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Executive summary

Environmental taxation, innovation and the green economy

'Environmental taxation can spur innovation.' This simple, compelling message was a central finding of a recent OECD study of taxation, innovation and the environment (OECD, 2010).

It is an insight of profound importance. Environmental policy instruments are frequently characterised as obstacles to economic activity but the OECD analysis suggests that environmental taxes can, in fact, be the opposite — serving as catalysts for the creativity that underpins thriving economies.

In the short term, such innovation can boost efficiency and competitiveness. In the long term it arguably holds the key to sustained prosperity by enabling economic growth to continue within environmental limits. Innovation, particularly the kinds of innovation stimulated by environmental policy, is essential in the process of creating 'green economies' that can deliver growing incomes while preserving natural systems and social equity.

Environmental tax reform (ETR) appears to offer an attractive mix for policymakers. It deters environmentally damaging activities by making them more costly, while incentivising the creation and diffusion of new technologies. For advanced economies like the EU, eco-innovation can also create opportunities to export new tools and processes globally.

While increasing the costs of polluting and using resources is likely, by itself, to subdue economic output, governments can use the tax revenues accrued to reduce the fiscal burden elsewhere. Cutting labour taxes, for example, can help boost work incentives — potentially increasing employment and offsetting negative economic impacts. Moreover, as the recent petre project (1) has demonstrated, governments can potentially enhance net benefits further by reinvesting some of the revenues secured through ETR in eco-innovation.

In view of the potential gains, there is clear value for policymakers and society more broadly in expanding the knowledge base on ETR and innovation. The present report aims to do just that, using two approaches: a literature review and a scenario-based modelling exercise. Together the two analyses confirm the important interplay between environmental taxes, innovation and macroeconomic performance — and the potential role of ETR in shifting to a green economy in Europe. The key findings are set out below.

Key findings of the literature review

The literature review identified four relevant groups of studies: assessments of environmental regulation's impacts on innovation; theoretical analyses of how different policy instruments influence innovation; empirical studies using statistical and econometric techniques to assess the impacts of 'actual' policy interventions; and case studies providing descriptive assessments of actual experiences.

In broad terms, the studies confirmed that environmental regulation in general, and price-based policy instruments (such as environmental taxes and investment subsidies) in particular, can and do increase innovation and diffusion of environmental technologies. The studies

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(1) The project 'Resource productivity, environmental tax reform and sustainable growth in Europe' (petre) was commissioned by the Anglo-German Foundation (AGF) in 2007. It used econometric and resource flow modelling techniques, surveys, and interviews to explore the implications — for Europe and the rest of the world — of a large-scale ETR in Europe designed to achieve the EU's 2020 greenhouse gas reduction targets. For more information see www.petre.org.uk or Ekins and Speck (2011).

of environmental regulation's impacts on innovation suggest that greater regulatory stringency is associated with increased innovation, although the effect appears small.

The empirical studies and case studies reviewed provided more comprehensive evidence. The empirical studies, covering technology areas such as energy efficiency, renewable energy, and air and water pollution abatement, revealed that environmental taxes and energy prices have a significant positive impact on both innovation and diffusion of existing technologies. However, the effects of taxes or prices may vary somewhat across sectors and innovation types. The case studies likewise indicate that environmental taxes and investment subsidies have generally, although not universally, had a significant positive impact on innovation and diffusion.

The literature also provides valuable insights on the impact of environmental taxes compared to other instruments and the conditions that can enhance or limit an ETR's impacts on innovation. For example, case studies focusing on the Netherlands and Germany highlighted the need for a tax rate that is sufficiently high to provide a meaningful incentive and signalling effect, and that is fixed for a sufficiently long period of time to reduce uncertainty about the future benefits of investment.

The theoretical studies reviewed indicate that the relative impacts of environmental taxes and other instruments on eco-innovation are far from clear cut. They often depend on the competitive structures of the markets and the ability of innovator firms to appropriate the benefits accruing to other firms during diffusion. Other factors also play a role, however. For example, market failures such as information asymmetries, principle-agent problems, capital market failures and positive adoption spillovers can all influence technology diffusion. Similarly, uncertainty over future returns and the (associated) use of high discount rates for investment decisions can also undermine the effectiveness of price-based instruments in stimulating diffusion.

Taken together, the literature underscores the potential for environmental taxes to catalyse innovation. At the same time, it also highlights the complexity of the issues and the difficulties in making generalisations about the impacts of environmental taxes and alternative policy instruments. The precise effects of environmental taxes and other measures on innovation are very specific to local realities and very much influenced by the stringency and point of incidence of the policy intervention. With this in mind, some authors stress that any analysis of policy impacts on innovation must be very nuanced, reflecting factors such as the direction, type and duration of innovation. Assessments of policy effectiveness require indicators that can convey an accurate and detailed picture of innovation in all its forms.

Key findings of the scenario analysis

The modelling exercise builds on the findings of the petre project, using the GINFORS model to assess economic and environmental impacts of using the EU Emissions Trading System (ETS) and ETR to reach the EU's 2020 GHG targets. It evaluates the overall effects of a European ETR compared to a projected baseline and develops scenarios in which eco-innovation or renewable energy technologies are supported.

The analysis employed three scenarios from the petre project. Together these illuminate the macroeconomic impacts of implementing an ETR designed to meet the EU's 2020 GHG target with revenues recycled through reductions in income tax rates and social security contributions, and through investment of 10 % of revenues in eco-innovation measures.

In addition, the present study used two addition scenarios, both based on the assumption that 10 % of revenues are invested in eco-innovation. The first examines the macroeconomic impacts in EU Member States arising from increased exports of renewable energy technologies, which is a plausible scenario based on the strong EU policy effort to increase the share of renewable energy in final energy consumption and the possibility of very strong world market development in the sector until 2020. The second analyses the macroeconomic effects of changes in the input structure of the energy sector, i.e. from conventional electricity production to renewables.

Overall, the analysis revealed that the modelled reforms delivered positive employment effects and only small negative impacts on GDP in the EU-27 Member States. The economic impacts depend on the levels of international energy prices used in the scenarios, the mechanism used to recycle revenues, and country specifics such as carbon and energy intensity and the structure of energy consumption.

At the EU level, the basic ETR scenario — assuming that revenues are only recycled via reduced income tax and social security contributions — results in EU GDP 0.57 % below the baseline in 2020. The additional assumptions in each of the alternative scenarios (investing 10 % of revenues in eco-innovation, increased exports of renewable technologies, and changes in energy sector inputs) each soften this negative impact on GDP.

Whereas all the scenarios indicate a small negative impact on EU GDP relative to the baseline, the impact on employment is positive in all scenarios. The scenario design implies that the structure of the EU economy shifts from energy-intensive to labour-intensive sectors. The magnitude of the employment gain is influenced by the carbon price and the tax shift, the underlying energy prices and the production loss. The largest part of the employment increase stems from the additional investment in eco-innovation, although a shift in industry structures and additional renewable technology exports are also positive for the labour market. As ETR is directly aimed at reducing labour costs, it will create additional jobs in the short and medium term. In the longer term, the cost reduction and new technologies arising from eco-innovation will play a larger role.

The results indicate that environmental tax reform can deliver environmental objectives, create additional jobs and trigger eco-innovation, while having negligible negative impacts on GDP. These findings are particularly evident in the scenario assuming that 10 % of revenues are invested in eco-innovation and EU exports of renewable technologies increase. In that case, EU GDP is just 0.04 % below the baseline in 2020 and employment is 0.51 % (or more than 1 million jobs) higher.

Like all fiscal reforms, a major ETR in Europe will create winners and losers. At the sector level, carbon- and material-intensive industries will face economic losses. At the country level, the carbon-intensity and overall flexibility of economies is important. Clearly, structural change away from carbon-intensive industries, together with technological change, is inherent in any successful climate mitigation policy. However, international cooperation and the revenues gathered through ETR and the EU ETS can help soften negative economic and social impacts.

Caution is needed in relating the findings of this study to the EU policy debate. In the model simulations, the single carbon price is the only instrument used to reach the EU's 2020 GHG targets. In reality, of course, other renewable energy and efficiency policies will also contribute to carbon reduction and have to be taken into account when comparing the results (especially the high carbon prices) to other studies. Both reduce the potential revenues from fossil energy carriers and carbon emissions.

A variety of renewable energy and efficiency policies could enable the climate and energy targets to be met while securing even better economic prospects. The results of the present study clearly indicate that the discussion on market-based instruments should be intensified. Ultimately, however, the EU will need a rich mix of policies to reach its GHG targets while maximising prosperity.

1 Introduction

1.1 Background

In 2005, the European Environment Agency (EEA) prepared a series of reports on the use of market-based instruments to achieve environmental goals. Environmental tax reform — defined as 'reform of the national tax system where there is a shift of the burden of taxes, for example on labour, to environmentally damaging activities, such as resource use or pollution' — was identified as a key tool in this context (EEA, 2006).

A central attraction of ETR is its capacity to steer incentives so that human endeavour and ingenuity can deliver maximum economic gains, while preserving the environment and social equity. To analyse this function further, the Anglo-German Foundation (AGF) commissioned a major body of research in 2007, 'Creating sustainable growth in Europe'. One project in this context, entitled 'Resource productivity, environmental tax reform and sustainable growth in Europe' (petre), started from the hypothesis that ETR could increase human well-being via two routes: improving the environment and generating economic activity and employment. The results of petre were presented in a final report (Ekins, 2009) and in a book (Ekins and Speck, 2011).

Petre used econometric and resource flow modelling techniques, surveys, and interviews to explore the implications — for Europe and the rest of the world — of a large-scale ETR in Europe designed to achieve the EU's 2020 greenhouse gas reduction targets, i.e. cutting GHG emissions by 20 % in the period 1990–2020 (or 30 % in a context of global cooperation). In order to investigate whether ETR could deliver these targets, six 'scenarios' were developed and modelled, using two well-known macro-econometric models: E3ME and GINFORS (2).

The results suggested that ETR is an effective environmental instrument that can enable the EU to meet its CO_2 targets. The models produce nearly identical results concerning labour and resource productivity, signalling that an ETR that meets the emissions target would raise employment, lower resource consumption and have negligible effects on GDP.

The petre project provided a compelling case for using ETR more widely but the findings also indicated scope to extend the analysis. For example, the results of one of the scenarios indicated that investment in green technologies in the EU could significantly reduce both the carbon price and GDP loss in reaching the 20 % target. Measures that could augment the net benefit of ETR are clearly worth exploring in more detail. Similarly, the petre project results also suggested that the varying national political, economic, institutional and cultural contexts across the EU-27 make introducing an ETR politically complex. Again, this suggested the need for additional analysis of ETR's social impacts to ensure that promising ideas can be translated into working policies.

In view of these findings, the EEA decided to commission a two-part study to analyse the issues in more detail. The first part focuses on links between ETR and eco-innovation and green technologies. The second addresses ETR's implications for the distribution of incomes across society.

Both of these issues are, of course, essential determinants of an ETR's potential contribution to sustainable growth and the shift to a green economy. Eco-innovation is an indispensible element in enhancing resource efficiency, i.e. delivering greater economic outputs and wellbeing at lower environmental impacts. Meanwhile distributional

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(2) See for more information with regard to the modelling framework the papers presented and to be downloaded at the website of the project (www.petre.org.uk) or Ekins and Speck (2011) and in particular Chapter 8 thereof.

impacts are central to an ETR's political acceptability and social equity — another essential aspect of sustainability. Any serious attempts to design ETRs must therefore include a focus on eco-innovation and distributional impacts. The present two-part study aims to contribute to the knowledge base for that analysis.

1.2 ETR and innovation

Innovation is a key determinant of domestic and international competitiveness and a vital engine for generating economic growth and highly skilled jobs. It also plays a central role in facilitating the shift to a green economy: enabling countries to decouple economic growth from resource use and environmental impacts.

Innovation's contribution to solving urgent economic and social problems is being discussed more now than ever before in Europe. This growing interest partly reflects a concern that some European countries may be falling behind other industrialised nations, both in developing and applying new solutions; in introducing modern management, production and working practices; and in opening up global markets. Only with greater ability to innovate, coupled with competence and willingness to be creative, can structural economic change be catalysed, enabling faster growth and creating new jobs.

The interest in innovation also reflects a recognition that even the most urgent of today's environmental problems are far from being solved. Innovation that specifically addresses environmental problems is needed to ensure long-term sustainable development. Basic innovation should be stimulated, opening up more environmentally sound development paths for products and technologies.

