environment industry and the relative importance of its core group of activities (OECD, 1996). The growing importance of cleaner technologies is likely to increase the role of small and medium-sized enterprises (SMEs), since cleaner technologies allow for entrance of specialised firms, likely to be based on emerging technologies such as ICT and biotechnology, that serve niche markets in the user industries.

It should be noted that the environmental goods and services sector is not the only sector responsible for environmental innovations. Innovations in a wide range of industries have significant environmental impacts. Innovations in power generation in terms of the type of fuel used and energy-efficiency gains have significant environmental effects when they are deployed. Some innovations induce structural changes in the economy, generating "unintentional" environmental benefits. The diffusion of ICTs is the case in point. The diffusion of these technologies is inducing structural shift away from traditional

manufacturing towards a wide range of service industries that are less resource intensive; hence, reducing negative environmental impacts (Romm *et al.*, 1999).

The shift towards cleaner technology also highlights the importance of organisational innovations in responding to the challenge of environmental sustainability. Enhancing resource efficiency which, in large part, depends on getting more out of energy and materials inputs and reducing wastes, depends not only on machines and equipment but how these are used in the production processes; in short, how the production processes within a firm or industry are organised. Also, designing more environmentally friendly products requires R&D and design capacity which are fostered through appropriate organisational innovations. Kemp and Arundel (1998) argue that the links between organisational change and environmental innovation go further than that required for other types of innovation which are based on direct profit motives, since incentives for environmental innovation are more complex and include regulations, better customer relations and social awareness.

As an area where knowledge and technology from diverse disciplines need to be combined to produce new and more efficient solutions, environmental innovations are underpinned by R&D. The shift towards cleaner technologies and pollution prevention rather than control implies increased importance of R&D, especially in applying emerging technologies. As yet, government R&D budget appropriations for environmental research in the OECD area remain small, at about 2%. Here again, as with the environmental goods and services industry, boundary definition problems arise and this is further complicated by the fact that the boundaries are defined differently according to the country. However, in all likelihood, this percentage clearly rises to about 5% when appropriations for environment-related research on other objectives, such as energy, agriculture and the atmosphere are added. Also, it is clear that the percentage is growing. For countries with large environmental goods and services industries, such as the United States, Japan and Germany, there is more active industry participation in environmental research (OECD, 1998a).

Not only is market failure inherent in environmental innovations as mentioned above, the fact that they constitute an application area in which innovations arise from research and development in different scientific and engineering disciplines in both public and private sectors, implies that environmental innovations are prone also to systemic failure. Insights from advances in various basic and applied sciences and engineering disciplines need to be combined to generate optimal solutions to enhance environmental performance. The shift towards cleaner processes and products amplifies the importance of interdisciplinary and intersectoral approach in environmental innovations. The optimal solutions may be found in an area remote from the core competence of the firm in search of such solutions. This implies that the market and systemic failure characteristic of environmental innovations may have a synergistic effect. The lack of investments in R&D arising from market failure may reinforce the barriers to generating knowledge about new techniques arising from systemic failure, thus creating a vicious circle hindering innovations. Here public policy has an important role to play in addressing these market and systemic failures to match demand and supply of appropriate innovations.

The market and systemic failures are aggravated by the complexity of the issues that environmental sustainability poses as a challenge for the socio-economic system. Roome (1992) argues that the environmental issues present a complex “problematic”, which arises from the fact that the environmental resources and constraints which are important to society are components of complex overlapping ecological, physical and human systems that are difficult to disentangle. The complexity of the issues demands cross-disciplinary interpretation and perspectives, requiring a systems approach to analysis and problem-solving; this ultimately requires that co-ordinated responses to environmental issues are fashioned by teams working across conventional disciplinary and organisational boundaries. It also arches across the public and private domain, obliging businesses to reconsider the boundary between private and public concerns and raising questions for corporate governance about the extent to which public interests should enter into private decisions.

What drives firms to enhance environmental performance?

The complexity of the environment "problematic" translates itself as the complexity in the responses it requires of the corporate sector. It is now widely viewed that the factors and incentives that drive firms to enhance environmental performance are complex (Roome, 1992, 1994; Kemp and Arundel, 1998). The shift towards cleaner technology further adds to this complexity, since this shift implies increasing diversity in the corporate response to environmental challenge. Galarotti (1995) argues that this diverse and complex set of factors creates a "managerial incentive structure" which serves as a basis for formulating corporate strategies. This incentive structure covers all dimensions of corporate management, from supply- and demand-side considerations, interdependencies in production and distribution to financial incentives. As a corporate response, these include: the need to take an integrated approach in enhancing eco-efficiency through technological and organisational innovations including inter-firm networking and co-operation; exploiting market demand for differentiated environmental products; creating "green" supply chain through procurement; and responding to the increasingly "green" corporate governance structure by improving the corporate environment performance.

One needs to realise that the corporate sector has not always been ready to respond to the complex strategic challenge of environmental sustainability. In fact, for some time the corporate response was defensive and reactive towards environmental regulations, and was characterised by "resistant adaptation" of minimal compliance to regulations, resistance to the introduction of new ones and the general reluctance to internalise environmental issues (Howes *et al.*, 1997; Fischer and Schot, 1993). Some time during the 1980s, however, this gave way to a more proactive and positive approach to enhancing environmental performance. This transformation in corporate attitude became manifest, for example, in the "Declaration of the Business Council for Sustainable Development", prepared to express the position of the Business Council for Sustainable Development at the Rio Earth Summit in 1992 (Schmidheiny, 1992). The declaration makes a clear commitment to sustainable development, with an understanding that economic growth is basic to achieving it and that new technologies are needed to permit growth while enhancing resource efficiency. It declares that "progress towards sustainable development makes good business sense because it can create competitive advantages and new opportunities", but at the same time it requires "far-reaching shifts in corporate attitudes and new ways of doing business".

What lay behind this shift in corporate attitude towards the environment? Two factors can be considered. One is the effect of regulations, and the other the commercial benefits of implementing environmental innovations. It is clear that over the past two decades environmental regulations have shifted away from command-and-control-type measures based on specific technology towards increased use of incentives for improved environmental performance. Most probably in accordance with this trend, there is some statistical evidence that the corporate response is shifting towards increased use of cleaner technologies. Lanjouw and Mody (1996), for example, show that the distribution of pollution abatement expenditure in the fields of air and water in the US manufacturing sector indicates a growing share of "change in process" and decreasing share of "end-of-pipe" throughout the 1980s.

Parallel to this transformation in the corporate sector, there has arisen a lively debate about the economic effects of environmental regulation on competitiveness. On the one hand, conventional economic thinking considers that developing environmental technologies for controlling pollution and improving environmental performance incur high cost to firms and would have the macroeconomic effects of stifling economic growth and competitiveness. A review of empirical studies examining the effects of environmental regulations on international competitiveness and investments, and industrial productivity in some sectors (Jaffe *et al.*, 1995), however, concludes that there is little statistical evidence of the adverse effects of environmental regulation on competitiveness, investments and productivity. On the other hand, there has emerged another line of argument by business management researchers, that contends that, on the contrary, regulations can, in fact, reduce production costs and stimulate growth and competitiveness. This

argument has been advanced mainly by Porter and van der Linde (Porter and van der Linde, 1995) and has come to be coined as the "Porter hypothesis".

At the core of the Porter hypothesis is the corporate benefits of pursuing dynamic efficiency gains through innovation which, in turn, are spurred by a "learning process" to overcome the resource inefficiencies that environmental regulations signal to firms. Environmental innovations can thus "offset" the cost of regulatory compliance through the dynamic innovation process, which in turn strengthens the competitive position of the firms and the industry. This generates the so-called win-win situation, being able to reap both the public and private benefits through regulation. A great deal of anecdotal evidence of such "innovation offsets" is cited.

This win-win hypothesis has met with criticisms both from environmental economists and other management researchers. Environmental economists point to the relative insignificance in terms of cost saving of such innovation offsets. Based on the analysis of the estimates of "cost offsets" associated with pollution abatement expenditures in the United States collected by the Department of Commerce's Bureau of Economic Analysis, which, according to the definition employed, includes both product and process offsets, Palmer *et al.* (1995) argue that these constitute less than 2% of estimated environmental expenditures. Walley and Whitehead (1994) criticise the easy win-win rhetoric of the Porter hypothesis by pointing to the fact that regulatory compliance is costly, especially in the traditional "dirty" industries such as petroleum, chemicals, and pulp and paper. They argue, however, that from the corporate point of view, the crucial issue is not so much the cost of regulatory compliance itself, but in using corporate spending for environmental improvement through such corporate strategies so that the shareholder value of the firm is also increased.

The debate surrounding the win-win or the double-dividend argument raises a few important issues for innovation policy. One is that whether significant net cost is involved or not, it is clear that the debate places innovation at the heart of the corporate response to improving environmental performance. There is some statistical evidence of this. A study correlating the relationship between environmental expenditures, on the one hand, and patenting in environmental technologies, on the other, has found that in the United States, Germany and Japan, environmental expenditures have spurred increased patenting in environmental technologies (Lanjouw and Mody, 1996). Another study has found that increases in compliance expenditures within an industry in the United States are followed by associated increases in R&D (Jaffe and Palmer, 1996). However, it still remains an unanswered question whether regulation-inspired R&D leads to lower costs of production or new and improved products in the future.

These studies point to the difficulty of establishing a causal relationship between changes in production costs, R&D inputs and process and product innovations, because of the unavailability of disaggregated data. Thus, as is also pointed out by Kemp and Arundel (1998), the double-dividend debate raises the issue of the general paucity of indicators on environmental innovation. In part, this is due to the lack of standardised environmental accounting methods that can be used by industrial firms, and the resulting lack of statistical information on cost and benefits. Development of such methods and the accumulation of relevant data is a gap that public policy could fill through intensified efforts by international organisations and national governments.

The few surveys that have been carried out (Green, *et al.*, 1994; Malaman, 1996) are at the national level. The Italian survey (Malaman, 1996) used the literature-based innovation output (LBIO) method in selecting environmental innovations developed by Italian companies between 1970 and 1995. The study found that product and process innovations are often linked with process changes leading to cleaner products, input substitution, energy saving, recovery and recycling. The adoption of cleaner technologies was highly dependent on environmental regulations. While reduction in production costs was observed in about half the cases, their development was not always dependent on links with fundamental research, but was often based on targeted use of available technologies.

Green *et al.* (1994) study sought to identify factors that drive UK firms to innovate more environmentally friendly products and processes, and to investigate the changes in R&D activity they have undertaken to facilitate such innovation. This was done through a questionnaire survey in 1993, sent to a sample 800 firms of all sizes and manufacturing sectors that had expressed an interest in the UK Department of Trade and Industry's Environmental Technology Innovation Scheme. The statistical analysis of this survey shows significant correlation between the influence of regulation and of commercial factors as driving forces for environmental innovation. Particularly strongly correlated were: the anticipation of regulation; the fear of rival products; and the threat to market share. According to the authors, this could be taken as an indication of a growing awareness of the longer-term competitive significance of being seen to be environmentally friendly and a commitment that goes beyond compliance. The study also shows that the greener social pressures exerted from outside the firms (the greener "selection environment"), have stimulated many firms to re-examine the technological bases of their activities, including a strategic re-orientation of the various aspects of the conduct of their R&D.

These studies point to the importance of taking into account the social values in business strategies and operations and proves the complexity of the incentive structure that drives firms to improve environmental performance. The incentives include not only regulatory and commercial ones, but also enhancing corporate value through taking socially responsible action through increased environmental awareness. Roome (1992) argues that the environmental problematic demands new forms of thinking and the development of strategies on the part of businesses towards the environment, including systems thinking and more co-operative forms of action. Various forms of organisational innovation play an important role. In particular, R&D and technology management for environmental innovations will need to be linked more firmly with a company's strategic planning, since process and product innovations will have to match "with the development and involvement in innovative forms of organisation" (Roome, 1994). The new forms of organisation encompass networks of collaboration and learning both within and with other companies and with stakeholder groups in society (Clarke and Roome, 1995). Recent WBCSD surveys of sustainable innovation confirm the importance of these. The results show that central to the success of these innovations is finding value-creating ways of responding to the diverse challenges that stakeholders pose regarding the role of business. This requires firms to extend the principles of transparency, and the tools of corporate social responsibility to encompass the full innovation process including research and development, technology selection, product and service design, and investment and employment policies. This requires firms to treat sustainability as a framework for business growth on which to extend established management principles including those for innovation management (see Chapter 7 of this volume).

Recent trends in environmental policies

In line with corporate response, public policy towards the environment has evolved over the last three decades. The change here is generally characterised by a shift away from a command-and-control-type regulatory regime based on technology specification to one that makes greater use of economic instruments. The change has been in the direction of putting in place a better incentive structure for improving environmental performance in the industrial sector through innovative responses, by integrating more flexibility in regulatory compliance.

It is argued that few environmental policy instruments employed in the past have stimulated innovation (Kemp, 2000). A study reviewing the innovation effects of various environmental policy tools concludes that some tools, most notably technology specifications, tend to stifle innovation, and in general, they differ in their effects on innovation (OECD, 1999a). Those that tend to have positive innovation effects, although in varying degrees, are product bans, performance standards, economic instruments and voluntary agreements. The basis of their positive impact is in the positive incentive and flexibility they introduce in regulatory compliance.

It is interesting to note that both the double-dividend argument and its critics agree that regulations are not equal in the kind of effects they have and point to the importance of incentive-based regulations. Porter and van der Linde (1995) contend that regulations need to be "properly crafted" to generate innovative responses and to enhance competitiveness. Such "properly crafted" regulations would be based on creating the maximum opportunity for innovation in which the industry, not the regulator, can choose the approach. Such regulations point to economic instruments such as pollution taxes and tradeable permits.

Jaffe *et al*. (1995) point out that environmental regulations are "not created equal" in terms of their costs or benefits, and argue that economic instruments are more cost effective than command and control type regulations. Hahn and Stavins (1992) assert that economic instruments are cheaper than imposing fixed technological or performance standards. This is because, under a market-based regulatory regime firms are likely to abate up to the point they find it profitable, and the firms that find it cheapest to reduce their levels of pollution will clean up the most. They provide ongoing incentives for firms to adopt new and better technologies and processes because under these systems it always pays to clean up more if a sufficiently cheap way of doing so can be identified and adopted.

Howes *et al*. (1997) summarise the advantages of economic instruments over standards as follows. First, in the short term, they can provide a given level of environmental improvement at a lower cost to society than is achievable by the introduction of standards by allowing the industry the flexibility to use the technology they judge to be the most efficient and appropriate for their circumstances. Second, in the long run, they can provide incentives for continual improvements beyond those demanded by fixed standards. These instruments could encourage polluters to change to cleaner technologies, and to develop new technologies since it pays to clean up more. Thus, the main benefits of economic instruments are their potential for stimulating more cost-saving approaches by allowing flexibility in the innovative response and the ability to create incentives for continued innovation to enhance eco-efficiency. These instruments clearly attach central importance to the dynamics of industrial innovation in promoting environmental sustainability.

Economic instruments have been applied in a number of contexts in OECD Member countries over the past few decades. Examples are water effluence charging in the Netherlands, Germany and France, NO_x charge and sulphur tax in Sweden, and the water effluence and sulphur emissions trading permits in the United States. However, despite their obvious theoretical advantages, evidence concerning their innovation effects are limited. One clear problem is the lack of data; however, a major difficulty in evaluating economic instruments is the fact that they are not applied independently, but are often used as

complements to more traditional regulatory regimes. Hence, there is difficulty in separating out their effects (OECD, 1997a).

Among the applications of economic instruments cited above, the most discussed example to date is perhaps the sulphur dioxide tradeable permits programme in the United States. This has been designed to encourage the electricity industry to minimise the cost of reducing sulphur dioxide emissions through the allocation of tradeable emission allowances. Allowance trading enables firms operating at high marginal pollution abatement costs to purchase permits from firms operating at low marginal abatement costs, thereby lowering the cost of compliance. The political factors that led to its design and implementation were the increased pollution control costs which had led to greater demand for cost-effective instruments. This was also designed to be an acceptable means of reducing total SO_2 emissions through the introduction of an emissions cap which was introduced along with the trading scheme (Burtraw, 1998; Stavins, 1998).

In terms of cost effectiveness, to date this programme has proved to be a great success. The marginal cost of compliance has been far less than projected at the time of the introduction of the programme. What were the factors contributing to this success? Title IV of the 1990 amendment to the Clean Air Act, under which the tradeable permits scheme was introduced, had allowed for the deployment of a variety of mechanisms to achieve compliance. These included intra-firm re-allocation of emission allowances, fuel switching/blending, installing scrubbers, retiring plants, re-powering plants, energy conservation, reduced utilisation and substitution among facilities. In fact, since 1990 the prices of abatement options underwent dramatic changes, stemming from changes in the prices of rail transport of low-sulphur coal and increased productivity in mining as well as from innovations in the use of fuel blending and in the design and use of scrubbers. As a matter of fact, not much trading took place. However, the trading programme did provide the incentive and flexibility to take advantage of the exogenous changes in input markets, including the decline in the cost and an increase in the availability of low-sulphur coal (Burtraw, 1996). It is clear that organisational innovations involving the firm, the market and the upstream suppliers played an important role (see Chapter 4 of this volume).

Fuel switching seems to have been a salient effect of the carbon tax in Sweden, introduced in 1991 as a complement to the country's existing system of energy taxes. This was mainly targeted at the residential and commercial sectors, with the industry and power generation sectors taxed at a lower level. The carbon tax stimulated the increased use of biomass in the Swedish district heating system. The increased demand for biomass has encouraged the development of new methods for utilising wood fuels which, in turn, has led to reduced prices for these fuels. However, it is pointed out that the impact of the carbon tax on energy and resource efficiency of the Swedish industry has been limited because of the lower tax rates enjoyed by the industry and because the most energy-intensive sector, the paper and pulp industry, mainly uses biomass and electricity instead of fossil fuels (see Chapter 5 of this volume).

These experiences with economic instruments in the past decade illustrate the importance of appropriate resource pricing in enhancing environmental sustainability through innovation. As put forward by Schmidheiny (1992), the basic issue is "getting the prices right", that is achieving appropriate pricing of resources that reflect the environmental cost of their use. Resource price changes can induce *de facto* environmentally friendly behaviour by stimulating cost-saving behaviour associated with improved resource efficiency. This can be seen in the Japanese industrial sector response to the petroleum crises of the 1970s, in which the petroleum price increase in the overwhelmingly petroleum-dependent economy provided a powerful incentive for energy-conservation efforts in the polluting mature sectors. The result was not only enhanced energy efficiency, but also the enormously improved environmental performance and perhaps the increased international competitiveness of many of these sectors in the 1980s (Fukasaku, 1995).

In product innovation, a study has found that increasing energy prices had an observable effect on which technically feasible models of air conditioners and gas water heaters were offered for sale in the United States over the last four decades. This "model substitution" effect was particularly strong after

product-labelling requirements went into effect. The empirical evidence suggest that 25-50% of the improvements in the energy efficiency of new models of air conditioners and gas water heaters were associated with rising energy prices since the first petroleum crisis in 1973 (Newell *et al*., 1999). Thus, energy pricing definitely has energy-efficiency-enhancing innovation effects. At the macro level, it is suggested that in order to eventually lower absolute energy consumption, as is the case in meeting CO_2 emission reduction targets, appropriate energy pricing needs to be coupled with active innovation programmes (Birol and Keppler, 2000).

The importance of appropriate pricing lends support to the importance of designing suitable economic instruments. However, in real life, it is often not easy to implement economic instruments. The introduction of regulatory regimes based on market instruments has been impeded by opposition from industries or disagreement about appropriate levels of taxes or charges, for example, in the case of the failure to institute an EU-wide carbon/energy tax and a system of tradeable sulphur quotas. Howes *et al*. (1997) observe that the process of negotiating a market-based instrument can be as tortuous as negotiating a traditional regulatory instrument, since a greater number of actors are involved, and often the industry is nervous about ceding more revenue-raising powers to government through taxation. Tradeable permits can set companies against each other whereas with traditional regulation, companies can enter a common cause against the government. Thus, although there is considerable consensus that economic instruments, in principle, offer a constructive way forward, they raise problems of equity and new procedural problems concerning their negotiation.

These practical problems of designing and implementing economic instruments, point to the importance of exploring and implementing other approaches. Another environmental policy approach that is in increasing use is voluntary agreements (VAs). Like economic instruments, VAs are not applied independently, but operate in the context of existing or new policy mixes where different policy instruments are combined. So far, these are used in the context of traditional regulatory regimes, but in the future, combination with economic instruments may be implemented in the context of new policy mixes to meet Kyoto targets.

Voluntary agreements are categorised into three types: *i)* public voluntary programmes involving commitments devised by the environmental agency to which individual firms are invited to participate; *ii)* negotiated agreements involving commitments for environmental protection developed through bargaining between a public authority and industry; and *iii)* unilateral commitments which are set by the industry acting independently without any involvement of a public authority. It is pointed out that as both empirical and theoretical economic analysis of voluntary approaches are still underdeveloped, assessment of their performance remains limited. Presently, it is argued that VAs are unlikely to provide firms with strong incentives to innovate due to the fact that they rarely set technology-forcing targets, but they are likely to generate significant “soft effects” in terms of dissemination of information and awareness-raising (OECD, 1999b).

Voluntary programmes often constitute a first step in exploring a new policy area such as climate change and waste recycling which entered the political agenda in the 1990s. This is the case with the Keidanren Voluntary Action Plan on the Environment in Japan, mainly designed to reduce CO_2 emissions to meet Kyoto targets. In Japan, there has been a pervasive use of negotiated agreements concluded at the local level, but the Keidanren programme is an example of unilateral commitment by industrial associations belonging to the Keidanren. The main rationale for the adoption of the Voluntary Action Plan seems to have been to avoid further government regulation and strong administrative guidance (OECD, 1999c). The cost of further regulatory action could impose a high cost on the Japanese industrial sector which already operates at a high level of energy efficiency and whose marginal cost of CO_2 reduction is high. Also, since in Japan in general neither the government nor the industries are in favour of energy/carbon taxes, voluntary approaches provide a way forward under the circumstances. However, this

plan does not appear to operate in complete isolation from government guidance, but involves reviews by government councils (see Chapter 6 of this volume).

Recent trends in innovation policies

The newer environmental policy approaches thus provide incentives for innovation. However, from the public policy point of view, because of the inherent market and systemic failures involved, reforms in environmental policy need to be complemented by strong initiatives from innovation policy to push forward the rate of innovation for environmental sustainability. It is argued that governments will need to employ a broad range of policy mechanisms that can effectively and synergistically create new technologies and new markets (see Chapter 8 of this volume). Also, some researchers see the need for government authorities to be explicitly concerned with technical change and be concerned with changing institutional arrangements, which in turn requires policies targeted at the determinants of innovation (see Chapter 3 of this volume).

Technology development depends on the effectiveness of the R&D efforts both in the public and private sectors. Definition and boundary problems aside, the share of environmental research and development in total government budget appropriations to R&D has increased in most OECD countries since 1980 (OECD, 1998). However, it is pointed out that in general, it is difficult to evaluate what types of support would be an appropriate and efficient use of public funds for environmental research and development (OECD, 2000a). In a survey of American firms in the environmental technology sector there was a wide consensus that firms had insufficient commercial incentive to undertake basic research, concentrating on more applied research with clearer short-term benefits. However, the firms also reported that a large share of original basic research which eventually led to important environmental innovations was not directly targeted towards an environmental problem (Environmental Law Institute, 1997). These results point to the gravity of the market failure in inducing sufficient investments especially on the basic end of the research and development spectrum, on the one hand, and, on the other, the importance of the serendipity factor in R&D for environmental innovations.

These characteristics of R&D relevant for the environment point to the importance of public support for research and development directed at environmental sustainability. Public support may be increasing in general, but its relative share of 2 to 5% of total government R&D appropriations is not large. Whatever the absolute funding level and whether it is increasing or not, it is important to enhance the effectiveness of existing budget allocations. This is probably the rationale for the increasing trend among OECD Member governments to adopt public/private partnerships to leverage private funds in environmental research (OECD, 1999a). Such partnership programmes to promote research and development attempt to stimulate R&D at various stages from basic to near-commercialisation stage, with the public funding share larger at the basic end. It is a characteristic of such public/private partnerships in the area of environmental innovation that many of them involve a variety of public and private actors in collaborative research efforts. Thus partnerships approach can address the systemic failure in R&D activities to enhance environmental sustainability.

Environmental sustainability is a long-term policy objective and the nature of innovations that contribute to this is not only broad, but has changed rapidly. It has been shown that emerging technologies such as biotechnology can make significant contributions (OECD, 1998b). A review of a number of technology foresight studies conducted in the 1990s shows that in the OECD Member countries, identifying technologies that can contribute to environmental sustainability is becoming increasingly important. A broad range of future technologies can be identified from these foresight studies that in the long range are viewed to contribute significantly to sustainability. The list includes applications of biotechnology and information and communication technologies, new materials and micro-scale manufacturing, new energy technologies, and innovative waste treatment and recycling technologies

(Fukasaku, 1999). Thus, focused foresight can identify research areas and technologies that are likely to contribute in an important manner to environmental sustainability.

The identification of future technologies needs to go a step further to make them real innovations. Some national foresight programmes in fact are taking this step. The need to link the public research base and the market was a major conclusion of the first round of the UK Foresight Programme undertaken in the early 1990s. The new round of the recently launched foresight exercise is doing exactly this. This programme moves in three stages from the identification of potential future technologies to the stimulation of private initiative to commercialise such technologies. The most recent attempt is to link the foresight exercise to regional cluster development (see Chapter 10 of this volume).

The Finnish Environmental Cluster Programme is one of the seven cluster programmes that the government has funded for 1997 to 2000. The objective of the programme is to improve the quality of the environment by promoting eco-efficiency, stimulate the development of new environmentally friendly products, and encourage entrepreneurship and create new jobs. It targets the emerging environmental goods and services industry, one of Finland's fastest growing sectors. The government provides seed funding for research on new environmental technologies to be carried out by consortia of producers and suppliers, universities and institutes. Collaborative projects enhance networking among researchers and users and facilitate innovation. Projects have been launched which aim at improving eco-efficiency through the application of life-cycle techniques in agriculture, forestry, basic metals and water management (OECD, 1999d; see also Chapter 9 of this volume).

Some of the innovations that contribute to environmental sustainability address the issue of transforming large infrastructures that have been built up over the long term. Transportation and power generation infrastructures are cases in point. And, it is clear that the existing infrastructures that accommodate increasing traffic and fossil-fuel-power generation with complex grid infrastructures are probably not sustainable in the long range. However, the relevant innovations that address these areas are necessarily systemic and, in order to induce systemic innovations, some researchers argue for the need to design new innovation policy tools, such as strategic niche management (Kemp *et al.*, 1998; Kemp *et al.*, 2000). Strategic niche management is a means of trying out new systemic technologies in a selected environment - niches - by real users. In niches, the technology is temporarily protected from full selection pressures of the market and the niche acts as a test-bed and incubator for the new technology. This has been applied in introducing the use of light-weight vehicles in a Swiss town, and in developing organised car sharing also in Switzerland.

Stimulating innovation for environmental sustainability: the role of policy

The discussion in this chapter demonstrates the importance of public policies and their appropriate design in both environmental and innovation policies, in order to move towards the objective of environmental sustainability by addressing market and systemic failures. Public policies need to be aware of the diffuseness of environmental innovations as well as of the complexity of the incentive structure that drives firms to innovate environmentally, in order to design and implement suitable policies.

It should be borne in mind that environmental sustainability is a long-term objective and ultimately requires radical changes to the existing socio-economic system. In this sense, this objective will in the future, determine the direction in which the techno-economic system will evolve. In accordance to this direction, the present technological regimes or paradigms will need to evolve. The role of public policy is to facilitate this transformation.

Environmental policies need to be designed to stimulate dynamic efficiency, and need to be flexible and incentive-based. Recent experiences with economic instruments and voluntary agreements seem to point to the effectiveness of these instruments but also demonstrate the difficulty in arriving at acceptable

design. Innovation policy approaches need to look for creative ways to enhance co-operation across sectors from research and development to commercialisation and market embedding of new technologies. Emerging innovation policy approaches such as public/private partnerships, technology foresight, innovative clusters and strategic niche management, when properly designed, hold promise of identifying, promoting and commercialising potential technologies that will lead to environmental sustainability.

NOTE

1. In addition to these core activities, the environmental goods and services industry normally includes four other activities: energy response/clean-up, environment assessment and monitoring, environmental services, and energy and urban amenities (OECD, 1996).

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PART I

ENVIRONMENTAL POLICIES TO STIMULATE INNOVATION

Chapter 3

TECHNOLOGY AND ENVIRONMENTAL POLICY: INNOVATION EFFECTS OF PAST POLICIES AND SUGGESTIONS FOR IMPROVEMENT

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Introduction: technology impacts of environmental policies

There exists a small literature on the impact of actual environmental regulations on compliance innovation and clean technology. This literature consists of the work of Ashford and Heaton in the 1980s in the United States, Kemp (1997) and a number of German studies (Hartje, 1985; Hemmelskamp, 1997; Klemmer, 1999). The focus of these studies is on technical innovation, not on organisational innovation. What these studies show is that the technology responses range from the diffusion of existing technology, incremental changes in processes, product reformulation to product substitution and the development of new processes. The most common responses to regulation are incremental innovation in processes and products and diffusion of existing technology (in the form of end-of-pipe solutions and non-innovative substitutions of existing substances). Often, the new technologies are developed by firms outside the regulated industry, which means that, in the past, industry was reliant upon suppliers, capital goods suppliers and environmental technology suppliers. (This is changing with the growing attention in environmental policy and industry to prevention and product change.) The studies also show, unsurprisingly, that the stringency of the regulation is an important determinant of the degree of innovation, with stringent regulations such as product bans being necessary for radical technology responses. Technology-forcing standards appear to be a necessary condition for bringing about innovative compliance responses. The studies also show that long before the regulations are promulgated there is a search process for solutions to the problem, both by the regulated industry (mostly for defensive reasons), their suppliers and outsiders. This happened in the case of PCBs and CFCs where firms both in and outside the chemical industry were looking for substitutes ten years before the use of PCBs and CFCs was banned (Ashford *et al*., 1985). Of course, the certainty that their product or activity would be subject to regulations was an important factor.

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* This chapter draws on earlier work done by the author on environmental policy instruments and environmental innovation, published in his book *Environmental Policy and Technical Change*, and recent work for two Dutch research projects, PRET and MATRIC.

As to the nature (incremental or radical, product- or process-related) and the source of technological solutions, an internal OECD report established that:

- High volume, mature sectors were resistant to change, although very amenable to environmental monitoring and process controls that improved efficiency. This fits with the Abernathy-Utterback product life cycle model that during the life time of a product a sector becomes rigid, especially those sectors that are capital intensive. An alternative explanation is that such sectors are powerful and able to fight off regulations that require a major change in their process technologies.

- Significant process innovations occurred in response to stringent regulations that gave firms in the regulated industry enough time to develop comprehensive strategies. There is a trade-off between achieving quick results and radical change.

- Smaller firms and potential new entrants tended to develop more innovative responses. A possible explanation for this is that incumbent firms, especially the big ones, are vested in old technologies – both economically and mentally.

- The environmental goods and services industry provided compliance strategies that were at best incrementally innovative but which diffused fast due to their lack of disruption and acceptability to regulators.

- Regulatory flexibility towards the means of compliance, variation in the requirements imposed on different sectors, and compliance time periods were aspects of performance standards that contributed to the development of superior technological responses.

What the studies show is that technology responses are not a simple response to regulatory pressure. Apart from the regulatory stimulus, many other factors exercised influence. This suggests that the stimulus-response model is too simple. For one thing, it assumes that social innovation starts with regulation, which is most often not the case. Regulation is not the be-all and end-all of social innovation. The knowledge for such innovations is usually available, regulations may provide the leverage or some extra stimulus for the exploitation. Regulation is but one of many stimuli. It may, in fact, not be needed for environmental innovation. Many technologies producing environmental benefits are adopted for normal business reasons of reducing costs and enhancing product quality. These options are referred to as eco-efficiency options.[1] However, even for environmentally beneficial technologies that do not combine environmental gains with economic gains, regulation may not be needed. In the case of an environmentally harmful product, there will always be pressures to reduce the harm. These pressures come from a range of actors: insurance companies, banks, customers, employees, environmentalist groups and consumer organisations through product tests that include environmental aspects.[2]

When the early synthetic detergents of the 1960s created very visible environmental problems (foam in surface water), the detergent companies and especially their suppliers developed new processes leading to biodegradable synthetic detergents, without government regulation (although with the expectation that there might be regulation in the future). The voicing of concern and the threat of regulation may be enough to induce industry to look for alternative solutions. This does not absolve the need for regulation. Regulation will be needed for the widespread diffusion of environmental technologies.

One should be careful in using regulation for promoting innovation. Given the information problem of the government, the threat of regulation may be a better means to stimulate technological innovation than actual regulations (Rip and Kemp, 1998). It is hard to craft regulations that are not disruptive in some sense. Environmental innovations, like any other type of innovation, must meet a variety of goals: they

should be expendable; it should be possible to fit them into existing processes; and, in the case of products, they should meet user requirements in terms of performance characteristics. Water-saving shower heads should be comfortable (have sufficient stream power) and environmentally improved detergents should have good washing performance. User benefits and social performance benefits must be balanced and co-optimised. It is the need for co-optimisation that creates a problem for innovators and for environmental regulators. For example, it proved to be very difficult to develop phosphate-free detergents with equal washing power to the phosphate-based ones. In the search for a phosphate substitute detergent, companies spent more than USD 250 million. The current regulations on phosphate content co-evolved with the results of product tests (both toxicological tests and tests comparing washing performance) (Hartje, 1985).

The example of detergents shows that innovations can not simply be "elicited by legal fiat" (Heaton, 1990). This fits with insights from technology studies which say that technology can not be moulded in a pre-defined, socially desirable shape. This is why emission limits are based on assessments about what is technologically possible and economically affordable, and why environmental permits are often based on the concept of Best Available Technology or Best Practicable Means that are specified in BAT lists or guidance notes for permitting agents. There is a dynamic interplay between innovation and regulation, with innovations often paving the way for regulations. The stimulus response model fails to appreciate this dynamic interplay and circular causality.

The obvious implication of all this is that the governance of technical change is not a simple matter. It is difficult to design instruments that do the job and do it well – in the sense that society as a whole is better off. Evaluation studies of environmental policy instruments show that the instruments in themselves are either ineffective in achieving a set goal or outcome, or inefficient in terms of costs or technology choice. An example is the ONO technology used in the Dutch metal-plating industry to control the release of metals in waste water which led to the production of toxic sludge containing heavy metals which had to be treated

The remaining part of this chapter provides a discussion of experiences with various environmental policies, especially subsidies and covenants.

Subsidies

Subsidies are an important element of government policy towards technology. They are a primary instrument of innovation policy. As a politically attractive instrument, they have been an important part of environmental policies. In the Netherlands, several studies have been undertaken into the effectiveness of investment subsidies for environmental technologies. A common outcome of such studies is that subsidies had a limited impact on decisions. This was true for investment subsidies under the "Wet Investeringsregeling" (WIR), which found that investment subsidies for environmental technologies (at 15% of total investment costs) induced only 8% of firms to undertake investments they would not have done otherwise (Tweede Kamer, 1987, p. 39). The same result is found in a study by Vermeulen (1992) which analysed the effectiveness of three types of investment subsidies. The results of this study, based on a questionnaire (like the study of the WIR), are presented in Table 1.

Table 1. **The (non-)effectiveness of investment subsidies for environmental technologies**

	PCBs[1]	Silent trucks	Manure storage
Very effective	0%	2%	1%
Reasonably effective	37%	22%	20%
Hardly effective	13%	23%	3%
Not effective	50%	52%	76%

1. Polychlorinated biphenyls.
Source: Vermeulen (1992, p. 210).

According to the study by Vermeulen, the investment subsidies for the replacement of PCB equipment, quieter new trucks and the storage of manure were effective in only a small number of cases. The subsidies were the primary reason for investing in environmentally beneficial technologies in 2% of cases for silent trucks and 1% for manure storage. For PCB replacement equipment, the figure was even zero. The investment subsidies were reasonably effective for 37% of the firms that used PCBs. In all three cases, other factors were more important than the subsidies. These included: fuel economy, road performance and comfort in the case of silent trucks; health and safety considerations in the case of PCB replacement; and environmental regulations in the case of the manure storage.[3] According to Vermeulen, under the three programmes, NLG 200 million (about USD 125 million) were spent without having any effect on polluter's purchasing decisions.

The same was true for investment subsidies for thermal insulation under the National Insulation Programme (NIP) in the Netherlands, of which the author studied the effectiveness. Econometric analysis was used for this in the form of diffusion models that were fitted to the data. The statistical analysis established that there was only a weak positive relationship between the subsidies for thermal home improvements which totalled NLG 2 billion (USD 0.9 billion at the current exchange rate) and the diffusion of thermal insulation technologies: the coefficients of the dummy variables for investment subsidies were positive but not significantly different from zero at the 5% significance level. This result was confirmed by another study which asked applicants for the subsidy about their motivation for investing in thermal home insulation. Only 11% of the respondents said that the subsidy was the primary motivation for investing in thermal insulation (Beumer *et al*., 1993, p. 42). Cost savings and improved comfort were the main reasons for investing in thermal home insulation.

Other evaluation studies of investment subsidies for environmentally beneficial technologies (including energy conservation, solar boilers and co-generation of heat and power) arrive at similar conclusions. With the exception of the investment subsidy for CHP and, possibly, the subsidy for wind turbines, the effectiveness of the investment subsidies in the Netherlands was small (Evaluatiecommissie WABM, 1992).

In all the above examples, the subsidies provided applicants with a windfall gain. It is unclear to what extent they encouraged technological innovation, but given that the subsidies hardly influenced adopter decisions, the innovation effects are likely to be small. This does not disqualify investment subsidies as such. There are examples of subsidy schemes that were effective. One such subsidy is that for clean automobiles (combined with a tax for cars with high emission levels) introduced in the Netherlands in 1986 to stimulate clean vehicles. The way in which the system worked was that the subsidies for clean cars (equipped with a catalytic converter) were paid out of the extra tax revenues from the sales of highly polluting cars. This policy proved to be very effective: the share of clean cars in new car sales increased from 15% in 1986 to 90% in 1990.[4] The same kind of policy was used to encourage the supply and distribution of unleaded gasoline to protect catalytic converter emission control systems used in cars. Due to a differentiation in excise taxes, unleaded gasoline (initially only regular, but later also super gasoline)

became cheaper than leaded gasoline. Oil companies quickly responded to these changes in the tax regime by offering unleaded gasoline for sale.[5]

What about the effectiveness of subsidies for the development of environmentally preferable technologies? Did R&D subsidies stimulate firms to undertake research in environmental technology that they would not have done in the absence of subsidies? This is a question which has not been studied in a systematic way, at least not in the Netherlands. However, the evidence that is available suggests that R&D subsidies in the Netherlands for environmental technology have been of limited effectiveness. According to the study by Olsthoorn *et al.* (1992, p. 18), the "Stimuleringsregeling Milieutechnologie" (STIR-MT) for the development of environmental technology did not elicit new research projects. This conclusion corresponds with the observation by de Jong and van der Ven (1985, pp. 78-79) that innovator firms develop environmentally beneficial technologies not because a subsidy is available but because they believe a market exists for the new technology. The conclusion is at odds with two other evaluation studies, quoted in Cramer *et al*. (1990), that find that of the ten projects that received financial support under the Clean Technology programme in the Netherlands, five would not have been initiated in the absence of support. However, it turned out that many of the projects funded under the programme were second-rate projects: of the ten projects, only seven were technically successful and only four were applied in practice. On the whole, the results are not encouraging: it may be that the R&D subsidies accelerated the development of environmental technologies, but this is unclear. There are few examples of successful clean technologies requiring a technology development programme.

The experience with the Danish Clean Technology Development Programme, described in Georg *et al*. (1992) is more positive. Under the programme, industries, private and semi-governmental research institutions could apply for financial aid for developing and implementing clean technology. The programme was oriented at stimulating preventive process solutions and co-operation among technology suppliers, research institutes, consultancy firms and users. The Danish Environmental Protection Agency played an active role in selecting environmentally beneficial projects and in finding the right partner with whom to co-operate. That is, the agency acted as a matchmaker to elicit environmentally innovative solutions, something that previous subsidy programmes had failed to do.[6] According to the authors, the Danish programme was a success. In almost all cases, appropriate technical solutions were found for the environment problems at hand. In more than half of the projects, substantial environmental improvements were achieved at low cost. Some projects led to net economic gains for the polluting firms. In the 1990s, the focus of the programme shifted towards generating in-house environmental competence and production innovation. Examples of projects in the Danish textile industry aimed at creating green product markets are described in Hansen *et al.* (2000). The creation of markets for green products proved difficult, far more difficult than finding ways of reducing waste, input use and emissions, in the absence of green demand. There seems to be a need for policy measures to assist in the creation of markets for green products.

Taxes and tradeable permits

What about the experiences with taxes and tradeable permits? Did they promote innovation? There is little evidence of this. The experiences with the tradeable permits for SO_2 are very positive as far as efficiency is concerned. In a first estimation, cost gains of 50% have been reported (Palmer *et al*., 1995). However, there is little evidence that they promoted innovation. The innovation effects of environmental taxes is a topic which has been barely analysed. Nevertheless, as the taxes are usually set at a low level, one should expect the innovation effects to be low.

Covenants

What are the experiences with covenants (environmental agreements between industry and government) in promoting innovation and environmental technology diffusion? Covenants are negotiated agreements between industry and the government in which the industry promises to reduce the environmental burden of their products and activities. They are a relatively new instrument of environmental policy. The effectiveness of eight product-related covenants in the Netherlands is analysed in Klok (1989a). These covenants covered mercury-oxide batteries, alkaline batteries, beverage packages, heavy trucks, and PET bottles, and the use of cadmium in beer cases, CFCs in aerosols, and phosphates in detergents. Most covenants were about the substitution of an environmentally hazardous substance. According to Klok, the effectiveness of covenants was typically small: when environmental improvements were achieved, this was more due to autonomous technological change, external regulations (such as EC guidelines), and the evolution of market demand than to covenants. There is little evidence that the covenants fostered technological innovation. An exception is the KWS-2000 programme in the Netherlands to reduce VOC emissions which stimulated research into low-solvent paints, especially for the housing market. Covenants are now used for achieving reductions in energy use in the Netherlands (and also in Germany), where sectors promised to reduce their energy use by 20% in 2000 compared to 1989 levels. Again, the impact on innovation is likely to be limited as such reductions can be met with existing technology. This demonstrates a disadvantage of covenants. If policy makers want to make greater use of covenants, these should be more oriented towards innovation.

Innovation waivers

One way to promote environmental innovation is through the use of innovation waivers. Innovation waivers are incentive devices built into environmental regulation. Generally, they extend the deadline by which industry must install pollution control equipment to meet emission limitation requirements. They exempt industry from penalties during trial periods and offer the prospect of cost savings derived from superior technology (Ashford *et al*., 1985, p. 444). In theory, innovation waivers seem very attractive for both potential innovators and the regulating agency. They have been used in the United States with little success. The reasons for this had to do with the short and inflexible deadlines which acted as a disincentive for innovation, especially for radical innovation, and shortfalls in the way in which the programme was administered. Under the Clean Air Act, the responsibility of issuing innovation waivers was given to the Stationary Source Compliance Division (SSCD) of the Environmental Protection Agency, a division with limited technical expertise, whose primary task was enforcement. As it turned out, the SSCD narrowly interpreted the waiver provisions and provided little guidance, which explains why the scheme failed to promote innovation.

In retrospect, it is easy to comprehend why innovation waivers were unsuccessful in the above case. This does not disqualify innovation waivers *per se*. There are several remedies to the problems encountered, such as administration of the programme by people trained to interact with industry, the establishment of a technology review panel, delineation of eligibility criteria, and longer time allowances. It does illustrate, however, the difficulties in designing regulations that encourage environmental innovation.

Turning to the topic of best policies to promote the development of environmental innovation and diffusion, there are two ways to approach this issue. One way is to focus on policy instruments and examine for what purposes (stimulation of innovation or diffusion or both) and context in which they may be usefully applied. This is what the author has done in a previous publication (Kemp, 1997). Another way to approach the issue is to take the dynamics of socio-technical change (including processes of assessment and anticipation) as the starting point for a discussion of governance: how can these be modulated into

more environmentally benign directions? The second approach has been explored by the author with Arie Rip (Rip and Kemp, 1996) and in the two Dutch projects in which the author is involved: the MATRIC and PRET projects. It uses the evolutionary view described in Dosi *et al*. (1988), Nelson (1994), Freeman (1992), Edquist (1997), Lipsey and Carlaw (1998), Metcalfe and Georghiou (1998), Rip and Kemp (1998), Kemp *et al.* (1997 and 1998), Schot (1998), and Smith (2000).

The pros and cons of environmental policy instruments

This section offers a discussion of the merits and limitations of environmental policy instruments. It addresses the question of what is the best environmental policy instrument to encourage technological innovation and diffusion. As I will argue below, there is no single best policy instrument to stimulate clean technology. All instruments have a role to play, depending on the context in which they are to be used. Suggestions are offered as to the purposes for which specific instruments may be used to obtain environmental protection benefits through the use of technology.

Environmental standards

As the previous section made clear, from an innovation point of view the experiences with environmental policies are mixed, and often negative. Emission standards were often based on available end-of-pipe technologies and provided little incentive for the development of new, more effective technologies; they merely stimulated the diffusion of existing technologies. This demonstrates the danger of using technology-based standards and the importance of taking a long-term view towards environmental protection.

Technology-forcing standards that require the development of new technologies are a better way of encouraging technological innovation, as the regulatory experiences in the United States demonstrate. However, they may impose high costs on industry unless the regulator is willing to soften and delay standards – although this will have a negative effect on the willingness of suppliers to develop innovations. Technology-forcing standards should only be used when technological opportunities are available that can be developed at sufficiently low cost.

In using standards, it is important that the regulator gives industry enough time to develop solutions that are environmentally benign and meet important user requirements. Time may also be needed to examine whether a solution is environmentally benign and does not pose other hazards. One way of dealing with the problem of compliance time is by giving firms innovation waivers that exempt them from regulations during a certain period. If innovation waivers are used, it is important that firms are given sufficiently long time allowances and that the eligibility criteria are clear. Another strategy is the setting of long-term standards that require the development of new technology.

Economic incentives

Decentralised incentive systems (such as taxes and tradeable pollution rights) are an alternative to command-and-control policies. They are favoured by economists and international organisations such as the OECD. The theoretical benefits of incentive-based approaches to reducing pollutant emissions are many. First, effluent fees (or charges and taxes) and tradeable quotas are more efficient because polluters are given the choice between compliance and paying the polluter's bill. The polluting firm cannot be forced to undertake emissions control for which the marginal costs would be higher than the effluent fee. This means that environmental benefits are achieved at the lowest abatement costs.[7] Second, there is a financial incentive to diminish all pollution – not merely up to the level of emissions standards. They

create a constant demand for innovation (Stewart, 1981, p. 1373). The economic belief that incentive-based approaches provide a greater inducement to innovate is based on this argument. Third, such a system depends less than standards-based policies on the availability of pollution-control technology and can therefore be introduced more quickly at lower decisional costs by reducing demands on the regulatory process to take decisions on complex, detailed engineering and economic questions (Stewart, 1981, p. 1374). Fourth, the danger that polluting industries fail to develop new technologies for strategic reasons is lower under an incentive-based regime. And, fifth, economic instruments tend to stimulate process-integrated solutions (including recycling technology) rather than the end-of-pipe technologies that have been overwhelmingly applied in the past.

A disadvantage of effluent charges is the uncertainty about polluters' responses. Another disadvantage is that the total environmental costs (abatement costs plus tax payments) are likely to be high, which lowers their political attractiveness, and may induce the regulator to set a low tax (as has happened in the countries in which they are used). Since freely distributed tradeable pollution quotas do not suffer from this, they may work better than taxes or charges in stimulating environmental innovations.

However, there are also other disadvantages to economic instruments. First, in order to be effective, polluters must be responsive to price signals, which is not always the case. For instance, two evaluation studies in the Netherlands showed that price considerations played a limited role in the timing of investments in thermal home improvements. This suggests that price incentives are probably better suited to changing the behaviour of firms than the purchasing decisions of consumers. Second, the price incentive must be sufficiently high to induce firms to develop and implement environmentally beneficial technologies. This was not the case in most environmental policies in which economic instruments were used (an exception is the effluent charge in the Netherlands discussed later on). And, third, in dealing with transnational environmental problems such as global warming, taxes should be used unilaterally only if their introduction does not put national industries at a serious competitive disadvantage. They should be introduced in those sectors where the environmental costs are a small part of total costs or in sectors sheltered from international competition.

Subsidies

Uncertainty about the demand for cleaner technologies, partly related to unpredictable government policy, may call for the use of R&D subsidies or loans. However, the agency responsible for the subsidy programme should be careful not to stimulate second-rate technologies. The use of subsidies should be restricted to environmentally beneficial technologies for which a market does not yet exist, for example, technologies with long development times (as in the case of energy technologies) or technologies for which there are problems in appropriating the benefits of innovation by the innovator (for example, when imitation is easy). R&D programmes may also be used to increase the number of technological solutions when there is uncertainty about environmental solutions. Subsidies for investments in pollution-control technology are less useful. They clash with the polluter-pays-principle and are expensive; in addition, evaluation research in the Netherlands has proved them to be only minimally effective. There is a great risk that such subsidies provide windfall gains for the firms and consumers receiving them. They should be used only when a switch to cleaner technology entails high costs and produces competitive disadvantages due to less strict regulation in other countries.

Communication

Communication instruments can be useful policy tools for addressing information problems related to products and processes. Environmental management and auditing systems in business (required in the

Netherlands for large firms), demonstration projects and information campaigns can be useful to ensure that firms make better use of the possibilities available for emission reduction, especially cost-reducing environmental measures. Information disclosure requirements, such as those in the United States, that force firms to communicate environment-related product information are also believed to be useful. They increase pressures on firms to improve their environmental record while enhancing the environmental awareness of firms. Ecolabels are very important for green purchases. They make the market for green products more transparent. Ecolabels do offer an incentive for producers to innovate but, as noted in Hansen *et al.* (2000), the requirements are not always technologically challenging. Information instruments are believed to be useful as additional instruments, not as substitutes for environmental regulations or taxes.

Covenants

Covenants are a new policy instrument within environmental policy in Europe and the United States. Covenants are contracts between industry or an industrial sector and government in which industry promises to progressively reduce the environmental burden of its activities within a certain period (often five to ten years) according to certain targets. They are also referred to as voluntary agreements, as firms belonging to a sector are free to enter the sectoral agreement (if they do not, they will be subject to regular licensing procedures). Covenants are attractive to industry as they provide greater freedom with regard to the method and moment of compliance, thus lowering the so-called regulatory burden. By handing over responsibility for achieving environmental improvements to industry, covenants may stimulate environmental responsibility in firms, which is important for the wider integration of environmental concerns in companies' decisions. From the viewpoint of the environmental control agency, covenants are attractive because they lower the administrative burden and help to establish a better, more co-operative relationship with business.

A clear disadvantage to the use of covenants is the danger of strategic exploitation of the agreements by industrial firms who may engage in free-rider behaviour, or, more likely, may under-exploit the opportunities for innovation by claiming that it is impossible to meet the targets through compliance technology that fulfils important user requirements. Such behaviour may jeopardise the fulfilment of environmental agreements. Further, the softness of covenants, or voluntary agreements in general, means that there is little incentive for third-party suppliers to develop compliance technologies as the market for the new technologies is insufficiently secured. If covenants continue to be used in the future, as they probably will be, they should be more oriented towards innovation. One way of doing this is through technology compacts between public authorities and private firms to implement long-term technological change (Banks and Heaton, 1995, p. 49). In the compact, industry commits itself to performance goals that require new and advanced technology in exchange for enforcement flexibility and guaranteed acceptance of a new technology. The system of technology compacts looks attractive but, as for covenants, it could be exploited by industry who has superior knowledge of what is technologically possible.[8]

This brings us to a more fundamental issue: the ability of the industry to influence and capture the details of environmental policies. Industry is known to have a great deal of influence over the details of environmental policies, especially standards. Thus, an additional criterion on which to judge environmental policy instruments is the possibility of institutional capture of policies by special interests.

Some policy suggestions

This section offers suggestions for the use of environmental policy instruments in different technological and economic contexts. These are summarised in a table in the Appendix. The table

describes the effectiveness and efficiency characteristics of different policy instruments, the purpose for which they may be used (to stimulate technological innovation or diffusion), and the context in which they may be applied, based on experiences with environmental policies and studies of environmentally benign technical change. It should be noted that they reflect the views of the author and are not the outcome of a rigorous model.

Economic incentives

Economic incentives have an important role to play in environmental policy. The case for them is strong: they leave freedom as to the choice and moment of compliance, and provide an incentive to go beyond environmental standards. Especially in the case of heterogeneous firms with different production technologies, economic instruments are attractive. They are more economically efficient than standards, providing equivalent environmental improvements at lower costs and thus, in principle, allow policy makers to achieve greater emissions reductions. They should be used more often, although there are limitations to their effective use that are not always recognised in discussions on the design of environmental policy. For example, there is a danger that economic incentives such as taxes and subsidies provide a too weak and indirect stimulus. Many studies of technology responses to environmental pressures take this view. In their study of clean technology in the United Kingdom, Irwin and Hooper (1992) found that state incentives had only a marginal impact on innovation. This and other considerations led them to the conclusion that "a sensitive but firm policy of putting regulatory pressure on waste and pollution output will be more effective in focusing industrial minds". Hartje (1984), in studying the innovation decisions of detergent manufacturers, doubted that a tax policy would have achieved a switch away from phosphate-based detergents. The 50% reduction requirement for phosphates created a market of significant size for phosphate substitutes.

The idea that regulations are more effective in making firms invest in environmental measures is also widely shared by environmental authorities. For example, in the United States, environmental authorities responsible for pollution prevention programmes stated almost without exception that stringent and certain regulatory demands (such as emission, effluent, or exposure standards, or product bans and phase-outs) are necessary to effectuate pollution prevention. Economic instruments are seen as complements to rather than substitutes for regulatory requirements (Ashford, 1993, p. 296). One system which combines the use of standards with economic incentives is tradeable permits, which makes them attractive for use.

In general, economic incentives may be better suited to stimulating technological diffusion than innovation. A clear example of the effectiveness of economic instruments is provided by the diffusion of biological waste-water treatment plants in the Netherlands. The increase in the effluent charge per unit of "population equivalent" (the typical measuring rod) from NLG 5.42 in 1973 to NLG 74.26 in 1991 induced many firms to invest in biological effluent treatment systems. The diffusion speed was considerably higher for indirect dischargers who discharged their effluent into a collective effluent treatment plant than for direct dischargers. A counter example, also from the Netherlands, is the diffusion of thermal home improvement technologies where subsidies and energy prices played a limited role in the timing of thermal home improvements.

R&D programmes

In order to stimulate technological innovation, a more focused approach may be needed. One way of doing this is through R&D programmes for environmental technologies or more environmentally benign energy technologies. However, as noted above with regard to R&D support, there is always the danger that the programmes promote second-rate technologies and provide windfall gains to the recipients.

Technology-forcing standards

Another strategy to promote environmental innovation is specifying strict environmental standards that require the development of new technologies. However, this should be done only in situations where the environmental risks are large and acute, and where there is consensus about the most viable technological solution or trajectory. If there is no such consensus, there is a danger that technology-forcing standards lock industry into overly expensive and sub-optimal technical solutions. In such circumstances, there is a need for further research and experimentation to learn more about the technological possibilities, about the disadvantages of particular solutions (and how they may be overcome), the economic costs and environmental gains of the technologies, and their acceptability to society. In using direct regulation, policy makers should give careful attention to the design of standards: their strictness, differentiation, timing, administration, flexibility and enforcement. The experiences in the United States with innovation waivers and tradeable permits (described in Hahn, 1989) illustrate that the ways in which the instruments are designed and implemented are important determinants of the technological responses of industry. This is also the conclusion of Blazejczak *et al.* (1999) on the basis of German studies. The authors developed a set of hypotheses about innovation-friendly environmental policy, relating to aspects of instruments, policy styles and configurations of actors that are innovation-friendly.[9]

Matchmaking

Another way of encouraging technological innovation is to build a network of technology suppliers, users and research institutes, as was done in the Danish Clean Technology Development Programme. This programme not only provided firms with economic incentives for developing and implementing clean technologies but, more importantly, provided them with incentives and necessary contacts for finding efficient technological solutions to specific environmental problems (Georg *et al*., 1992, pp. 545-546). Of course, such a policy is not easy; it requires special competence on the part of policy makers. They must have a technological understanding of the production processes, the associated environmental problems and possible solutions if they are to act as a "matchmaker" and identify the relevant participants for the development projects. They must also ensure that more radical solutions with potentially larger environmental benefits are developed and used.

Technology compacts

Technology compacts, described in Banks and Heaton (1995), are another way to promote technological innovation by setting an agenda of phased increments of technological change. As with covenants and negotiated rule making, there is a risk of strategic behaviour on the part of industry who may claim that it is impossible to develop technology that is both environmentally superior and economically feasible.

Exploiting synergies between instruments

From the discussion, it should be clear that there is no single best instrument. Generally, policy instruments should be combined with one another to benefit from synergistic effects. A combination of standards with economic instruments is particularly useful since it combines effectiveness with efficiency. A good example of an effective and economically efficient environmental policy are the US corporate automobile fuel economy (CAFE) standards which set progressive fuel economy targets for automobile manufacturers in the 1979-85 period under penalty of a fine of USD 50 per car sold for each mile per gallon of shortfall. Tradeable pollution permits also deserve to be used more as they too combine effectiveness with efficiency. At this moment, a nation-wide market exists for SO_2 in the United States

where utilities can trade SO_2 rights at the Chicago Board of Trade. Early results suggest that the tradeable permits for sulphur dioxide emissions will reduce the costs of the 1990 acid rain programme by 50% or more (Palmer *et al*., 1995).

Modulating dynamics of socio-technical change through public policy

This section offers an alternative view on government policy for achieving environmental protection benefits, based on insights from technology dynamics studies. Within the alternative view – which I have termed the "modulation" approach – the starting point for policy and entrance point of government interventions is the capabilities, interests, interdependencies and interactions (games) of social actors around an environmental problem instead of the environmental problem itself and how this problem may be solved through the use of environmental policy instruments. It was seen above that the environmental policies currently being applied were not effective in securing goals (where goals were obtained, it was usually through other developments). The policies were also found not to be efficient: the same results could have been achieved at lower cost; sometimes the costs exceeded the benefits from environmental protection, sometimes it was the other way round. An explanation for this is that the instruments did not fit the economic-institutional context in which they were applied. This context consists of: *i)* the private and public companies engaged in activities that cause environmental problems and their customers; *ii)* the actors who could supply a technical solution to the problem (capital good suppliers, government labs, consulting companies and other knowledge institutes, and the problem industry); and *iii)* other actors such as environmental pressure groups, banks, insurance companies, users, scientist groups and, of course, the government and politicians – each with their own interests, resources, views, assumptions and values. In this context, the environmental problem is typically contested. Reasons for this include uncertainty about the causes and effects of an environmental problem and different world view and values of policy actors. The same holds true for solutions. Different actors favour different solutions. There is a continuing battle over both problem definitions and solutions in an evolving socio-technical landscape.

These battles are not a peripheral thing: they have a significant influence on the choice and practical design of instruments (Hahn, 1989; Majone, 1976; Bressers and Huitema, 1996). According to Majone, the performance of policy instruments depends more on the institutional framework in which they are used than on their technical characteristics: "The actual outcomes of environmental policies are affected more by the institutional arrangements emerging from the political process than by the technical characteristics of the instruments employed; to use a statistical image, the 'within group' effects (the differential results obtained when the same tool operates under different institutional circumstances) dominate the 'between groups' effects (the results of different tools used under approximately equal conditions)", which leads him to the view that "the significant choice is not among abstractly considered policy instruments but among institutionally determined ways of operating them." (Majone, 1976, p. 593).

Economists – more than any other profession – tend to find the influence of societal actors through politics on the choice and design of policy instruments, a nuisance – something that gets into the way of obtaining environmental benefits in an efficient way and elevating society to a higher level of well-being. However, instead of deploring such societal interactions, they should be taken into account. Policy should not be viewed as something that can occur outside a society, especially not a democratic one. The government itself not only accommodates different interests but also houses them. This should not be assumed away. The modulation approach first sketched in Rip and Kemp (1998) and further developed in Rip and Schot (1999) helps to find a way out of this problem by focusing on societal interactions: how the games that occur and the different stakes may be exploited in ways that benefit society at large. Within a modulation view, the task for government is to modulate the dynamics of socio-technical change into desirable directions, to ensure that the outcome of interactions – between firms and other actors in markets and policy arenas – lead to desirable outcomes from a societal point of view. Within a modulation view, the different interests and problem-solving capabilities of actors, their agendas, expectations, ties and

dependencies and the rules of the game (for example, the way in which the policy-making process is structured) are the entrance point of interventions.

The modulation view also says that the focus of environmental technology policy should be on all technologies. Any technology which uses less materials and energy is *de facto* an "environmental technology", although some people may object to the use of this word. Such technologies should be an important target point of policy that tries to reconcile economic goals with environmental protection goals. It also says that, apart from changing frame conditions for technical change in an environment-friendly way, there is a need for environmental policy to be explicitly – rather than implicitly – concerned with technical change. Here the main difference lies with economic views on environmental policy.

The overall idea is that of modulating technical change in environmentally beneficial directions. Key terms are alignment, network management, game management and process management. Within a modulation view, government interventions should go beyond changing the cost and demand structure in which technical change occurs. Policies should be concerned with fostering linkages and establishing a guide for environmental investment though, for example, the setting of goals. This should be done in consultation with industry. Policy makers should be forward-looking and less reactive. Policies should take into account technical developments and utilise these for achieving environmental improvements. One way to do this is through foresight exercises involving industry and science. Foresight exercises can help to set challenging goals. Modulating the dynamics also requires interventions; for example, when industry is resistant to exploiting certain possibilities because it has an interest in incumbent technologies. A way to do this is through game management: interventions in the competitive games between private companies and interactions between companies and social groups over problem definitions and appropriate solutions.

The aim of game management is to create a situation in which there is a search for environment-friendly solutions and to select the best one. This can be done in various ways: by changing the "rules of the game" or by changing the way in which the game is played. Examples of game management are: increasing the number of players (bringing in outsider firms with different interests and capabilities); prolonging the game when no satisfactory results are likely to emerge; empowering certain voices; and manipulating technological and economic expectations, for example by securing a (future) market for a new product or by announcing that there will be a ban on a substance if scientific evidence tells or strongly suggests that it is dangerous. Game management seeks to exploit differences in economic interests by changing the stakes. It thus helps to go beyond win-win solutions. The power of markets is utilised by incorporating ecological concerns in the competitive process, for example by allowing only those products that are best from an ecological perspective. This helps to promote a search process for solutions, both by companies who are supplying an environmentally disruptive product and outsider firms operating in a different market. Game management creates winners and losers. Of course, this will create political problems and is not easy. In less conflict-ridden situations, government agencies could act not as a game manager but as a matchmaker by bringing together technology suppliers to work on a problem, promote learning and providing financial assistance. In the case of technological controversies, they could organise discussions between proponents and opponents in order to generate a better understanding of the issues at stake and guide technology developers in their decisions. Here, they act as a mediator or moderator.

In addition to game management, network management and changing the economic and legal framework conditions (through the use of taxes, covenants, standards, subsidies, etc.), there is also a need for policy to be oriented towards capacity building: enhancing the ability of companies to design environmentally improved products and their ability to adopt clean technologies. Lenox and Ehrenfeld (1997) speak about a company's "environmental design capability": the ability to incorporate environmental concerns into product development. This capability depends on the integration of diverse knowledge resources through communicative linkages and on the use of practical tools (such as design for the environment and green accounting) but also on the "interpretive structures" of the actors. In their study

on green product development, Lenox and Ehrenfeld found that resources are insufficient if they are not linked with design teams and embedded in interpretive structures that value and understand the environmental information received (Lenox and Ehrenfeld, 1997, p. 195). Environmental management systems – which are compulsory for big environmentally intensive companies in the Netherlands – are one tool which can be used to achieve this and were introduced for precisely this reason by the Dutch authorities. Here, we see that governments are already engaged in alignment policies, assuming a role as capacity builder and alignment agent.