Of course, research must focus not only on technology but on the necessary framework conditions to bring about environmental innovation. Policy of all sorts — not least environmental policy — can promote or restrict innovation. It is perhaps surprising, therefore, that there has been limited focus on the interplay between environmental policy and innovation theory.

In view of its huge importance, there is clear value in analysing how policy instruments affect innovation.

1.3 Report structure

The present report brings together two approaches to examining eco-innovation.

Chapter 2 comprises a **literature review**. It looks briefly at definitions of innovation and the factors driving innovation in the economy, and describes the methodology used to identify relevant literature. It then provides a more detailed review of four groups of studies:

- assessments environmental regulation's impacts on innovation;
- theoretical analyses of how different policy instruments influence innovation;
- empirical studies using statistical and econometric techniques to assess the impacts of 'actual' policy interventions;
- case studies providing descriptive assessments of actual experiences.

Chapter 3 presents a modelling exercise, based on **scenarios in which ETR revenues are used to foster innovation**. The modelling builds on the petre project, evaluating the overall effects of a European ETR compared to a baseline development and goes on to examine scenarios to support eco-innovation or renewable energy technologies.

2 Review of literature on environmental tax reform and eco-innovation

There is a relatively large and growing literature — both theoretical and empirical — on the relationship between environmental policy interventions and technological innovation. While this covers a wide range of policy instruments (i.e. command and control regulations, environmental taxes, permit trading schemes and voluntary agreements), only one of the identified references explicitly considers the impacts of an environmental tax reform (ETR) programme. Consequently, the present literature review focused on studies that assess the impacts of environmental taxes (and in some cases, factor prices) on innovation. However, in order to provide some context, the impacts of environmental regulation more generally were also considered.

The literature review employed a two-step methodology. In the first step, potential references were identified and screened to determine their relevance and to classify them according to four relevant criteria. In the second step, those references identified as having significant relevance were reviewed in detail to distil the key conclusions regarding ETR's potential implications for eco-innovation.

Before proceeding, it is worth clarifying what is meant by innovation in general and by eco-innovation in particular. Following Schumpeter (1942), the process of technological change is typically broken down into the following three stages (3):

- **invention** — the first development of a scientifically or technically new product or process;
- **innovation** — the commercialisation of the new product or process;
- **diffusion** — the adoption of the product or process by firms and individuals.

The first two stages are closely related, although not all inventions will make it through to commercialisation. They typically both occur in private companies in a process that can broadly be termed research and development (R&D).

When considering the impacts of environmental policy interventions it is important to be clear which stage of the technological development process one is considering as different instruments may be more or less effective for different stages. Many studies explicitly identify the technological development stage to which they relate. For those that do not, it is sometimes possible to infer the stage from the context or characteristics of the study (e.g. the measure of innovation that is used). However, some studies refer only to 'investment in technology' and it is not clear whether this means investing in the development of new products or production processes (i.e. invention and innovation), or purchasing new plant and equipment from other companies (i.e. diffusion).

The term '**eco-innovation**' is taken to mean technological development that generates products, equipment or production processes that reduce environmental risk or minimise pollution and resource use. As such, the term encompasses all three stages of the technological development process: invention, innovation and diffusion.

A range of different indicators can be used to measure innovation. Essentially these indicators fall into three groups: those that measure the **inputs** (or resources) devoted to the innovation process; those that measure the **outputs** from the process; and those that focus on the economic **impacts** of the innovations that are generated (Johnstone et al., 2008).

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(3) Some authors break down the innovation stage into two: the application of inventions in demonstration projects; the development of niche applications and markets (e.g. Christiansen and Skjaerseth, 2005).

The most common input indicator is **R&D expenditure** but it has several shortcomings. While public sector R&D expenditure data is generally available, private sector data are incomplete and usually only available at the aggregate level, making it difficult (or impossible) to identify environment-related R&D expenditure. Furthermore, given the inherent uncertainty of the innovation process, the link between effort and resulting outputs is often very weak.

As a result, output indicators such as **patent applications** are likely to provide a better method to measure eco-innovation. Patent application data provide a reasonably comprehensive picture of innovative outputs (4), they are based on objective standards that change slowly and they are readily available. Their main advantage however is the fact that patent applications are classified into detailed technologies using the International Patent Classification (IPC) system developed by the World Intellectual Property Organisation. This allows environment-related patents to be identified and broken down between different application areas, such as climate change, air pollution, water pollution and waste management.

Impact indicators (also termed 'progress indicators') are more relevant to the diffusion stage and include **increases in market penetration** of particular eco-technologies and **reductions in (marginal) abatement costs** (5). However, it should be noted that cost reductions can be driven by a range of factors and may not necessarily imply that innovation has occurred.

2.1 Initial screening

Potential references were identified based on a review of journal citations, internet searches using keywords and recommendations from within the project team. The references fall into three broad groups:

- refereed journal articles;
- books and book chapters;
- reports by consultants and experts.

In total, 37 potential references were identified, the majority (28) being refereed journal articles. The references were then classified according to four criteria: type of study; policy instrument(s) covered; policy area; and technological development stage. On the basis of this classification, each reference was then assessed in terms of its relevance.

Types of study

A distinction is made between five different types of study:

- **Theoretical studies** use mathematical models to assess the impacts of 'idealised' policy instruments on firms' innovative behaviour under alternative assumptions about market structure and different parameter values. In most cases, the studies consider several alternative instruments and are interested in the relative ranking of the instruments, either in terms of the amount of innovation that they induce or in terms of the resulting levels of social welfare.
- **Empirical studies** use a range of statistical and econometric techniques to analyse quantitative performance data in order to assess the impacts of 'actual' policy interventions. Given the relative scarcity of environmental taxes in the past, there are few direct empirical studies focusing on them. However, a number of studies consider the impacts of changes in energy prices, which give an indirect indication of the potential impact of taxation.
- **Reviews** summarise or compare the findings of previous studies (either theoretical or empirical) and may synthesise them to draw wider conclusions.
- **Case studies** provide descriptive assessments of actual experiences, often comparing across countries.
- **Qualitative studies** consider some of the issues that can affect the performance of a particular policy instrument in practice.

Together, these last two types of study can provide valuable insights on the practical and 'political economy' aspects of instrument performance to supplement the theoretical and empirical analyses.

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(4) While a patent may prevent rival firms from using an innovation (without paying royalties), it has the disadvantage of putting it into the public domain. In some cases, firms may prefer to keep the innovation secret rather than apply for patent protection.

(5) More precisely, the indicator of abatement is a shift in the abatement cost curves, which reduces the cost of a fixed amount of abatement. Reductions in abatement costs due to movements along the cost curve (i.e. due to changes in the level of abatement) do not provide an indicator of innovation.

Policy instrument addressed

The second classification criterion concerns the policy instruments that are addressed by the study, with a distinction being made between five specific instrument types.

The first three are market-based, or price-based, instruments: **environmental taxes and charges, tradable permits and investment subsidies and tax allowances**. All three act by changing the prices of input factors in one way or another. As has been noted above, some studies consider the impact of energy prices rather than energy taxes. However, since the findings of these studies are directly transferable, they are classified under the tax heading.

The fourth instrument type is **voluntary or negotiated agreements**, under which firms or sectors enter into agreements with government to achieve certain performance targets or undertake specific actions.

The fifth type is **command and control regulations**, which encompass technology mandates, emission limits and performance standards (e.g. for specific energy consumption).

The final classification, **regulation**, is used for studies that consider the weight or stringency of environmental regulation in general, rather than a specific policy instrument.

Policy area addressed

With regard to the policy area(s) covered by the studies, a distinction is made between five areas, including **energy and climate change, air pollution, water pollution** and **other**.

The final classification, **general**, is used for studies that consider the impacts of environmental regulation in general rather than any specific intervention or where the policy area is not specified (e.g. in theoretical analyses).

Stage of technological development

The final classification criterion concerns the stage of the technological development process that is addressed by the study. As has been noted above, the process is typically divided into three stages: invention, innovation and diffusion. In practice, however, the studies do not distinguish between the first two stages (often just referring generically to R&D). They have therefore been combined for the purposes of the classification, so that the only distinction is between the innovation and diffusion stages.

Results of the classification exercise

Subsequent to classifying the studies, each was scored in terms of its relevance to analysing ETR's impacts on eco-innovation. A three tier qualitative scoring system was used. One star (*) indicates that the study is of only minor relevance, two stars (**) indicates that it is of moderate relevance and three stars (***) that it is of significant relevance. Such a scoring system is inevitably subjective but it provides a pragmatic mechanism for identifying the key references to be included in the detailed review. In determining the scores, particular emphasis was placed on whether the study is empirical in nature and whether it considers environmental taxes (or factor prices).

Annex 1 shows the classifications of the 28 journal articles that were identified. Thirteen are empirical, seven are theoretical, three are case studies and four are qualitative, while four provide reviews of previous work in the area (including most of the identified studies) (6). Around two-thirds of the papers consider the impact of environmental taxes (or energy prices), often comparing these with the impacts of other policy instruments. Eleven consider the impact of investment subsidies.

Most of the theoretical analyses are not area-specific (only discussing environmental damage in general terms). The empirical studies are spread fairly evenly across policy areas, with five addressing

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(6) Some studies are classified under more than one heading. For example, a study may contain both a theoretical model of behaviour and an empirical assessment of the model.

energy and climate change, five addressing air pollution and three addressing water pollution. In terms of the stage of the technological development process, there is an even split between innovation and diffusion, with many of the papers covering both stages. In total, eighteen of the references are included in the detailed review.

Annex 2 shows the classifications of the five book chapters and Annex 3 covers the four reports (7). As might be expected, these sources put less emphasis on theory, with only one reference including any formal analysis. They are split fairly evenly between empirical studies, reviews and qualitative assessments. All but one consider the impact of environmental taxes or energy prices, while seven consider the impact of investment subsidies. As with the journal articles, there is a fairly even spread across policy areas and between innovation and diffusion. Five of the references are included in the detailed review.

2.2 Detailed review

The detailed review focuses on the impacts on eco-innovation of the two 'price-based' policy instruments that are directly relevant to ETR: environmental taxes; and investment subsidies and tax incentives (e.g. R&D and capital allowances) (8). A priori, each instrument might be expected to stimulate innovation — the first by increasing the benefits of innovation by reducing tax payments, the second by reducing the costs of developing and adopting new technologies. However, in order to provide a broader context for the impacts of these two instruments, the review starts by considering the relationship between innovation and the stringency of environmental regulation in general.

As can be seen from the initial screening (see Annexes 1–3), the large majority of studies consider more than one policy instrument within a unified analytical framework — either comparing their relative impacts, or assessing the impacts of instrument combinations (or packages). In particular, all but one of the papers that assess the impacts of investment subsidies, either theoretically or empirically, also assess the impacts environmental taxes (and sometimes other policy instruments). Consequently, for the purposes of this review, it is convenient to consider the impacts of taxes and subsidies at the same time, rather than sequentially. In addition to avoiding the need for any repetition (about model structures, assumptions, etc.), this facilitates identification of potential interactions and synergies between the two instruments.

Apart from Section 2.3 on the impact of environmental regulation in general, only those references identified as being of significant relevance (***) in the initial screening are included in the review. References are summarised in chronological order under three headings: theoretical predictions (Section 2.4); empirical evidence (Section 2.5); and case studies (Section 2.6). At the end of each section, an attempt is made to synthesise the findings of the studies but the scope of the present review did not allow for critical analysis of the studies to identify their respective strengths and weaknesses, or to resolve any apparent conflicts between their findings.

2.3 Environmental regulation studies

Lanjouw and Mody (1996) use aggregate pollution and control expenditure (PACE) data as a proxy for the stringency of environmental regulation and compare this with data on the aggregate number of environmental patent applications for Germany, Japan and USA. They do not perform any formal statistical or econometric analysis of the data. However, based on simple graphical analysis, they identify a relatively clear correlation between expenditure and patents over the 1970s and 1980s, with a time lag of one to two years. They also find some indications in the data that patenting in one country also responds to increasing stringency of environmental regulation in the other two. In addition, they consider the diffusion of environmental technologies by looking at trade

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(7) Two of the reports emanate from the study by Ecologic and DIW of ETR in Germany. Details of the assessment of the impact on innovation and market diffusion are provided (in German) in Görlach et al. (2005), with a summary (in English) in Knigge and Görlach (2005).