The policies of alignment, capacity building and exploiting differences in economic interests through game management are not a substitute for traditional policies. Within a modulation view, there is a need for corrective policies, in the form of taxes, tradeable permits, environmental standards, fines, and so on – policies that change the framework conditions for economic behaviour and technical change. The modulation approach thus does not preclude the use of traditional policies; rather, it shows how such policies may be used in a different way. It helps to identify useful points for intervention and exercise some leverage and helps to fine-tune policy instruments to the techno-economic and institutional contexts in which they are applied. This is important because in order for policy interventions to have a decisive influence they must tip the balance of economic decision making.

A modulation approach thus helps to see new entrance points for intervention for governments and for other actors (like NGOs) who want to further environmental goals. This is important because changing the framework conditions through a pollution tax or regulation may not be sufficient to bring about innovative responses. As noted in structuralist-evolutionary approaches of technical change (Freeman, 1992; Nelson 1994; and Dosi, 1988) – and as any management expert can tell you – economic actors are not automata responding mechanically to changes in cost and demand conditions. What an organisation and the people in it can do technologically is determined by what they have been doing in the past. Organisations have developed strategies and the people in them are equipped with a certain outlook on problems, and certain capabilities and ways of doing things which also act as a shaping factor. At the same time, organisations are not altogether victims of the past. They have developed systems for dealing with change. Companies, especially the multi-billion ones with large capital assets in dynamic markets, are forward-looking, they scan new technological developments and engage in the surveillance of market developments – the outcomes of which inform their research agenda and strategies. It is these things (the expectations, processes of anticipation, but also the capabilities and outlooks) that could become an entrance point for government intervention, or at least an important consideration in the choice and design of government policy. Modulating the dynamics of socio-technical change should be pursued under the label of sustainability policy. This would require the alignment of environmental policy and innovation policy. It is a new frame for old policies but also suggests some new entrance points for intervention.

Examples of such entrance points for modulation policies are described in Rip and Schot (1999), Geels (1999) and Kemp *et al.* (2000). Key entrance points for interventions for governments (but also other actors) to promote environmental goals are:

- Processes of anticipation and assessment (orientation towards the future) that might be improved. Actors do assessments all the time: they make assumptions about where their market is going; they scan possible technological futures and make guesses about the impacts of changes in the socio-technical landscape (such as the emergence of Internet and public call for corporate responsibility) for their sector and company. Existing attempts at assessment might be broadened to include environmental considerations. Discussions on sustainable futures and the development of images of sustainability are one way to bring environmental concerns into the processes of anticipation.

- Networks for learning and interaction could be created with the help of government, either directly or indirectly through the funding of collaborative research.

- Promises-requirements cycles: to assist in the articulation of new technological possibilities, the articulation of problems connected with their use and the articulation of needs and wants. Technology experimentation and agenda building are ways to do this.

- Niches: spaces in which technologies are protected against selection pressures, acting as a learning environment and possible-stepping stone for overall system change.

One tool to improve processes of anticipation and assessment and shape research agendas is the use of scenarios. Geels (1999) has described how the development of socio-technical scenarios (STSc) can contribute to processes of anticipation and alignment, and thus serve as a vehicle for change. He identifies three purposes for which STSc may be used. The first purpose is that of promoting strategic thinking. STSc may help actors think more systematically about the possible impacts of technologies and their role in the co-evolution of technology and society. As noted by Rip and Schot (1999), business decisions and social interactions are informed by "diffuse scenarios". Economic actors are guided by assumptions about the role of humans, artefacts, organisations in future worlds. STS can be used to make the diffuse scenarios explicit and increase their quality.

A second purpose for which STSc could be used is to build "road maps" and explore technological paths and technological "forks", which then serve to inform public and private policy. STSc may be used to identify pathway technologies: technologies that allow one to move away from an existing technology regime to a new one. On the basis of their socio-technical scenarios about future transport systems, Elzen *et al*. (1998) identified light-weight electric vehicles as a possible important stepping-stone towards a more environmentally benign transport systems. Light-weight electric vehicles have a high innovation-cascade potential, and allow for a co-evolutionary learning process in which people's ideas of what a car should do may change.

The third purpose for which STSc may be used is to facilitate processes of mutual understanding between antagonistic actors. The framework on which STSc are built requires that participants make their assumptions explicit, which is a precondition for mutual understanding. Differences in assumption and values may be unravelled through "argumentive scenarios". This has been done by Rip, Smit and van der Meulen (1994) on the issue of long-lived radioactive waste disposal. It would also seems to be potentially useful for biotechnology, a technology that is believed to possess a significant potential for achieving environmental benefits.

The first two purposes have to do with orienting actors to the future and stimulating strategic thinking and thought experiments. The third, with mediating conflicting views and interests.

Socio-technical scenarios are referred to by Geels as "a tool for reflexive technology policy". They do not deliver "silver bullet" solutions or offer ready-made advice in terms of what to do. The same is true for modulation policies. They offer a somewhat different perspective on governance that may be applied in an instrumental way, to achieve desirable outcomes.

An example of a modulation policy is strategic niche management. Strategic niche management (SNM) is a new approach, first suggested by Rip and further developed by Schot *et al.* (1996), Kemp *et al*. (1998) and Weber *et al*. (1999). SNM aims to modulate the dynamics of socio-technical change through the creation and management of spaces (niches) for the use of a new technology. In these spaces, the technology is partly and temporarily protected from the normal selection pressures of business.[10] The creation and management of niches is a way to work towards regime change.

SNM thus involves the real use of technologies in selected settings. The actual use of a new technology helps articulation processes take place and allows lessons to be learnt about the viability of the new technology and builds a network around the product whose semi-co-ordinated actions are necessary to bring about a substantial shift in interconnected technologies and practices. As I have argued, this is important in fostering technological regime shifts.

SNM is especially appropriate for so-called pathway technologies. Pathway technologies are technologies that pave the way for new developments. They may also be called bridging technologies or enabling technologies. They help to bridge the gap between the current socio-technical regime (in which they may be used for certain purposes) and a new and more sustainable one. Pathway technologies are compatible with both the old and new regimes and allow for a cascade of innovations. Energy storage is an example of a pathway technology: the storage of energy is important for the use of renewables but also useful within the centralised energy system as it may serve to deal with peak demand, helping to reduce peak loads. Electric propulsion and transport telematics (such as transit electronic information and reservation systems) are examples of pathway technologies for public and intermodal transport. Both have been supported by public policies through special research programmes and there has been investment from industry in these technologies but there still is a gap between research and diffusion. A special type of support action is needed to bridge this gap. The Zero Emission Mandate of California which required that a certain percentage of new vehicles sold (2% in 1998 and 10% in 2003) should be zero-emission vehicles (at the point of use) is an attempt to cross this gap. It consisted of a forced commercialisation of zero-emission vehicles in the market. It gave a big boost to the development of batteries, electric propulsion systems and quick recharging systems. It did not result in the wide use of BEVs but it forced automobile manufacturers to work on electric propulsion systems and to re-think car design. The attention to alternative fuel vehicles has resulted in the development of hybrid electric vehicles (in which batteries are combined with an internal combustion engine) and fuel cell vehicles. The latter will be introduced in the market in 2003. Hybrid electric vehicles are already for sale.

The advantage of SNM is that it combines elements of push and pull. For example, user experiences are used to inform private investment and government support policies. By carefully choosing an appropriate domain of application, the costs (of discomfort) for the users may be kept low. It exploits windows of opportunity at the local level and sets in motion learning processes that other actors may benefit from. Through SNM, a transition path may be created to a new and more sustainable system in a gradual, non-disruptive way. It helps actors at the local level to negotiate and explore various interpretations of the usefulness of specific technological options and the conditions of their application. Thus, SNM highlights choices and options and makes the introduction process more transparent and do-able for all parties involved, including producers, users and policy makers (Weber *et al*., 1998).

SNM is not entirely new. It has been attempted by companies for radical innovations such as optical fibres, cellular telephones, aspartame, and computer axial topography (CT) scanners (Lynn *et al*., 1996), who probed early markets as a stepping-stone for penetrating mass markets. For government actors, SNM is a new approach – although some government policies such as the ZEM in California and the Danish policy towards wind power could be labelled as *de facto* SNM policies.

SNM is not a substitute for existing policies, but rather a useful addition to existing policies which is appropriate for working towards more sustainable technology systems. It is an example of an "evolutionary" policy, aimed at deliberately creating paths through circles of virtuous feedback through carefully targeted policy interventions, rather than at correcting perceived market failures. It helps to work towards system renewal instead of optimisation.

Final remarks

In this chapter, I have argued for the use of a modulation approach that is aimed at steering processes of co-evolution rather than at achieving particular policy outcomes, such as a specific reduction of pollutants. Examples of modulation policies are game management and the use of taxes. There are two kinds of modulation policies: those that are explicitly concerned with processes of learning and innovation, and those that are not. Taxes, subsidies, standards and covenants fall into the second category as they are not concerned with learning and innovation in a direct way. They have an important role to play in environmental policy as alternative mechanisms for delivering environmental improvement (such as the demand for green products or companies going "green" because they feel that it is the right thing to do) are weak. However, there are limits to what can be achieved with policies that change the economic and legal framework conditions. Such policies are unlikely to bring about an eco-restructuring although they may be used to achieve an "environmental upgrading" of a sector or chain – what Elzen *et al.* (1996) call "system optimisation". However, they are less well-suited to achieving "system renewal" or "eco-transformation" since this involves a transformation of existing systems and trajectories of development which, some people believe, is necessary in order to achieve sustainability goals. Achieving system renewal requires a different type of approach, involving probing and learning and specific technology support. Discussion is necessary in order to obtain a sense of direction, and support efforts should be informed by technology assessment and foresight exercises and should involve experimentation at the local level with new technologies. Possible government policies to work towards system renewal include: the creation of spaces for learning about new technologies; the establishment of long-term goals; and indicative, adaptive planning to guide private and public investment in new directions.

This requires a different type of approach to policy making, one that is more inclusive and participatory, and policies that are forward-looking and adaptive. Learning about environmentally advantageous possibilities should be an important aim. This requires monitoring and evaluation of policies and developments. Designing environmental policies that promote innovation and dynamic efficiency (as opposed to the achievement of short-term environmental goals) is not an easy task. This chapter has suggested a number of practical ways of meeting this challenge, using old and new entrance points for intervention.

APPENDIX

Policy instruments to promote the development and use of environmentally beneficial technologies in different contexts

Policy instrument	General inherent characteristics	Purpose for which they may be used	Context in which they may be applied
Technology-based environmental standards	• Effective in most cases (when adequately enforced) • Uniform standards give rise to inefficiencies in case of heterogeneous polluters	Technological diffusion and incremental innovation	• When differences in the marginal costs of pollution abatement are small and economically feasible solutions to environmental problems are available
Technology-forcing standards	• Effective (in focusing the attention of industry on environmental problem) • Danger of forcing industry to invest in overly expensive and sub-optimal technologies • Problem of credibility	Technological innovation	• When technological opportunities are available that can be developed at sufficiently low cost • When there is a consensus about the appropriate compliance technology
Innovation waivers	• Same as technology-forcing standards	Technological innovation	• When technological opportunities are available and when there is uncertainty about best solution
Eco-taxes	• Efficient • Uncertainty about industry response • Danger that they provide a stimulus which is too weak and indirect • Total environmental costs for industry are likely to be high • Limited political attractiveness	For recycling and material and energy saving Technological diffusion and incremental innovation	• In case of heterogeneous polluters that respond to price signals • When there are many different technologies for achieving environmental benefits
Tradeable permits	• Effective • Cost effective (which means that environmental benefits are achieved at lowest cost)	Technological innovation and diffusion	• Same as for taxes • Costs of monitoring and transaction should not be prohibitively high

Policy instrument	General inherent characteristics	Purpose for which they may be used	Context in which they may be applied
Covenants and technology compacts	• Uncertainty about whether industry will meet agreements; should be supplemented with penalty for non-compliance • Low administrative costs	Technological diffusion	• In case of many polluters and many technological solutions • When monitoring environmental performance is expensive
R&D subsidies	• Danger of funding second-rate projects • Danger of providing windfall gains to recipients	Technological innovation	• When markets for environmental technology do not yet exist and when there is uncertainty about future policies • When there are problems of appropriating the benefits from innovation • When there are important knowledge spillovers • In case of large social benefits and insufficient private benefits
Investment subsidies	• In conflict with polluter pays principle • Danger of windfall gains • Politically expedient	Technological diffusion	• When industry suffers a competitive disadvantage due to less strict regulations in other countries
Communication (*e.g.* eco-labels)	• Helps to focus the attention of firms and consumers on environmental problems and available solutions to these problems • Little coercive power	Technological diffusion	• When there is a lack of environmental consciousness • When there are information failures
Environmental management and auditing systems (EMAS)	• Enhance environmental knowledge and competence • Little coercive power	Technological diffusion, product improvement and good housekeeping	• In case of lack of environmental knowledge and competence
Network Management	• Creates a platform for learning and interaction, to stimulate alignment and co-ordinate interdependent activities solutions may be tailored to specific needs • Requires technological understanding of processes and products	Technological diffusion and Innovation	• When there are Information failures
Societal debates on environmental issues		For stimulating mutual understanding and learning about values and belief systems For improving processes of anticipation	• In case of controversies over problems and solutions

Policy instrument	General inherent characteristics	Purpose for which they may be used	Context in which they may be applied
Sustainability foresight studies	• Broadens processes of assessment • Enhances strategic orientation	For learning about sustainability options (beyond eco-efficiency) For altering fixed ideas and mind sets	
Setting of goals and use of indicative planning	Provides clarity and (strategic) orientation	For shaping business expectations and guiding strategic decisions	
Game management		Radical innovations with significant sustainability benefits that do not offer a win-win solution	• In case of oligopolies engaged in strategic behaviour over environmental issues
Strategic niche management		For learning about radical innovations and for stimulating processes of co-evolution	• For pathway technologies to a more sustainable system • In case of attractive domains of application

NOTES

1. The term eco-efficiency was coined by the World Business Council for Sustainable Development. See Schmidheiny (1992).

2. According to Baynes, an environmental programme manager at Sony, environmental aspects account for about 20% of the score of consumer products in consumer organisation product tests. A discussion of the factors that led to the use of ONO installations for the control of metal discharges is offered in Kemp (1997).

3. Vermeulen also analysed whether the information provided by government authorities about the availability of subsidies and about the adverse environmental effects of existing technologies and practices influenced the decisions of firms to invest in environmentally preferable technologies. This was only found to be the case for PCBs, which not only had adverse health and detrimental environmental effects, but also posed a fire and security risk for PCB-using firms.

4. Evaluatiecommissie WABM (1992, p. 39), based on Klok (1989b).

5. The rapid response of the oil companies was due in part to the fact that the manufacture of unleaded gasoline did not require any technological innovation. The manufacture of (high-performance) unleaded gasoline was something oil companies in the United States had already mastered in the 1970s, to comply with US environmental regulations (Ashford *et al*., 1985, pp. 435-436).

6. The project was more than a subsidy programme: it brought together firms with environmental problems and firms and institutes that could provide solutions to these problems.

7. According to Hahn and Hester (1989, pp. 100-101), the US emission trading programme introduced in 1974 resulted in cost savings in emission control of between USD 1 billion and USD 13 billion. Almost all of these savings resulted from internal trading.

8. Aggeri (1999) offers a discussion of the usefulness of co-operative approaches to promote innovation. He also provides useful suggestions for managing the process of collective learning.

9. According to Blazejczak *et al.*, innovation-friendly policy instruments should rely on the use of economic incentives, act in combination, be based on strategic planning and formulation of goals, support innovation as a process, and take account of the different phases of innovation. Innovation-friendly policy styles are based on dialogue and consensus, are decisive, proactive and ambitious, open, flexible and knowledge-oriented. Innovation policy should include network management.

10. The protection of innovations is not unusual. Many innovations depend on research carried out in public laboratories or universities with the help of public money. In addition, companies themselves create a protected space for research by allowing researchers to do particular kinds of research, using office time, space and equipment. Sometimes an entirely new company unit is created in which a new product is developed free from the usual decision calculus. An example is the Smart car, for which a technological niche was created through company subsidies with the hope that the car would be financially viable or that the knowledge obtained would pay off in some manner. Sometimes research in companies is kept secret from the rest of the company either because it may threaten positions within a company or through fear of failure.

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Chapter 4

INNOVATION UNDER THE TRADEABLE SULPHUR DIOXIDE EMISSION PERMITS PROGRAMME IN THE US ELECTRICITY SECTOR

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Introduction

Title IV of the 1990 US Clean Air Act Amendments (CAAA) instituted an emission allowance trading programme to regulate emissions of sulphur dioxide (SO_2) from electric generating facilities. The industry is allocated a fixed number of total allowances, and firms are required to hold one allowance for each ton of sulphur dioxide they emit. Firms are allowed to transfer allowances among facilities or to other firms, or to bank them for use in future years.

A less widely acknowledged, but equally important, feature of Title IV is the annual cap on average aggregate emissions by electric generators, set at about one-half of the amount emitted in 1980. The cap accommodates an allowance bank, so that in any one year aggregate industry emissions must be equal to or less than the number of allowances allocated for the year plus the surplus that has accrued from previous years.

For years economists have urged policy makers to use incentive-based approaches to control pollution (taxes or tradeable permits) to encourage industry to minimise the cost of reducing emissions. A conventional approach to environmental regulation might force firms to emit SO_2 at a uniform rate or to install specific control technology. The trading programme is designed to enable firms operating at high marginal pollution abatement costs to purchase SO_2 emission allowances from firms operating at lower marginal abatement costs, and thereby limits SO_2 emissions at a lower overall cost than traditional command-and-control approaches.

Incentive-based approaches to regulation also are believed to encourage industry to minimise costs over time, promoting so-called “dynamic efficiency”. This is achieved by providing firms with an incentive to innovate, because firms can expect to keep some or all of the gains from innovation

* The author owes a debt for many of the ideas in this paper to Curtis Carlson, Richard Newell and Karen Palmer. Responsibility for how these ideas have been portrayed rests solely with the author.

through reduced abatement costs plus reduced payments for taxes or permits. This incentive is typically weak or absent with conventional regulatory approaches, especially technology standards, which provide little reward to the development of alternative technologies or processes.[1]

A significant literature has investigated the expected performance of different environmental policy instruments in promoting research and development. Most of the literature has argued that incentive-based approaches provide greater incentives for innovation than conventional approaches (*e.g.* Downing and White, 1986). Milliman and Prince (1989) and Jung *et al.* (1996) find that among incentive-based instruments, the incentives for innovation are greatest under auctioned emission permits, followed by an emissions tax, and least under free (grandfathered) emissions permits. These are all found to be more effective than direct controls or performance standards. Fischer *et al.* (1999) analyse the incentive-based instruments and find that under different sets of circumstances each of the three policies may induce a significantly higher welfare gain (including environmental benefits) than the other two policies. The relative ranking depends on the ability of adopting firms to imitate the innovation, as well as the cost of research and development and the nature of environmental benefits. In general, the literature offers the following broad consensus. While, not as important as the environmental benefits that are achieved (Parry *et al.*, 2000), or even as important as achieving cost-effectiveness in the short-run, incentive-based approaches offer important advantages over conventional approaches in reducing the long-run cost of pollution control.

The SO_2 allowance market presents the first real test of the wisdom of economists' advice, and therefore merits careful evaluation. How has trading affected the distribution of benefits and costs in the programme? Has the allowance market significantly lowered the costs of abating SO_2? And most central to this chapter: compared to other conventional regulatory approaches for controlling pollution, how has the programme affected the nature and pace of innovation?

This chapter addresses these issues in a survey of the recent literature to assess the actual performance and success of the programme, and then by attributing this success to various sources, including innovation. First, the chapter provides a basic description of the programme and the historical setting in which it emerged. Second, it addresses the environmental performance and the cost of the programme, especially compared with expectations of cost and the difference in cost compared to conventional regulatory approaches. Subsequently, the chapter turns to a survey of innovations that can be attributed to the programme.

The conclusion offered, in brief, is that the SO_2 programme has been a noteworthy success from the standpoint of comparing benefits and costs. Emission allowance trading has not lessened, and may have contributed to, the environmental benefits of SO_2 reduction. Meanwhile, trading has contributed to significant cost reductions, compared to original forecasts of cost.

Innovation also accounts for a large portion of these cost reductions, but not simply in the way that is typically formulated in economic models of research and development efforts to obtain patentable discoveries. This is consistent with the sparse empirical literature on the economic incentives for innovation created by environmental and energy regulation. Jaffe and Palmer (1997) found a positive relationship between regulatory stringency and R&D expenditures, but no statistically significant relationship between compliance costs and patenting activity at the industry level.

In the SO_2 programme, flexibility in compliance has provided the lion's share of cost savings to date – a greater share than the exchange of emission allowances through trading. Similarly, Kerr and Newell (1997) investigated lead-reducing technology adoption decisions by petroleum refineries during the phase-down of lead in gasoline and found that changes in regulatory flexibility lead to noticeable differences in technology responses across firms.

Also in the SO_2 programme, input markets for electricity generation redirected investment dollars to take advantage of new opportunities for low-sulphur coal that were created by the SO_2 emission allowance trading programme. Similarly, Newell, Jaffe and Stavins (1997) explored the effect of economic incentives and direct regulation on energy-saving innovation, finding that manufacturers redirected product-level innovation significantly in an energy-efficiency enhancing direction during periods of energy price increases.

Generally, rather than patentable discoveries, innovation under the SO_2 programme has involved organisational innovation at the firm, market and regulatory level and process innovation by electricity generators and upstream fuel suppliers. An important portion of the cost-reductions were already "in the works", independent of the SO_2 programme. Nonetheless, a conventional regulatory approach would have failed to capitalise on many of these advantageous trends, and arguably it would have discouraged them. The SO_2 programme deserves significant credit for providing the incentive and flexibility to accelerate and fully realise exogenous technical changes that were occurring in the industry.

Institutional background

Since 1970, the SO_2 emissions of electric utilities have been regulated in order to achieve federally mandated local air quality standards (the National Ambient Air Quality Standards). For plants in existence in 1970 these standards, codified in State Implementation Plans, typically have taken the form of maximum emission rates (pounds of SO_2 per million Btus of heat input). Plants built after 1970 are subject to New Source Performance Standards (NSPS), set at the federal level. Since 1978, NSPS for coal-fired power plants have effectively required the installation of capital-intensive flue-gas desulphurisation equipment (scrubbers) to reduce SO_2 emissions, which was an attempt to protect the jobs of coal miners in states with high-sulphur coal. This regulation has significantly raised the costs of SO_2 abatement at new plants in areas where emissions could have been reduced more cheaply by switching to low-sulphur coal.

During the 1980s, over 70 bills were introduced in Congress to reduce SO_2 emissions from power plants, especially those existing before the NSPS took effect. Some would have forced the scrubbing of emissions by all electric generating units, while others would have provided limited flexibility by imposing uniform emission rate standards, to give firms some opportunity to choose a compliance strategy.

The 1990 Clean Air Act Amendments for regulating SO_2 move away from these types of uniformly applied regulations. Instead, reductions are to be achieved by setting a cap on emissions while allowing the trading of marketable pollution permits or allowances. The eventual goal is to cap average annual SO_2 emissions of electric utilities at 8.95 million tons – about half of their 1980 level. This is to be achieved in two phases. In the first phase, which began in 1995, each of the 110 dirtiest power plants (with 263 generating units) were allocated allowances sufficient for an emission rate of 2.5 pounds SO2 per mmBtu of heat input. Firms can voluntarily enrol additional generating units ("Compensation and Substitution" units) in Phase I, subject to the constraint that the average emission rate of all units does not increase. In the second phase, which began in the year 2000, all fossil-fuelled power plants larger than 25 megawatts are annually allocated allowances sufficient for an emission rate of 1.2 pounds of SO2 per mmBtu heat input. In both phases, heat input is based on the 1985-87 reference period.

The key features of the SO_2 programme are themselves innovative. The primary focus is concern for the environment that is addressed through significant *reductions* in aggregate emissions. The firm

national *cap* on emissions ensures that these reductions will be maintained even as the economy and electricity demand grow in the future. *Measurement* of emissions ensures that the cap will be met.

Additional key features are *flexibility* and *simplicity*. While we discuss the importance of flexibility at length, suffice it to say that simplicity in the programme's design makes the programme transparent to industry and environmental advocates alike, while also building trust in its performance. *Automatic penalties* remove the role of negotiation and uncertainty in the case of non-compliance. Finally, the programme is national, but it does not supersede *local standards* that are set to protect human health and guard against potential local "hot spots" of pollution.

Allowance trading takes advantage of the fact that emission control costs vary across generating units, and encourages firms with the cheapest control costs to undertake the greatest emission reductions. Unfortunately, firms may not have adequate incentives to minimise SO_2 compliance costs because of decisions made by some state public utility commissions (Rose, 1997; Bohi, 1994; Bohi and Burtraw, 1992). For instance, to protect the jobs of miners in high-sulphur coal states, some regulators pre-approved the recovery of investment in scrubbers, while leaving it uncertain whether the cost of other possible compliance measures would be similarly recoverable. The allowance programme itself encouraged scrubbing by allocating 3.5 million "bonus" allowances to firms that installed scrubbers as the means of compliance, for the explicit purpose of protecting jobs in regions with high-sulphur coal. In addition, investments in scrubbers can be depreciated and in some cases expensed (deducted against taxable income) as soon as the scrubber is installed. In contrast, in many states the cost of purchased allowances cannot be recovered until they are used for compliance (Lile and Burtraw, 1998). These facts suggest that – through no fault of its own – the allowance market might not succeed in capturing all the potential gains from emission trading.

Environmental performance

Facilities affected under the trading programme have been 100% in compliance. The opportunity to bank emission allowances for use in later years, especially in Phase II when the annual allocation of allowances was decreased significantly, had led to significant over-compliance in Phase I. Of course, this means the postponement of emissions rather than their elimination. This section describes what is known about the environmental benefits of the programme, from an economic perspective, including the environmental effects of trading and banking.

Comparing benefits and costs

The primary measure of success of the SO_2 programme, from the perspective of economics, should be the comparison of benefits and costs. Burtraw *et al.* (1998) report the results of an integrated assessment of the benefits and costs through the year 2030, with benefits quantified for health, visibility and lake recreation. Midpoint estimates of the benefits and costs per affected capita for the year 2010 are summarised in Table 1. The cost and benefits estimates are not additive because they do not describe consistent geographic areas. Costs and health benefits are calculated for the entire nation. Visibility benefits are calculated at selected cities or states. Lake recreation benefits are calculated for the Adirondacks only. Hence, the values are expressed per affected capita to illustrate the potential relative magnitude of these benefits.

Table 1. **Benefits and costs *per affected capita* in 2010**[1]

Effect	Benefits and costs *per affected capita* of expected emission reductions in 2010 (1995 USD)
Benefits:	
Morbidity	4
Mortality	69
Lake recreation	1
Recreational visibility	4
Residential visibility	7
Costs	6

1. Benefits are not additive because affected populations differ. However, morbidity and mortality benefits and costs are calculated for the entire nation.
Source: Burtraw *et al.* (1998).

The study finds that benefits of the SO_2 programme are an order of magnitude greater than costs, a result that contrasts sharply with estimates in 1990 that pegged benefits about equal to costs (Portney, 1990). What explains the difference between the earlier and recent estimates?

On the cost side, compliance has and will cost in the future one-half or less of what was anticipated in 1990, a point we subsequently consider in detail.

Meanwhile, the lion's share of benefits result from reduced risk of premature mortality, especially through reduced exposure to sulphates. These expected benefits measure several times the expected costs of the programme. Significant benefits are also estimated for improvements in health morbidity, recreational visibility and residential visibility, each of which measures are approximately equal to costs. These areas, namely human health and visibility, were not the focus of acid rain research in the 1980s, and new information about health epidemiology suggests that these benefits are greater than were previously anticipated (Burtraw *et al.*, 1998).

In contrast, benefit areas that were the focus of attention in the 1980s including effects to soils, forests and aquatic systems have not yet been modelled comprehensively, but evidence suggests benefits in these areas to be relatively small. It is surprising to many that relatively low benefits are estimated by economists for improvements in lake recreation (Burtraw *et al.*, 1998), or are expected to result from effects of acid rain reduction on forests and agriculture. One reason is that willingness to pay for environmental improvement depends on the availability of substitute assets. Economists would not expect changes in quality at one site to elicit large benefits if there are many sites available for comparable recreational opportunities. In contrast, individuals do not have the same kind of substitution possibilities with respect to health and visibility, which may help to explain the relatively larger benefit estimates for these endpoints. Furthermore, one should note that the low benefit estimates stem from an assessment of use values, or commodity values in the case of agriculture. Environmental changes may also yield non-use values, but estimates for non-use values are not yet available. The evidence, based on a small number of relatively narrow studies, suggests that these values may be significant.

There are huge uncertainties, especially on the benefits side of the ledger, and especially in valuation of mortality. Recent economic critiques have argued that the use of the value of a statistical life as the basis for valuing health risks from air pollution, instead of a more appropriate measure of quality-adjusted life years lost, could grossly overestimate mortality benefits. In addition, economists

have questioned the appropriateness of using labour studies of prime age men to value changes in life expectancy that occur among an older population (Johannesson and Johansson, 1996; Krupnick *et al.*, 2000). On the other hand, because environmental exposures are involuntary while labour market risks are assumed to be voluntary in nature, the labour market studies may underestimate willingness to pay to avoid environmental exposures.

Burtraw *et al.* (1998) used Monte Carlo analysis and a parametric one-sided sensitivity analysis to investigate some of these sources of uncertainties. Their analysis finds that there is no year in which health benefits of the SO_2 emission reduction programme at the 5% confidence interval are less than the levelised expected costs. As noted, significant benefits are also estimated for improvements in health morbidity, recreational visibility and residential visibility, each of which measures approximately equal to costs. Despite tremendous uncertainties about benefits and costs, the main conclusion that benefits soundly outweigh costs appears to be robust.

The effects of banking

The banking provision of the programme resulted in an accumulated surplus of allowances of over 11 million tons by the year 2000, when Phase II of the programme began. Beginning in 2000, allowance allocations to Phase I facilities were decreased and additional facilities were covered by the programme, and it is expected that the allowance bank will be diminished over a period of several years.

The opportunity to bank allowances plays a significant role in reducing compliance cost because it affords firms the flexibility to plan their investment activities. However, it has an ambiguous effect on benefits. To build up a bank, firms are expected to take advantage of relatively low-cost compliance options in the early years of the programme resulting in lower emissions than would occur were they not able to bank allowances. This leads to greater environmental benefits in the early years. However, after 2000 when the bank is drawn down, emissions are expected to be greater than would occur absent the opportunity to bank, and hence environmental benefits are expected to be less.

The evaluation of the environmental consequences of banking is potentially complicated, depending on whether there are threshold effects in environmental or public health response and at what level of exposure those are achieved. The dominant view in health epidemiology regarding exposure to particulates is that the concentration-response function is linear over the range in which changes will occur. Hence, at least with respect to public health, the trade-off of exposure and response in the later years for less exposure and response in the near term is neutral with respect to the effect on health. From an economic perspective, benefits achieved sooner are viewed as superior to benefits achieved later due to discounting. However, population growth implies that greater numbers of people will potentially be exposed in the future.

Burtraw and Mansur (1999) explore this issue with a benefit-cost model (Burtraw *et al.*, 1998; Bloyd *et al.*, 1996) to compare two scenarios. One is a default scenario intended to represent compliance with Title IV as it is taking shape. For comparison they constructed a scenario that was identical except that allowances could not be banked, so emissions in each period must be less than or equal to allowance allocations in that period. Also, they assume that no scrubbers are built in Phase I, based on estimates from Carlson *et al.* (2000) suggesting that, in the absence of the bonus allowances, scrubbers were uneconomical, even with the opportunity to bank allowances at those facilities.