(8) While the large majority of revenues raised under an ETR are likely to be used to reduce taxes on labour, a small proportion may be used to encourage innovation or promote the take-up of environmentally friendly technologies.

flows in capital goods used for pollution reduction and find that these too show a correlation with total abatement expenditure.

Jaffe and Palmer (1997) also use PACE data as a proxy for the stringency of environmental regulation and evaluate its impact on two different measures of innovation: total private expenditures on R&D and the number of successful patent applications by US manufacturing industries. Unlike the previous study, they undertake formal econometric analysis of the data, using panel data at the two-digit and three-digit SIC code industry level for the period 1978–1991 and a fixed effects model. They find a statistically significant positive relationship between compliance expenditures (capital expenditures only) and R&D expenditures after controlling for industry-specific effects (9). However, they can find no significant impact on patenting activity. This is not entirely surprising given the fact that their data is for all types of patents, not just those relating to environmental technologies and products. Indeed, given that the same is true for the R&D expenditure data, it may be more surprising that they find a significant relationship between pollution compliance and R&D.

Brunnermeier and Cohen (2003) also use a panel data model to assess the impact of pollution abatement expenditures on patenting activity by US manufacturing industries. However, unlike the previous study, they use only environmental patent applications in their analysis. They also control for other potential explanatory factors, such as the stringency of monitoring and enforcement (as measured by number of inspection visits); industry size (value of shipments); market structure (four-firm concentration ratio); capital intensity; and exposure to overseas competition (export intensity). They estimate four different models for the period 1983–1992, with their preferred model being a negative binomial random effects model. The coefficient for PACE is positive and statistically significant (in all four models), as are the coefficients (in the preferred model) for industry size, concentration and export intensity. However, the magnitude of the coefficient (which represents the semi-elasticity of patents with respect to PACE) is only 0.0004. Thus, ceteris paribus, an increase in abatement expenditure of USD 100 million results in an increase in the mean number of patents of only 4 %.

Key findings of the environmental regulation studies

All three environmental regulation studies use PACE data as a proxy for the stringency of environmental regulation (10). While there are obvious pragmatic reasons for doing this (i.e. availability of data), the validity of the approach may be open to question. As **Brunnermeier and Cohen** (2003) note, expenditure may be affected by factors other than environmental regulation, such as external pressures from interest groups, or a desire to promote or maintain 'green credentials' with customers. Furthermore, the reported data may not cover all pollution abatement costs and activities (particularly process-related activities) and may be prone to over-statement by reporting firms for strategic reasons. However, to the extent that the reported PACE data is correlated with the stringency of environmental regulation, the analyses suggest that the latter does have an impact on innovation (at least in USA), although the scale of the impact appears to be small.

2.4 Theoretical studies

Although several previous studies has analysed the impact of different environmental policy instruments on technological change, **Milliman and Prince** (1989) were the first to consider the entire process of technological change, encompassing innovation, diffusion and optimal agency response (11). Using a relatively simple graphical analysis of shifting marginal abatement cost curves, they deduce a relative ranking of five instruments (direct controls, auctioned permits, freely allocated permits, emission reduction subsidies (12) and emission taxes) in terms of firms' incentives to promote technological change. They conclude that emission taxes provide greater incentives for innovation and diffusion than direct controls or

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(9) When they allow the slopes of the PACE variable to vary across industries (in addition to the intercept), they find considerable variation in the estimated coefficients across industries, with several being negative.

(10) However, the studies do not all use the same definition of PACE. Lanjouw and Mody (1996) include (real) investment expenditures, regulation and monitoring costs, and research and development by all levels of government, private manufacturing and non-manufacturing firms. The other two studies both use compliance cost data for private manufacturing firms (at the industry level) only. However, while Jaffe and Palmer (1997) use capital cost data in their analysis, Brunnermeier and Cohen (2003) use operating cost data.

(11) Milliman and Prince (1989) identify a number of studies going back to 1970.

(12) These are payments for emission reductions, not technology subsidies for environmental investments.

freely allocated tradable permits, although not as great as auctioned permits. However, the optimal agency response is likely to face less opposition (and in some cases actually be favoured) under emission taxes than under auctioned permits (13).

Jaffe and Stavins (1995) develop a theoretical framework for comparing empirically the impacts of alternative policy instruments on the diffusion of a new technology (14). They model the investment decision for both an existing firm and a new entrant, in each case assuming that over time the firm minimises the present value of its cost streams (operating costs, investment cost net of any government subsidy, emission taxes, and the implicit costs of violating either a performance or technology standard, if applicable). For an existing firm, the problem is to choose the optimal timing of the retrofit and the authors show that the new technology will be adopted at a particular time if operating cost savings plus savings from reduced emission tax payments (plus any avoided penalties for not adopting a technology standard or exceeding a performance standard) in that period are greater than the net investment costs less the time rate of change of net investment costs. For a new entrant, the problem is to choose whether to use the new technology at start-up. A necessary condition for doing so is that the present value of operating costs savings and reduced tax payments (plus any avoided penalties) over the entire time horizon is greater than the net investment cost. Thus, while the conditions differ, in each case the introduction of either an emissions tax or an investment subsidy (or increases in the respective values) changes the benefit-cost balance in favour of the new technology, bringing forward its adoption by existing firms and increasing the likelihood of adoption by new entrants.

Kemp (1997) compares the abatement R&D expenditure levels of an individual firm under direct regulation (i.e. an emissions limit); an equivalent emission tax (15) and freely allocated tradable permits, using a cost minimisation analytical framework and a specific functional form for the abatement cost function. He shows that both the level of R&D expenditure and the level of emissions reduction increase as the emissions tax rate increases and that both are greater under the tax than under direct regulation. The corresponding levels under the tradable permit regime will be greater under the emissions tax if the (exogenous) permit price is higher than the tax rate, and vice versa. Kemp also considers the impact of subsidising the cost of the firm's R&D effort and shows that increasing the subsidy rate causes a rise in pollution-control R&D. More interestingly, the impact of the subsidy is greater if it is combined with an emissions tax than with an equivalent emissions limit.

Fischer et al. (2003) develop the approach used by Milliman and Prince (1989), although their analysis differs in that it does not include the final agency response stage and the diffusion of the technology is determined by market forces with an equilibrium royalty price (16). They compare an emissions tax with auctioned and freely allocated permits using a three-stage model of innovation, diffusion and emissions abatement. In the first stage, the innovating firm decides how much to invest in R&D to develop an emissions abatement technology. In the second stage, other firms decide whether to adopt this technology in return for a royalty fee, or whether to use an (imperfect) imitation technology. In the final stage, all firms choose their level of abatement to minimise costs given an emissions tax or permit price. They show that the level of innovation (i.e. the level of R&D chosen by the innovating firm) is determined by equating the marginal cost of innovation with the marginal (private) benefit. The latter has four components — an abatement cost effect, an emissions payment effect, an imitation effect and an adoption price effect — and the last two components are negative (17). Using this model, the authors demonstrate that freely allocated permits provide the lowest incentive for innovation. However, in contrast to Milliman and Prince, they conclude that the relative ranking of the emissions tax and auctioned permits is ambiguous. It depends crucially on the extent to which the technology can be imitated and hence, the extent to which the innovator can appropriate the gains accruing to

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(13) For an emissions tax, the downward shift of the industry marginal abatement cost curve as a result of diffusion causes the agency to reduce the tax rate, assuming that marginal damages are increasing in emissions. For permits (auctioned or freely allocated) it causes the agency to reduce the number of permits.

(14) The empirical application of this framework is summarised below under Section 2.5 on empirical evidence.

(15) That is, the emissions tax is set equal to the firm's marginal cost of abatement under the direct regulation.

(16) In addition to assessing the impacts on demand for innovation, Fischer et al. (1998) consider the impacts of the innovation and diffusion processes on social welfare in order to compare the overall economic efficiency of the different instruments.

(17) Milliman and Prince capture only the first two effects in their analysis.

the other firms in the form of royalty payments. If imitation is high (easy), then auctioned permits provide the greater incentive for innovation. However, if imitation is low (difficult), then the emissions tax provides the greatest incentive.

Montero (2002) assesses the impacts of alternative policy instruments on environmental innovation (as measured by R&D expenditure) under conditions of imperfect competition. In his model, two firms compete in either quantities (i.e. Cournot duopoly) or prices (i.e. Bertrand duopoly), while being subject to some form of environmental regulation. Where the regulation takes the form of tradable permits — either auctioned or freely allocated — the market is also assumed to be imperfect, the firms competing in permit quantities. The interaction between the two firms is modelled as a multi-stage game, with the number of stages depending on the instrument being analysed. In this framework, a firm's incentive to invest in R&D comprises two components: a direct or cost minimising effect; and a strategic effect, reflecting the impact of its R&D expenditure on the other firm's output decision. The latter may be positive or negative depending on the market-regulatory structure. Under Bertrand competition (i.e. where products are strategic complements), freely allocated permits provide the lowest incentive for innovation, followed by the emission-standard. The relative ranking of an emissions tax and auctioned permits is ambiguous, depending on model parameter values. Under Cournot competition (i.e. where products are strategic substitutes), the relative ranking of the emissions tax, auctioned permits and the emissions-standard are ambiguous, although all provide a greater incentive than freely allocated permits. Indeed, Montero provides a numerical example where the emissions standard provides the greatest incentive for innovation. Finally, he considers the impact of increasing competition (increasing the number of firms) and concludes that under perfect competition the emissions tax provides the greatest incentive for innovation.

Millock and Nauges (2006) use a simple profit-optimisation model to analyse a firm's choice of abatement effort to reduce emissions per unit of energy used in production. While they do not explicitly identify it as such, this effort can be interpreted in terms of diffusion of an existing technology — with higher effort corresponding to greater diffusion. This is consistent with the overall objective of their study, which is to assess the impact of combining an emissions tax with a subsidy on (existing) abatement equipment (18). In their model, the firm simultaneously chooses the levels of its energy input and abatement effort, given exogenous output and energy prices, and a cost function for abatement effort (19). They show that while increases in the subsidy rate (expressed as a percentage of the gross investment cost) unambiguously increases abatement effort, the impact of increases in the tax rate depends on whether the direct impact of tax increase on the marginal benefit of abatement effort (shifting it up) outweighs the indirect impact via the resulting reduction in output (shifting it down). If the latter dominates, then increases in the tax rate will reduce the optimal level of abatement effort. The authors show that a necessary and sufficient condition for the direct impact to dominate is that the slope of the firm's (inverse) demand for energy is greater than the average emissions tax payment per unit of energy in relation to total energy use (20).

McGinty and de Vries (2009) analyse the relationship between environmental subsidies, the diffusion of a clean technology and the degree of product differentiation in an imperfectly competitive output market. In their model, a fixed number of firms can choose individually between using a 'clean' production technology and a 'dirty' technology. Both technologies exhibit constant marginal production costs and constant emission rates (with the clean technology having a lower emission rate and higher unit cost) and consumers are assumed to be able to differentiate between products on the basis of the technology used in their production (21). The subsidy regime is different to that considered by the other studies, in that it is applied to the production cost of the clean good and thus reduces the (constant) marginal cost of production for that good. As such, it is equivalent to an output subsidy for the clean good. The authors derive the equilibrium diffusion rate for the clean technology (i.e. the proportion of firms using

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(18) In the second half of their paper, Millock and Nauges (2006) undertake an empirical evaluation of such a scheme that operated in France during the 1990s for SO_2 and NO_X emissions. The results of this analysis are summarised under Section 2.5 on empirical evidence.

(19) Abatement effort is assumed to exhibit decreasing returns to scale, i.e. the cost function is increasing and convex.

(20) If output is held fixed in the profit maximisation problem then increases in the emissions tax rate unambiguously increase the optimal level of abatement effort, as found by Kemp (1997) who uses a cost-minimisation framework for his analysis.

(21) The model assumes imperfect substitution between the 'clean good' and 'dirty good', with the willingness-to-pay for one good being a linear function of the quantities of both goods individually – i.e. $Pk = ak - bYk - cYj$.

that technology) and show that an increase in the subsidy value increases diffusion for all degrees of product differentiation. The impact is greater as the substitutability of the two goods increases. They also briefly consider the impact of a technology subsidy that reduces the fixed cost of the clean technology and conclude that this too will stimulate diffusion but will be less efficient than the output subsidy ([22]).

Key findings of the theoretical studies

As is often the case with theoretical analyses, the specifications of the models and the underlying assumptions of the studies reviewed here significantly influence the conclusions. Nevertheless, there is a reasonable degree of consistency between their findings. The studies can be classified into two broad groups: those that consider innovation and diffusion within an industry setting; and those that consider an individual firm's decision whether to undertake R&D (i.e. innovation) and invest in an abatement technology (i.e. diffusion) in order to reduce its own cost of abatement.