The result of this comparison indicates that emissions fall or stay constant in 1995 compared to the default. However, in 2005 emissions increase in most states and in the total. The associated change in total health benefits (mortality and morbidity) that result from the opportunity to bank are valued for

1995 and 2005. All numbers are in 1995 dollars, but they are not present valued. There are about USD 4 billion more in health benefits in 1995; however, in 2005 there are about USD 2.1 billion in decreased benefits. The harm is less in 2005 than the improvement in 1995, but one should not be mislead by this comparison, because draw down of the allowance bank is expected to occur over a longer horizon than did its build-up. However, what one can conclude is that there is a fairly transparent trade-off between near-term and longer-term emissions when banking is allowed. In general, the effect is to shift emission reductions towards the present. In the absence of other scientific or social considerations, this would seem to be a good thing, especially when it allows the emission reductions to be achieved at significantly less cost.

Regional effects of trading

Legislative debates about acid rain in the 1980s had a sharp regional character. Since acid deposition typically occurs far from the source of emissions (which are somewhat concentrated in the Ohio Valley), many observers claimed that emissions from these power plants were contributing to environmental degradation in the north-east. Long-range transport of emissions from the Ohio Valley does have an important effect outside the region. However, the regional decomposition of health benefits from reduced emissions is less provincially divisive because atmospheric concentrations are affected closer to the source of emissions than where acid deposition occurs. Burtraw *et al.* (1998) found that, expressed in per capita terms, those states providing 75% of the emission reductions accrue about 60% of total health benefits.

To explore the regional effects of trading, Burtraw and Mansur (1999) employed the benefit-cost model to compare trading and no-trading scenarios in order to calculate the distribution of benefits in the years 1995 and 2005, while holding the aggregate level of emissions approximately constant.

To model this, Burtraw and Mansur (1999) chose to constrain aggregate emissions in the no trading scenario to equal those in the modelled baseline (with trading). Figure 1 presents the results in a qualitative manner by illustrating that the effect of trading is to increase emissions in the Ohio Valley, but not in a uniform way. In 2005, the effect of trading will be to increase emissions from Illinois, in percentage terms. The effect of trading on most states outside the Ohio Valley is to reduce emissions.

The more important measure is the effect of trading on health benefits. Figure 2 illustrates that trading undermines the health benefits of the programme in areas closest to where emissions increase. There has been significant concern that trading might serve to contribute to the transboundary effects of pollution, with the result that citizens in New England and along the eastern seaboard may suffer effects from emission increases in the Ohio Valley. However, those increases in the Ohio Valley imply decreases in other states that have an equal or greater impact on citizens in the east. As a consequence, it appears that trading actually leads to improvements in air quality in the east. The conclusion is that trading has not led to a deterioration of air quality or environmental assets in the north-east, as some critics feared. Moreover, the slight changes are not significant compared to the 50% reduction in aggregate emissions that are being achieved (Swift, 2000). In other applications of a trading programme, such as trading of SO_2 in Europe (Burtraw Harrison and Turner, 1998) or NO_x in the eastern United States, the geographic effects of trading may be an issue that would have to be tackled directly in designing the programme. It does not appear to be important in the US trading programme for SO_2.

Figure 1. **Percentage change in Title IV baseline utility emissions attributable to trading for 2005**

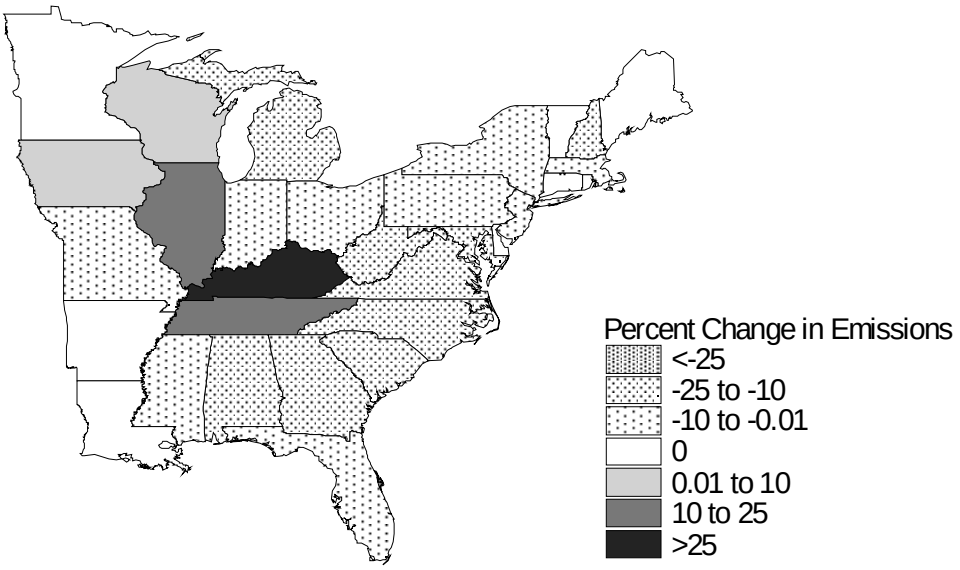
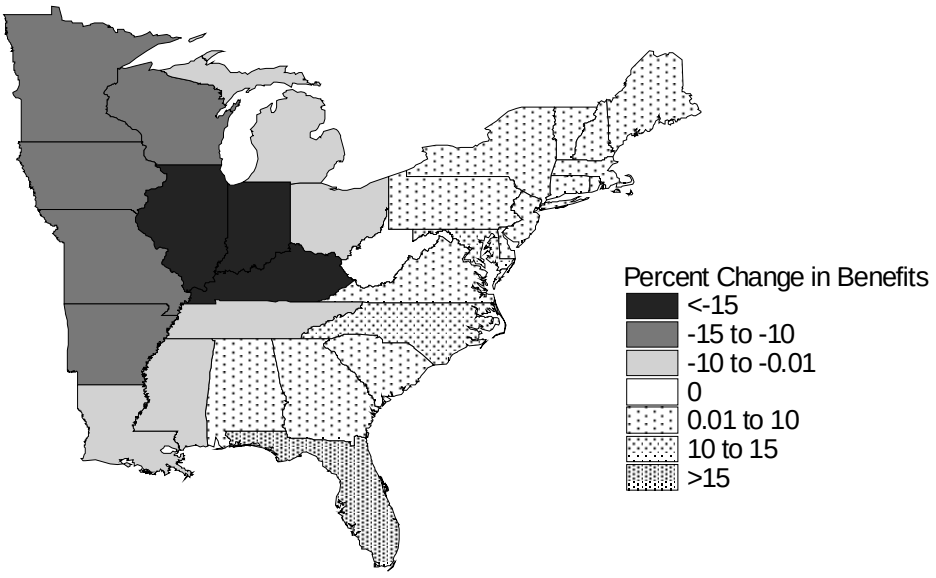


Figure 2. **Percentage change in Title IV baseline benefits attributable to trading for 2005**



Cost savings

Although they are substantial by any accounting, cost savings sometimes have been exaggerated. Advocates of ambitious climate change policies have suggested that SO_2 allowance prices are "so low" and that economists and engineers got it "so wrong" that policy makers should virtually ignore cost projections when developing new regulations such as a carbon or NO_x permit trading programme. Some have claimed that cost savings of nearly fifteen-fold are attributable to the trading programme based on a comparison of recent allowance prices just above USD 100 with projections of long-run marginal costs near USD 1 500 per ton of abatement.[2]

This argument is flawed for several reasons (Bohi and Burtraw, 1997; Smith, Platt and Ellerman, 1998). First, analyses that took into account the ultimate design of the programme suggested that long-run marginal costs would be about USD 700. Second, historical estimates of marginal costs were generally for the second phase of the programme, and therefore cannot be compared with Phase I allowance prices unless they are discounted to the present. The present discounted value in 2000 is roughly 40% of the value of costs incurred around 2010, when the second phase is in full effect and the allowance bank is expected to be depleted. Third, marginal costs are likely to be a poor proxy for total costs (or cost savings). Even if allowance prices were equal to marginal abatement cost in the least-cost solution, it would not follow that all trading gains were realised. Price can equal marginal abatement cost even if many firms fail to participate in the market.

Together, these factors suggest that Phase I allowance prices in 1997 of about USD 125 should be compared to a figure of about USD 235, which is what USEPA (1990) predicted would obtain as Phase I marginal abatement costs in 1997.[3] This comparison suggests that marginal costs have fallen by over half, compared to the vantage point in 1990. Indeed, the performance of the programme is very good; there is no need to exaggerate! A critical question is: to what extent can this decline in cost be credited to the allowance trading programme? Subsequently, we ask the main question of interest: to what extent can this decline be credited to innovation?

Marginal and annual costs

Carlson *et al.* (2000) offer an econometric model to explore the role of allowance trading in achieving cost savings. The model uses marginal abatement cost functions derived from an estimated long-run cost function for electricity generation for over 800 generation units over the years 1985-94 to predict the cost of emissions reductions at fuel-switching generators.[4]

To estimate potential gains from allowance trading in the long run, Carlson *et al*. compute the least-cost solution to achieving the 8.95 million ton SO_2 cap in the year 2010. Several assumptions are critical to the calculation and they are explored in sensitivity analysis. Real prices of high- and low-sulphur coal are assumed to remain at 1995 levels while the rate of technical change experienced between 1985 and 1994 continues through 2010. Baseline emissions – those that would have prevailed in the absence of Title IV – are calculated using 1993 emissions *rates* applied to 2010 levels of electricity production.

Under the above assumptions, the total annual cost of achieving the SO_2 cap of 8.95 million tons in 2010 is estimated to be USD 1.01 billion (1995 USD). Of this total, USD 380 million represents the cost incurred by plants that switched fuel, which account for about 60% of reductions from baseline emissions, with the remainder incurred by plants that installed post-combustion control. The marginal cost of emissions reduction, which should approximate the long-run permit price, is USD 291 per ton of SO_2.

Annual compliance costs of USD 1 billion per year are less than half of the estimates of compliance costs originally predicted when the 1990 Clean Air Act Amendments were drafted (USEPA, 1989; 1990). This is reported in the first row of Table 2.

These estimates can be compared with the USEPA estimates from 1989 and 1990, at the time the Clean Air Act Amendments were being discussed. The comparison illustrates that the failure to anticipate changes in fuel prices and the change in technology at the power plant explains the difference between the Carlson *et al.* estimates and those that formed the basis of expectations for the programme. Under the maintained assumption that fuel switching determines marginal abatement cost, the assumption of stable 1989 fuel prices and technology (the third row of the table) produces marginal cost estimates approximately as large as those predicted when Title IV was written (the fourth and fifth rows of the table).

Table 2. **Long-run cost estimates**[1]
Phase II, year 2010

Scenario	**Annual cost** (billion 1995 USD)	**Marginal cost per ton SO_2** (1995 USD)	**Average cost per ton SO_2** (1995 USD)
Preferred estimate	1.0	291	174
W/ 1995 technology	1.6	436	198
W/ 1989 prices and 1989 technology	1.9	560	236
USEPA (1990)	2.3-5.9	579-760	299-457
USEPA (1989)	2.7-6.2		377-511

1. Rows 2 and 3 report on sensitivity analysis. Holding technology constant at 1995 levels, compared with the preferred assumption of continuing trends in technology improvements, *increases* marginal abatement cost by about 50%. The assumption is that setting fuel prices at 1989 levels, compared with the preferred assumption of 1995 levels, further increases marginal abatement costs by nearly 20%.
Source: Carlson *et al.* (2000) compared with previous studies.

Annual costs continue to differ significantly among these rows. A major factor explaining the difference in annual cost is the assumption by the USEPA in 1990 that a greater number of scrubbers (37) would be built than were actually constructed in Phase I (28) or than are likely to be built under the preferred estimate. Also, USEPA (1990) failed to anticipate improvement in performance of scrubbers, increased utilisation of these units and greater utilisation of nuclear units to meet baseload capacity. Since fuel switching is a marginal compliance option, the estimates of marginal cost remain close in the comparison, but differences in scrubber estimates help explain differences in infra-marginal costs and total cost.

Also important to total (annual) cost are differences in the baseline from which emissions reductions are measured. In all of our calculations, we assume that the emission *rates* (lb. of SO_2/mmBtu) that would have prevailed in the absence of the 1990 Clean Air Act Amendments are those that prevailed in 1993. These are much lower than 1989 emission rates, hence the reductions in emissions necessary to achieve the 8.95 million ton cap, by our calculations, are much lower than imagined in 1989 (specifically, about 2 million tons lower). Holding marginal abatement cost curves constant and thus lowering the necessary reduction in emissions, will lower total compliance costs.

From these experiments, the characterisation of technological change emerges as the most important assumption in explaining the difference between the econometric estimates and previous studies. Changing assumptions about other factors, such as fuel prices, retirement and monitoring each

weigh in as significant but of much less importance. The important caveat is to recognise that to a large degree these changes were exogenous to the SO_2 trading programme.

Potential cost savings from allowance trading

To calculate the cost savings from trading emission allowances, Carlson *et al.* compare the cost of meeting the SO_2 cap using a command and control approach with the least-cost (preferred) solution identified above. The command and control approach is modelled as an average emissions rate of 1.2 pounds of SO_2 per million Btus of heat input.[5] The estimated potential gains from trading are USD 784 million, or about 44% of the cost of command and control.

While these potential gains are significant, they are not as large in absolute terms as were originally predicted. The USGAO (1994) estimated greater gains in both absolute and relative terms, suggesting that a per-unit cap on emissions would cost approximately USD 5.3 billion annually – 140% more than their least-cost solution (USD 2.2 billion).

The explanation for relatively modest estimates of trading gains found by Carlson *et al.* is that many of the factors that have caused marginal abatement costs to fall also would have lowered the costs of achieving the SO_2 emissions cap via some forms of command and control policies. These factors include the fall in the price of low-sulphur coal and technical improvements that have facilitated fuel switching. Burtraw (1996) suggests that incentives under the allowance trading programme have accelerated the pace at which these changes have occurred. However, to the extent that these innovations would have emerged under a command and control approach, they lower the potential cost savings from trading compared to a command and control baseline.

In addition to *lowering* marginal abatement cost curves, the fall in low-sulphur coal prices has made marginal abatement cost curves *more homogeneous*. This is because the cost of transporting low-sulphur coal to more distant locations, for example, the east and south-east, has fallen, rendering differences in transportation cost a less important component of the overall cost of fuel switching. Since a major source of trading gains is differences in marginal abatement cost curves among units in the market, this increased homogeneity is also responsible for lowering gains from trade.

In summary, estimates of costs for both a command and control approach and allowance trading have fallen over time due to a number of factors. Allowance trading is resulting in cost savings relative to a command and control approach, but the absolute magnitude of these savings is expected to be somewhat less than previously envisioned due to changes in fuel markets and technology. These changes made the trading of allowances somewhat less important in reducing costs, but made the aspect of flexibility in firm's compliance decisions even more important. Finally, note that Carlson *et al.* (2000) model a flexible type of command and control policy (performance standards). A more rigid approach that forced firms to adopt specified technologies would have precluded them from taking advantage of the full range of options that have emerged in compliance with the programme. Compared to a more rigid command-and-control policy, Carlson *et al.* (2000) conclude that allowance trading could be argued to provide even greater savings.

Innovation

Heretofore, we find the SO_2 programme has realised tremendous cost savings compared to a conventional approach and even compared to expectations at the time the programme was initiated. A portion of these savings are due to trading emission allowances, but a large share of cost savings have been achieved outside the formal allowance market. The present question of interest is: to what extent can the cost savings be attributed to innovation?

We find evidence of several forms of innovation, but one common feature in this evidence is that the innovation generally is not patentable. Most of the innovations can be catalogued as changes in production processes, organisational behaviour, regulation, markets, etc.

An individual facility has a variety of mechanisms for compliance under Title IV in addition to allowance trading, including intra-firm reallocation of emission allowances, fuel switching and/or blending, installing scrubbers, retiring plants, repowering plants, energy conservation, reduced utilisation and substitution among facilities, and increased utilisation of lower-emitting facilities. To survey the role of innovation, we consider these compliance options as input supply including post-combustion control (scrubbing). Subsequently, we consider innovations at the organisational level.

Technological change at input supply level

The most important development in the implementation of Title IV has been the fall of prices in coal markets and of the operating cost of scrubbers. One explanation for this is the unanticipated degree to which input markets have been brought into direct competition. SO_2 allowance trading provides utilities with the flexibility to choose among several options for compliance in addition to the purchase of allowances. This flexibility provides the opportunity for vendors of various technologies to compete with emission reduction strategies at the power plant, and this additional competition can ignite a wider search for ways to reduce costs among suppliers of competing technologies. The result has been cost-reducing investments resulting in a decline in allowance prices below forecast in every potential option for compliance (Burtraw, 1996).

The most visible changes have occurred in the delivered cost of low-sulphur coal. Under the 1977 Clean Air Act Amendments, there was little value to the sulphur differentiation in coal because new source performance standards (Section 111) effectively forced adoption of specific technologies. Rules written in 1979 to implement the 1977 amendments imposed a minimum SO_2 reduction standard of 90% on high-sulphur coal and 70% on low-sulphur coal at all new facilities, effectively requiring the use of scrubbers and thereby eliminating the incentive for use of low-sulphur coal. So-called "compliance coal" (low-sulphur coal) with an emission rate below 1.2 lb. SO_2 per mmBtu remained in demand by facilities built between 1970 and 1977. But, for facilities built before 1970 and after 1977 there was no economic incentive or requirement to use lower-sulphur coal for compliance with environmental goals.

About half of the reductions in sulphur during Phase 1 of the programme have been achieved by changing to coal with lower sulphur content. A primary explanation, hinging on market fundamentals, is the low cost of this strategy. Another compelling explanation, hinging on institutional issues, is that this strategy is relatively non-capital intensive. In a period of uncertainty regarding the allowance market, cost recovery and especially competitive pressures facing the entire electricity industry, fuel switching and fuel blending are low-fixed-cost strategies that allowed affected utilities to comply with little risk.

The market for low-sulphur coal has grown and is expected to continue growing. Low-sulphur western coal has penetrated mid-western and eastern markets in record quantities, and eastern low-sulphur coal is being supplied at lower prices than anticipated as a result of increased mining productivity, lower rail rates and competition from western mines.

Changes in rail transport of coal

Many analysts have suggested that a large share of emission reductions achieved in Phase I were predestined by actions taken before the 1995 start of the programme (Ellerman and Montero, 1998; Burtraw, 1996; Carlson *et al.*, 2000). Emissions from facilities affected by Phase I totalled 9.3 million tons in 1985 and allowance allocations to these facilities for Phase I beginning in 1995 total 6.9 million tons. However, by 1993, emissions had already fallen to 7.5 million tons. This decline was due to demographic shifts in electricity demand toward areas more proximate to low-sulphur coal, coupled with increased availability of low-sulphur coal, not only as a low-cost compliance option for the SO_2 programme but as a cheaper fuel for power production at many facilities. Hence, the decline in price of low-sulphur coal may well have stimulated a decline in emissions even in the absence of the SO_2 programme.

However, Carlson *et al.* (2000) find that an important portion of potential cost savings through fuel substitution and trading were unrealised in Phase I. This was due to historical forces and the traditional regulation of electric utilities, which has been changing rapidly. Since an important portion of savings were left unrealised, it is difficult to establish what portion of cost savings that were realised would have occurred in the absence of the programme. Given that the incentive to switch to lower-sulphur coal is greater with the programme in place than if the programme had not existed, it is reasonable to assume that the programme contributes importantly to the switching to low-sulphur coal. This is the finding of Carlson *et al.* (2000), who control for "economic switching" and find additional switching achieved for compliance with the SO_2 programme to be much more important.

In any event, it is clear that the deregulation of the railroads in the 1980s led to greater competition among railroads for coal transportation business that emerged just at the time of the Clean Air Act Amendments. This competition led to a significant decline in coal transport costs, which is a major component of the delivered price of coal (Carter, 1996; Heller and Kaplan, 1996). Coal transport is the leading source of revenue for rail freight. The enthusiasm with which rail has competed for coal transport results from the Staggers Act of 1980 that largely deregulated railroads. In the 1980s, rail rates fell 35%, yet profits went up due to increased flexibility in tariffs and increased incentives to reduce costs.

Many observers in the Clean Air Act debates conjectured that bottlenecks would occur in rail transport that would preclude western coal from playing a big role in compliance plans of eastern utilities. Hence, price forecasts hinged on prices for low-sulphur Appalachian coal that was locally available to eastern utilities. However, these potential bottlenecks failed to materialise. Burtraw (1996) reports that investment plans by railroads were realigned after passage of the CAAA in 1990, and the railroads were anxious to capture a share of the expected rapid growth in coal transport given the incentive to switch to low-sulphur fuel. Realignment of investment plans to take advantage of new technologies such as increasing size of car fleets and unit trains, AC motors, laying double and triple tracks, increasing the number of locomotives, use of aluminium cars and increasing car dump speed. This is not the usual form of innovation imagined as part of technical change. However, it does represent a diffusion of new technology and an organisational adaptation to market opportunity. When investments are realigned, then cost reductions in one arena are associated with delayed investments and foregone opportunities in other arenas. It is important to recognise these opportunity costs in order to characterise properly the costs of regulation. However, the costs are inevitably lower given the incentive and opportunity to realign investments in this manner.

The primary question, then, is whether opportunities for rail transport of low-sulphur coal would have existed under a counter-factual environmental regulation using conventional approaches. A technology standard that took the form of forced scrubbing at major electricity generating facilities was a leading proposal in the 1980s and characterised new performance standards after 1979. Clearly

this approach would have precluded any advantage to low-sulphur fuel because scrubbers remove 95% of emissions rendering the additional cost of low-sulphur fuel unnecessary.

A performance standard that established emission rates at plants would have promoted a large amount of switching to low-sulphur coal, as illustrated by Carlson *et al.* (2000). However, it would not have provided an incentive for over-compliance at facilities relatively close to supplies of low-sulphur coal in order to reduce costs at facilities further away. Hence, it would not have complemented the allowance market or granted as much flexibility to firms as has the SO_2 programme. In summary, the SO_2 programme deserves substantial credit for not precluding, and arguably for accelerating, environmentally beneficial trends that were occurring in fuel markets. This outcome would have been unlikely under alternative approaches.

Innovations in fuel blending

Blending coals is not as important as switching coals, but has provided significant cost savings. Fuel blending involves mixing high- with low-sulphur coals to reduce average SO_2 emissions. Like fuel switching, fuel blending has lower capital costs than scrubbing. Generally, electric generating facilities are designed for a particular type of coal.

In the late 1980s, it was widely believed that fuel blending was not practical in cyclone boilers because of the anticipated impact on the operation of the existing plant and boiler. Deviations in any of several important properties may impair plant performance or harm equipment. Low-sulphur sub-bituminous western coal would be most troublesome in this regard because it does not share the characteristics of commonly used bituminous coal, including moisture content, heat content and ash properties. (Equipment likely to be affected by blending coals include the coal handling system, the fuel preparation and firing system, the primary air system, the steam generator and the particulate removal system.)

Fuel blending falls soundly into the category of an unanticipated innovation that resulted from the programme. Experimentation prompted by the allowance trading programme has led to an improved understanding of the ability to blend fuels, and the detrimental effects of blending have been found to be less than originally supposed. While, in the late 1980s, the rate at which it was thought low-sulphur sub-bituminous coals could be blended with high-sulphur coal was less than 5%, today coals are blended at rates of 30 or 40%. This process innovation was simple to achieve, but it was unanticipated and resulted from the incentives provided by the programme.

Innovations in the scrubber market

Scrubbers are a capital-intensive post-combustion compliance strategy with a larger initial cost and lower operating costs than most other strategies. The electric utility industry had relatively more experience with scrubbers prior to 1990 than with fuel switching and/or blending.

Keohane (2000) finds that capital costs per installed kw of capacity have remained fairly constant for many years. Taylor (2000) finds that capital costs have declined significantly over time. In any event, this experience did not foreshadow the fact that under the SO_2 programme, less capacity was needed to achieve roughly equivalent reductions. Previous to the CAAA, scrubber systems usually included a spare module to maintain low emission rates when any one module was inoperative. One estimate of capital costs indicates that they would increase by one-third with a spare module (USEIA, 1994, p. 92). An important innovation in the scrubber market is the reduced need for spare absorber modules. As long as emission allowances are a sufficient compliance strategy, utilities can save

considerable capital costs by eliminating the spare module and using allowances during periods of maintenance or unplanned outage. In addition, new scrubbers exhibit increased efficiency and reliability. Improvements in scrubber design and use of materials have reduced maintenance costs and increased utilisation rates, also reducing the need for spare modules.

Another significant technical implication of the CAAA is the incentive for improved efficiency in scrubbing. Increasing SO_2 removal from, say, 90 to 95% can be cost-effective compared to the overall cost of SO_2 removal and the opportunity cost of allowances. The incentives are such that upgrading of existing scrubbers through improvements including larger modules and elimination of reheat is likely to occur (Torrens *et al.*, 1992, pp. 221-222). These incentives did not exist under previous regulations affecting only new sources.

Keohane (2000) and Taylor (2000) both find that abatement costs per ton of removal have gone way down, especially in retrofit scrubbers installed for compliance in the SO_2 programme. The retrofit scrubbers burn higher-sulphur coal, which leads to higher abatement rates and thus lower per-ton costs (assuming some abatement costs are insensitive to the amount of abatement – *i.e.* fixed costs of labour and maintenance are tied to the hours of operation rather than the tons of SO2 removed.)

In addition, there is significantly increased utilisation of scrubbed units (Ellerman and Montero, 1998; Carlson *et al.*, 2000). Increased utilisation is important to reducing the average cost of scrubbing because it spreads capital costs over more tons reduced. Previous to the SO_2 programme, scrubbers did not exhibit reliability rates sufficient to achieve the current level of utilisation. The increase in reliability is at least in part a response to incentives provided under the trading programme, because of the permit cost savings associated with incremental reductions in emissions.

Organisational innovations

Process changes and realignment of investment priorities are a subtle manifestation of innovation. An even more subtle but also significant type of change has occurred in organisational behaviour in firms, markets and regulators.

Firms and markets

In 1990, in many firms the response to the "revolutionary" (and, some deemed, bureaucratically inspired and foolish) SO_2 programme was a conservative one. The responsibility for compliance with the unprecedented programme was given to engineers or chemists typically charged with environmental responsibilities.[6] Unfamiliarity with the new programme led many to pursue a policy of "autarchy" – no trade – and self-sufficiency in compliance (Bohi, 1994; Bohi and Burtraw, 1997; Ellerman, 2000; Hart, 2000).

Several years later one can observe responsibility for compliance resting more often with financial vice presidents, who have learned to treat SO_2 allowances as a financial asset. Decisions about how to manage allowance portfolios are treated analogously to decisions about how to handle fuel purchases; indeed, allowances are often bundled with fuel purchases. Several companies have developed software to manage their portfolio of emission allowances and to help make decisions about compliance (USEPA, 1996). The result is a much smoother and administratively less costly mechanism for planning and decision making within the firm.

Meanwhile, the market for SO_2 allowances has matured considerably since the early 1990s. In previous small-scale permit trading experiments in local air quality districts, transaction costs often

approached 30 to 40% of the value of the allowances. Today, the transaction cost associated with SO_2 permits is about 1% of the value of an allowance. And, the number of allowances trading virtually doubled each year between 1994 and 1998 (Kruger and Dean, 1997).

Convenience value of allowances

Although allowance trading is not the major form of compliance, the opportunity to trade allowances has an influence beyond the exchanges that actually occur. Furthermore, even in the absence of extensive trading, allowances potentially can play a constructive role in facilitating the optimal timing of investments. Firms considering capital investments in scrubbers may benefit from the option to delay investments if delay leads to the resolution of uncertainties pertaining to the planning process. (Kaslow and Pindyck, 1994). In Phase I, many firms expressed reluctance to engage in new capital investments, especially given the direction that restructuring of the electricity industry is likely to take. Chao and Wilson (1993) illustrate a "plausible" option value of USD 85 on allowances valued at the marginal cost of scrubbing (which they assume to be a relatively high USD 400). Allowances also provide insurance against unanticipated events such as unplanned equipment failures. The insurance value stems from the possibility of stiff penalties being imposed were the utility found to be in non-compliance. Hence, even allowances provide sources of value that were not widely appreciated in the design of the programme and that do not hinge on actual trading.

Regulatory reform

The reach of innovation extends right into the regulatory administration of the SO_2 programme (Kruger *et al.*, 2000). The USEPA has taken advantage of exogenous technological change, especially the information revolution, to reduce administrative costs incurred by the agency and by firms. Monitoring of emissions is achieved through continuous emission monitors installed on every stack. Data streams into the USEPA in electronic form and is organised by personal computers involving a staff that is just a small fraction of the size of staff managing other regulatory programmes. The USEPA's Allowance Tracking System (ATS) is an electronic system that facilitates enforcement and monitoring by the agency, industry and the public. And, industry has learned to use the ATS as a way to confirm and record the transfer of allowances.

The SO_2 programme is part of a fleet of regulatory changes including deregulation of the railroads, energy markets and the electricity industry, and it has benefited from these other changes. In particular, ongoing deregulation of the electric generating sector was set in motion by the Energy Policy Act of 1992 and accelerated by the issuance of FERC Order 888 in April of 1996, and related state-level deregulatory activities. This reform is creating greater competition among electric generators and associated pressures to reduce compliance costs, providing greater incentives to take advantage of the flexibility embodied in the SO_2 programme.

Conclusion

This assessment concludes that the SO_2 programme has been an environmental success. It has achieved 100% environmental compliance, and over-compliance in Phase I. The effect of trading and banking are roughly neutral with respect to the environmental benefits. An economic assessment of benefits is that they are substantially greater than the costs of the programme.

Particular interest is focused on the costs of the programme because of the innovative design of the SO_2 trading programme. Detailed analyses have found that the costs are one-half to one-quarter of projections. They are substantial and contribute to the tremendous success of the programme.

Most of the cost savings have been achieved outside the formal allowance market. But, after all, the point of allowance trading is not to trade allowances. The point is to give firms the flexibility to achieve emission reductions in the least costly manner. The SO_2 programme gives utilities the incentive and flexibility to capitalise on advantageous trends in fuel markets. Also, the programme has placed numerous options for environmental compliance into direct competition with each other. This has helped to reduce the cost of compliance.

Innovation in a variety of forms is evident in the SO_2 programme. Econometric estimates of the magnitude of innovation are difficult to achieve because they are not easily separable from other forces that have decreased the cost of compliance. Indeed, to an important extent they stem from the unprecedented incentive and ability of firms to take advantage of these other forces of technological change. Further, the innovation that is in evidence has not been in the nature of patentable discoveries, but rather it is in the form of the subtle process changes and the changes in markets and organisational behaviour that were seized upon to reduce costs once the incentive to do so was present.

NOTES

1. Another type of dynamic efficiency promoted by incentive-based regulation is so-called "allocative efficiency". This results because these approaches internalise some portion of the social cost of economic activity. For example, environmental taxes invoke costs associated with abatement activity (as does command and control) and also invoke costs associated with the tax payments, thereby having a greater effect on product prices than just the cost of abatement. Similarly, tradeable permits invoke abatement activity and also invoke costs associated with the opportunity cost of using a permit that could otherwise be sold to another firm. In a competitive market, this opportunity cost would be added to the cost of abatement in determining marginal costs of production. The consequence is to provide a more accurate signal of resource use in product prices both to consumers and to potential entrants in the market (Spulber, 1985).

2. See, for example, "Economists' Cold Forecast; Assumptions: Expect their Dire Predictions about the Impact of the Global Warming Treaty on the United States. Ignore All of Them", by Elaine Karmarck, *Baltimore Sun*, 28 December 1997.

3. USEPA (1990) predicted USD 210 (in 1995 USD) for the year 1995. Inflated at a 6% rate of interest, this is equivalent to USD 235 for the year 1997.

4. The cost function treats fuel type (high-sulphur and low-sulphur coal), labour and generating capital as fully variable inputs. The econometric model consists of the cost function plus two share equations that specify the share of total costs attributed to capital and labour, and an equation for the firm's mean annual emission rate. The study uses a translog form for the cost function, adding dummy variables for each plant in the database to measure fixed effects that vary among the plants. Costs for units with scrubbers are taken directly from reported data.