The studies in the first group conclude that under conditions of perfect competition, emission taxes and auctioned permits provide greater incentives for innovation than direct controls or freely allocated permits. However, there is some disagreement over the relative impacts of the two instruments. Under the assumption that the innovator appropriates a fixed (exogenous) proportion of the gains accruing to the technology adopters, **Milliman and Prince** (1989) conclude that auctioned permits provide the greatest incentive, although the government may find it easier to adjust emission taxes in response to the resultant downward shift in marginal abatement costs. However, when the proportion is determined endogenously — in the form of a royalty payment — **Fischer et al.** (2003) find that either auctioned permits or emission taxes can provide the greater incentive. Emission taxes are likely to provide the greatest incentive if the innovator can appropriate a large proportion of the gains (because the technology is difficult to imitate).

Montero (2002) uses a slightly different framework to compare the impacts of different instruments on innovation (in the form of R&D expenditure) in a situation of imperfect competition and finds that the ranking depends on the nature of the competition ([23]). Under Bertrand price competition in the output market the results are the same as under perfect competition: the relative ranking of auctioned permits and taxes is ambiguous but both provide greater incentives for innovation than emission standards and freely allocated permits. However, under Cournot quantity competition, any of the instruments apart from freely allocated permits can provide the greatest incentives, depending on the model parameter values.

The studies looking at an individual firm's decision also show that an emissions tax can stimulate innovation and diffusion. **Jaffe and Stavins** (1995) explicitly consider the firm's decision criterion for investing in a new abatement technology and show that by increasing the benefits of investing the introduction of an emissions tax should bring forward its adoption by existing firms and make its use by new entrants more likely. The other two studies consider the firm's choice of optimal 'abatement effort' in the context of maximising its total profits or minimising its total cost of emissions reduction. This effort can take the form of R&D (innovation) or expenditure on abatement equipment (diffusion). The decision problem is the same in each case, i.e. to choose the optimal level of effort.

Kemp (1997) assumes that the firm seeks to minimise its total cost of emissions reduction — implicitly assuming that its output level is fixed — and demonstrates both that abatement effort increases as the emissions tax increases and that the optimal effort is lower under direct regulation than under an equivalent tax. However, when the firm's output level is allowed to vary — as is the case with the profit maximisation problem considered by **Millock and Nauges** (2006) — the impact of an increase in the emissions tax rate on the level of abatement effort depends on the relative magnitudes of the direct impact and the indirect impact (via changes in output levels) on the marginal benefit of abatement effort. If the latter dominates, then an increase in the emissions tax rate leads to a reduction in the optimal level of abatement effort.

([22]) McGinty and de Vries (2009) derive expressions for the necessary technology subsidy values when diffusion is 0 % and when it is 100 %. They state — without proof — that the latter is greater than the former. Provided that the relationship between the subsidy and diffusion is monotonic, this is a sufficient condition for increases in the subsidy value to cause increases in diffusion.

([23]) Montero's model does not include diffusion. However, it does include spillover effects, where R&D by one firm reduces the abatement costs of the others.

Only one of the industry models considers the impact of investment subsidies. Using a product differentiation model of imperfect competition, **McGinty and de Vries** (2009) show that subsidising the unit cost of a clean production technology can accelerate its diffusion. However, the impact depends on the degree of substitutability between clean and dirty products, diminishing as the products become more differentiated. In contrast, all three of the individual firm analyses consider the impact of investment subsidies, with all demonstrating that increasing subsidies induce greater abatement effort. Furthermore, **Kemp** (1997) shows that the impact of an R&D subsidy is greater in the presence of an emissions tax than it is under an equivalent emissions limit.

2.5 Empirical studies

Jaffe and Stavins (1995) use their theoretical framework (outlined above in Section 2.4) as the basis for assessing the diffusion of thermal insulation in new home construction in the United States, using state-level panel data for the years 1979–88. They derive a reduced form equation for the energy efficiency level chosen by developers from the marginal cost-benefit condition, in which the explanatory variables include energy prices, installation costs and the presence of a relevant building code (as a dummy variable). Separate equations are estimated for ceiling, floor and wall insulation, with the coefficient for energy prices being positive in all three equations. Although it is only significant (at the 95 % level) for floor insulation, the joint hypothesis that all price coefficients are zero is strongly rejected. However, the coefficients for installation cost (which are all negative, as expected) are around two to three times greater in magnitude and of comparable significance. The coefficients for the building code dummies are consistently insignificant (and negative in two cases), indicating that this form of direct regulation had minimal impact on household energy efficiency levels over the period. The authors use the estimated models in a simulation to compare the effects of a 10 % increase in energy prices (i.e. an energy tax) with those of a 10 % reduction in installation costs (i.e. a technology subsidy), with each applied over the whole ten-year period. While the tax increases diffusion by 2–6 % by the end of the period, the technology subsidy increases diffusion by between 4–15 %.

Kemp (1997) models the diffusion of biological water treatment technology in the Dutch food and beverage industry based on a rational choice threshold model of technology adoption decisions. In this model, a firm chooses to adopt an abatement technology if the resulting reduction in emission-tax payments is greater than the annualised total costs of the technology, where a discount factor is applied to the savings to reflect uncertainty and risk aversion on the part of the decision-maker. This is translated into a probabilistic model under the assumption that both the savings and the costs follow a log-normal distribution across plants. The model is estimated econometrically using data for the period 1974–91 under different assumptions for the functional form of the discount factor and allowing for adjustment costs (24). The estimated parameters for the preferred specification of the discount factor are all significant and of the expected sign and magnitude, and the model provides a very close fit to the actual diffusion of waste-water treatment technologies over the period. This leads the author to conclude that the effluent charges were a significant positive factor in the diffusion of treatment technologies. Indeed, he estimates that only around 4 % of plants would have installed waste-water treatment equipment by the end of the period if the charge had remained at its (low) 1974 level, compared to the actual figure of over 40 %.

Newell et al. (1999) estimate the impact of energy prices, energy efficiency standards and other factors on the energy efficiency of three types of electrical consumer durables (room air conditioners, central air conditioners and gas water heaters) in USA between the 1970s and 1990s. The analysis utilises a product characteristics model in which the frontier of technologically feasible products is described by a 'transformation surface' that relates the bundle of product characteristics to the real cost of producing that bundle. In this framework, innovation is represented by movements of the surface and movements along the surface. In particular, the authors identify three types of innovation: shifts in the surface towards the origin (overall technological change); changes in the slope

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(24) Adjustment costs are accounted for by estimating a partial adjustment model in which the actual change in adoption is some fixed fraction of the desired change (estimated from the threshold model).

of the surface (directional technological change); and changes in the mix of products along a given surface (model substitution). They define the surface in terms of two characteristics, energy flow and cooling capacity, and incorporate innovation by allowing the coefficients of the two variables to vary with time and (in the case of energy flow) energy prices and efficiency standards. Separate equations are estimated for each durable type with slightly differing sets of explanatory variables and time periods. The authors find little evidence that either energy prices or energy efficiency standards had any impact on overall technological change. While all but one of the relevant coefficients have the expected sign, none are significant. In contrast, they do find evidence that energy prices had an impact on directional technological change, with the relevant coefficients being of the correct sign and significant for both room and central air conditioners.

Popp (2002) uses patent data to estimate the effect of energy prices on energy-efficiency innovations in USA between 1970 and 1994. He regresses normalised energy-efficiency-related patent applications against energy prices, controlling also for lagged knowledge stock and government R&D (25). The estimated coefficient for energy prices is highly significant, producing a short-run price elasticity of 0.06 and a long-run elasticity 0.354. Thus, a 10 % increase in energy prices would be expected to increase the number of energy-efficiency-related patents by around 3.5 % in the long run. The estimated mean lag is less than four years, leading the author to conclude that the imposition of a carbon or energy tax would lead to a fairly quick shift towards environmentally friendly innovation.

Hoglund Isaksson (2005) estimates abatement cost functions for the reduction of nitrogen oxide (NO_X) emissions in three industrial sectors in Sweden (energy, pulp and paper, chemicals and food). The analysis uses a double-hurdle model applied to a pooled sample of 114 plants across the three sectors. The data cover the period 1990–1996, which spans the introduction of the charge on NO_X emissions in 1992. The estimated cost curves have a similar shape in all three sectors, with minimal (or even negative) costs over a relatively broad range of emission reductions and then a steep rise as reductions exceed a threshold level. The analysis does not explicitly consider the issue of innovation. However, it does find that abatement cost curves shifted downwards significantly over the period. In the energy sector for example, the emission rate threshold for significant cost increases fell by around 45 % between 1991 and 1996 (from 550 to 300 kg/GWh). The author surmises that this is due to a combination of technological development and the discovery of previously unrecognised opportunities. Unfortunately, while this shift coincided with the introduction of the NO_X charge, the analysis does not provide any evidence of a causal link.

As part of their analysis of the impacts of the French tax-subsidy scheme for NO_X and sulphur dioxide (SO_2) emissions, **Millock and Nauges** (2006) estimate the impact of the emission taxes on a plant's decision to install end-of pipe abatement equipment. While the study is not concerned with innovation per se, the results of this part can be interpreted as showing the impact of emission taxes on the diffusion of abatement equipment. Under the scheme, taxes were imposed on the emissions of these air pollutants (and VOCs) by all plants satisfying certain criteria. The revenue raised by the taxes was earmarked for subsidising the cost of qualifying abatement technologies, for technical studies (i.e. R&D) and for investment in air quality surveillance systems. Using panel data for 226 plants in three industries (iron and steel, coke and chemicals) for the period 1900–1998, the authors estimate a Probit model for the probability that a plant will install abatement equipment. They find that the total value of emissions taxes paid by the plant (i.e. for both pollutants) has a positive impact on its decision to invest in abatement equipment. However, the magnitude of the effect varies considerably across the sectors and is only significant for the iron and steel sector.

Frondel et al. (2008) analyse responses to an OECD survey on environmental policy tools (conducted in 2003) to identify the factors that affect a firm's decision to adopt an environmental management system (EMS) voluntarily and their environmental innovation behaviour. Innovation is captured by a binary variable that indicates whether the firm has 'undertaken significant technical measures or changes to reduce the environmental impacts of

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(25) Normalised energy efficiency patent values are calculated by dividing by the total number of patents granted. This accounts for exogenous changes in patenting behaviour that affect all types of patents. Popp constructs a value for existing knowledge as the stock of previously granted patents, weighted by estimates that he derives for knowledge productivity. He demonstrates that the exclusion of this variable from the model leads to biased estimates for the energy price coefficient.

production' (26). The analysis is based on survey responses from 899 firms in Germany. Latent variable equations for EMS adoption and innovation are estimated simultaneously, with each equation including the same four sets of variables, relating to motivations, policy instruments, pressure groups and facility characteristics (27). The policy instrument variables include five dummy variables indicating the importance of different types of policy instrument, including market-based instruments such as emission taxes and tradable permits. While the perceived stringency of environmental policy is found to be a significant factor in the decision to innovate, there is no evidence that any of the individual policy instrument variables had any impact. The authors surmise that this suggests that it is stringency of environmental policy, rather than the choice of specific instrument, that is important for innovation. However, as the authors note, their results reflect the perceptions of the survey respondents and should therefore be treated as correlations rather than causal relationships.

Johnstone and Hascic (2008) assess the impact of a range of environmental policy instruments — including tax measures and investment incentives — on innovation in the renewable energy field. They analyse the impacts for five different groups of renewable energy technologies — wind, solar, ocean, biomass and waste-to-energy — using a panel dataset of European Patent Office (EPO) patent filings for these technologies across 26 countries over the period 1978–2003. A fixed effects negative binomial model is estimated, controlling for electricity prices and consumption, public sector R&D expenditure (as a proxy for scientific capacity) and total EPO filings (as a proxy for differences/changes in patenting propensity). The various policy instruments are represented by dummy variables indicating whether they were in place in a particular year. As such, the model takes no account of the stringency of the instruments — in particular the differing magnitudes of the tax measures and investment incentives (28). Initially, the authors estimate the model with all of the policy instruments included individually. They find that while public policy plays an important role in inducing innovation, the impacts of the individual instruments vary across the different technologies. In particular, tax measures are significant for wind and biomass technologies, with investment incentives being significant for solar and waste-to-energy technologies, and obligations/tradable certificates being significant for wind technologies. However, the authors express concerns that there may be multicolinearity between the policy variables (particularly between investment incentives, tax measures and tariffs) and also that there may be interaction effects between some of the variables. Consequently, they estimate two alternative versions of the model, the first using a composite policy variable representing the number of policy instruments in place and the second using clusters of 'similar' policy instruments (29). The results or these two models confirm the initial findings. The composite policy variable is significant for all of the technology groups, while the significance of the clusters varies across technologies. The price-based cluster is (highly) significant for solar, biomass and waste-to-energy. The quantity-based cluster is significant for wind technologies. The authors surmise that this may be due to the different economic characteristics of the technologies. For example, the significance of investment incentives for solar and waste-to-energy may reflect the capital intensity of these technologies with large up-front investment costs.