5. This approach already encompasses many of the beneficial incentives of the SO_2 trading programme compared to a technology-forcing approach by providing individual facilities with flexibility in achieving the standard. Other command and control approaches that were seriously considered in the United States, such as forced scrubbing at larger facilities, could have cost substantially more.

6. Stavins and Whitehead (1996) describe the organisational barriers to taking advantage of incentive-based environmental policies that exist in many firms that are used to conventional approaches to regulation.

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Chapter 5

THE CARBON TAX IN SWEDEN

by

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Introduction

In 1999, the Swedish Parliament established 15 environmental quality objectives. The overall aim is to be able to hand over to the next generation a society in which the major environmental problems have been solved (Swedish Environmental Protection Agency, 2000). The climate target is considered to be the most difficult one to achieve (Swedish Environmental Protection Agency, 1999).

Carbon dioxide emission is responsible for approximately 80% of the Swedish anthropogenic contribution to the greenhouse effect (Government Commission of Measures against Climate Change, 2000), and about 93% of the CO_2 emission is the result of fossil-fuel combustion.

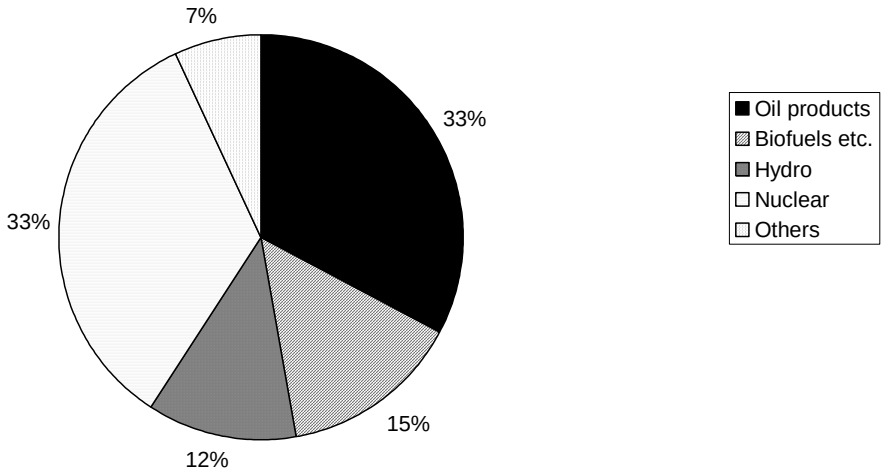
Taxes on energy have for many years played an important role in Sweden, both as a source of fiscal tax and as a policy instrument. In 1991, the energy taxation system was reformed and a carbon tax was introduced. The carbon and energy taxes are very closely connected and have to be considered together. Other economic incentives that affect the energy sector are the sulphur tax and the nitrogen oxides charge. Regulations have historically been important in reducing emissions from both stationary and mobile sources. Regulations have, so far, had relatively little effect on CO_2 emissions.

This chapter aims to describe the structure of the Swedish carbon and energy tax system and the consequences this system has had on the structure of the Swedish energy system. The relationship between this tax system and other policy instruments is discussed. Finally, there is a brief discussion of the effect that the carbon tax or other policy instruments is likely to have had on innovation in Sweden.

Characteristics of the structure of Swedish energy supply and demand

Swedish energy supply is summarised in Figure 1.

Figure 1. **Swedish energy supply in 1998**



Source: Swedish National Energy Administration (1999a).

The Swedish energy system has at least three characteristics that make it different from most other industrialised countries:

- Swedish electricity production is almost entirely fossil-free and is based on nuclear and hydro power. There is also some electricity production in co-generation plants in industry and district heating.

- Renewable energy contributes 27% to the Swedish energy supply. Biomass is the dominating source with hydro power and provides approximately 15% of the energy supply. The high importance accorded to renewable energy is a result of favourable geographical conditions, industrial structure and governmental policies. The Swedish population density is low and the country has large forests from which significant amounts of biomass energy can be extracted. Energy use in industry is heavily dominated by the forestry industry which enjoys excellent opportunities to utilise its by-products to respond to internal energy demand. Government policies have historically supported the development of hydro power and biomass energy.

- Per-capita electricity use in Sweden is very high, partly because of the rapid expansion of electric space heating during the 1980s and partly because of a large electricity-intensive industrial sector. Currently, about 35 TWh of electricity per year is used for space heating (Johansson, 1995; Swedish National Energy Administration, 1999b). This equals to approximately 25% of total electricity demand.

Taxes on energy in Sweden

The Swedish energy tax system underwent reform in 1991. During the 1980s, the focus had been on oil substitution and the tax system was therefore designed to discourage oil use. The new taxation system was based on a carbon tax and a energy tax on fuels (the latter is not directly connected to the carbon content of the fuel). Simultaneously with the introduction of the carbon tax, general energy taxes were reduced by 50% (Energidata Göteborg *et al.*, 1995).

In addition to the two taxes mentioned above, other taxes were applied to electricity production, consumption, etc. (Table 1). In 1991, a value-added tax on energy consumption was introduced.

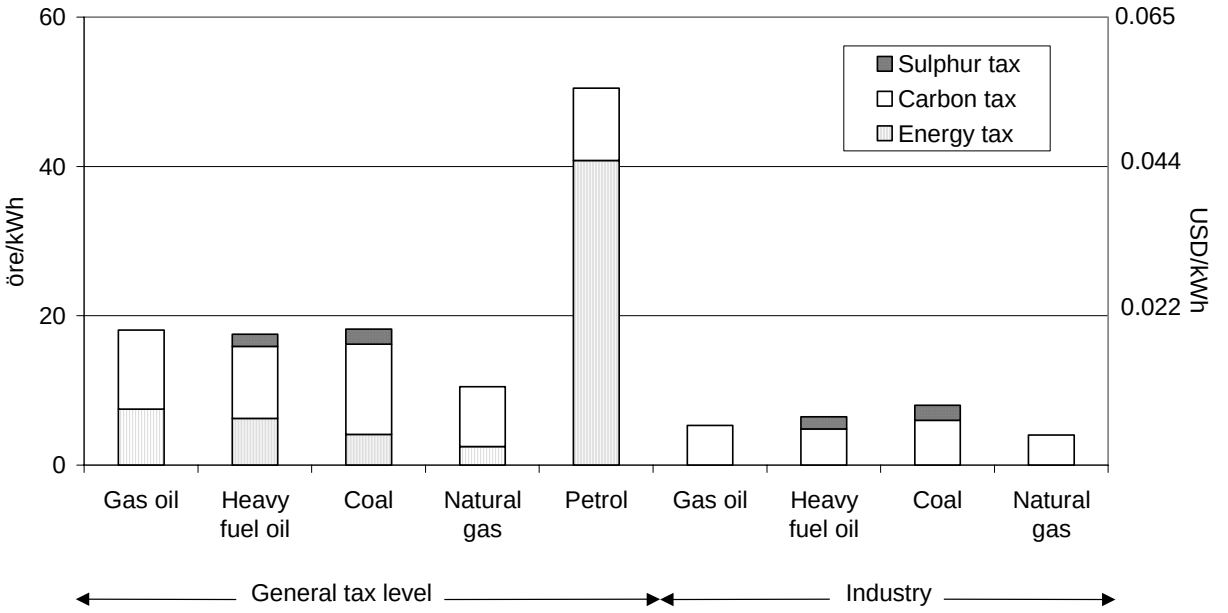
Table 1. **Summary of current taxes and charges applied on energy in Sweden**

Type of tax	Tax level	Comments
Energy tax	Differs among the fossil fuels, see Figure 1	Applied on all fossil fuels. No tax on fuels used in industry or for power generation
Carbon tax	General level 0.36 SEK/kg CO_2 (USD 150/tonne C)	No tax is applied to fuels used for power generation and 50% of the general level on fuels used in industry
Sulphur tax	30 SEK/kg S (USD 3.3 /kg S)	Applied on heavy fuel oils, coal and peat. If sulphur is removed from the exhaust gases the tax could be refunded in accordance with that
Nitrogen oxides charge	40 SEK/kg NO_2 (USD 4.4/kg)	Applied on heat and power plants which use more than 25 GWh/yr. The charge is refunded to the group in proportion to their energy use
Tax on nuclear electricity production	2.7 öre/kWh (USD 0.003/KWh)	
Electricity consumer tax	11-16 öre/kWh (USD 0.012-0.017/kWh)	No tax on electricity used in the industrial sector
Value added tax		Applied on all energy consumed

In 1993, industry was exempted from the energy tax and had to pay only 25% of the general carbon tax. This tax reduction was introduced to preserve the international competitiveness of Swedish industry. In 1997, the carbon tax on industry was raised to 50% of the general level . For energy-intensive industries special rules apply that allow further reductions of the carbon tax. The 1991 and 1993 tax reforms led to reduced tax levels for industry, amounting to reductions of over 50% for some fuels (Energidata Götrborg *et al.*, 1995). There is no energy or carbon tax on electricity production, although non-industrial consumers pay an electricity consumption tax.

The current general carbon dioxide tax is 36.5 öre/kg CO_2/ (~USD 150/tonne C). The energy tax on fossil fuels, especially on petrol but also on other oil products, are rather high and acts therefore, outside the industrial sector, as a powerful complement to the carbon tax. Current rates of energy, carbon and sulphur taxes for various fossil fuels are shown in Figure 2.

Figure 2. **Energy, carbon and sulphur taxes in the energy sector**



Source: Swedish Energy Administration, 1999.

The effects of the carbon and energy taxes

The most obvious effect of the reformed taxation system has been the expansion of biomass use in the district heating system (Figure 3). Since 1990, biomass use has also increased in industry, although to a lesser extent, from 45 TWh/year to 54 TWh/year (Swedish National Energy Administration, 1999).

The reason for the expansion can be easily understood by comparing heat production cost for biomass-based heating plants with the heat production cost for fossil-fuel-based plants (Figure 4). Under the new tax system, biomass has become the cheapest option for new heat production in district heating systems.

There are several reasons to explain why the effect of the carbon tax in industry has been rather small:

- The industrial tax level is much lower than the tax level in district heating, see Figure 4.
- When the tax was introduced, only a relatively small fraction (30%) of the energy supply to industry was fossil-fuel-based, see Figure 5.
- The total taxation level on fossil fuels in industry was reduced in the 1991 taxation reform.
- For most industrial companies, the fuel cost is a relatively small fraction of total costs and is therefore given low priority.[1]

Figure 3. **The use of biomass in Swedish district heating systems**

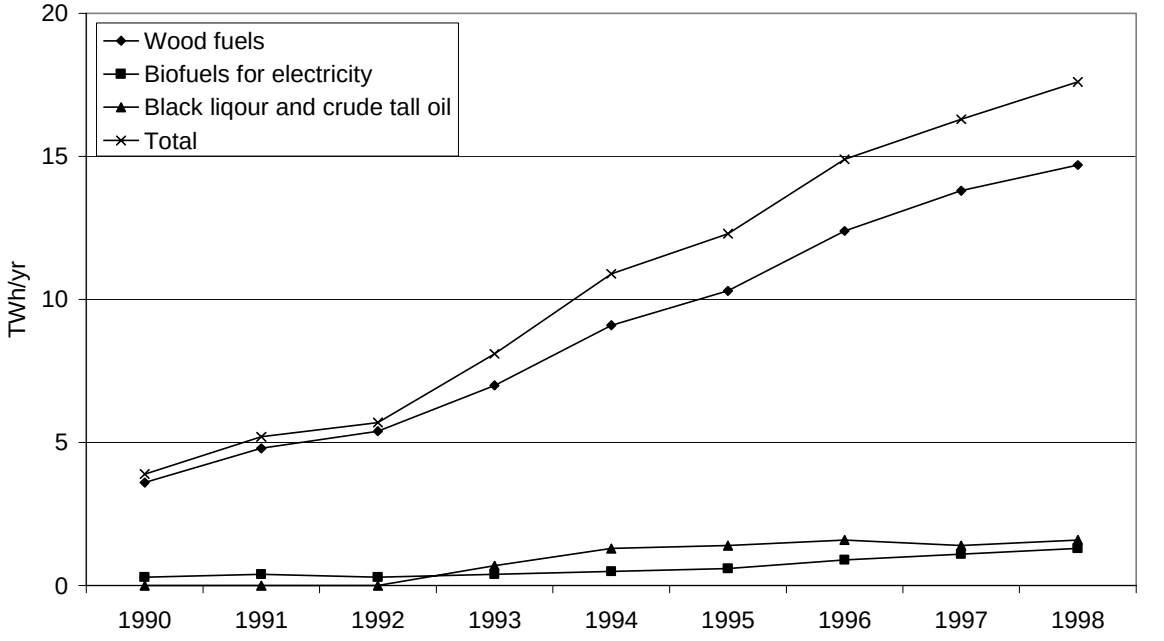
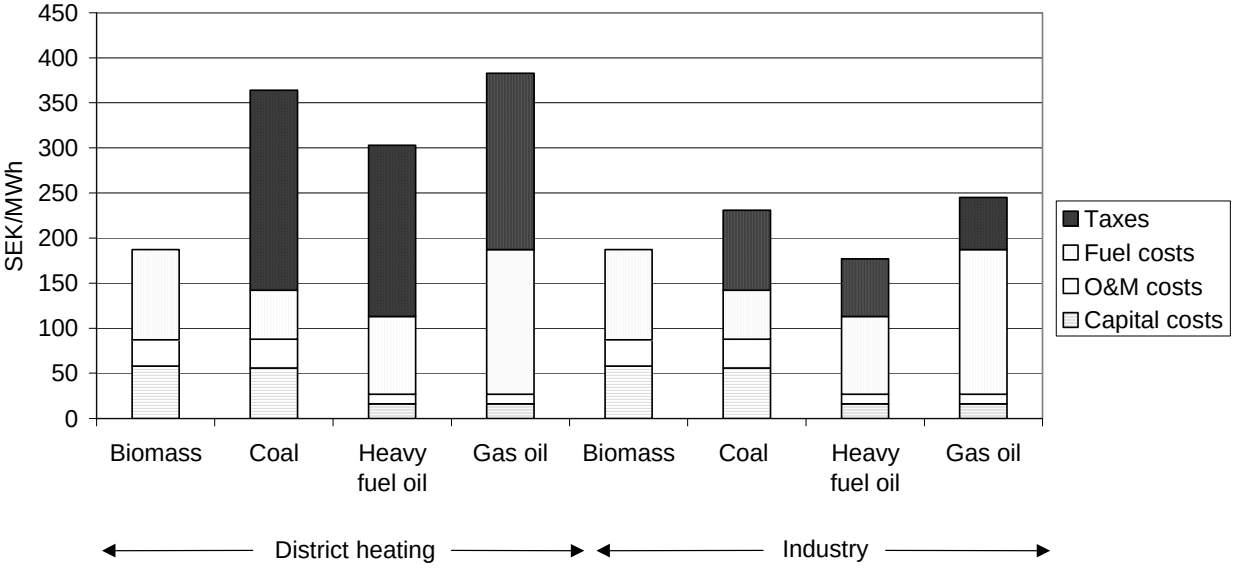
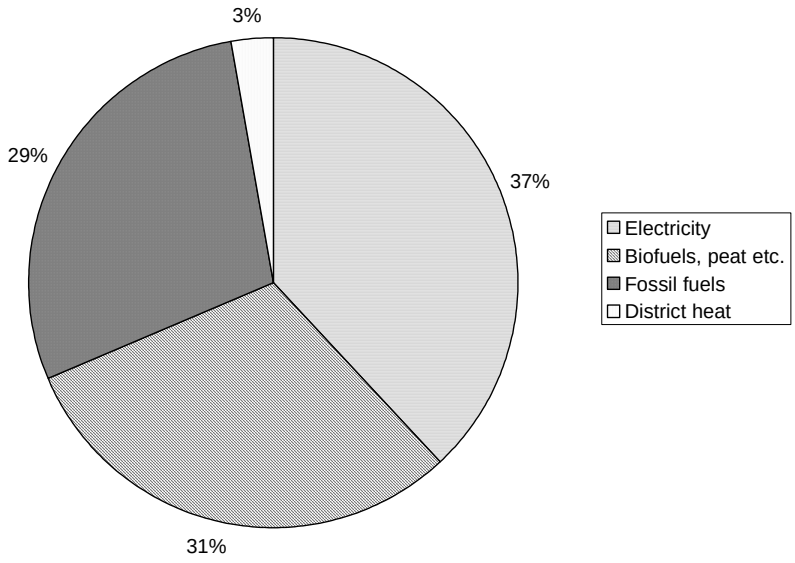


Figure 4. **Heat production costs for new plants**



Source: Swedish National Energy Administration, 2000.

Figure 5. **Energy use in industry by source, 1990**



Source: Swedish National Energy Administration 1999.

The differentiation of the carbon tax among sectors has had some effect on the behaviour of companies. Between 1993 and 1997, when the tax difference between fuels used in district heating systems and fuels used in industry was larger than it is today, some industries sold their by-products to the district heating companies while they themselves burned fossil fuels. This was not an efficient solution but was an effect of the structure of the tax system.

A number of studies have tried to quantify the impact on CO_2 emissions of the policy instruments implemented since the beginning of the 1990s. For example, the Ministry of Environment (1997) shows in its second national report on climate change that CO_2 emissions in 1995 were about 15% lower than would have been the case if the policy instruments of 1990 had remained in use. It was estimated that by the year 2000, CO_2 emissions would be 20-25% less than if the 1990 policy package had remained in place. Almost 90% of this reduction was the result of the reformed tax system, while the remaining 10% was a result of investment grants and government programmes on energy efficiency. The CO_2 tax has, however, not been sufficient to reduce total CO_2 emissions; these increased by 3% between 1990 and 1998 (Government Commission of Measures against Climate Change, 2000).[2]

The effects of sulphur taxes, nitrogen charges, regulation and investment grants

Both the sulphur tax and the nitrogen charges have had an effect on emissions. However, nitrogen charges are applied only on stationary combustion plants producing more than 25 GWh/year (these plants are responsible for only a small proportion of total NO_x emissions in Sweden) and therefore have an impact on a very small fraction of total emissions. An evaluation from the Swedish Environmental Protection Agency (1997a) shows that the taxes and charges have been cost-effective. In 1989-95, the sulphur tax was responsible for emission reductions equal to about 30% of the 1989 level of Swedish emissions. NO_x emissions from the plants on which the NO_x charge was applied were reduced by 60% between 1990 and 1995, of which about 80% directly resulted from the nitrogen charge (Swedish Environmental Protection Agency, 1997a).

The evaluation shows, however, that regulations have also had a significant effect on emission reductions. For the implementation of combustion improvements and exhaust gas treatment on large plants and reductions of the sulphur content of fuel, regulations do seem to provide cost-effective measures. In addition, a new environmental code came into force in Sweden on 1 January 1999, according to which energy and resource efficiency as well as CO_2 emissions are to be examined when considering permits for environmentally hazardous activities.

As a result of the reluctance to introduce carbon taxes on electric power generation and the fact that electricity prices have fallen significantly during the 1990s, the political goal of increasing the share of renewable electricity has been implemented through the introduction of investment grants for biomass-based power plants as well as on wind power generation plants. Furthermore, an environmental bonus has been applied to electricity produced in wind power plants. These investment grants have played an important role in the expansion of power generation technologies, and wind power generation systems have become, with this support, competitive with other power generation technologies. The construction of biomass-based co-generation plants has certainly been encouraged by these economic support measures, but another reason for biomass-based co-generation can probably be found in political decisions in the municipalities controlling the district heating systems. The investment grants for biomass-based plants have not been large enough to make the biomass-based power generation competitive.

The effects of economic policy instruments on innovation

There are no studies available to show the effect of carbon taxes on innovation in Swedish industry. However, there are reasons to believe that the relatively low taxes on industrial energy use have resulted in only minor improvements in energy efficiency within the industry. The same conclusion was drawn in an interview study which found that the level of the energy tax did not provide sufficient incentives for industry to invest in energy-efficient technology (Energidata Göteborg AB *et al*., 1995). Since then, however, the carbon tax has doubled to 50% of the general taxation level.

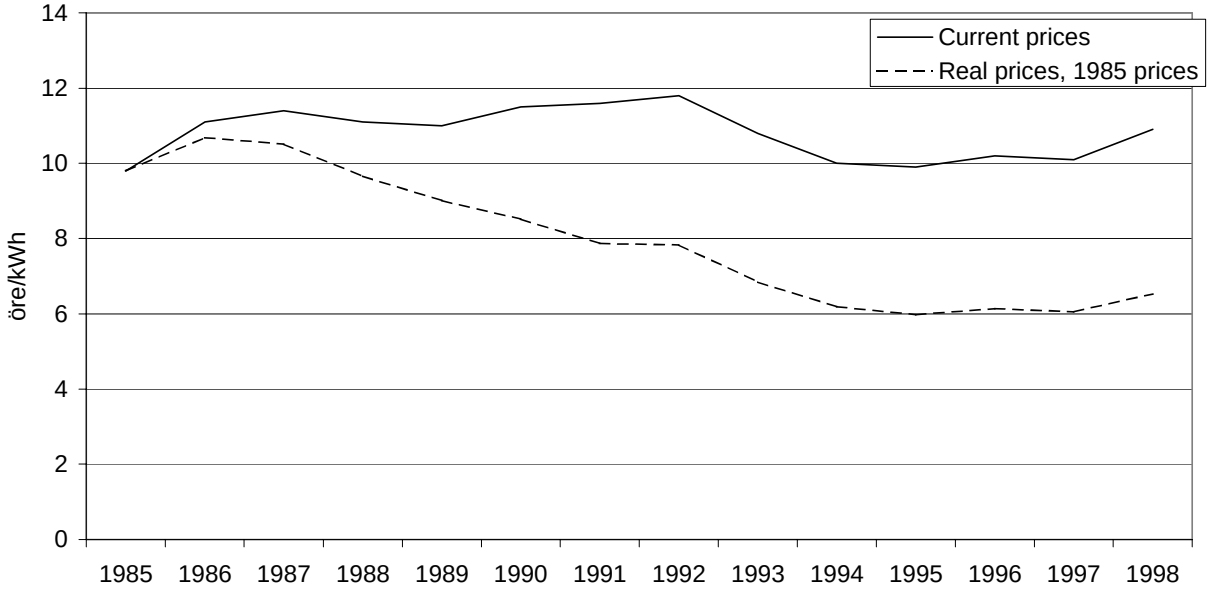
The most important result of the new taxation system is probably the development of new methods of biomass extraction and a biomass market. The increase in biomass demand resulted without any increases in biomass prices, in fact current biomass prices have remained at the same level as in the middle of the 1980s, *i.e.* there have been substantial cost reductions in real terms (Figure 6).

As the demand for biofuels increased during the 1990s, several new technical solutions were introduced. These include multi-treehandling/felling in smallwood thinning, compaction equipment for logging residue, and heavy duty chippers (Brunberg *et al*., 1998). New methods for simultaneous extraction of log and logging residues are being developed. These methods, including a harvester technology that accumulates the tops and branches as the stems are processed and then compacts the material into composite residue logs, could reduce both the demand for machinery and costs by 20-40% (The Forest Research Institute of Sweden, 2000).

A biomass market has also developed, enabling a widening of the potential biomass suppliers to the major heat production plants. The combination of increased demand for biomass with simultaneous market pressure has given rise to increased demand with falling prices.

The expansion of biomass in district heating has led to the introduction of flue-gas condensation and enabled efficiency gains in biomass plants of 10-25% (Swedish Environmental Protection Agency, 1993).

Figure 6. **Prices of forest fuels in Sweden**



Source: Swedish National Energy Administration 1999.

A number of technical developments can be attributed to the introduction of the sulphur taxes and nitrogen charges (Swedish Environmental Protection Agency, 1997). Simpler and cheaper instruments for emission measurements, calculations and evaluations have been developed. SCNR systems for nitrogen oxides reductions have also been developed as a direct effect of the nitrogen charges. One result of the sulphur tax is that existing exhaust gas desulphurisation devices have been able to reduce the emissions to much lower levels than they were originally designed for (Swedish Environmental Protection Agency, 1997).

Conclusion

Together with other taxes, the carbon tax has played an important role in limiting CO_2 emissions during the 1990s, with as its main effect the expansion of biomass use in district heating systems. This in turn has led to developments in the technology for biomass extraction in forestry and the implementation of more efficient heat plants in district heating systems.

NOTES

1. The industrial sector's fuel cost accounts, on average, for somewhat less than 1% of the sector's total expenses (Statistics Sweden, 1998). However, the cost share differs significantly between various sectors.

2. If the values are corrected for climate variations, the increase is smaller (1%).

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Chapter 6

EFFECTIVENESS OF VOLUNTARY AGREEMENTS: RESULTS OF THE SECOND FOLLOW-UP TO THE KEIDANREN VOLUNTARY ACTION PLAN ON THE ENVIRONMENT

by

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Introduction: Keidanren and environmental issues

The Keidanren Voluntary Action Plan on the Environment is an example of a useful option to meet the goal of reducing carbon dioxide emissions. Keidanren's membership consists of about 120 leading business organisations and the more than 1 000 corporations which do business in Japan. Keidanren is the largest economic organisation in Japan. Since its founding in 1946, it has participated in the policy formulation process in Japan through recommendations based upon committee deliberations on issues such as economic policy, tax reform and regulatory reforms. Over a long period of time, an institutional set-up has evolved in which, through Keidanren, individual companies and organisations work together as a business community and engage in dialogue with the government, political parties and other stakeholders. In addition, as is the case of Keidanren Voluntary Action Plan on the Environment, agreements reached in committees are approved in the Meeting of the Board of Directors as the agreement of the business community they thus become binding on all members.

With respect to environmental issues, Keidanren has taken a proactive stance. It adopted the "Keidanren Global Environment Charter" in April 1991, providing guidelines for corporate action and management policies to protect the global environment. The charter stated explicitly that "endeavouring to deal with environmental problems is an essential condition for corporate existence and activities" and declared its intention to pursue voluntary and active efforts on behalf of environmental preservation. Five years later, in July 1996, it released the "Appeal for the Environment", setting out measures that industry had to adopt to deal with climate change. The Appeal specified concrete policies for promoting measures to deal with global warming and for promoting a recycling-based society; it also identified courses of action for the creation of environmental management systems, the implementation of environmental audits, and the inclusion of environmental considerations in overseas business activities. In June 1997, based on the Appeal, Keidanren formulated and published the "Voluntary Action Plan on the Environment", a compilation of the voluntary plans undertaken individual industry organisations (the Action Plan also includes targets for the reduction of industrial wastes).

The Keidanren Voluntary Action Plan

Environmental problems such as global warming, which are long-term in nature and arise on a global scale, have causes that relate to all business activities and that touch on every aspect of our daily lives. Their pervasive nature renders impossible the imposition of uniform limits on activities and hinders the implementation of adequate responses through the adoption of conventional regulations. Replacing the traditional regulatory measures which were effective in dealing with pollution and other problems in the 1970s, voluntary action represents a promising approach with respect to the global-scale issues of the 1990s. Voluntary actions are effective because they allow the people with the best knowledge about their own businesses to propose and execute measures that are effective from a cost-benefit standpoint and are based on a comprehensive consideration of technical trends and other management-related issues.

The highlighting feature of the Voluntary Action Plan is that it is entirely based on voluntary efforts by the private sector and focuses on an awareness of environmental problems. From the business point of view, the private sector's voluntary initiatives offer promising options in encouraging the adoption of best practices and a continuous effort taking into account the different economic and social settings of the participating industries and firms. Voluntary actions are also able to enhance self-responsible and cost-effective actions in various ways.

A crucial element in promoting this kind of voluntary effort is the incorporation of a scheme that allows "incentives in the form of public promises". This is brought about by requiring participating firms and industries to declare specific goals, by conducting follow-up evaluations annually on progress being made towards those goals and by making progress public.

From this perspective, industry conducts annual follow-ups on progress being made under the Voluntary Action Plan and releases this information to the public. On the other hand, the Government of Japan has identified the follow-up to the Keidanren Voluntary Action Plan on the Environment as an integral component of the measures being implemented under its "Guideline of Measures to Prevent Global Warming", which was developed and adopted in June 1998. Accordingly, in its various related councils, the Japanese Government reviews progress on the action plans of the various industries from a third-party standpoint, and publicises the results of the reviews.

The basic scheme of the Keidanren Voluntary Action Plan on Climate Change consists of four steps:

- Establishment and compilation of voluntary action plans.
- Reporting and follow-up.
- Implementation of action plans.
- Periodical review and improvement of action plans.

In the first step, *establishment and compilation of voluntary action plans*, individual industries establish their own voluntary action plans, including setting numerical targets and outlining specific measures for climate change mitigation and reduction of industrial waste. These plans are then reviewed and compiled by the Keidanren committees and published as a Keidanren Voluntary Action Plan which is accepted as a commitment between industries and their stakeholders.

In the second and third steps, *reporting and follow-up* and *implementation*, in order to ensure the credibility and transparency, the industrial firms are required to report on their action plans, and the

progress is reviewed by the industrial associations as well as by the Keidanren. The progress and the review results are published periodically. At the same time, the action plans are integrated into national climate change policy (the government's "Guideline of Measures to Prevent Global Warming"). Therefore, a co-ordinated approach with national policies and measures is pursued as a part of the implementation of the voluntary action plans.

The last step, *periodical review and improvement of action plans*, involves a rigorous assessment of progress to ensure the credibility and effectiveness of the approach, including:

- Checking the progress of voluntary action plans based on actual performance (against CO_2 emissions or energy consumption in the previous year, for example).

- Review of numerical targets and measures including an evaluation of the cost-effectiveness of specific measures.

The results of these assessments are published.

These steps will be executed on a regular basis. Because the participating industries are fully aware of the significance of implementing the action plan, performance is likely to continuously improve; the plans are expected to make a substantial – and cost effective – contribution to the national commitment

The Plan has been recognised as a major component of the policies and measures to be implemented by the private sector, which is in line with the national commitment set out in the "Guideline of Measures to prevent Global Warming". As of today, the Keidanren Action Plan is indeed the only commitment with a numerical target supported by enforcement procedures in the national Guideline.

It should be noted that about a year after Keidanren announced its Voluntary Action Plan, the Japanese Government amended the Energy Efficiency Law to promote rational energy use in factories and business sites. For example, factories and department stores which consume large amounts of energy are obliged to submit their plans to promote rational use of energy.

With respect to waste-related measures, Keidanren has carried out an annual survey of the status of actions undertaken by the major industries since 1990, and has made the results public. Moreover, to strengthen the waste-related measures, Keidanren integrated such measures into its Voluntary Action Plan on the Environment in 1997, when the action plan was adopted. In December 1999, it declared a quantitative target on the waste issue as well for industry as a whole, and is currently in the process of the first annual follow-up.

Results of the second follow-up

Thirty-one business sectors participated in the Voluntary Action Plan at the time of the second follow-up. Their aggregate target is to reduce CO_2 emissions in 2010 to below the 1990 level of 129 million t-C (tonnes of carbon dioxide). In 1990, this amount represented approximately 75% of the total emissions from the industrial sector in Japan, and about 42% of the emissions of the country as a whole.

Results from the second follow-up show that CO_2 emissions in 1998 amounted to 126 million t-C, or 2.4% less than 1990 and 6% less than 1997. Reasons for the decline in CO_2 emissions include

decreased production by the energy-conversion and industry sector, reflecting the current weakness of the economy, as well as reflecting efforts to reduce CO_2 emissions on energy input per unit output.

In the meantime, CO_2 emissions are forecast to be 134 million t-C in 2005, or approximately the same level as in 1997, taking into consideration the expected recovery of the economy. Assuming a business-as-usual case, emissions in 2010 are forecast to rise to 142 million t-C, or about 10% above the level of 1990. These results illustrate that, while industries are making progress in terms of reducing their CO_2 emissions and energy inputs per unit output, a further strengthening of their efforts is needed if they are to achieve their targets for 2010.

Innovation and the Voluntary Action Plan

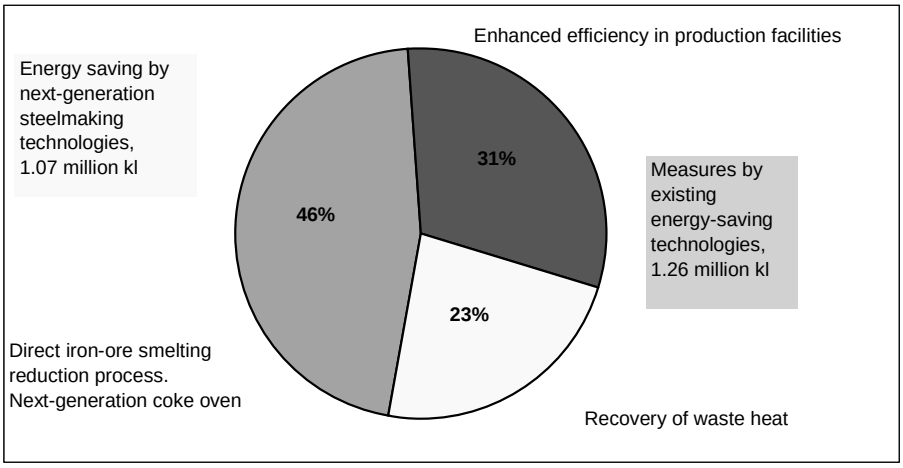
Regarding the relationship between innovation and the Voluntary Action Plan, it should be borne in mind that in responding to the demands to reduce the carbon dioxide emissions, companies will tend to focus initially on improving existing technologies and adopting them. As a second step, they will turn to the development of next-generation technology.

The steel industry

The steel industry, for example, has adopted the target of reducing its total consumption of energy by 2.33 million kilo litres crude oil equivalent by 2010. It achieved a reduction of 3.39 million litres between 1990 and 1995 and the industry estimates that 54% of the target can be achieved by improving existing energy-conservation technologies (Figure 1). These include waste heat recovery from coke dry quenching and top pressure recovery turbines; enhanced efficiency through improving existing production facilities in continuous casting, coal blending, direct current electric furnace and high efficiency on-site power generation. However, it is forecast that the remaining 46% of the target reduction in energy consumption can only be achieved by the adoption of the next-generation steelmaking technologies: the direct iron-ore smelting reduction process and the next-generation coke oven.

Figure 1. **Energy saving in production processes, 1995-2010**

To achieve energy savings of 2.33 million kl of crude oil equivalent



It is estimated that an additional reduction of 0.86 million kilo litres would be possible through utilising waste plastics by blast furnace injection, provided that the following conditions are realised:

- Efficient systems for collecting waste plastics and other systems for promoting the utilisation of waste plastics in blast furnaces are developed. (The Voluntary Action Programme estimates 1 million tonnes of plastics could to be fed to blast furnaces.)

- Technical problems are solved, through the development of technologies to remove foreign matter from waste plastics, and to remove chlorine from chlorine-containing plastics such as vinyl chloride.

Other industries

Recent trends indicate that in many of the mature, resource-intensive industries that account for a significant proportion of carbon dioxide emissions, including steel, chemicals, cement, petroleum refining and pulp and paper, both energy and carbon dioxide intensity in production have improved only slightly. On the other hand, in the gas, camera, aluminium and shipbuilding sectors, both energy and carbon intensities have improved significantly, although these industries are not large emitters of carbon dioxide. However, all these industries rely on innovation to improve production efficiency and further reduce carbon dioxide emissions. Waste heat recovery and other energy conservation and efficiency measures, as well as the recycling of products in such industries as pulp and paper and aluminium, are the main innovative responses to be pursued with a view to meeting the targets of the Voluntary Action Plan.

Conclusions

The companies participating in the Keidanren Voluntary Action Plan on the Environment claim that through their own creativity, they are steadily and in a flexible manner implementing voluntary efforts and producing results. Innovations, including the improvement of existing technologies and the prospective adoption of new-generation production equipment form an integral part of their efforts.

Most importantly, they are committed to maintaining their number 1 position in the world in terms of energy efficiency. It should be noted that Japanese business circles are strongly opposed to the introduction of a new tax, because, among other things, they have doubts about the effectiveness of a carbon tax and are concerned about the impact on international competitiveness. They are also against the imposition of caps on companies, fearing the possible emergence of economic controls on top of the various difficulties concerning the equitable distribution and monitoring of emission quotas.

With regard to an environment tax, unless it is so high as to threaten the very survival of the company, it would not lead to any action beyond voluntary efforts towards innovation. Indeed, many energy-intensive companies, including steel manufacturers, argue that an environment tax would actually be a demerit, because it would reduce the resources available for innovation by the amount of the tax.

PART II

DRIVERS OF ENVIRONMENTAL INNOVATION AND INNOVATION POLICIES FOR ENHANCING ENVIRONMENTAL PERFORMANCE

Chapter 7

SUSTAINABLE INNOVATION: DRIVERS AND BARRIERS

by

Andrew Dearing*
World Business Council for Sustainable Development

Summary

People often describe sustainable development as requiring a joint and long-term outlook by society that integrates social, economic and environmental objectives. Today, the private sector's contributions come from developing and using environmentally better, eco-efficient, ways to produce and provide products and services and by creating wealth and employment respectful of changing expectations of corporate responsibility and behaviour.

Delivering and extending this contribution beyond eco-efficiency depends upon the continued innovation that effective design and the development and use of better technologies will make possible. Sustainable development is a metaphor for opportunity and progress as well as a reminder of obligations and uncertainty. It requires a step-change improvement in performance. Merely doing better what we are already doing is not sufficient to meet with dignity the needs and aspirations of a growing world population.

At the same time, commercial success depends upon carrying out business in value-creating ways. Increasingly, the World Business Council for Sustainable Development (WBCSD) believes that this can be achieved by addressing innovative opportunities that reflect changing social expectations and support a transition to greater sustainability. Whereas our research suggests that no single approach will apply to all firms in all situations, some common underlying principles emerged, which are summarised below:

- Sustainable development offers an organising framework based on opportunity and respect for human values. Innovation is about using change to better meet human needs and values. The connection seems obvious although it is hard to realise in the absence of clear market signals and a common language, especially since innovation can come unexpectedly "out of left field" and have uncertain consequences.

* This chapter reflects work carried out in discussion with over 1 500 people in a wide variety of organisations worldwide. The WBCSD is very grateful to these people for the insights, ideas and data that have made the project possible. Nonetheless, responsibility for the conclusions that are drawn lies with the task force itself.

- Better design and new technologies provide the means to act smarter and in more sustainable ways but this technology also creates uncertainties, for example about the consequences of the scale and scope of application. Using these tools well depends upon understanding what the public expects and being able to meet these needs cost-effectively and without raising alarms and fears.

- The process of innovation is taking place within increasingly networked economies with changing social values and growing environmental pressures. While these forces are unavoidable, they are not unmanageable. Successful commercial approaches depend on having the flexible, multidisciplinary skills to respond to this changing context. Sustainable development is not unusual in this respect.

- Within developing nations in particular, technology's contribution to sustainable development comes largely through business-to-business transactions. Here, the large gap in performance is typically not a consequence of the lack of cost-effective technologies. The priority is to increase the capacity to apply available solutions well. Key focus areas are to develop skills and capacity especially in the small and medium-sized enterprise (SME) sector and to find ways to reduce project investment risk. Overseas development assistance (ODA), foreign direct investment (FDI) and the newer flexible market instruments such as the Clean Development Mechanism can be brought together to support innovative and effective public-private partnerships to address these points.

- In some situations, people respond best to sustainable development as a vision, whereas in others, more pragmatic approaches work best. Whichever approach is preferred, innovation often comes from facing strategic dilemmas that can only be resolved by finding new approaches. This is one reason why credible stretch targets can be an effective way to secure major improvements.

- The leadership task is to harness economic and social trends, capture the tremendous amount of knowledge and experience that exists in networks worldwide and combine these in ways that command respect, generate enterprise and create value. Traction is likely to be greatest when the management approach is positioned appropriately for the company in its network and seen by staff to be relevant and self-evident, if not simple, in purpose and content. This needs clear direction backed up by resources, management support and good metrics.

- We believe that achieving this requires extending the principles of transparency and learning, corporate social responsibility and eco-efficiency throughout the innovation process. This process extends from research and development through technology selection and use, product and service design, investment and employment policies and global and local business activities, as well as to issue management and government relations.

In summary, the commercial challenges are to learn to treat sustainable development as a framework for innovation and to use and extend established management principles to make this framework operational and effective.

Already, leading companies have demonstrated the willingness to express what they stand for and in turn understand what society expects of them. These companies are actively developing and incorporating the tools to improve performance across the three pillars of sustainable development. They are learning how to stimulate innovation and are setting focused targets that measure progress and assure the link between their own values and those of their customers. However, there is much

more to be done and important lessons to be learned and applied, especially to obtain innovation that addresses the social pillar of sustainable development.

There are many ways in which other stakeholders can assist these efforts. For example, governments can design regulatory frameworks that set the direction, encourage and reward the experimentation that fosters innovation and improves sustainability. They can demonstrate (through procurement policies and the information provided to the public) that they are committed to achieve the same objectives that are expected of others.

Innovation and sustainable development

Firms have used technology as an engine of progress since at least the time of the Industrial Revolution, which gave remarkable ways to marshal the physical world for human benefit. Innovation, which we use to mean the successful implementation of new developments and ideas, depends upon much more than technological advance, but technology has consistently provided the opportunities from which to make and sell better goods and services and to do so more cleanly and more safely.

Many of today's social and economic developments are a result of technical discoveries and developments in fields such as communications, information processing, health sciences and energy supply. These promise smarter, more tailored solutions to the tasks we wish to accomplish. Rather than being monolithic in approach, the tools are used by dynamic and responsive networks of small and large, public and private organisations, working together and in competition in ways that were never before possible.

The changes are tremendous and the opportunities profound, but it has become clear that technology can only be part of achieving a more sustainable development and its contribution is not always as positive as we might wish. Furthermore, other factors that can drive and support progress are themselves changing and need to be understood.

For example, the well-defined social categories for which post-war Western institutions were designed no longer fit well with people's aspirations and values. Richer countries are experiencing a shift towards an increasingly multidimensional and diverse "mosaic society", with uncertain needs but very real concerns about many subjects including science and technology. At the same time, despite there being greater affluence than at any time in history, most of the world's population remains poor yet increasingly aware of its relative poverty. For these people, the economic and social benefits of globalisation and global markets are increasingly being questioned.

Many other writers have offered cogent, visionary ideas of the improved sustainability that can be obtained by marshalling recent developments. The focus of this chapter is on how firms can organise themselves to realise these opportunities in ways that will benefit and be acceptable to society and also create the value that permits them to remain in business.

The approach that is suggested is based on understanding how companies have handled the concepts of corporate social responsibility and eco-efficiency, examining how they are now managing innovation and technology and finding ways that will bring these approaches together in today's and tomorrow's economies.

Leading companies have built their approaches to sustainable development upon principles that can be summarised as follows:

- *Attitude*. Ensuring the corporation understands what society expects of it, in return expressing clearly what the firm itself stands for, then reinforcing these values in ways that stretch the organisation and create a spirit of continuous improvement.

- *Build the capacity to act*. Developing the tools and approaches to improve performance across the social, environmental and economic pillars of sustainable development and incorporating these tools within routine business processes.

- *Check progress*. Setting focused targets and putting in place the means to measure performance and confirm that the targets are being achieved.

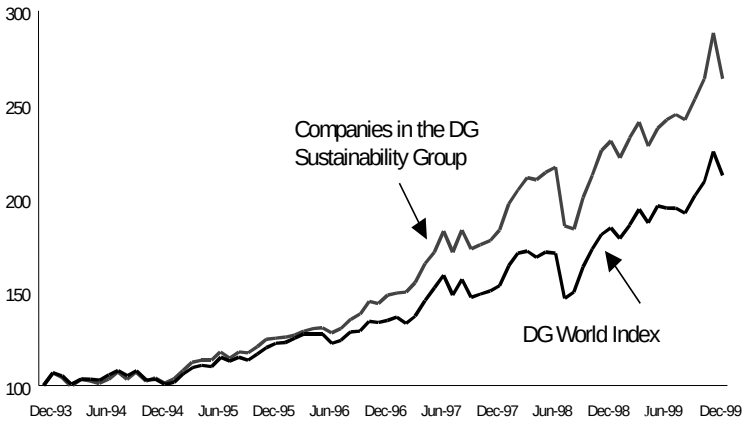
For existing business operations undergoing normal business development, these are mutually reinforcing principles. They provide a positive and effective framework that firms can use in mitigating environmental impact and allaying public distrust.

Whereas 20 years ago, most companies based performance standards on regulatory requirements, today many choose to go beyond regulation because they see commercial benefit in doing so. Established practice in areas such as safety and quality management has demonstrated that uncompromising principles are perfectly compatible with the spirit of continual improvement.

Stakeholder dialogue now helps firms learn more about others' points of view and then use this understanding to set better priorities and move away from confrontational approaches. In extending systems of financial control and audit to cover environmental impact, they have recognised the need to gain early "buy in" by ensuring relevance to the specific priorities of individual business units. Technology is playing a central role by providing the means to move forward and engineers generally seem to relish the opportunity to find more eco-efficient solutions once the parameters for improvement have been established and agreed.

The stock market returns achieved by those companies included in the recently launched Dow Jones Sustainability Index suggest that investors are now recognising the management qualities that have made this progress possible (Figure 1).

Figure 1. **Dow Jones Sustainability Group**



Good enough or could do better?

This is intended to be a rhetorical question. During the last decade, the arguments and counter-arguments about rates of improvement have been well rehearsed. Economic focus leads to "short-termism". Regulatory frameworks offer too much (or too little) "command and control", so we are not properly pricing public goods, environmental services and social well-being. New approaches are uneconomic in the face of established manufacturing capacity.

Undesired impacts are associated with large, interdependent infrastructures (for example, the car, its fuel and the city), so require more systemic approaches that can transcend traditional business and political boundaries and avoid stranded assets. Technical progress is slower than expected, gets side-tracked through lack of customer pressure or creates "rebound effects" by stimulating new demand that consumes the improvements that have been achieved.

These concerns are valid but (with considerable effort and a fair dose of humility) there are ways to overcome them. In some cases, effective solutions are already available; in others, we may need to change the market's rules of the game. For example, it seems likely that economic instruments such as tradeable carbon emissions permits will improve the market's effectiveness in dealing with climate change. Demonstrating that these instruments do work well requires agreement on rules and modalities and the willingness to take action and learn from our mistakes.

In other words, sustainable innovation involves risk but it also requires structure. While much can be achieved by "continuing to do better", it will be far more challenging and rewarding to learn how to:

- Bring design, smart technologies and the "new economy" together to drive growth in ways that reflect the changing concerns and values of a connected world.

- Support faster and more sustainable development in the developing nations.

We believe that success in these tasks can turn sustainable development into an approach that is intrinsically value creating. But we also believe that some established ways of doing business and the assurance processes that accompany them will need improving in order to achieve this.

For example, sound science is a lynch pin of corporate approaches to technology risk management. Even though no-one questions the need for high safety standards, too much recourse to scientific evidence and argument can now seem complacent and paternalistic. The public's sense of the role of technology has changed and its awareness of previous mistakes has grown. We need to find better ways to show that firms (and governments) are keeping their scientific houses in order.

A paradox is that the success of today's activists owes much to their mastery of communication technologies in getting their messages heard. Governments, inter-governmental bodies and corporations now find themselves to be hopelessly cumbersome in the face of resolute single-purpose advocacy. Stakeholder dialogue offers a powerful way forward but requires that we learn how to achieve open discussion about subjects for which the risks seem large and the benefits unclear.

Thinking about innovation and technology

In preparing for an uncertain future, we need a sense of what might develop while avoiding placing expensive bets on particular outcomes. Scenario planning offers one way to extend our strategic thinking. The WBCSD has used this tool in several projects and we have found the approach

helpful in looking at the broad questions of business-led innovation and use of technology. The paper we contributed to the OECD's December 1998 workshop in Budapest gave a detailed assessment of the global scenarios. This section briefly summarises these and our more recent biotechnology scenarios.

The global scenarios (FROG!, GEOPolity and Jazz) explored sustainable development in terms of two parameters:

- *Uncertainty*. How we will recognise the resilience, limits and critical thresholds faced within the global ecosystem.

- *Governance*. What forms of social system can best respond to the challenge of sustainable development.

FROG! describes a low-trust world in which people focus on jobs, economic survival and short-term financial returns. Although people believe they value sustainable development, local economic pressures dominate their thinking. After all, people (at least those who are already affluent) find it obvious that their neighbourhoods have become far cleaner, presumably because they have already adopted the right approaches.

This local focus leads to a poor reading of signals. Signs of global environmental problems such as the risk of climate change and growing social inequity either go unnoticed or trigger disagreement about what the signs of change mean. No action will be taken until it becomes impossible to continue ignoring the signs, by which time it will be correspondingly harder to respond effectively.

In the meantime, the public takes advantage of what business offers and punishes companies that are seen to cause harm through their goods and services and ways of operating. Voter-sensitive governments ensure that exposures are discovered and dealt with promptly, so firms act defensively to anticipate and limit liabilities.

FROG! generates solid economic growth yet this will probably be unsustainable because no-one takes care to address sustainability as their ambition. There will be technological progress but this is unlikely to be directed towards greater sustainability; instead, existing approaches, ways of working, etc., will be extended rather than replaced by something better. There will be an emphasis on tools for monitoring, quantifying and documenting the performance of existing operations rather than going proactively beyond these standards.

Governments will legislate, set technology policies and support R&D in order to stimulate local competitiveness and aspirations. Aspects of these policies, and the innovations that result, may accidentally align with the ambitions of sustainable development. Ambivalent consumer attitudes and lack of long-term thinking about ethical and other implications will limit the sustainable value of the results.

GEOPolity starts with a recognised environmental crisis. The palpable failure of national governments and multinational companies to deal with the crisis as well as past problems destroys the already limited credibility of these existing institutions. People recognise the need for new mechanisms to address global issues such as the health of the planet and to resolve conflicts of interest in a peaceful manner.

The spirit of the age – the "mood of the Millennium" – captures the attention of people who have the ambition to put things right. This aligns their effort into a collective sense of purpose and they build an interlocking global governance system co-ordinated at an international level.

GEOPolity reflects a human desire for big solutions to grand challenges. Its institutions work towards market-based solutions but set new rules and regulatory frameworks for markets to follow. To achieve greater sustainability, these global institutions may engage companies in a joint attack on big challenges. Consequently, this will be the scenario that develops world-scale technologies and drives forward major global infrastructure projects. One can imagine the 21st century equivalents of Concorde and Apollo, designed to address climate change, provide equitable supplies of clean water and food, manage critical eco-systems and foster "connectedness" and opportunity.

In such a world, technological prowess will be a key tool that firms use to ensure credibility and secure their licence to operate, shape legislation and achieve competitive advantage. Technology-rich companies may see great value in encouraging and becoming contractors to these initiatives. (Today's nuclear industry developed very rapidly in a world rather reminiscent of GEOPolity.) They are likely to prefer process and product technologies that can be patented to intangible knowledge-based approaches.

A strength of GEOPolity is its ability to set decent rules and regulations to steer our collective effort. This scenario will probably be very effective if global standards and regulatory frameworks are necessary (and can be agreed) in order to build better solutions. Its weaknesses include the difficulty of changing those existing institutions that already feel empowered to deal with matters and the general risk of bureaucracy and slow response associated with "big institution" processes.

As a result, there may be undue up-front selection of "winners" within GEOPolity, too little engagement of customers in the choices being offered and too little attention to unintended consequences and side effects.

Jazz describes a world in which people recognise that they can care about issues such as sustainable development without needing others to legislate the solution. These people harness the markets to find solutions to their concerns, in the process creating a complex market-led world of ad hoc experimentation.

This is a demanding world of partnerships between consumers, businesses, governments and non-governmental organisations. Alliances form and break fluidly to meet civil demands. High transparency enforces quick learning by allowing the public to identify and punish companies and governments that break the social norms. In Jazz, the public sees no need to applaud expert opinion for its own sake.

In this world, technology is a cross-fertiliser that enables firms to work within diverse partnerships but it also creates challenges for them to overcome. For example, in a transparent world, innovative companies need new ways to safeguard their intellectual assets. This will encourage greater speed of use of these ideas and emphasise the less-tangible, knowledge-rich technologies suitable within a service economy.

Jazz can align people worldwide to a common cause but the nature of their alignment cannot be taken for granted. Initiatives such as the large-scale redesign of infrastructures and the handling of sensitive new technologies still require a consensual basis and public ground swell to move forward. Furthermore, in spite of the public desire to achieve progress across a broad front, communities and organisations that lack resources and skills may find it hard to join the Jazz band.

Implications for company-led innovation

Scenarios are intended to help focus thinking and sharpen understanding of the diverse forces within today's society. As a result of participating in the global scenarios project, quite a number of

people have expressed the desire to realise the benefits of the dynamic Jazz world and look for solutions that will foster its innovative spirit and market-based approach. Others recognise this spirit but feel that Jazz will be a very challenging world in which to live and work and consequently may not deliver everything they wish to achieve. GEOPolity offers other ways to approach these challenges.

The stories suggest that sustainable innovation will involve companies in:

- Taking advantage of dynamic, experimental approaches while providing consumers with the information and price signals to exercise informed choice.

- Being willing to build and work within institutional structures that can co-ordinate large-scale tasks and constrain unacceptable behaviour while avoiding the tendency to use these structures to plan overly ambitious solutions.

- Expanding local focus to legitimise action on a broader front, for example by actively disclosing impact and working with the public on risks and benefits.

An important conclusion is that the approaches taken to education, regulation, social values, public understanding of complex subjects such as technological risk and the precautionary principle strongly influence how well societies can address their sustainable development. With no single point of leverage, a broad base of action is needed that will extend throughout and beyond the firm. In this sense, the social dimension of sustainable development seems to take on a particularly important role in stimulating innovation.

This conclusion was also reached in a subsequent WBCSD scenario project on biotechnology, which focused on the certainty that someone, somewhere will put scientific developments to use and also on the inevitable human anxieties about the unknown. It explored the impact of unintended consequences on the acceptability of a technology, the balance of risk and liability issues and consumer choice on sustainable development and the consequences of a widely accepted biotechnology industry.

The results demonstrated that, depending on the nature of public reaction to the unintended events that new technology triggers, the acceptance of technology can vary widely. Furthermore, apart from any such event, an industry that grows up around the new technology could prosper or not for reasons that depend on factors other than technology or sustainable development. A third unknown has to do with the consequences of a successful and widely accepted technology-based industry. What kind of world might this produce and how might such acceptance come about and be assured?

Finding good ways to deal with these types of issue is perhaps more important than understanding and developing the inherent potential of the technology itself. Although the scenarios do not give easy recipes for success, they do highlight the importance of gaining the public's support in whatever is being attempted.

Social expectations as a driver for sustainable innovation

We have discussed these conclusions with people and organisations worldwide to learn their views on the role of company-led innovation in supporting concerned sustainable development. What we heard confirmed many of the tensions apparent in the global and biotechnology scenario studies:

- Growing awareness of social values in driving environmental issues.
- Rediscovery of the sense of co-dependency.
- A more determined public with different priorities for innovation and use of technology.

Many people perceive innovation as technological progress related to indiscriminate economic growth, leading to depletion of the natural environment and increasing pollution. A real commitment on the part of corporations, rather than technology itself, is seen as the prerequisite for creating the conditions for sustainable growth and better quality of life. Consumers expect companies to go beyond minimum requirements and be main actors in realising these conditions.

Some leading companies have recognised that resolving these tensions provides the only basis for their profitability in the years ahead. Put one way (by Richard Branson) "the brands that will be big in the future will be those that tap into the social changes that are taking place". Or, as Roger Cowe expressed it recently ("Account-Ability", *The Planet on Sunday*):

> "Once a company has acknowledged it has to account for pollution … it is harder to deny wider social responsibilities. And once outsiders have been through the gates, it is impossible to stop them looking beyond one narrow aspect of business. Curiously, this odd little world of social auditing threatens to fuel a debate about the purpose and nature of 21st century capitalism which has escaped the politicians for decades."

The sense is that markets will increasingly be characterised by the power of vision: to think the future, imagine the future and shape the future. In other words, firms are being expected, and some are themselves expecting, to address sustainability by design. Examples such as Dupont's "To Do List for the Planet" demonstrate that this is already happening.

How companies manage innovation

We surveyed around 80 firms that have indicated their commitment to sustainable development and environmental protection to explore how this commitment has been incorporated into their approach to innovation management and learn about the opportunities and barriers they are experiencing. Wherever possible we approached senior business managers with responsibility for aspects of innovation, product development and technology management, such as heads of R&D or Technology Development.

A first observation was that the commitment to sustainable development within these firms extends well beyond those who work in corporate offices. Of those interviewed, 88% "strongly agreed" or "agreed" that sustainable development is a key business driver for the firm and 83% confirmed that sustainable development is an explicit part of the firm's mission and values. (Those that felt otherwise generally argued that this reflected the wider priorities of the marketplace.)

At the top of the list of items supporting this view are perceptions of company image and brand value. New product and service advantage, staff values and principles and cost advantage rank

midway. Direct pressures from regulators, customers and special interest groups seem the least important of the factors we tested. This highlights an interesting and important paradox; conventional thinking would surely suggest that company image and brand value relate closely to the firm's sense of customer pressures. One measure of a successful value-based approach to sustainable development might be to see this connection regained.

Most of these firms have formal processes for innovation management and technology development. Generally the processes require staff to take sustainable development into account: 55% of firms expected this for both environmental and social matters; 28% for environmental matters only. Responsibility for integrating these and other commercial considerations is considered to be a shared responsibility rather than of one role such as the Chief Technology Officer.

One of the clearest benefits of managing sustainable development this way has been to focus attention on the technological opportunities at the firms' disposal. Practically everyone considered that improved technology and better engineering skills are, and will remain, essential tools for supporting sustainable development. Many of the examples that were quoted during the survey were consistent with this technology-based perspective.

Information and energy supply technologies were rated highly: 92% and 88% of those interviewed see these as important in supporting greater sustainability. However, 25% rated developments in the biosciences as neutral or indeed inhibiting progress. This probably reflects the negative publicity over GMOs, which flared up around the time the survey was taking place.

Thirty per cent of respondents expressed neutral or negative views about measurement technologies. This can be interpreted as evidence of a movement beyond regulatory reliance on such tools to measure impact and assess performance or a feeling that the technical ability to measure surpasses what is required in order to assess and address the risk.

Achieving and measuring progress

A key challenge for staff in many of the companies we approached is to understand and make an effective business case (*i.e*. present a convincing argument in business terms) for investing in more sustainable products and services. There is an underlying belief that customers are keen to purchase more sustainable products but will not pay a significant price premium despite assertions in market research that they would do so.

Several managers commented on this tension between meeting short-term business goals and dealing with the uncertain, longer-term nature of sustainable development. Taken together, there is still the risk that sustainability considerations are seen as additional selling points "other things being equal".

In general, respondents also felt rather uncertain of their ability to manage and assess the creative skills required to address the broader agenda of sustainable development. Other challenges, such as existing capital assets, managing partnerships (important in a networked economy for obtaining improvements throughout the supply chain), understanding the role of design and dealing with product launch strategies were felt to present less substantial barriers to successful innovation.

The survey probed how close firms are towards having a fully integrated management process that places sustainable development squarely within the innovation process. Responses resembled a normal distribution centred on "half way there". Paradoxically, firms that had obviously made

substantial efforts reported only modest progress. Others, newer to the game, felt they were further down the road. Perhaps the scale of the task only becomes apparent once the journey has really begun.

Most interviewees reported that considerations of sustainable development have helped the firm launch new products and improve existing products and processes. They find it more difficult to demonstrate that these have improved profitability. They also commented on the lack of adequate metrics for the social dimension of sustainable development and of ways to assess the ideas generated by employees in response to the corporate commitment.

Differences in patterns of response between industry sectors were not marked and seemed to depend largely on how the person interviewed interpreted the questions we asked.

Those working for manufacturing firms tended to see sustainable development as a particularly important business driver and stimulus to innovation. They also felt best able to measure progress. In the chemicals sector, there was more emphasis on cost reductions and dealing effectively with stakeholders and a lower-than-average sense of success in finding innovative solutions. Those in the service sector tended to be less positive about the benefits of the business drivers we mentioned and less focused on technology as part of the solution.

Regional patterns were more apparent. Asian companies saw most direct connection between their commitment to sustainable development and sales, were most likely to believe that sustainable products and services will offer competitive advantage and expressed the strongest sense that corporate values are driving events.

Australian companies saw themselves in the early stages of addressing sustainable development. North American companies focused on cost advantage and were less likely to make sustainable development an express part of their published mission. Finally, responses from European-based companies fell close to the average for the survey as a whole.

In conclusion, the survey demonstrated that companies are in a dynamic situation of embracing sustainable development, understanding its implications and disseminating a leadership approach throughout their businesses. Several comments reflected these views. While “sustainable development is ripe with opportunity”, “the executive suite believes in the benefits but is still in the realm of affirmation”. Partly this is because “the benefits are long-term gains” and “only the cost savings show up quickly”.

The commercial benefits seem more likely to come from driving product innovation that supports brand preference and improves market share, rather than from improving margins directly. Corporations are looking for innovative ways to align corporate and customer values towards sustainable development. They are generally placing strong reliance on technology and believe they can access the technologies they will need. However, they lack the tools to support other management tasks such as measuring progress and mentoring staff, particularly in respect of the social dimension of sustainable development.

Technology co-operation within developing nations

We explored the link between innovation, use of technology and the sustainable development of emerging economies in a recent article in the OECD's *STI Review* (Issue 25, 2000). This section summarises some of the main conclusions of that article.

Developing nations seem to face desperate challenges in addressing sustainable development, with little choice but to adopt approaches that are less than state-of-the-art. Yet the problem is usually not the lack of cost-effective environmental technology or even examples of "best practice" that can be copied and improved. Attempts to overcome the central challenge of poverty are undermined by a host of problems such as limited resources and skills, small and ineffective markets, poorly developed legal frameworks and our widespread inability to learn from examples of success. It is also clear that public attention is being drawn to examining the benefits of globalisation in ways that closely interweave issues of trade, technology and sustainability. Furthermore, the contributions that multinationals make towards overcoming these problems are highly sensitive and their records are coming under closer scrutiny.

Companies may find it hard to respond to this scrutiny unless local communities view their presence as beneficial. Evidence so far has often come from the labour standards offered by the multinational and the economic and social contributions it extends to the local community. Increasingly, firms are being judged more holistically, for example on their contribution towards improving the performance of local businesses and attitudes towards corruption and on the relative economic performance of the developing nation within the global economy.

More generally, the risks and benefits of foreign direct investment (FDI) will be interpreted in terms of these local social and economic issues. In other words, the more firms' actions take place globally, the more their contributions will be assessed through local eyes.

During the WBCSD's regional dialogues, partner organisations confirmed the important role played by small and medium-sized enterprises (the SME sector) in getting a country out of poverty to become a dynamic part of the world economy. They told us that such firms might be far less able than the multinationals to mitigate their environmental impact but nonetheless have a wealth of practical experience and understanding that is not available to their counterparts in other countries. They also remarked on the Western tendency to lecture others about free trade while ignoring the barriers around our own markets.

One way to contribute to faster and environmentally better economic growth is to improve the availability and use of appropriate technology. Consequently, some have suggested that governments within the developed nations should transfer modern technologies to other nations as a matter of course.

This approach – "technology transfer" – has been widely discussed as a way to help developing economies to "leap frog" over environmentally and economically less effective approaches and avoid repeating others' failures. Unfortunately, the initially high expectations have not been met. Technology becomes useful by being applied, which happens mainly within and between companies and through the products and services they generate. Governments have neither "owned" the technology nor been well placed to create the skills and facilities to apply it properly.

Since technology is disseminated primarily through business-to-business transactions, the WBCSD (and many governments) now prefers to focus on market-oriented approaches that we refer to as technology co-operation. Below, we have attempted to identify the most important factors in making these approaches successful.

Explicit and tacit know-how

Using technology competitively depends both upon having the right know-how and access to the right tools. This know-how has at least two components:

- The *explicit* skills to assess the problem and use the necessary tools.
- The *tacit* skills to solve the problem effectively and appropriately in its setting.

Explicit skills can be taught but tacit skills are learned through practical experience and are difficult for either the technology-rich company or the local community with practical understanding of what works and does not work to record and teach.