De Vries and Medhi (2008) also use patent data to investigate the relative importance of environmental regulations and fuel prices on innovation in automotive emission-control technologies, distinguishing between post-combustion devices and engine redesign technologies. They estimate a panel data model using data from Germany, Japan and USA over the period 1978–2001, controlling for industry value added (as a proxy for the scope of technological opportunities), and total patent

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(26) The next question on the survey asks whether these are changes in production processes or end-of-pipe technologies. However, no distinction is made between these two types of innovation in the present study.

(27) In order to avoid identification problems, some individual variables are omitted from one equation or the other.

(28) This shortcoming is recognised by the authors, who state that it is unavoidable in any cross-comparative analysis in which multiple instruments are included.

(29) The clusters are price-based instruments (investment incentives, tax measures and tariffs), quantity-based instruments (obligations and tradable certificates) and voluntary programmes.

applications (as a proxy for differences/changes in patenting propensity). Environmental regulation is represented by two dummy variables indicating the introduction of on-board diagnostic (OBD) regulations in USA (30). The results of the analysis suggest that the relative impacts of regulation and market forces differ between the two types of technology. For post-combustion technologies, both of the regulations are significant, while fuel prices have no significant impact. In contrast, the opposite is the case for engine redesign technologies, with fuel prices having a significant impact but regulation having no discernable effect. While the analysis does not explicitly consider the impact of fuel taxes, it suggests that an increase in automotive fuel taxes would have a major impact on innovation in relation to engine design. The estimated coefficient for fuel prices (1.287) implies that a USD 0.10 increase in fuel prices would induce a 14 % increase in patenting activity (31).

Key findings of the empirical studies

The empirical studies considered above cover a range of different technology areas, spanning energy efficiency (both product and process), renewable energy, and air and water pollution abatement. While in some cases they assess the impact of energy prices rather than environmental taxes per se, they provide a clear picture of the likely impact of environmental and energy-related taxes on eco-innovation.

Three of the studies assess the impact on diffusion of existing technologies. All find that environmental taxes/energy prices have a positive impact on diffusion. In particular, the water effluent charges in The Netherlands appear to have had a major impact on the adoption of waste-water treatment equipment by the food and beverage industry in that country. However, there is some evidence to suggest that the effectiveness of taxes/prices may vary across sectors (e.g. NO_X/SO_2 abatement in France) and that investment incentives/subsidies may be more effective in some cases (e.g. thermal insulation in USA).

Three of the studies use patent data to assess the impact of environmental taxes and energy prices on innovation, with one of these also assessing the impact of investment incentives. All find a significant positive impact, although this depends on the particular sub-sector (e.g. renewable energy) or the type of innovation. In particular, the evidence from the automotive emissions control study suggests that taxes/prices may be more effective in promoting process-related innovation (e.g. engine redesign) than innovation in end-of-pipe technologies. One of the studies takes a different approach, using a product-characteristics model to decompose improvements in the energy efficiency of consumer durables. This finds that while electricity prices did not appear to affect overall technological change (i.e. shifts in the product cost/energy efficiency frontier), they did have a positive impact on directional technological change (i.e. the slope of the frontier).

2.6 Case studies

Christiansen and Skjaerseth (2005) undertake a comparative analysis of the impacts of climate change policies on the petroleum sectors in Norway and the Netherlands during the 1990s. These countries were selected because of their very different policy approaches, with the Norwegian petroleum sector subject to a carbon dioxide (CO_2) tax since 1991 as part of a portfolio of measures (32), and the Netherlands relying on a series of voluntary agreements on energy efficiency (33). Both approaches appear to have been effective, in that CO_2 emissions per unit production fell by around 22 % between 1990 and 2001 in Norway, while energy efficiency improved by around 35 % in the Netherlands over the same period. However, there were marked differences between the two countries in terms of the nature of the innovation that

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(30) Because of the international nature of the automotive industry and the importance of the US market, regulations introduced in USA appear to have been an important driver for innovation by overseas manufacturers. Regulations mandating the installation of OBD systems were first introduced in California in 1988. A more sophisticated system was mandated by the 1990 US Clean Air Act Amendments, taking force in 1996.

(31) The coefficient represents the semi-elasticity of patent applications with respect to fuel prices. While the authors do not state so explicitly, the implication is that prices are expressed in US dollars (they are obtained from the IEA Energy Prices and Taxes Database). Consequently, the impact of a 10 US cent increase in the fuel prices is given by $\exp(1.287 \times 0.1) - 1 = 0.137$.

(32) In addition to the tax, the portfolio included publicly funded R&D support schemes, gas flaring permits and mandatory environmental impact assessments.

(33) The Dutch oil and gas industry first signed a declaration of intent with the government in 1995. This was translated into a long-term agreement (LTA) on energy efficiency in the following year, with an improvement target of 20 % over the period 1989–2000. In 2001, a new LTA was signed, which committed firms to implementing energy efficiency measures with a positive NPV at a 15 % discount rate or a five year payback period.

occurred. In the Netherlands, technological change was incremental, reflecting a steady diffusion of available (i.e. known) technology. In contrast, the authors find evidence of more radical innovations and adaptations by the Norwegian petroleum sector, including the development of energy-efficient gas turbines, installation of waste heat recovery units, process modifications and improved use of process heat. While the authors acknowledge the impossibility of proving a causal link between policy intervention and innovation (in the context of their case study), they conclude that the CO_2 tax played a key role in the development and implementation of these radical innovations and the benefits of reduced tax payments provided an important incentive. However, they also conclude that the impacts of the two instruments were conditioned by the political contexts in which they were applied and the problem characteristics in the respective countries (e.g. the economic significance of the sector and the size of installations).

Knigge and Görlach (2005) summarise the findings of a comprehensive analysis of the impacts of the ETR in Germany. That analysis, undertaken jointly by Ecologic and the German Institute for Economic Research (DIW Berlin), included the impacts on innovation and market diffusion of environmentally friendly products and technologies (34). Based on a series of case studies, the study concluded that the ETR had a 'noticeable effect' on innovation and diffusion, although it was not possible to quantify the scale of that effect. In particular, ETR is identified as being a central factor in the development of gas-powered vehicles. The study identifies a number of different routes by which the ETR produced impacts. First, the payback period for energy-efficient products was reduced as a result of the energy tax increases and the various exemptions favouring efficient energy use and renewable energy sources. Second, the predictable nature of the energy taxes (as opposed to widely fluctuating oil prices) reduced uncertainties about the benefits of energy-efficiency investments. Third, the reduction in employers' social contribution payments tended to reduce the costs of labour intensive innovation processes, such as research and development, energy consultancy and technology installation. Finally, the ETR had a signalling effect, strengthening awareness of the need for more efficient and rational energy use.

Mickwitz et al. (2007) examine a number of 'claims' that have been made in the environmental policy literature about the relationship between policy instruments and innovation, based on experiences in two industrial sectors in Finland: pulp and paper, and the manufacture of diesel engines for ships. In particular, they assess the claims that 'environmental taxes are superior to other policy instruments with respect to innovation' and that 'R&D subsidies have limited impacts on innovation'. With respect to the first claim, the evidence provided by the two case studies is mixed. The authors conclude that energy taxation had a negligible impact on innovation in the pulp and paper industry. However, this is likely to have been due to the low level of the tax and the exemptions that applied to the sector. In contrast, they find that the differentiation of Swedish fairway and port fees (on the basis of SO_2 and NO_X emissions) was a significant factor driving the installation of in-engine NO_X reduction equipment in ferries operating between the two countries (35). With respect to R&D subsidies, the authors conclude that the evidence does not support the claim that these have little effect. In particular, they find that R&D subsidies accelerated the development of ship engine emissions-reduction technologies.

The findings of the three case studies are consistent with those of the empirical analyses reviewed in the previous section. Environmental taxes and investment subsidies have proven significant in promoting both innovation and diffusion, although not universally so. Furthermore, the case studies provide some useful insights about the ways in which the impacts occur and the factors that may be important in promoting innovation. In particular, they suggest the need for a tax rate that is sufficiently high to provide a meaningful incentive and signalling effect, and that is fixed for a sufficiently long period of time to reduce uncertainty about the future benefits of investment.

2.7 Conclusions

The studies reviewed in the preceding sections suggest that environmental regulation in general, and price-based policy instruments such as environmental taxes and investment subsidies in particular, can (in theory) and do (in practice) have a positive impact on both innovation and diffusion

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(34) A separate report in German by Görlach et al. (2005) provides details of the evaluation of the innovation and diffusion impacts.

(35) Although the tax was introduced in Sweden, it was also payable by Finnish ferry operators entering Swedish ports and hence affected their investment decisions. This is another example of the cross-border impact of environmental policy interventions on innovation found by Lanjouw and Mody (1996) (see Section 2.3).

of environmental technologies. However, the supporting empirical and case study evidence is not universal and the effectiveness of these instruments would appear to vary across different sectors and different types of innovation.

To a certain extent, such differences can be explained by the theoretical models. In particular, the impact of environmental taxes (relative to other instruments) is predicted to depend on the competitive structures of the markets in which the regulated firms operate and on the ability of innovator firms to appropriate the benefits accruing to other firms during diffusion. However, a number of other potential factors have been identified in the literature which may affect the impact of price-based policy instruments on innovation.

Jaffe et al. (2002) caution that the impact of price-based policy instruments on technology diffusion may be adversely affected by a number of potential market failures, including information failures, principle-agent problems (e.g. landlord-tenant), capital market failures and positive adoption spillovers. In addition, while not market failures as such, uncertainty over future returns and the (associated) use of high discount rates for investment decisions can also undermine the effectiveness of price-based instruments in stimulating diffusion. However, as was noted above, the findings from the case study of ETR in Germany suggest that an environmental tax may actually reduce the level of uncertainty over future returns provided that it is of sufficient magnitude and longevity.

Skjaerseth and Christiansen (2005) emphasise that the relationship between policy instruments (of all types) and technological change is extremely complicated. They argue that account must be taken of the political/industrial context in which policy instruments are introduced, and the nature of the environmental problem that they are intended to address. In particular, they make a distinction between 'malign problems' where technological change involves net costs for target groups, and 'benign problems' where there are widespread 'no-regret' opportunities for change. Based on a comparative analysis of four different case studies, they conclude that mandatory policy instruments (including environmental taxes) are more effective in promoting short-term technological change when the problems are malign, but that low legitimacy (with the target group) may undermine long-term technological change. However, when problems are benign, or when long-term change requires cooperation, voluntary policy instruments are likely to be more effective.

Johnstone (2005) questions the focus of the theoretical and empirical analyses (reviewed above) on the impact of environmental policy instruments on the rate of technological change. He argues that the direction of technological change is as important, if not more so. In addition to the quantity of innovation, it is also important that innovation be socially optimal in the sense that it minimises the cost of attaining a particular environmental goal in the long term. Inappropriate innovation today may result in 'lock in' to a suboptimal technological path for the future.

With this in mind, Johnstone identifies a number of issues that can adversely affect the direction of innovation and should be taken into account when selecting and designing policy instruments: technological market failures (36); missing markets for certain environmental attributes of innovation; policy incidence; and joint production of emissions. Most studies of the innovation effects of environmental policy instruments assume that the only missing market is that for the environmental good (or bad). However, in practice there may be other markets that are missing (or incomplete), which can adversely affect transmission of innovation incentives. This is particularly so in the area of waste and resource management, where instruments applied at the end of the product life cycle may have little or no impact on product design innovation. Even if all markets are complete except for the environmental externality, the point of incidence of the policy intervention may be more important for the direction of innovation than the choice of a particular policy instrument. For example, a limit or standard applied directly to the emissions of a pollutant may be more effective in promoting optimal innovation than a tax applied to a proxy input variable. Finally, when there is joint production of pollutants (e.g. CO_2 and air pollutants from vehicle engines), there is a danger that if policy instruments (of whatever type) are applied to one pollutant in isolation, the resulting innovation may

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(36) These are the same market failures identified by Jaffe et al. (2002).

reduce emissions of that pollutant at the expense of increases in the others.