These skills combine to provide the knowledge capital that the economy requires to grow. Unlike physical assets, many can possess the same knowledge capital at the same time and use it in different ways to create value.

Sometimes, economies have been described as pipelines for converting raw materials into products. Today, it seems more appropriate to view them as dynamic networks that transmit learning and generate value through connectedness. Indeed, some describe economies using the language of ecology and give similar explanations for their success and failure.

The resources and skills that multinational companies, governments and non-governmental organisations, universities and civil society deploy within these networks are essential to sustainable development. Within this networked economy, people need to acquire more know-how and refresh this know-how more frequently in order to become, and then remain, successful.

Even within developed nations, the OECD recently estimated that the average half-life of worker skills has shortened to three and a half years. In the developing nations, the challenge of skill generation and skill maintenance is further magnified by the changing nature of technology and by the imbalance between local needs and global trends.

While the larger companies cannot remove this hurdle by themselves, progress is likely to be slow without their active participation. Using their economic power to strengthen and extend the connections within the networks helps reinforce people's awareness and understanding of what needs to be achieved and provides the means to transform values and local priorities into action.

As networks evolve, roles will also change. Increasingly, the multinationals' commercial success comes from funnelling skills, technologies and sources of investment rather than holding proprietary control of all the key technologies and production processes. This makes it particularly important that they work in ways that will enhance the effectiveness and legitimacy of these channels.

Project investment and risk management

Economic growth requires investment as well as know-how and this investment spreads most easily towards projects that offer good financial returns and present low risk. It may be helpful to view the situation as an iceberg. What lie above the water are the project opportunities that will be successful in any case. Below the surface are a far larger number of potentially vital projects.

Some of these projects may be commercially attractive but unnoticed; others may be desirable from the point of view of country development but too risky for the private sector to address. One

challenge for governments, firms and the international community is to find ways to increase the number of projects that are actually selected for investment and progress to completion – to improve the "supply side". This depends on reducing the risk of key projects "close to the water line" and generally raising the level of other projects that today lie deep below the surface.

Project risk has many components: location, choice of partners, suitable technology and means of finance. The market may seem too small or ineffectively regulated, the workforce unskilled, intellectual assets poorly protected, or the restrictions on repatriating profits too stringent. Only some aspects can be expressed objectively. Yet obtaining productive investment requires finding approaches that minimise the risks perceived by the investor.

Smart partnerships

Overseas development assistance (ODA), including debt write-off, has been one vital tool for addressing the intractable needs of the poorest nations. Arguably, its real justification is to deal with the socially vital projects deepest beneath the water line in ways that also build capacity for the future. However, too often it seems to be applied ineffectively as far as reducing future project risk is concerned.

In the course of this work, we learned about the contribution that can be obtained through public-private initiatives: "smart partnerships" as the Commonwealth Partnership for Technology Management describes them. These partnerships can operate at all scales from the skilled engineer upwards. They provide the means to learn from and combine the tremendous experience available in small and large companies, governments and civil society.

Combining grant-based, capacity-building approaches with practical experience, education and skill development increases both the competence of the individual to address local needs and the international community's understanding of these needs.

Sound legal frameworks make it more likely that this capacity will be used to good purpose and increase the likelihood of making correct decisions about design and construction. This helps ensure that the international partner is able to complete projects more effectively, producing a virtuous circle that further improves local capacity and makes future investments less risky.

The newer market instruments such as the Kyoto Protocol's Clean Development Mechanism, tradeable emissions permits, etc., offer ways to further increase project visibility. We feel it is useful to view these as development tools that can tip the balance in favour of cost-effective investments addressing particular policy goals (in this case reduced carbon emissions).

Provided it is possible to agree the rules and modalities, these instruments can be used to reduce overall portfolio risk and shift investment towards greater sustainability without constraining the investor to use pre-determined solutions. We believe that running these schemes in ways that encourage participation rather than create bureaucracy will provide substantial leverage and improve project visibility.

Points of leverage

However committed a firm is to sustainable development, it is likely to be challenged on its record in the emerging economies in the face of growing concerns about globalisation. In working towards technology co-operation and smart partnership, the main messages are to focus on economic development, learn from examples of success and work in ways that will improve skills, reduce risk, foster partnership and extend the network.

There is a widespread willingness (and the resources) to invest where the skills, capacity and institutional frameworks can support that investment. Technology follows investment and when the perceived rules of the game change, so too will people's behaviour. As economies develop the SME sector plays a particularly crucial role as a hot-house of effort with tremendous understanding of what is possible but often stretched in its ability to take up and use the tools already available to the multinational. Without a vibrant SME sector, economies do not flourish.

Finding innovative ways that can better drive this dynamic is a test of co-operative economic leadership, in which governments, multinational companies and local businesses each have key roles to play.

A management framework for sustainable innovation

The messages we have about the connection between innovation and sustainable development offer a clear sense of both opportunity and obligation. Once the public believes (rightly or wrongly) that corporations – specifically the multinationals – are the main actors able to influence the future and drive innovation and the development of technology, corporate social responsibility inevitably extends to cover these processes.

At a dialogue workshop held to explore the work covered in this report, participants from outside the business community told us to:

- Pay more attention to how business is being framed and recognise that few people are actually promoting the benefits that companies themselves consider that technology is providing.

- Recognise that innovation can be highly disruptive and requires ethical guidelines that are fit for the time and place.

- Pay more attention to the contributions made by government and regulation and not believe that a Jazz world can be achieved by industry alone.

- Learn how to structure dialogue on the difficult issues surrounding the use of advanced technologies to obtain challenge without polarising matters to a point at which progress becomes impossible.

- Take what we have learned and ensure it gets put into practice.

Eco-efficiency shifted the response to environmental impact from end-of-pipe solutions towards ways of eliminating impact at source. Its success has come from expressing a clear but challenging objective "to do more with less" that channels our aspirations to find environmentally better and more cost-effective solutions. Once companies recognise this is possible, eco-efficiency could become an established approach.

Similarly, there is no future in looking at sustainable development simply in terms of costs and obligations. This is one way to get caught in the commodity trap. To be a successful, integral part of business thinking, sustainable development has to provide the food for long-term growth and profitability. To nourish innovation, its roots have to grow from deep within companies' business units, not the corporate centres where the early attention to sustainable development has often been focused.

The nature of the challenge is apparent from the results of the company survey. It concerns people and economics much more than technology. Individual firms with different spheres of business will encounter different aspects of this challenge.

In larger companies, the required skills may already exist but may not be combined as a team. For example, technology management is often treated as an engineering task receiving little input from the social sciences. SMEs may be particularly strong in their design skills, in science or in their appreciation of the needs and values of the local economy, but weak in other important areas. Sustainable innovation requires us to combine these skills without creating inflexibility, reinforcing the ongoing shift towards dynamic, results-oriented styles of management that is already happening for other reasons.

We have not attempted here to identify which technologies might solve which sustainability goals or which innovations will be successful and sustainable. That is something that (in general) we believe is best determined through well-regulated markets. However, we suggest that it is worthwhile for firms to look in more depth at how they manage innovation and consider how this can respond to the challenge of sustainable development during a period of rapid commercial, social and technical change.

One useful tool for presenting the distinct stages of discovery, development, deployment and maturity of ideas and technologies is the S-curve. This illustrates how impact starts off low and remains low while the scope and nature of the idea or discovery are being mapped out. It then grows rapidly after substantial investment has moved the idea into development, flattens off after the idea is implemented widely, then falls away as replacements (developed along their own S-curves) come along.

This reminds us that businesses need a balance of activities to remain profitable. What seem to be good business practices such as focusing investments and technology on the most profitable products currently in high demand (*i.e*. close to the top of their S-curves) can ultimately weaken the firm. The same is likely to be true when addressing sustainable development.

Breakthrough innovations of whatever form are likely to be rejected by mainstream customers because they cannot use them. Consequently, firms with too strong a customer focus may fail to create the new markets for products of the future and become exposed to more nimble competitors. On the other hand, firms that invest too much in new technology fail because of the time it takes to bring these options to market.

Furthermore, depending on the nature of the technology and the degree of awareness of its potential consequences, public concerns about technology arise at different stages in its development and require different risk management responses.

So the question is one of balance. Ways of managing innovation and technology development to achieve this balance change over time. Around 1970, many large firms separated the management of their R&D and business operations. R&D was often equated with innovation and treated as a corporate responsibility that involved generating new options for business units while keeping an eye on the

horizons of science and minimising technology-related risk and environmental impact. Business units were responsible for understanding the evolving market's requirements and for creating products from the options available to them.

In many firms, this separation of roles disappeared towards the end of the 1980s as their core technologies became mature and market forces required greater integration of product development and technology deployment. At the same time, innovation came to be seen as much more than the product of R&D. Eco-efficiency became a priority which large corporations were in a position to address cost-effectively using the technical capabilities at their disposal.

Reinforcing trends

In determining the best approach to innovation and technology management in future, corporations must take into account many trends. Some are directly related to the growing attention given to environmental and social performance; others may be co-incidental. Nonetheless, we do not believe that any of these can be treated independently from each other.

The trend towards networking has already been mentioned several times. Another factor is that time-to-market has shortened dramatically in some sectors. The nature of new technologies, combined with large companies' focus on core competencies, has made it possible for small firms to take a leading role in these networks in bringing new ideas rapidly to market. Many younger people now prefer to work in these small firms and do not expect the certainties that large corporations used to offer.

In turn, large companies now spread their antennae much more widely to obtain the competitive tools they use in their businesses. The trends go together and it would not be possible for the new SMEs to be successful without strong connections to larger organisations.

Another important development is the changing profile of public concerns about technological risk and technology ownership. When most of the life cycle happened inside a large corporation, public concerns tended to arise during the later parts of this cycle (at the top of the S-curve), hopefully after companies had taken steps to understand and minimise the risk.

Today, concerns become visible sooner ("novelty" leading to "uncertainty") and the extent of use of some technologies goes beyond the scale that people can comfortably handle ("too big"). This means that new mechanisms may be required to ensure that what is introduced is, and will remain, acceptable to the public.

Shaping the future or responding to the past?

One way to formulate the question of balance is to ask what corporate social responsibility means for companies operating within a networked world. The research described above suggests that no single approach will apply to all firms in all situations, but there are some clear common principles:

- Sustainable development offers an organising framework based on opportunity and respect for human values. Innovation is about using change in ways that better meet human needs and values. The connection between the two seems obvious although, in the absence of clear market pressures and a common language, it can be hard to realise, especially since innovation can come unexpectedly "out of left field" and have such uncertain consequences.

- Some organisations respond best to sustainable development as a vision, while others prefer more pragmatic approaches. Clear direction backed up by resources, management support and good metrics seems more likely to achieve the desired results than reinventing business processes to accommodate sustainable development.

- Whichever approach is preferred, innovation has often been the result of presenting (or being presented with) a credible strategic dilemma: a shock that can only be resolved by developing wholly new approaches.

- Economies are networked, social values are changing and environmental pressures are here to stay. These are unavoidable but not uncontrollable forces. Commercial success depends on having the flexible, multidisciplinary skills to respond. This applies as much to sustainable innovation as in any other area. Metaphorically, we must ask ourselves whether to concentrate on stopping the tide from coming in or using it to get where we want to go.

- Innovation based on better design and new technologies gives us the means to act smarter and in more sustainable ways. Using these tools well depends upon understanding the public's expectations and concerns and being able to meet needs cost-effectively without raising further alarms over the scale or novelty of technology.

- The leadership task is to harness these economic and social trends, capture the tremendous amount of knowledge and experience that exists in networks worldwide and combine these in ways that create value. Traction is likely to be greatest when the management approach is positioned appropriately for the organisation in its network and seen by staff to be relevant and self-evident, if not simple, in purpose and content.

- Corporate social responsibility and eco-efficiency form important elements of the business response. Attention to these principles must be devolved throughout the corporation.

Achieving this success will require new business ideas and new ideas on business. These ideas are likely to be design-based, amplifying the emerging signals from the marketplace in ways that cannot be reduced to either a "technology push" or a "market pull" approach.

This chapter has concentrated primarily on what companies can do, but it is important not to overlook the role that others play in supporting companies' actions. An important role of governments is to provide the climate for sustainable innovation, the regulatory frameworks that reduce uncertainty as to whether better solutions will succeed in the marketplace. Governments also act in ways that can reinforce the standards of behaviour that are sought of others, for example within public procurement policies.

The financial markets have an important role to play in funding and rewarding the more sustainable solutions developed by companies. They are most likely to do so when there is compelling evidence that sustainable development has economic value. In March 2000, John Prestbo, Editor Dow Jones Indexes, commented about the new Dow Jones Sustainability Group Index:

> I believe that the Dow Jones Sustainability Group Index will [continue to] outperform general market benchmarks over time. Enlightened and effective management means sustainability companies deliver more predictable returns, which also could be articulated another way: fewer negative surprises.
>
> It is well known among money managers that the easiest way to beat your benchmark is not to find a bunch of hot stocks but simply to avoid owning the stocks that turn into

disasters. Investors will seek out leading sustainability companies not for outsized performance, which is always temporary, but for the above-average growth on which they can rely.

The challenge for these companies is to find new ways to align innovation with public expectations and so provide a management framework that is based on discussing, deciding and then delivering sustainable value.

Leading companies have understood that this depends upon understanding the evolving nature of society and redefining the relationships they want to build with customers, employees and suppliers, with governments and with the public at large. This approach involves recognising the connection between rights, roles and responsibilities in society.

Dealing well with these responsibilities takes time, needs an effective view of what the future may offer as well as leadership, courage and measures of progress, but is essential for the influence of the private sector to be accepted.

Chapter 8

BEYOND THE DOUBLE DIVIDEND: PUBLIC AND PRIVATE ROLES IN THE SUPPLY OF AND DEMAND FOR ENVIRONMENTALLY ENHANCING TECHNOLOGIES

by

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Introduction

At the core of the concept of sustainable development lies a tension between economic growth and environmental protection. For some time, in both industrialised and developing countries, environmental protection has been viewed by many as a brake on economic development. More recently, in both academic and policy circles, this view has been challenged and replaced with a growing interest in understanding when and how we can protect the environment while fostering economic development.

Michael Porter and Claas van der Linde's work crystallised and brought to a larger audience this debate about the relationship between environmental protection and economic performance (Porter and Van der Linde, 1995a, 1995b). Their work resulted in what is often called the "Porter hypothesis" which states that environment and competition are not incompatible and that properly designed environmental regulation can act as a trigger to innovation which will in turn make companies more competitive. This ability to simultaneously profit and improve environmental performance has been dubbed the "double dividend". This chapter critically assesses the theory and evidence for this hypothesis, emphasising our growing understanding of the conditions under which it holds. While Porter and Van der Linde did a great service by refocusing the debate, showing that competitiveness and environmental protection can be compatible, this chapter suggests that the discussion needs to be expanded beyond environmental regulation to include the broad range of government activities that influence private sector decisions to innovate for the environment.

This chapter is divided into two main sections. The first begins by reviewing the theory and evidence for the Porter hypothesis. From the standpoint of empirical evidence, the focus is largely on micro-level evidence. It then examines our growing understanding of the conditions under which the double dividend is created and captured from two perspectives. From the viewpoint of business, it examines the conditions under which businesses choose to innovate for the environment. From the viewpoint of governments, it examines the evidence regarding the types of policy that stimulate innovative responses. The second section looks beyond environmental regulation towards the full range of actions available to governments

to foster the technological innovation that can make environmental protection and economic competitiveness compatible. Through three cases in the energy sector (wind turbines, gas turbines and energy efficient office products), it demonstrates how the use of a broad range of policy mechanisms can effectively and synergistically create new technologies and new markets. It concludes that governments must consider how to support technology development (supply-push) as well as creating markets (demand-pull) for environmentally-enhancing technologies, particularly during the period spanning pre-commercialisation through lead adoption.

Assessing the Porter hypothesis

In 1995, Porter and Van der Linde wrote two seminal articles in which they claimed that environmental protection and competition are not incompatible. Rather, through technical innovation that increased resource productivity, companies could simultaneously reduce environmental impacts and increase profit. They further hypothesised that properly designed environmental regulation could act as a trigger to innovation that would make companies more competitive. Porter and Van der Linde identified several possible sources of resource productivity, which they termed "innovation offsets". For process innovation, enhanced resource productivity could be achieved through technological changes leading to: higher yields, less downtime, material saving, better use of by-products, lower energy and material consumption, reduced storage and handling costs, and conversion of waste into valuable inputs. For product innovation, innovation offsets could include higher quality and better performance, increased safety, lower cost, higher resale or scrap value, and lower disposal costs.

In the case of complete innovation offsets, while environmental regulation was not necessary, it could serve as a stimulus for firms to search for ways to increase resource productivity. In the case of incomplete offsets, environmental regulation was needed to provide incentives for firms to innovate for the environment. Environmental regulation is also important in levelling the transitional playing field. Technological innovations may require long lead times and large investments. New products and processes may eventually be cost-competitive (even without considering environmental costs and benefits), but they may require a transition period as they are often initially more expensive and cannot compete in the market place with existing plants and products that have poorer environmental performance.

Porter and Van der Linde, while heating up the debate about the relationship between environmental regulation and competitiveness, were not the first authors to examine this issue. While a few authors were writing about the possibilities for environmental regulation to promote technology innovation (Ashford and Heaton, 1983; Ashford, 1993; Rothwell, 1992; and Wallace, 1995), much of the previous work in this field focused on whether environmental regulation was a burden on the economy. This body of work argued that environmental regulation decreased competitiveness for several reasons. First, complying with environmental regulation increased capital and labour costs. Second, it diverted management attention and crowded out more productive investments. Third, environmental regulation often exempted existing plants from stringent requirements, providing incentives to reduce capital stock turnover. Given that new plants and equipment in general are more economically and environmentally efficient than older equipment, this served to reduce both competitiveness and environmental protection. Fourth, some argued that environmental regulation created perverse incentives: because better environmental performance carried with it the threat of tighter standards, firms wanting to avoid government-mandated requirements stayed away from innovation for the environment. Finally, some argued that stringent environmental regulation created capital flight to "pollution havens", *i.e.* companies moved to countries or regions that had less environmental protection. These concerns are not without some rationale. Examples where environmental regulation had each of these anti-competitive effects can be found. However, after reviewing over 100 studies which attempted to systematically measure these impacts, Jaffe *et al*. concluded that there is no evidence of a strong competitive disadvantage or advantage due to environmental regulation.[1]

Given the evidence of specific instances in which environmental regulation had anti-competitive effects, it is important to emphasise that the argument for compatibility between environmental regulation and competitiveness stresses the need for well-designed environmental regulations. Porter and Van der Linde argue that properly designed regulations can increase competitiveness in several ways. First, regulations can require firms to generate information that raises corporate awareness of opportunities for increasing resource productivity and signal areas where there are opportunities for increasing resource productivity. Secondly, environmental regulation can reduce uncertainty about future requirements for environmental performance, creating competitive pressures between firms and nations. Finally, environmental regulation can level the transitional playing field by requiring all firms to move to new, more environmentally enhancing practices and thus creating a competitive environment in the search for alternative processes and products. Just as there are examples of environmental regulation decreasing competitiveness, there are numerous examples of firms profiting while improving environmental performance as well as examples where environmental regulation has been the stimulus for this increased competitiveness.[2] These will be discussed in some detail in the following section.

Evidence for the Porter hypothesis

There are many case studies at the industry sector and firm level that demonstrate the potential for the double dividend (Hoffman, 2000; Reinhardt, 2000; DeSimone and Popoff, 1997; Cairncross, 1995; Schmidheiny, 1992; and Smart, 1992). There is also evidence that not all investments in environmentally enhancing technology provide competitive advantage. While not all investments in technology innovation in general are profitable, orienting innovation towards environmentally enhancing investments creates an extra challenge since it must compete with other types of technology innovation that are more within the core competencies and core businesses of a corporation and that may be less risky or hold greater potential for profitability. This is why policy, in the form of environmental regulation but also taking the forms of R&D investments, information, voluntary agreements and technology assistance, may be necessary to focus firms on the win-win potential of environmental technology innovation, or to create win-win possibilities. The examples discussed below highlight not only the existence of a double dividend, but also the challenges of creating and capturing a double dividend when we move away from incremental process and product improvements towards radical changes in processes and products.

Starting first with process improvements, over the last couple of decades many firms have demonstrated the ability to save money while reducing inputs and wastes through incremental changes in their processes. Some of these programmes are fairly well known as they have been reported in the literature for some time, such as 3M's Pollution Prevention Pays programme (3P) (DeSimone and Popoff, 1997). Most large companies have programmes in place for capturing the benefits of input and waste reducing incremental improvements, and many small and medium-sized enterprises have made improvements in this area, often with the help of government-sponsored technical assistance. Nonetheless, there continue to be great opportunities in this area, in part because of ongoing technological improvements and in part because full attention has not been given to these issues throughout the economy. In the United States, a variety of federal and state voluntary and technical assistance programmes are challenging firms to capture these savings (EPA, 1996).

Investments in radical process change are more risky. The two examples given here are non-chlorine bleaching and low-salt dyes. In the United States, investments in non-chlorine bleaching paper mills, to this point, have not been competitive with existing chlorine-based mills. Environmental regulation has not required non-chlorine bleaching, and consumer demand for non-chlorine paper products has been low. The situation is somewhat different in Europe due to a variety of factors including technological trajectories, government regulation, firm initiative, and consumer demand (Norberg-Bohm and Rossi, 1998). This example points out, however, that investment in radical technology in anticipation of environmental regulation that supports its use will not always be profitable. We must be clear about the risks that businesses take in this area. The story of low-salt dyes is somewhat comparable. Although these dyes are

far superior from a water quality standpoint and total manufacturing costs can be lower using these dyes, they are more expensive than traditional dyes. Sales of low-salt dyes have not grown as quickly as anticipated, pointing out another challenge to firms that invest in environmentally enhancing innovations (Reinhardt, 2000).

In terms of products, distinguishing between incremental and radical changes is also important. Changes that work within the current product paradigm can be considered incremental, which does not minimise the challenge they may pose to current business models. Examples include product take-back and moving from product to service. The efforts by Xerox and other companies to build recyclable products and components and to develop the infrastructure to profitably reclaim for re-use and recycling is an example of product take-back. Xerox has pursued this through its Asset Recycle Management Programme in which it leases copiers and then takes them back for remanufacturing and re-lease (Reinhardt, 2000; Smart, 1992). Cartridges are sold, but their return for remanufacturing is facilitated by Xerox.

Two examples of moving from product to service in order to reduce environmental impacts are Interface Carpet and Enron's energy-efficiency business. Interface Carpet has taken on the long-range goal of making the entire company sustainable. Interface Carpet recognises that this is not a challenge for the faint of heart and has put considerable effort into the development of business models that will help achieve this goal. A key component of Interface's efforts is to lease rather than sell carpet. Interface plans to develop carpets that are fully recyclable and in this way minimise the new resource input into their products as well as the waste streams created through the disposal of used carpet (Fishman, 1998; Munio, 1999). A second example is Enron's recent entry into the energy services business. In this business, Enron is contracting with other companies to provide all of their energy services; *i.e*. companies are outsourcing their energy function to Enron. Enron will take over all energy functions from purchasing fuel and making capital investments in energy facilities to replacing the light bulbs. Enron enters into long-term contracts to operate facilities at a percentage of the companies' current fixed price, taking all the risks. Enron can do this not simply because of their role as gas and power supply company but because of the large opportunities for energy savings.

For more radical product innovations, firms may be looking at technological regime shifts that require substantive changes not only for themselves, but also for suppliers, users and society more broadly. This type of technological innovation can require the development of new infrastructure and new business models as well as the resolution of new social concerns. For radical innovation, policy most often plays a critical role in creating the opportunity to profit from these new technologies. For example, in the case of biotechnology, where there is ongoing debate about the environmental and health impacts of the new technology, policy plays a gate-keeping function.[3] Regulations regarding testing, use and sale strongly influence the profitability of biotechnologies. For some other radical technological innovations, policies may be needed to invest in R&D, create niche markets and develop compatible infrastructure for new products that have long lead times and require large and risky technology investments. These products have higher costs when initially introduced but have the potential to be competitive with greater market penetration. Low-emission vehicles are example of this type of technological innovation.

A final piece of micro evidence is worth mentioning. The US data on the environmental technology market shows that the process and prevention technology segment grew by 23.3% per year from 1989 to 1998. While this sector represents only 1% of the "environmental technology market", it is the fastest-growing segment. Predictions are that this segment will continue to grow at a faster rate over time. This evidence from the private technology market reflects the interest of both government and firms to move away from pollution control towards pollution prevention, *i.e.* it reflects shifts in both public and private environmental policy and management.[4]

In sum, there are many examples of individual firms finding "innovation offsets". But theory, case study and macro-level evidence have not been able to answer the question of the size or frequency of the

double dividend. Engineering studies often suggest a large double dividend, and there is a long debate about whether the studies accurately represent transaction costs and consumer preferences. The implementation of voluntary programmes to save energy and water suggest that, at least from the standpoint of process cost savings, there are considerable untapped possibilities. It is more difficult to judge the extent to which there is an untapped double dividend in radical process and product change, and to what extent policy will be needed in order to focus attention or overcome incomplete innovation offsets.

Capturing the double dividend through corporate strategic planning and properly designed environmental policy

Capturing the potential for simultaneously improving environmental protection and economic development is not automatic. Rather it is dependent on corporations integrating environmental concerns into their strategic planning and on government designing and implementing environmental regulation that stimulates innovation. It is beyond the scope of this chapter to thoroughly investigate these issues and they are discussed in other papers presented at this workshop. Herein is provided a brief review, with references to some of the key work in this area.

There is a growing body of research examining the conditions under which firms can profit from environmentally enhancing investments (Hart, 1997; Hart and Millstein, 1999; Hoffman, 2000; GEMI, 1999; Reinhardt, 2000). The Global Environmental Management Initiative (GEMI) provides one useful taxonomy of areas that firms should examine when looking for competitive advantage through environmental investments. Specifically, GEMI suggests that there may be opportunities to take actions that improve environmental performance and competitiveness in the following areas: regulatory compliance, operational efficiency, risk management, capital investment, market growth and strategic direction. In each of these areas, technology strategies involving process and product changes may be an avenue for achieving the double dividend (Hoffman, 2000).

Similarly, there is growing research on the relationship between environmental policy and technological innovation (Ashford, 1993; Ashford, 1999; Gottlieb, 1995; Jaffe *et al*., 1995; Kemp, 1997; Norberg-Bohm, 1999, 2000; Klemmer *et al.*, 1999; Clayton *et al.*, 1999). This body of research has identified several characteristics that are important for creating an environment where the private sector will innovate, including stringency, flexibility, adequate timeframe for implementation of innovative solutions, and certainty. Although there is argument by some that economic approaches will be better for innovation (Jung, Krutilla *et al*., 1996; Milliman and Prince, 1989), detailed case research suggests that the ability of regulation to capture the full set of characteristics outlined above is the key to creating a policy that stimulates innovation, rather than a preference for any particular mechanisms (Klemmer *et al.*, 1999; Hemmelskamp and Rennings, 2000). This most often requires the use of multiple policy mechanisms, as will be discussed below.

Thus far, we have fewer examples of radical innovation for the environment (with its potential for larger improvements in environmental performance) than of incremental innovations and end-of-pipe responses. However, we are in a period of transition. Governments are paying more attention to designing environmental regulation in ways that foster innovation and competitiveness, and also looking to a broader range of policy instruments in support of these goals. Furthermore some firms are starting to view environmental issues as internal strategic issues. This combination of well-designed environmental regulation and proactive firms holds the potential to increase the compatibility between environmental protection and economic development.

Beyond environmental regulation: simultaneously supporting the supply and demand for environmentally enhancing technology

The evidence presented thus far suggests that in many cases innovation offsets exist, and thus firms will be able to capture a double dividend by investing in technological innovations that simultaneously protect the environment and increase competitiveness. It has also discussed the importance of environmental regulation in directing firms' attention to the opportunity to achieve a double dividend, or creating the double dividend in the context of incomplete innovation offsets. Yet environmental regulation, in the form of standards, taxes and subsidies, and information disclosure are only a subset of the tools that governments have available to foster a synergy between environmental protection and competitiveness. Appropriately designed investments in or incentives for R&D can be as important as, and work in concert with, regulation in encouraging firms to move their processes and products onto a more environmentally sound trajectory. This section first discusses briefly the rational for governmental efforts throughout the technology innovation process for environmentally enhancing technologies, making a case for the deployment of a broad range of policy mechanisms that can effectively and synergistically create new technologies and new markets. The section then presents three cases in which government efforts in supply-push and demand-pull worked synergistically in the development and deployment of environmentally enhancing technologies.

Policy for environmentally enhancing technology innovation

Well-understood market failures have led to government support of basic science and technology research and support for the diffusion of technologies where social benefits outweigh social costs. Public support for R&D is based on the fact that knowledge is a public good and thus individual researchers or firms cannot retain all the benefits from investments in basic R&D, leading to under-investment. Public support for the diffusion of proven technologies with public benefits is based on efforts to reduce high transaction costs and address the divergence of private and public discount rates. Between basic R&D and diffusion lies commercialisation and this has been a more controversial area for government action, at least in the United States (Branscomb and Keller, 1998). However, in the case of environmentally enhancing technologies, the market failures associated with environmental externalities operate throughout the process of technological change, contributing not only to under-investment in basic R&D and diffusion, but equally important to difficulty in commercialising new environmentally enhancing technologies. In particular, environmentally enhancing technologies may be more expensive when first introduced and, due to their inability to capture a market niche because their added benefits are public rather than private, may never have an opportunity to go through the process by which many technologies become competitive. Governments can overcome this problem through risk-sharing in technology innovation (*i.e.* R&D investments or tax incentives) as well as environmental regulation that creates market demand during the period spanning pre-commercialisation though lead adoption.[5]

An alternative perspective that also supports government investments in R&D as well as market creation is based on the co-production of environmental regulation and technology innovation (Bijker *et al*., 1987; Boden, 1994). Environmental regulation is often the art of the possible. Rule-making generally requires that environmental protection agencies weigh the costs and benefits of environmental regulations, and thus make trade-offs between the costs of new technologies and environmental benefits. Given the huge uncertainty associated with many environmental problems and the sometimes higher costs of new technology, this often leads to regulations that do not force innovation. Public investments in R&D can move technologies closer to the market, making it easier for regulatory agencies to require or provide incentives for the use of technological innovations.

Supply and demand working synergistically: US wind turbine policy in the 1980s[6]

During the 1980s, California experienced a wind rush. Installed capacity for grid-connected wind-generation grew from zero in 1980 to 1 600 megawatts by 1991. During this period, there was a five-fold decrease in the cost of wind-generated electricity, from 25 cents per kilowatt hour in 1980 to 5 cents per kilowatt hour in 1995. Although at the end of this period wind generated electricity was not yet competitive with the alternatives, this history nonetheless demonstrates how supply and demand can act synergistically to foster technology innovation that is environmentally enhancing. If the demand policies had not ended abruptly, technological progress most likely would have continued, with the development of a competitive wind industry, if not yet a technology that was competitive with the alternative sources of electricity.

US government support for wind energy and other renewables during the 1970s and 1980s was based on the dual goals of reducing reliance on imported oil and reducing the environmental impacts from energy generation. To meet these goals, US federal and state governments enacted a variety of policies that supported wind turbine development and deployment. In terms of supply-push, the US federal government took two approaches to sponsored R&D. The first was a "big science" approach, with the aim of developing large turbines for grid-connected electricity generation. This programme was largely a failure and did not result in commercial turbines. The second approach to R&D was practice driven, focusing on component innovation for somewhat smaller turbines, again aimed at the grid-connected market. It looked to the challenges faced by wind turbines in operation to define the research agenda for component innovation. This programme was a success, contributing substantially to improvements in wind turbine efficiency during the 1980s. Of the 12 key innovations in wind turbine components that we identified, seven relied on partial or total public funding.

Federal and state policies together created demand for wind-generated electricity, which was more expensive than alternatives throughout this period. At the federal level, the government offered tax credits and also passed the Public Utilities Regulatory Policy Act (PURPA), which required that utilities buy back power from small renewables generators at avoided costs. PURPA was implemented at the state level. California's implementation of PURPA included generous avoided costs and equally important long-term purchase contracts. California also passed state-level tax credits and sponsored a wind resource assessment that identified the best sites for wind installations. Together these state and federal policies created a market for wind turbines.