In a related point, Johnstone highlights the importance of using appropriate indicators when assessing the impact of policy instruments on innovation, emphasising the need for these to reflect both the rate of innovation and the direction. A necessary condition for this is that the indicators must provide an accurate and detailed picture of actual innovation. Unfortunately, this is difficult to achieve in practice. For example, the use of patent data as a measure of innovation requires the identification of relevant environmental technologies. This is likely to be easier for end-of-pipe technologies than for process-related technologies, meaning that the latter tend to be under-represented relative to their actual incidence. To the extent that process-related innovation is growing in importance, or is more important for certain sectors or types of environmental problem, changes in the value of the indicator may significantly understate the actual rate of innovation and misrepresent the direction.

All of this suggests that caution should be exercised in drawing general, definitive conclusions about the impacts of price-based policy instruments such as environmental taxes and investment subsidies on innovation, particularly relative to other policy instruments. While it would appear that they can be effective in stimulating both innovation and diffusion in many cases — at least in terms of the rate of technological change — there may be situations in which other policy instruments may be more appropriate. In general, the stringency and point of incidence of an environmental policy intervention may be more important than the choice of a particular policy instrument in determining the rate and direction of eco-innovation.

3 Modelling of ETR impacts on eco-innovation

3.1 Scenarios assessing the implications of ETR for eco-innovation

Scenario analysis provides a useful means of improving understanding of how the different revenue recycling methods and various scales of ETR can help meet different greenhouse gas emissions targets.

To investigate the impacts of an ETR for Europe, the petre project elaborated a range of different scenarios reflecting various tax reform options. In addition to employing several of these original scenarios, the present study compiled two new scenarios to analyse the implications of ETR for eco-innovation. All scenarios were examined in both E3ME and GINFORS ([37]).

3.1.1 Original petre project scenarios

The key petre scenarios relevant for the present study are:

- scenario BH: baseline scenario with high energy price (reference case);
- scenario S1H: ETR designed to meet the EU's unilateral 2020 GHG target (high energy price) with revenue recycling;
- scenario S2H: ETR designed to meet the EU's unilateral 2020 GHG target (high energy price) with revenue recycling and 10 % of revenues spent on eco-innovation measures;

Each of the ETR scenarios has the same key taxation components:

- a carbon tax rate is introduced to all non-EU Emissions Trading System (EU ETS) sectors equal to the carbon price in the EU ETS that delivers an overall 20 % reduction in greenhouse gas emissions by 2020 and in the international cooperation scenario this is extended to 30 %;
- aviation is included in the EU ETS at the end of Phase 2;
- power generation sector EU ETS permits are 100 % auctioned in Phase 3 of the EU ETS;
- all other EU ETS permits are 50 % auctioned in 2013 increasing to 100 % in 2020;
- material taxes are introduced at 5 % of total price in 2010 increasing to 15 % by 2020.

In scenario S1H, environmental tax revenues are recycled through reductions in income tax rates and social security contributions in each of the Member States, such that there is no direct change in tax revenues. In scenario S2H, 10 % of environmental tax revenues are recycled through spending on eco-innovation measures and the remaining 90 % is recycled through the same measures as in the other scenarios. The eco-innovation spending is split across power generation and housing according to tax revenues from the corporate and household sector.

In GINFORS (the model used for analysing the implications of ETR and eco-innovation) the share of renewable sources in electricity production is increased due to the additional investment. The rest of additional investment goes to household energy efficiency spending. Investment needed for a certain increase in renewable energy production or efficiency improvement is based on Austrian and German experience (Lehr et al., 2008 and 2009; Grossmann et al., 2008; Lutz and Meyer, 2008). This assumption is quite conservative as parameters for other countries can be assumed to be more positive (meaning that less money is needed for renewable energy technology installation or energy efficiency gains).

In scenario S1H the 20 % GHG target translates into a 15 % reduction in energy-related carbon emissions relative to 1990 as other emissions, such as methane and nitrous oxide, have already been reduced by

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([37]) The E3ME and GINFORS models are introduced in Chapter 1 of the present report. A detailed discussion of the models and scenarios used in the present study can be found in Ekins and Speck (2011).

more than 20 % (in terms of carbon equivalents). The target is reached by a tightened EU ETS cap and the introduction of a carbon tax on the non-ETS sector. The tax rate applied is equal to the carbon price in the EU ETS that will deliver a 20 % GHG reduction by 2020.

The burden of ETR taxes are allotted to energy outputs (i.e. the final use of energy) and will be based on the carbon content of each fuel. Carbon prices are assumed to be fully passed on to consumers. All carbon taxes are in addition to any existing unilateral carbon and energy taxes. The carbon reductions in the different EU Member States will be those that result from a uniform carbon tax increase across the EU.

All of the revenues, including EU ETS auctioning revenues, carbon tax revenues and material tax revenues will be recycled. The proportion of tax raised by industry will be recycled into a reduction in employers' social security contributions, which will in turn reduce the cost of labour. Recycling will be additional to the existing ETRs in some Member States. Revenues raised from households will be recycled through standard rate income tax reductions. Traditional energy tax revenues will be lower compared to their respective baselines, as the tax base (energy consumption) is reduced. So for an ETR, revenue-neutrality does not mean budget-neutrality.

3.1.2 Factors affecting the macroeconomic impacts of RES technologies

Earlier analyses (Lehr et al., 2008; Fraunhofer ISI et al., 2009; DTI, 2004; Kammen et al., 2004; Moreno and López, 2007) have studied the impacts of large renewable energy source (RES) shares in the energy mix for different countries. The overall question in these studies has been the impact of increasing RES shares on the economy, especially on the labour market. For the present study, it is interesting to note that macroeconomic impacts of higher RES shares mainly depends on the following five factors:

1. additional investment in RES (minus lower investment in conventional sources, i.e. fossil and nuclear power), with the impact increasing if a country manufactures the RES technology in question;
2. additional (net) exports due to improved international competitiveness of renewable energy sources (first mover advantage);
3. lower fossil fuel needs;
4. the cost differences between RES and conventional energy;
5. the shift from capital- and energy-intensive industries to labour- and technology-intensive industries.

All five factors are driven by international energy prices, carbon prices, the policy framework and RES technology development itself. Innovation comes into the play at various stages. First, innovation drives the currently positive additional costs of RES technologies down and even into negative realms, depending on the fossil fuel scenario. Second, innovative RES technologies are likely to have a competitive advantage in international markets. Although a significant proportion of RES technology produced in Europe is traded in Europe, innovation will still provide an edge in current and emerging international markets.

The EmployRES study (Fraunhofer ISI et al., 2009) finds for Europe that current strong investment, reflected in installations in Europe and exports to the rest of the world, dominate the economic impact of RES policies and therefore lead to positive overall effects. The study's results suggest that this positive balance can only be kept up in the future if the competitive position of European manufacturers of RES technology is improved. The authors strongly recommend 'policies which promote technological innovation in RES and lead to a continued and rapid reduction of their costs.'

Factors 1 and 2 will have substantial macroeconomic impacts in the short and medium terms, whereas factor 3 accumulates and will show positive impacts mainly in the long term. Factor 4 strongly depends on the global developments, while factor 5 may have significant effects on employment.

3.1.3 Additional scenarios

Impacts of additional investment (factor 1) have already been analysed in scenario S2H of the petre project. To focus on the other impacts of eco-innovation, two additional scenarios were designed, building on scenario S2H of petre:

- S2HE: ETR with revenue recycling designed to meet the unilateral EU's 2020 greenhouse gas (GHG) target (high energy price). Ten per cent of revenues are spent on eco-innovation measures and trade shares of EU-27 economies with the rest of the world in machinery and electrical machinery increase by 0.1 % due to the deployment of the fast growing RES markets. This assumption is based on the strong EU policy effort to increase the share of renewable energy in final energy consumption to 20 % by 2020

Table 3.1 Main results under the different scenarios

Scenario	Target in 2020	CO_2 price	GDP		Employment	CO_2 reduction	
		EUR_{2008}/t	pc against baseline		pc against baseline	pc against 1990	pc against baseline
	in year	2020	2015	2020	2020	2020	2020
BH		18				– 7.2	0.0
S1H	20 % GHG	68	– 0.22	– 0.57	0.36	– 15.1	– 8.4
S2H	20 % GHG	61	– 0.13	– 0.30	0.41	– 15.2	– 8.5
S2HE	20 % GHG	61	– 0.09	– 0.04	0.51	– 15.1	– 8.4
S2HI	20 % GHG	61	– 0.06	– 0.24	0.45	– 15.2	– 8.4

(Fraunhofer ISI et al., 2009) and the possibility of very strong world market development of the RES sector until 2020 (EREC, 2008), which offers additional export opportunities for European RES industries.

- S2HI: ETR with revenue recycling designed to meet the unilateral EU's 2020 GHG target (high energy price). Ten per cent of revenues are spent on eco-innovation measures and input structures of the energy sector are changed according to the input structure of the German RES industry (Lehr et al., 2008).

S2HE looks at the possible role of international trade, S2HI analyses changes in the input structure of the energy sector, i.e. from conventional electricity production to renewables. In the petre project (as in GHK et al., 2007) only the energy inputs of the energy sector were adapted to changes in the energy input mix.

Both S2HE and S2HI focus on RES and efficiency technologies. As mentioned above, an ETR will trigger a variety of innovations. Therefore the results can be thought of as conservative in the sense that innovations (e.g. automotive energy consumption, industrial efficiency, etc.) are not explicitly included.

3.2 Overview of modelling results

The main results of the simulations are presented in Table 3.1. In the baseline scenario BH with high energy prices, EU-27 carbon emissions will be 7.2 % below the 1990 level in 2020 (38). The EU-15 has committed in the Kyoto Protocol to reduce its GHG emissions 8 % below 1990 levels in the period 2008–2012. As emissions in the new member states are substantially below their 1990 levels today, that implies that the EU-27 will keep its emissions more or less constant over the coming decade. As in the PRIMES baseline, an ETS price of 18 EUR/t in 2008 prices is assumed in 2020.

In scenario S1H the ETS price and carbon tax rate has to be increased to 68 EUR_{2008}/t of CO_2 to reach the 20 % GHG reduction target, which is equal to a 15 % reduction of CO_2 emissions against 1990 as other greenhouse gases have already been reduced above average by more than 20 % in terms of CO_2 equivalents. Compared to the baseline, CO_2 emissions are 8.4 % lower in 2020 which means roughly an additional 1 % reduction annually in the period 2012–2020. GDP will be about 0.6 % lower compared to the baseline in 2020. This means that annual average growth rates will be less than 0.1 % below their baseline development. This is especially low compared to the current financial and economic crisis, with a GDP deviation against the baseline of around 6 % in 2009.

As the recycling mechanism reduces labour costs and the tax burden is shifted from labour-intensive to carbon- and material-intensive sectors, employment will be 0.36 % (or more than 800 000 jobs) higher than in the baseline. The ETR is not fully budget neutral, potentially enabling EU economies to slightly increase their net savings. If

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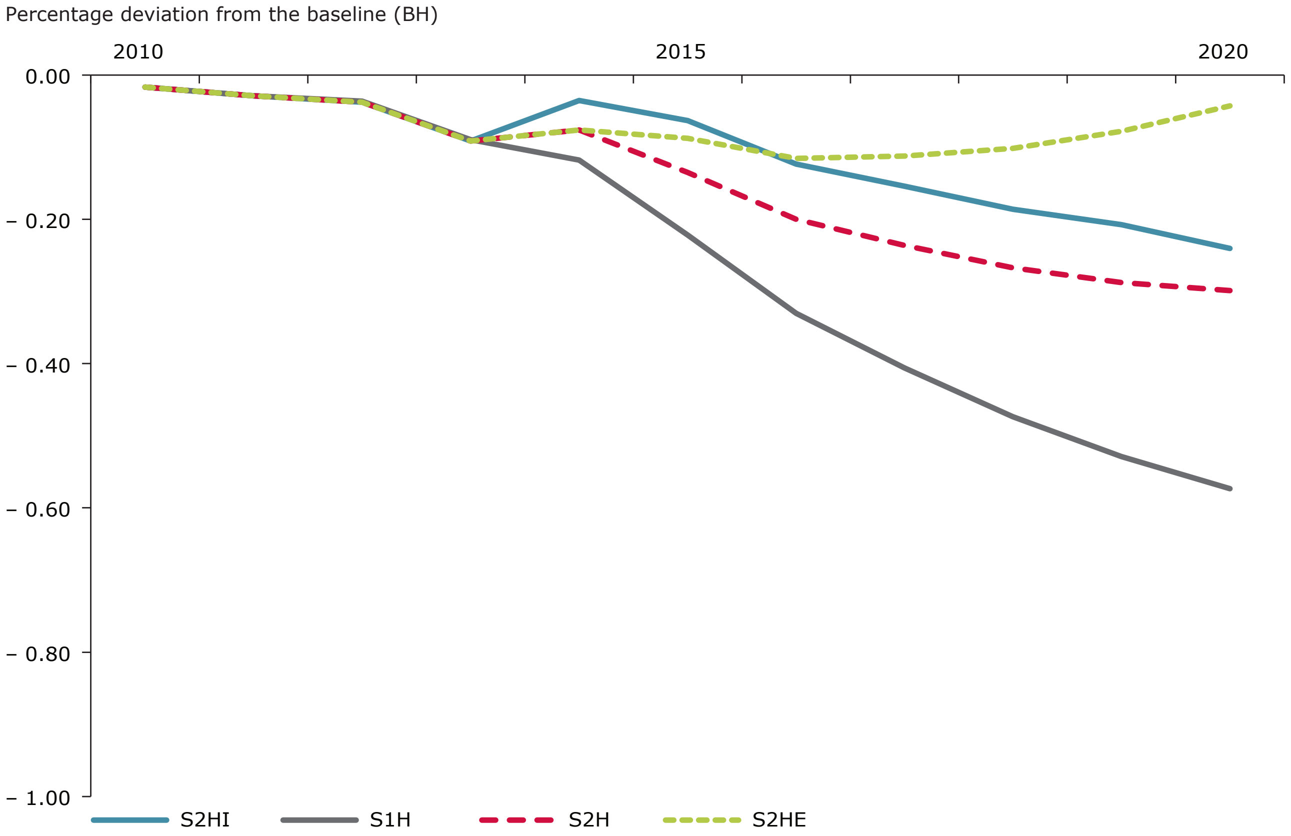
(38) The modelling exercise in the present study was conducted in 2009 and therefore does not contain the latest data on EU-27 GHG emissions, which were significantly influenced by the global economic slump of the late-2000s.

Figure 3.1 EU-27 GDP according to four scenarios — deviation from the baseline (BH)



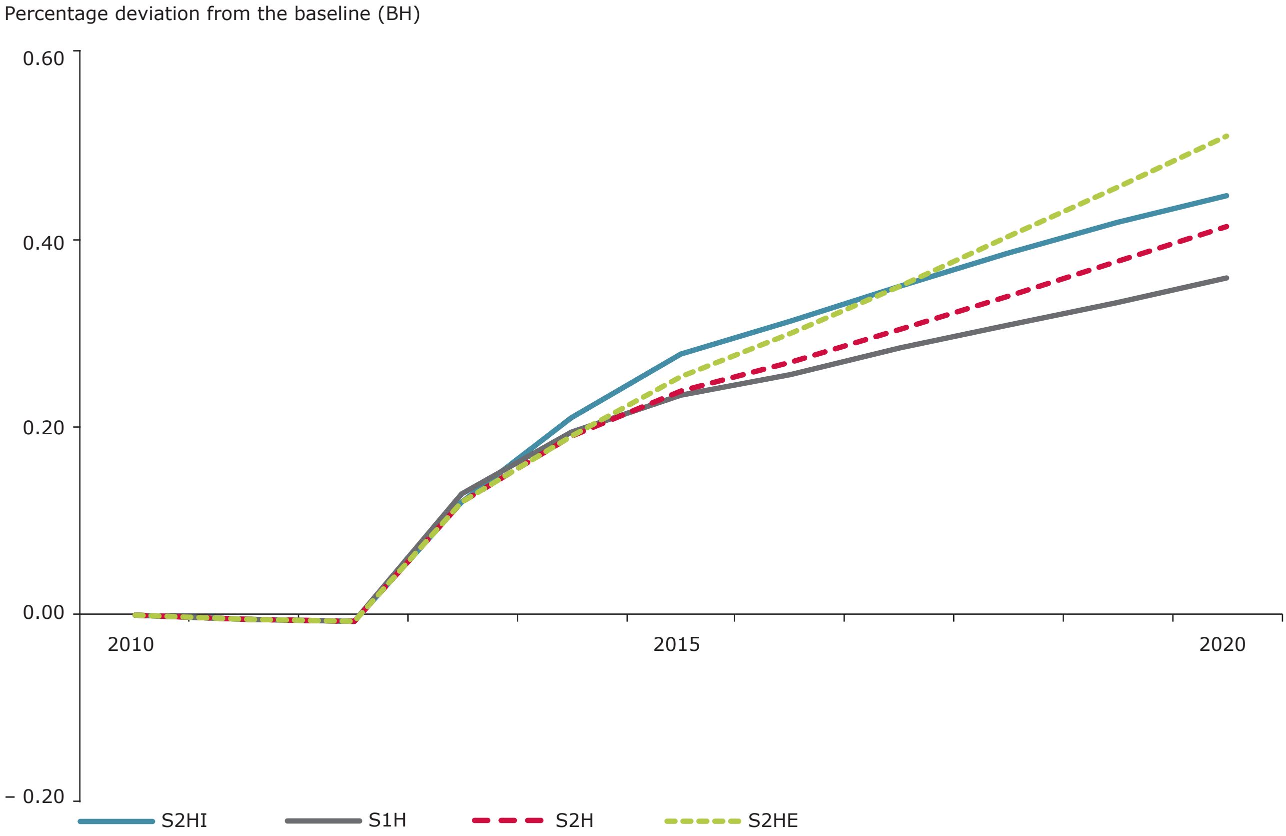
this extra saving is spent, negative GDP impacts will be further reduced.

In scenario S2H part of the revenues is invested in low-carbon technologies. This reduces the carbon price to 61 EUR$_{2008}$/t in 2020, halving the GDP loss relative to scenario S1H to only 0.3 %, as the investment in renewable energies is assumed to be additional. Employment impacts are also more positive than in scenario S1H. The 10 % investment in low-carbon technologies amounts to more than EUR 20 billion in 2020.

Assuming additional EU exports of RES technologies in scenario S2HE, GDP almost matches the baseline in 2020 and employment is 0.51 % (or more than 1 million jobs) higher than in the baseline. In scenario S2HI, a shift in the input structure of the energy sector towards machinery and electrical machinery, reflecting the different nature of RES relative to conventional electricity generation, also has smaller additional positive impacts on GDP and employment compared to scenario S2H.

The following figures show impacts of the different scenarios in comparison to the baseline BH. As Figure 3.1 illustrates, all the alternative scenarios imply GDP lower than the baseline. However, comparing scenario S1H with the other three scenarios shows that additional RES investment (S2H), additional RES exports (S2HE) and the inclusion of different input structures of the RES industries (S2HI) each have positive GDP impacts. These results are in line with model-based analysis in the EMPLOY-RES study (Fraunhofer ISI et al., 2009).

Figure 3.2 EU-27 employment according to four scenarios — deviation from the baseline (BH)



In contrast to GDP, employment increases relative to the baseline in all the alternative scenarios (Figure 3.2). Due to the scenario design the structure of the EU economies is shifted from energy-intensive to labour-intensive sectors. The magnitude of the employment gain is influenced by the carbon price and the tax shift, the underlying energy prices and the production loss. The largest part of the employment increase stems from the additional RES investment (scenario S2H), although a shift in industry structures (S2HI) and additional RES exports (S2HE) are also positive for the labour market.

3.3 Macroeconomic impacts at the national level

In general terms, it is clear that national ETS and ETR impacts depend significantly on country specifics, including energy use, economic structure, social system and behaviour (e.g. reactions to labour cost changes). In countries with high carbon intensity in their energy mix, additional revenues and expenditures are higher than in countries with lower carbon intensity.

Scenario S2H provides an interesting tool for analysing the macroeconomic impacts of ETR at the national level because 10 % of the additional generated revenues are used for eco-innovation investments meaning that only 90 % of the revenues are recycled back into the economy by reducing income tax rates and social security contributions.

Figure 3.3 GDP in 2020 in selected countries under scenario S2H — deviation from the baseline (BH)

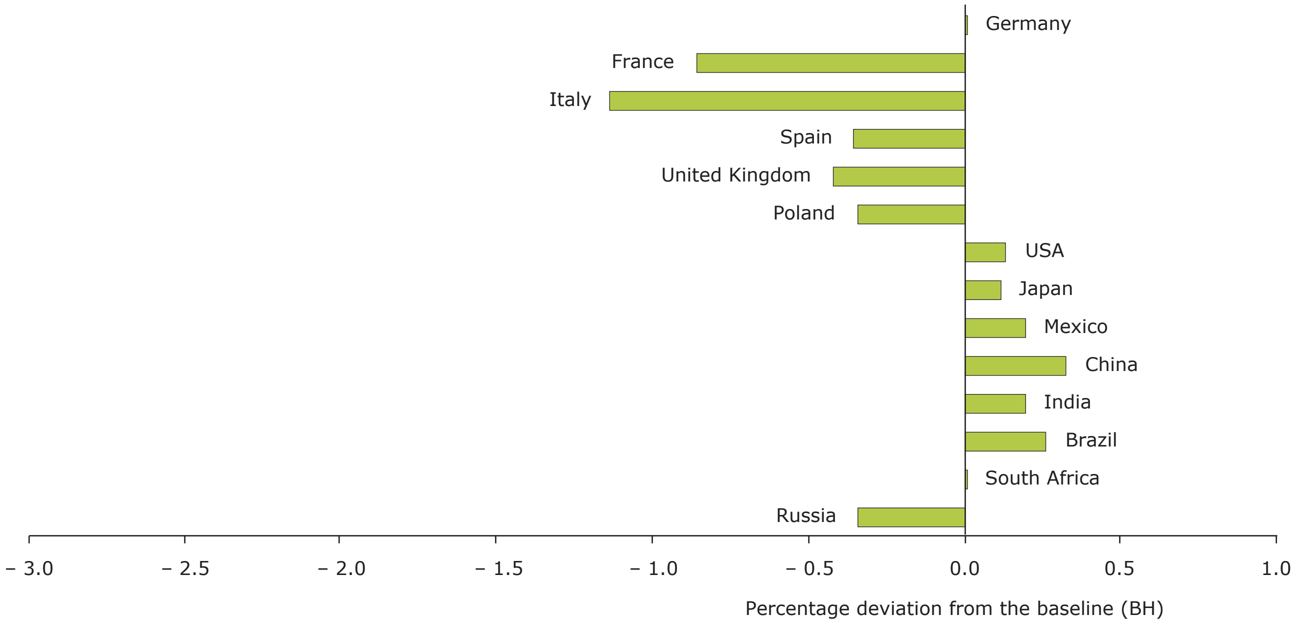
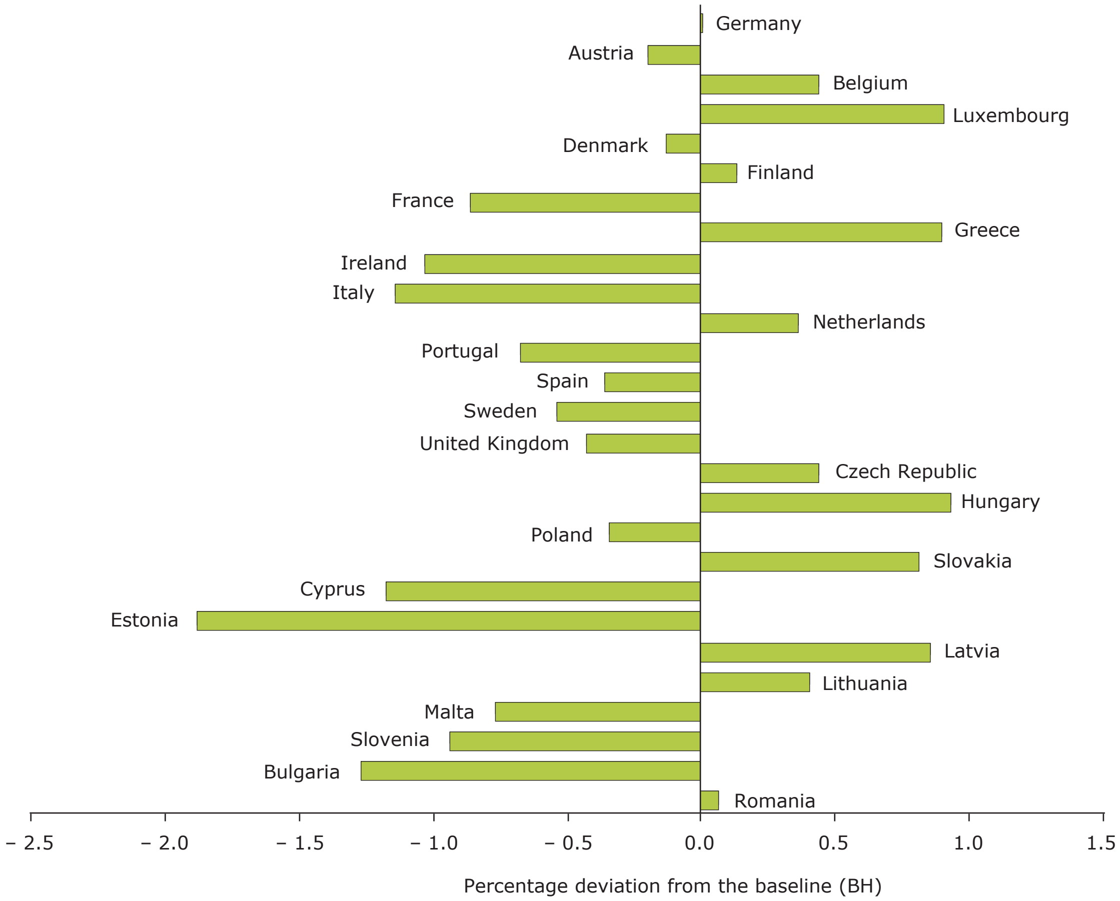