The synergism of these supply and demand mechanisms was crucial for the rapid technological development of wind turbines during this period. Government support for radical component innovation was necessary – the market was too immature and too insecure to attract significant private funding for R&D. Experience with installed wind farms not only helped guide government R&D efforts, but the emerging market also led to incremental innovation by turbine manufacturers. Unfortunately, the demand-pull policies were too short-lived to create a lasting industry. They only acted in concert and strongly over a short period of time. With the elimination of long-term contracts in 1985 and California tax credits in 1987, the market for new wind turbines dried up and most US manufacturers did not survive this downturn in the market.

Supply and demand working synergistically: US gas turbine policy in the 1990s

In 1992, in response to a legislative mandate, the US Department of Energy launched the Advanced Turbine Systems programme. The goals of ATS were to develop an ultra-high-efficient, super-clean, cost-competitive turbine. More specifically, project goals were: efficiency greater than 60% for utility scale systems, NO_x emissions of less than 10 ppm, and electricity costs 10% less than the existing generation of gas turbines. The ATS project is reaching its goals for efficiency, environmental performance and competitiveness (US Department of Energy, 1999). General Electric has completed full-scale testing and

will be conducting demonstrations in 2001. Siemens-Westinghouse is in the process of field testing and will conduct demonstrations in 2002 (Layne, 2000). These advanced turbines are an example of the double dividend. They not only provide environmental benefits, but the US turbine manufacturers have a competitive advantage over foreign counterparts, at least in the short term.

ATS was an R&D programme with some interesting and unique approaches to achieving its goals. The government shared risk with the private sector through cost-sharing. In the early phases of the programme which focused on systems development, the firms contributed 10%. By the later phases of technology development, firms' contribution ranged from 40-70%. In addition to working with turbine manufacturers, the programme included support for university and small innovative firms for near-term and medium-term application-driven R&D. This was done through an industry-directed university consortium, and through the provision of testing facilities at the National Energy Technology Laboratory. Through these efforts, as well as annual meetings and conferences, the programme led to development of new partnerships between universities and industry, and between multiple firms. The ATS programme contributed to several key innovations, including steam cooling, advanced thermal barrier coatings, single crystal blades, and low-NO_x combusters. These innovations are making it possible for the next generation of General Electric and Siemens-Westinghouse turbines to meet the ATS goals.

When ATS was started in 1992, synergistic demand-pull policies were already in place. Advances in gas turbine technology during the 1980s, combined with the deregulation of electric power and natural gas in the United States and many other parts of the world during the late 1980s and 1990s, made gas turbines the technology of choice for power generation in many parts of the world. Environmental standards relating to SO_x and NO_x (to manage acid rain and urban smog), as well as growing anticipation of climate change policies for limiting CO_2 emissions, also gave gas turbines an advantage over alternative fossil-fuel-power technologies.

This case again demonstrates that government policies for supply-push and demand-pull can act synergistically, thus helping firms capture a double dividend of environmental protection and economic competitiveness. However, there are key differences from the wind turbine case that are worth discussing. In contrast to the wind turbines in the 1980s, by 1990 gas turbines were a mature technology with an established and growing market. Furthermore, the firms producing gas turbines have deep technological and financial capabilities. This raises the question of the need for government involvement in moving this technology forward, raising the counter-factual question of what turbine manufacturers would have done in the absence of an ATS programme, both in terms of economic competitiveness and environmental performance. Part of the answer lies in the sources of innovation for land-based gas turbines. Over the past three decades, gas turbines for land-based applications have drawn heavily on jet engine technology as a source of innovation to improve efficiency and reliability. These jet engine innovations were supported heavily by government-sponsored military R&D. The innovations that came out of the ATS programme were not applicable to jet engines, and this provides one rationale for government involvement. In order to achieve higher efficiency and lower NO_x turbines, it was necessary to invest in risky applied research. The programme was also clearly aimed towards creating a competitive advantage for US manufacturers as well as high-tech manufacturing jobs for US workers. From the standpoint of the double dividend, the critical question to ask is not whether government efforts on the supply-side were instrumental, as in this case government risk-sharing did play a role in the technology development. Rather, we need to consider whether government investments in the ATS programme were appropriately balanced between near-term and long-term R&D. This is particularly relevant with relation to the NO_x question. While the ATS turbines made great progress in terms of NO_x, environmental requirements in many US cities already exceed their capability. Work on finding solutions to NO_x control should have been supported at higher levels earlier. In other words, greater synergism between supply-push and demand-pull mechanisms to stimulate environmentally enhancing technological innovation was warranted.

Stimulating private sector technology innovation efforts: US Energy Star Office Products

Energy supply technologies may be unique with regard to the level of government R&D support they receive as well as the high level of government technological capability in national labs and regulatory agencies. This raises the question of the appropriate role for government in other industry sectors. The argument for government involvement in supply and demand will not transfer exactly to many industries, although the prescription for government to concern itself with both fostering technology innovation and creating markets for innovation holds. Energy Star provides an example of how the creative use of labelling, voluntary commitments and procurement worked together to stimulate both technology development and greater technology diffusion.

The Energy Star programme has the dual goals of expanding the market for energy-efficient products and increasing the energy efficiency of products. In other words, it has goals for both technology innovation and technology diffusion. The approach of the Energy Star Office products was three-fold.[7] First, the programme set a standard, in consultation with industry, for the performance level necessary to receive the Energy Star label. Second, the programme encouraged firms to sign memorandums of understanding to produce Energy Star products. Third, the programme encouraged firms and governments to specify Energy Star products in their procurement policy. In 1993, the President supported the Energy Star programme by issuing a federal executive order requiring government procurement offices to purchase Energy Star products when possible. Given that the government is such a large customer, this was important in creating the market for Energy Star Office products.

The Energy Star Office products programme can be judged as a success, with nearly 100% industry participation, *e.g.* all manufacturers produce Energy Star computers. Participating companies grew from 10 in 1992 to 600 by 1998. The programme has also fostered ongoing technological innovation through upward revision of the standard (in consultation with industry). This programme first worked to transfer an existing technology to a new category of products ("sleep mode" from laptops to desktop computers), but over time, by raising the bar for the Energy Star label, it created competition to improve the energy efficiency of computers. In sum, Energy Star has resulted not only in the more rapid diffusion of new technologies, but also competition to develop more energy-efficient technologies that will then be specified as the new standard.

Conclusion

This chapter began by reviewing the potential for the double dividend, concluding that there are indeed many opportunities to simultaneously protect the environment and improve economic competitiveness. While it is difficult to answer the question of how widespread these opportunities are, it is clear that changes in the approach of both corporations and governments will lead us to discover and create greater opportunities for making environmental protection and economic growth compatible. Corporations are likely to discover currently untapped innovation offsets, particularly opportunities for radical changes, only when they integrate environmental concerns into strategic planning. From the standpoint of governments, policy must be explicitly designed to foster innovation. To accomplish this, regulations must be stringent, flexible, provide long-time frames and reduce uncertainty.

This chapter has gone beyond advice on designing environmental regulation, however, to point out the importance of considering a full range of government policies that can create innovation offsets. In particular, the cases in this chapter point to the potential synergistic effects of simultaneously investing in R&D and creating markets through environmental regulation. The cases suggest that it is important to use the supply-push and demand-pull mechanisms synergistically, particularly during the period spanning pre-commercialisation through lead adoption. Granted, the cases described in this chapter are all drawn from the energy sector where government has a much deeper history of involvement in technology

innovation. For other sectors, governments must consider how to creatively use a variety of policy instruments to stimulate technological innovation and diffusion.

NOTES

1. Jaffe *et al*. (1995) reviewed a broad range of studies before reaching this conclusion, including studies on international trade, direct foreign investment, regional patterns of domestic investment, and economic growth.

2. Behind these arguments and evidence for and against the existence of a "double dividend" is a more ideological debate. Neo-classical economics treats firms as profit maximisers. If firms do act in this way, there would be few untapped opportunities to profit, and thus a negligible untapped double dividend. While the concept of profit maximiser may be useful for many aspects of economic analysis, this is one place where it falls short. There is considerable evidence that firms are bounded in their rationality. Thus, it is not surprising that we see many examples of individual firms finding "innovation offsets".

3. Monsanto's strategic move into biotech is discussed by Hoffman (2000) and Reinhardt (2000).

4. Environmental Business International Inc. (1997) as cited in Hoffman (2000), p. 150.

5. These arguments are more fully developed in Norberg-Bohm (2000).

6. This story is presented in greater detail in Loiter and Norberg-Bohm (1999).

7. This case was drawn from Howarth, Haddad and Paton (2000) and personal communication with Paton.

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Chapter 9

ECO-EFFICIENCY, ENTREPRENEURSHIP AND CO-OPERATION: THE FINNISH ENVIRONMENTAL CLUSTER RESEARCH PROGRAMME

by

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Introduction

Industrial clusters have been a major focus of the debate in Finnish technology policy in the 1990s. In terms of industrial and technological policy, clusters are networks of enterprises and communities with similar interests. Clustering helps them to improve their operating potential and competitive capacity through co-operation. The key agents in clusters are the producers and users of knowledge: enterprises, the public and private service sectors, the public authorities and the research and educational system. The underlying foundation of clusters is a strategic competence network created through co-operation, where knowledge and expertise are disseminated effectively and combined in innovative ways. Clusters are often a better representative of the operative structure of industries than the traditional division into lines of business.

The focus in industry is shifting away from capital- and material-intensive to knowledge-intensive operations. This development has been especially rapid in Finland, where the electronics industry now plays a major role among exporting industries. However, it is not only in modern information technology, but also in other clusters that success seems to depend crucially on the ability of enterprises to utilise knowledge, expertise and modern information technology.

In Finland, for a number of years a systematic effort has been made to build a national innovation system based on co-operation between the producers and users of knowledge. Cluster programmes are the most recent addition to this system.

Cluster programmes

The Finnish cluster programmes form a set of public programmes that are organised under sectoral ministries. In the beginning, the programmes were scheduled for the period 1997-99. They aim to produce new knowledge, competence, services and co-operation to promote entrepreneurship, economic development and employment. One important aim is to break down the barriers between scientific disciplines and lines of business and thereby tap new sources of innovation. Cluster programmes are

extensive research projects undertaken collaboratively across political sectors in an effort to integrate the objectives of research, technology and employment policies with sectoral policies, including research and development projects conducted within enterprises and in the public and private service sectors.

Co-operative projects help to consolidate contacts between researchers and the clients of research institutes and to promote co-operation between the public providers of funding. The development of clusters requires good co-operation, both between the public and the private sector and within the public research community.

To date, cluster programmes have been launched in the environmental sector, but also in the transport, forestry, foodstuff and welfare sectors. In addition, a working life development programme and a networking programme for SMEs have been started. The majority of the programmes rely significantly on modern information technology. Programmes incorporate more than 300 separate projects performed by over 400 organisations. More than FIM 600 million have been invested in the programmes, of which approximately 60% comes from public funding.

The Environmental Cluster Research Programme

The goal of the Environmental Cluster Research Programme is to enhance eco-efficiency and thereby improve the state of the environment and promote innovation. The programme also aims to create new opportunities in environmental entrepreneurship. A further objective is to promote co-operation between researchers, business, public authorities and funding organisations in accordance with the cluster approach and thereby integrate environmental issues even more closely with the Finnish system of innovation.

The following topics will be covered by the environmental cluster research projects:

- Material flows and life cycle assessment.
- Eco-efficiency in production processes and products.
- Environmentally friendly infrastructure.
- Management of environmental knowledge and information.
- Promotion of environmental business, ecological exports and marketing.
- Environmental and innovation policies.

The Finnish Ministry of Environment is responsible for the administration of the programme. Certain aspects of implementation and funding are also undertaken by the Ministries of Trade and Industry, Agriculture and Forestry and Labour, TEKES (the Finnish National Technological Agency) and the Academy of Finland. Funding for the first stage of the programme (1997-99) totalled FIM 80 million. Approximately half of the total amount was contributed by research units and other financial institutions.

Funding proposals for individual projects are made by the steering group of the research programme, which consists of representatives of the financing organisation, Ministry of Transport and Communications and Industries. About 400 applications have been received, of which 60 have so far been allocated funding (a detailed list of projects can be found at the programme's Web site: http://www.vyh/tutkimus/). Major Finnish environmental research institutes, including 180 research units and about 70 enterprises, participate in the programme.

The extent of the programme and, even more importantly, the research project approach will make it possible to use research as a tool to orient environmental policies in a completely novel way. The integration of the concepts of eco-efficiency, integrated control of emissions and environmental impacts, and integrated product policies are key elements of this new approach to research.

Eco-efficiency

Eco-efficiency is the key concept in the environmental cluster research programme. The term eco-efficiency refers to the utilisation of our natural resources in the most economically, socially and ecologically efficient manner possible. The principle of eco-efficiency connects environmental protection with technological and economic efficiency. The focus of environmental protection simultaneously shifts from emissions and waste to possibilities of saving natural resources and energy and diminishing and preventing environmental hazards throughout the life cycle of the product.

The OECD survey of eco-efficiency underlined the conclusion that the target levels in eco-efficiency cannot be reached by technical means alone, *i.e.* through the development of new machinery and equipment or the improvement of the old stock. Social innovations are also needed: new ways to utilise products effectively; new types of co-operation; completely new lifestyles and consumption habits. Any analysis of eco-efficiency must thus be based on the environmental load per service produced.

One of the basic aims of eco-efficiency is to eliminate the correlation between economic growth and increased use of natural resources, on the one hand, and an increase in emissions, on the other. Therefore, one of the key questions of eco-efficiency is how growth in productivity, the economy and living standards will be possible in the future with decreasing raw material and energy inputs and environmental stress. In the case of emissions, there are already instances where growth has been successfully de-linked from an increase in emissions. For example, discharges from Finnish forest industries into lakes and rivers grew at the same rate as the increase of production up until the mid-1970s; however, since then, production has continued to grow while emissions have been declining. A similar trend can be observed in sulphur oxide emissions.

The management of material flows and life cycle thinking are special tools that can be used to promote eco-efficiency. They are also central aspects of the cluster programme. The life cycle projects will apply to agriculture as well as to the forestry, metal processing and construction industries, electrical and electronic industries, water supply and stone quarrying and processing industry.

The material flow project is the first effort to analyse material flows throughout the national economy. The aim is to analyse interdependencies between the use of natural resources and economic growth and industrial structure and, at a second stage, to identify the strategic points for reducing material use in the economy.

Integrated control of emissions and environmental impacts

The aim of these projects of the cluster programme is to develop methods for an integrated assessment of environmental and economic effects of emissions, energy and resource use at the plant level in the context of environmental permitting. The focus is on a holistic and integrated approach based in accordance with the IPPC (Integrated Pollution Prevention and Control) Directive of the European Union. The projects produce practical approaches, methods and tools for permitting authorities and plant operators in the pursuit of reliable options in integrated permitting.

The aim is also to make it easier for operators to predict the authorities' requirements and thus enable them to find the most effective methods in pollution prevention and control. In this light permitting is seen as an open and dynamic process between installations, authorities and other stakeholders. The outcome of the process should encourage all parties to make new innovations and adopt new ways to tackle environmental problems brought forward by research.

Product policies and innovations

In international environmental policies, the focus is shifting away from limitations on emissions to concern for the hazardous impacts of emissions throughout a product's life cycle. Although many countries have been able to effectively reduce their industrial emissions, the use and disposal of various products appear to cause greater environmental problems than their manufacturing. Integrated product policies (IPP) have been discussed in the EU, OECD and the Nordic Council of Ministers.

A product-related environmental policy has much in common with eco-efficiency thinking, *e.g*. life cycle thinking and market orientation. However, it is more clearly an environmental policy strategy and programme, in which the role of government and of various control methods is inevitably underlined. These concepts should not be developed separately from each other; instead, it is important to find ways in which eco-efficiency thinking and the factor goals it includes can be considered when a product-related environmental policy is being developed.

The Environmental Cluster Research Programme aims to provide a solid knowledge base for Finnish product policies. The programme includes life cycle analyses in different fields of production, surveys of the best available technologies and a material flow analysis of the entire national economy. These activities will enable an assessment of the eco-efficiency potential of different fields of production and the identification of points in the production chain where eco-efficiency can be increased in the most cost-effective way.

The resulting knowledge base will enable enterprises to optimise their product development and environmental authorities to outline environmental policies in such a way that they will both support high-level environmental protection and enhance the competitiveness of the national economy.

Development of environmental business

An important feature of the environmental cluster is the emphasis on the networking of researchers, funding organisations and users of research findings. The programme aims not only to consolidate the knowledge base of environmental policies and generate innovations, but also to strengthen the national system of innovations and support the development of environmental business.

The programme includes projects that encourage co-operation between entrepreneurs who utilise the natural environment for eco-business and seek optimal operating strategies for enterprises specialising in environmental technologies. Two additional projects will be undertaken to develop methods for designing environmental policies that create greater incentives to innovate. In some projects, the goal is to set up a new marketplace for environmental products on the Internet.

Assessment of the efficacy of the programme

Most of the projects included in the first stage of the Environmental Cluster Research Programme will be completed in spring 2000; an evaluation of the programme will be carried out during autumn 2000.

However, it is already quite clear that the goals set by the funding organisations have been attained. Co-operation has been flexible and the number of co-operative projects has increased. The research institutes have also networked in a significant way. Each cluster project involves about three research units; this figure is certainly higher than the average. In addition, 70 industrial enterprises participate. Most of these participate through a representative in the steering group of the research organisation; only a sub-set of the projects are co-ordinated by industrial enterprises. One reason for this is that companies are reluctant to involve their R&D projects in a programme whose findings are public and freely accessible to potential users.

The programme is a significant educational forum for new environmental researchers and it allocates resources to areas where new knowledge is needed and where new jobs and enterprises can be created. The programme encourages co-operation between researchers and the users of results. The evolution of a new research culture enhances co-operation, the utilisation of research findings and efficacy as well as the acquisition of outside financing. This will serve to increase the share of non-governmental research funding for the units.

Continuation of the programme

The Environmental Cluster Research Programme is continuing in 2000. The following pilot studies have been launched to elaborate the plans for further research:

1. Infrastructure of sustainable society.

2. Information society and sustainable development.

3. Environmental effects of hormone-like substances: the need for national research.

The planning of the second stage of the programme is based on the fact that the public funding for the term 2000-01 will be at least FIM 30 million. Based on the pilot studies, targeted invitations for applications have been issued for items 1 and 2 above. The need for further studies on eco-efficiency has also been recognised.

Special emphasis will be placed on the sub-programme dealing with sustainable development and the information society. So far, the main impact of the emerging information society on environmental protection has been the need to recycle and re-use electronic waste. The modern information technology, however, provides interesting opportunities to promote sustainable development.

In production, favourable environmental impacts mainly take the form of dematerialisation. The structure of industrial production will change: the significance of energy and material-intensive industries will decrease while the development of control systems throughout the production processes will allow products to be manufactured using less raw materials and less energy.

Consumption will be characterised by immaterialisation, *i.e.* material products will be replaced by immaterial ones. Sooner or later, all the products and services that can be marketed and delivered to the consumer in the form of information will be electronically marketable. Although the processing and transmission of information will always require a material carrier and a transmitted bit may leave a clear ecological footprint, we can still justifiably speak about increasing immaterialisation.

According to a pilot survey (Kahilainen, 2000) carried out by the Environmental Cluster Research Programme, we will need to know more, particularly about immaterialisation, if we wish to aim for a sustainable information society – which has already been accepted as a national goal in Finland.

Dematerialisation will proceed in industries even in the absence of new environmental policies and projects related to dematerialisation were launched at the very first stage of the cluster programme. Immaterialisation is more problematic in this respect since increased consumption may well cancel out its environmental benefits. On the other hand, immaterialisation may open up major new opportunities to the extent that we are able to anticipate and utilise them in ways that benefit sustainable development. In particular, it is important to better understand the impacts of information technology in the following fields: lifestyles and cultural change; consumption habits; networking of consumers and trade in consumer goods; the replacement of products with services; and the management, processing and dissemination of environmental knowledge.

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Chapter 10

LINKING THE RESEARCH BASE AND THE MARKET THROUGH TECHNOLOGY FORESIGHT

by

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Introduction

This chapter assesses the progress of the UK Foresight initiative and its impact on stimulating private sector activity and businesses in the environmental sector. It gives a brief overview of the stages of the Foresight programme in the United Kingdom. It then describes examples of the successful stimulation of private initiatives and action in the energy/environment and in the sustainable transport fields. The wider impact of the Foresight scenarios and methodology is also discussed. The chapter then moves on to outline some of the continuing challenges that face full integration of Foresight in the innovation and commercialisation process. This addresses the changing structure of industrial sectors, disciplines and of the social and market conditions within which innovation and commercialisation must now take place. The chapter concludes with a discussion of plans to address some of these difficulties by public sector action. This is placed in the context of UK industrial and regional policy, the emphasis on cluster development, and the changing regulatory and fiscal regimes following from the UK climate change levy and the Kyoto agreement.

Stages of UK foresight

The UK Foresight programme was launched in 1993, following a government white paper on science, engineering and technology. It has a panel-based structure and operates on a five-year cycle. The programme brings together the voices of business, government, the science base and others to identify the threats and opportunities that we are likely to face over the next ten to 20 years. In doing so, Foresight aims to bring about a culture of change in how business, academia and government relate to each other and to the future.

In 1999, the Foresight process in the United Kingdom moved on to a new round of activity with new panels. Previous activity had been focused around panels which, to a large extent, reflected economic sectors (chemicals, transport, energy, etc.). That earlier work was undertaken in two broad

tranches; the first giving an overview of broad priorities in the area, and the second trying to take some of the priorities in more detail and engage industry, academia and government in joint actions.

The new round of Foresight has recognised that many of the emerging challenges are cross-sectoral. Hence, the new panels are more concerned with groups of areas (see Box). In addition, there have been three thematic panels - covering "ageing population", "crime prevention" and "manufacturing 2000". All panels are asked to consider the implications of their findings for education, skills and training and for sustainable development.

New round panels

- Build environment and transport
- Chemicals
- Defence
- Aerospace and systems
- Energy and natural environment
- Retail and consumer services
- Financial services
- Food chain and crops for industry
- Health care
- Information, communications and media
- Materials

As the new panels have only been underway for nine months or so, much of what is described in this chapter relates to the implementation of the work of earlier panels.

It is important to note that the key feature of Foresight is the process itself. The aim is to change the culture of business, academia and government to recognise future threats and opportunities. Measuring the effectiveness of a programme with such an aim is difficult. In this new round, there is an attempt to set up a suitable monitoring and evaluation process. This is not yet in place. Hence, in this chapter, we have adopted some rather simple criteria, namely the degree to which the private sector has been involved in the process and particularly the extent of joint private-public investment in new areas/ideas that have been identified by Foresight.

The chapter does not attempt to give a full evaluation. Rather, it aims to give examples of the impact in order to illustrate some of the ways in which the programme was linked to the market and the research base in the environmental field.

Examples of the outputs

Joint working

One measure of success is whether groups bought together through the Foresight process take over the initiative and continue to work together independently of the programme. An example of this is the "Advanced Power Generation Task Force". This is now led and funded by industry itself and includes such major companies as Alstom Power, PowerGen, Rolls-Royce and Mitsubishi. They are working together to develop a common R&D agenda for advanced power generation, recognising the need to find technologies and approaches that considerably improve efficiency and also reduce carbon emissions to very low, if not zero, levels.

Arising from the work of the Transport Panel is the "Foresight Vehicle". This is a joint government/private sector initiative. Government has contributed GBP 10 million in research funding and the Foresight Vehicle programme has attracted matching funds from the business sector to pursue a range of related R&D exercises all focused on the Foresight Vehicle. To date, there are some 25 projects under way, covering areas such as: hybrid electric/alternatively fuelled vehicles; structure and materials; advanced electronics; powertrain; and telematic systems. Companies such as Ford, Daewoo, GKN, British Steel are contributors and participants in the programme.

New funding programmes

The UK Government has set up the Foresight Challenge Fund to help Foresight move beyond the identification of R&D needs and opportunities to joint action.

This requires joint bids from business and academia to develop key themes and R&D aspects emerging from the Foresight panels. Support is only given to projects which obtain private sector funding as well.

Core government funding amounts to some GBP 30 million. The Fund has attracted over 500 applications, which is a measure of the strong interest generated through the Foresight process. Of these, 24 projects have been selected. The public funds have in this case leveraged in some GBP 62 million of private sector funding.

In a separate initiative, the UK Department of Trade and Industry is in the process of setting up the Sustainable Technologies Initiative. This was in large measure stimulated by the work of the Foresight Panel and Sub-panel working in the area of environment and sustainable technologies. It is proposed that the government will subscribe GBP 20 million to the fund which will support R&D and D in this field to projects that meet the aims of this initiative. Projects must have at least matching levels of private sector funding.

Scenarios – changing culture

An important aspect of Foresight is to change the culture of government, academia and business thinking to consider the need for change in the light of future opportunities and threats. Foresight is not designed to predict the future. Nevertheless, the uncertainties and possibilities of the future must be faced up to.

To help in this process, the Natural Environment Panel of Foresight undertook a scenario-building exercise. This attempts to map out a range of possible "futures". Indeed, it provides four broad scenarios covering the whole of the potential "possibility space" for the United Kingdom in a global context.

The aim is to stimulate users to ask themselves whether their current activities and proposals for future development are robust in the face of these alternative futures. By gauging the degree to which they are prepared for the threats and opportunities of these differing scenarios, participants can identify actions and R&D innovation needs that will enable them to prosper in a range of alternative futures and hence to face the uncertainties of the future.

The scenarios were built after an extensive review of existing work and then developed with the help of both public and private sector groups. Since being developed, they have been used in-house by companies, by the UK climate change programme in identifying how regions should respond. They

have also been used by the UK Cabinet Office to test forward thinking and by a number of the UK Regional Development Agencies to test the robustness of their economic/industrial plans. A handbook has been produced as a tool to help small and medium-sized companies use the scenarios for their own in-house foresight exercises.

Continuing challenges and responses

Continuing challenges

Innovation in the environment continues to pose challenges which come on top of the difficulties of innovating in any standard industrial sector. All sectors and branches of the economy have to respond to the environmental challenge, and this is especially important as we move beyond "end-of-pipe" and repair approaches to integrated, cleaner technologies and products or preventative approaches. The responses then become an integral part of all sectors and technologies of the economy.

It is exceedingly difficult to focus and define the scope of innovation and the environment given its wide area for action and application. Indeed, it can appear to encompass almost everything.

This raises one of the key dilemmas of innovation policy in the environmental field. Should it be integrated in all fields? Clearly, the answer is "yes". However, this brings with it the danger that it is not strongly pursued because environment is, for many in the different sectors, only a secondary consideration. Hence, it does not receive the emphasis it should. On the other hand, if work on environmental innovation is confined to specialist programmes, this undermines integration.

There are a series of related problems. Much environmental work and application requires interdisciplinary work. Yet, in the United Kingdom at least, academic institutions, learned and professional societies and the main routes for R&D training are set up largely along traditional disciplinary/professional lines. It is not so easy to get research funding nor to find the highly respected academic journals that are an important part of the academic research support framework. Thus academics in the field are operating with "new" initiatives and approaches such as the Sustainable Technology Innovation mentioned above. You have to be innovative in your research funding and organisation before you can be innovative in the environmental field.

The integrated nature of the responses required by the environment also poses difficulties. The more holistic response means that many stakeholders are involved. For example, lifelong stewardship involves producers and consumers. Life cycle analysis involves an even longer chain. Innovation in these wider circles makes the task of development and application more difficult.

At the same time, industry itself is recognising that both vertical and horizontal integration are going on. Manufacturers are becoming more aware of the service their goods are supplying and hence beginning to regard themselves as much as service providers as manufacturers (*e.g.* the move towards leasing products – solvents) or the integration of communications and content producers in the media field. These changes add to the shifting landscape within which innovation has be developed and applied.

Finally, under the list of challenges, the international dimension must be recognised. Many of the major environmental challenges must be tackled in developing countries as well as in those countries that are already well industrialised. For example, India and China are both likely to build their rapidly growing economies with a large amount of energy for fossil fuels. Means of reducing "greenhouse" gas emissions must be applicable in new countries. Water scarcity will affect many people in the

future. It is estimated that by 2025 two out of three people will live in water-stressed areas. There will be increasing competition among countries and among uses for water (domestic vs. industrial vs. agriculture). Hence, the development, for example, of drought- or saline-tolerant crops must find application in those countries most at risk – including the Middle East and Sub-Saharan Africa.

Another example is the need to reduce the embodied energy in building and construction. By 2025, the urban population of the globe will increase by some 2.5 billion. This implies a huge volume of building – with all that this entails for energy and materials use – most of it in countries outside the OECD area.

In all of these examples, if innovation is to have any impact on some of the main environmental questions, it must find adoption in countries outside the OECD.

Some responses

The current UK Foresight Energy and Natural Environmental Panel is only part way through its work. However, it is having to address the types of challenge highlighted above and we can outline some of the initial ideas here.

Integrating environmental considerations across the board is a key message we wish to get across. However, it remains important to maintain a high profile for environmental challenges and issues. One solution is to have a set of "sustainability R&D and D" programmes with the task of championing these areas, each working throughout the disciplines and sectors and funding key high-profile projects that are interdisciplinary and cross-sectoral. These will then form a theme around which other work can be co-ordinated and branded so that a critical mass of work can be seen and identified with.

The funding of such programmes would need to be substantial. Fundamentally, because the level of funding itself is a major signal as to how much we really wish to champion the development of these approaches and how seriously we take it. To date, the levels of funding and support from government and industry are perceived as small and fragmented and therefore send out the signal that innovation in the environment is not a high priority.

As so much of the market for these new approaches will be global, there is a strong argument for this champion programme to be able to encourage and fund joint or partnership approaches between researchers and firms in the United Kingdom (or OECD countries) and in other countries where application will be funded.

Hence, we might look for joint programmes on clean coal/zero emission generation with India or China; on sustainable, low energy and materials construction and infrastructure with partners in South East Asia or Latin America; or on drought-/saline-tolerant crops and reduced water usage with Middle East or African partners.

Within the framework of the Kyoto protocol and the clean development mechanism, there is the potential to find sources of funding for environmental R&D and application. In the United Kingdom, the proposed climate change levy may give an opportunity for increased R&D funding. The proposal is for this levy to be tax neutral, returning the revenue in the form of reduced social charges on employers. However, some of the funds might be recycled through environmental trusts dedicated to support R&D and innovation – much as occurs with the current land- fill tax in the United Kingdom.

Much has already been written about the "innovation-forcing" effect of various environmental regulatory regimes. There is now a move towards greater liberalisation of energy supply in many

countries. In the context of the pressing environmental problems arising from energy use, more attention should be paid to the impact of energy regulation on environmental innovation. The same may be said about the impact of product regulation in general, responding to the increasing integration of environmental performance in products.

The emphasis on integration of environmental issues strongly suggests that environmental innovation must be seen as part and parcel of more general industrial modernisation and improved competitiveness. Work on competitiveness and on regional economic development increasingly emphasises the importance of "clusters" in developing strongly competitive and innovative economies. Silicon Valley in the United States and the so-called "Cambridge Phenomenon" in the United Kingdom are but two examples. The notion of the success of clusters of companies competing and co-operating to serve broadly similar markets is not new. Such areas tend to have strong R&D capacities – in the companies and in universities, a well and appropriately trained workforce, access to knowledgeable venture capital and all kinds of informal and trust-enhancing relationships.

The UK Government is strongly supporting the concept of clusters in its science policy white paper and in its approaches to regional economic development.

The growth of such regional clusters and the linkages they give rise to could provide a useful integrating framework with which environmental innovation is championed and widely applied. This is because, in such clusters, horizontal and vertical integration is easy and the transfer of experience and techniques between companies and different applied disciplines becomes commonplace.

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OECD PUBLICATIONS, 2, rue André-Pascal, 75775 PARIS CEDEX 16
PRINTED IN FRANCE
(92 2000 11 1 P) ISBN 92-64-18574-7 – No. 51561 2000