Figure 3.4 GDP in 2020 in EU-27 Member States under scenario S2H — deviation form the baseline (BH)



Under scenario S2H, the GDP of large EU economies deviates from baseline projections by between 0 and – 1 % with the exception of Italy (Figure 3.3). Germany's GDP is even forecast to match the baseline level in 2020 due to the country's strong RES industry. Outside Europe, some countries gain slightly against EU Member States in terms of competitiveness, as export prices in most EU Member States and sectors increase, and GDP in those countries exceeds the baseline projections as a result (Figure 3.3). This is mainly because carbon tax revenues are recycled via income tax reductions which are not part of production costs. However, energy exporting economies such as Russia or South Africa will lose exports if EU demand for fossil fuel imports declines. The development of all EU Member States is shown in Figure 3.4.

Employment impacts of scenario S2H are positive for almost all EU Member States, as lower labour costs increase labour demand and labour intensity (Figure 3.5). The highest absolute increases are shown for Germany, the Netherlands, Italy and the United Kingdom. For EU-27 as a whole, employment will be almost one million higher than in the corresponding baseline BH in 2020.

The scenarios have not been designed with a view to meeting the EU renewables target of a 20 % renewables share in final energy consumption in 2020. Nevertheless the scenarios provide some interesting insights. The share is projected to increase from around 10 % in 2009 to above 14 % even in the baseline as instruments such as feed in tariffs and biofuel quotas will continue. In scenario S1H the target will be missed with around 18 % in 2020. Only in scenarios S2H, S2HE and S2HI is the target met (approximately 20 %).

Figure 3.5 Employment in 2020 in EU-27 Member States under scenario S2H — deviation from baseline (BH)

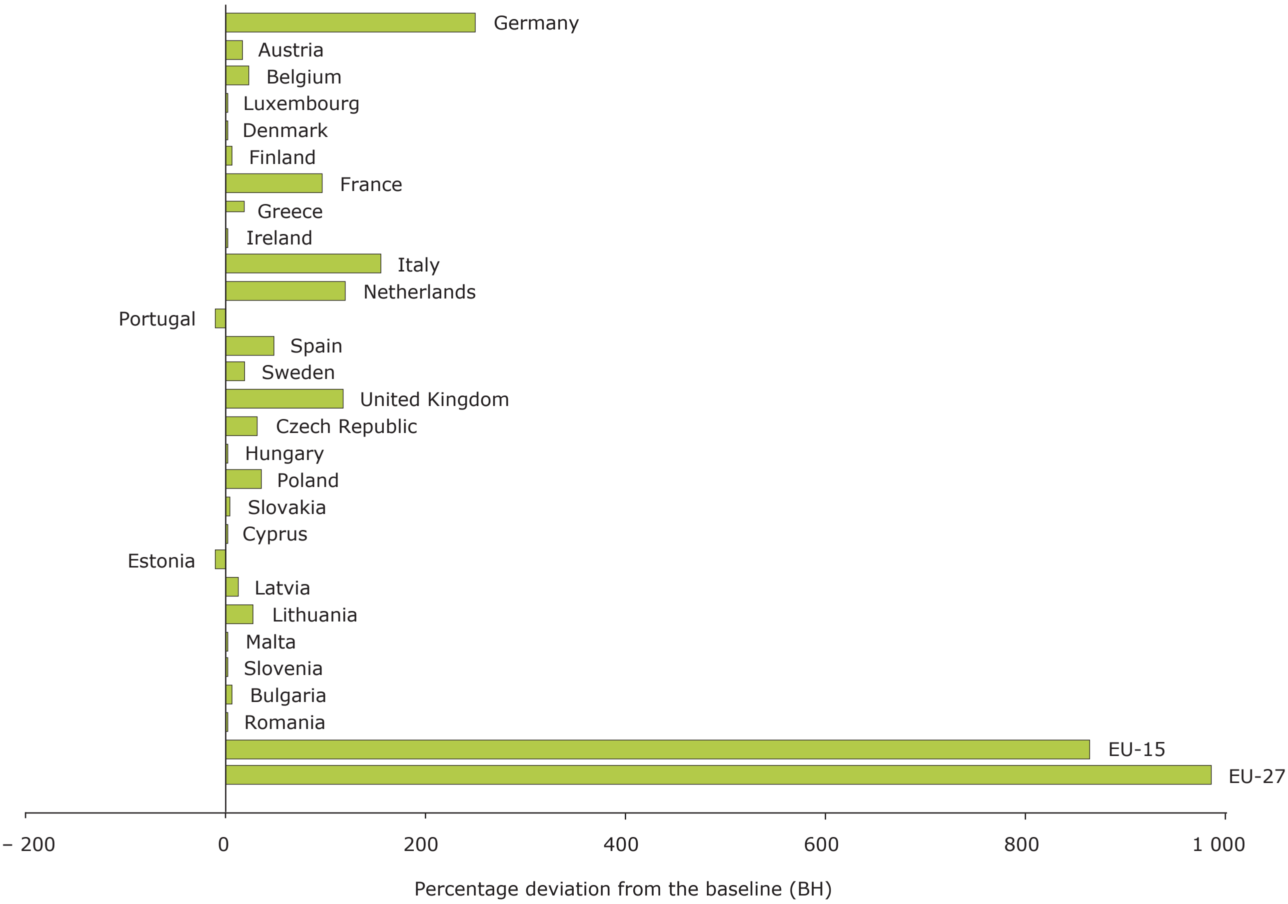
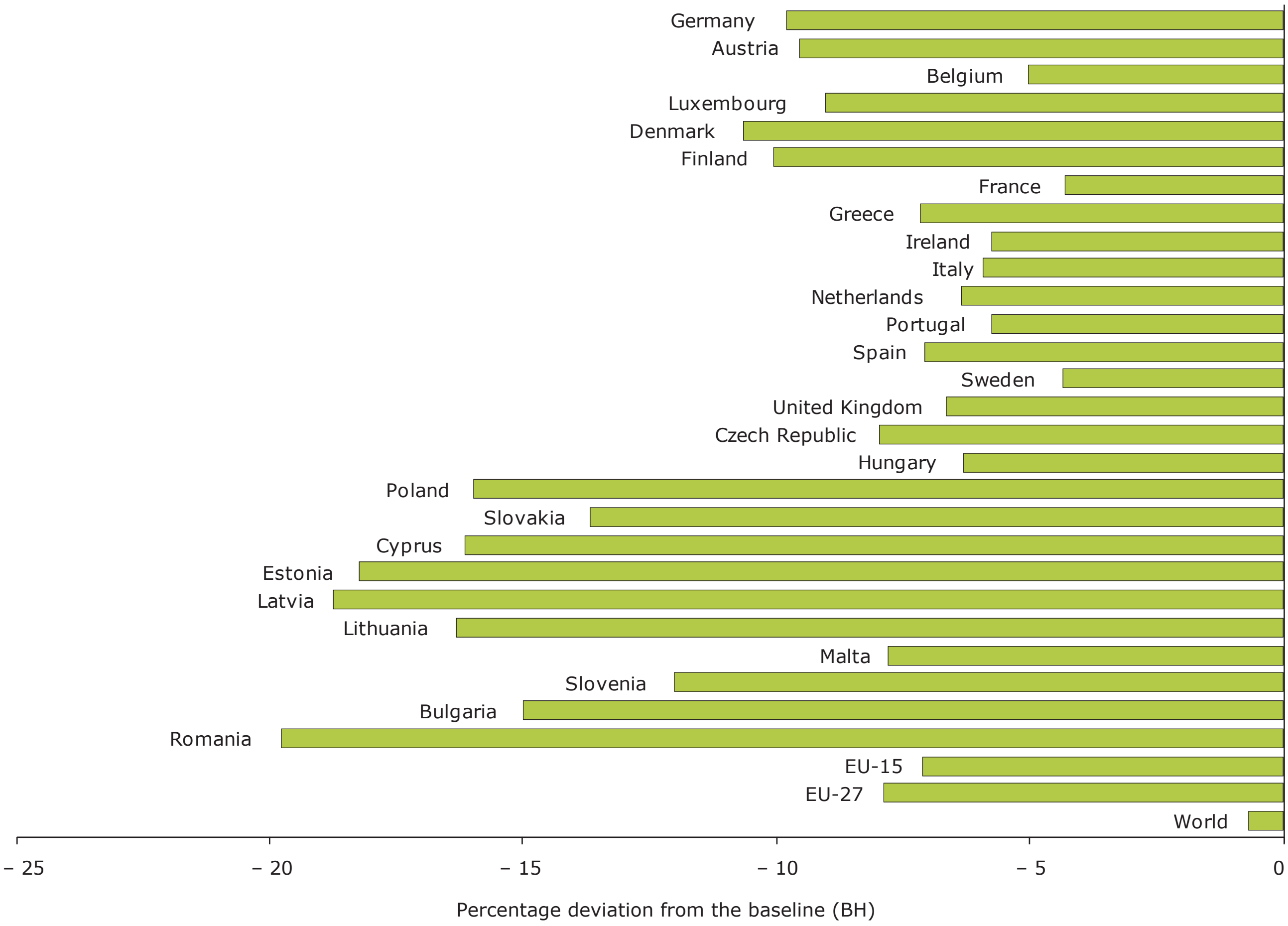


Figure 3.6 Energy-related CO_2 emissions in 2020 under scenario S2H — deviation from the baseline (BH)



Under scenario S2H, energy-related carbon emissions are reduced in all EU Member States relative to the baseline (Figure 3.6). The highest percentage reductions can be seen in many of the EU-12 Member States with still high energy intensity and low energy prices. In these countries the relative price increase is higher than in countries like Germany or the United Kingdom with already high energy taxes and overall energy prices.

Additional ETS revenues, material tax revenues and carbon tax revenues from the industry sector are recycled back to industry via reductions in employers' social security contributions (or wage subsidies in some countries). The revenues from the carbon tax on households set out in Table 3.2 (totalling 0.33 % of GDP in Germany, for example) are used to reduce income tax. For the EU-27 overall revenues from ETS and ETR reach about 2 % of GDP in 2020, although these figures may be excessive because additional EU efforts to increase energy efficiency and renewable energy, which will reduce the ETS price, are not taken into account. The use of flexible tools such as the Clean Development Mechanism will further reduce the revenues and earmarking of part of the revenues for mitigation and adaptation measures in emerging and developing countries limits the recycling into labour costs.

In addition, the scenarios do not take the current global economic problems into account. According to the IEA (2009), the downturn will also reduce carbon emissions in the long run, which will lead to lower carbon prices and revenues to reach fixed targets (or make tighter targets less costly).

The ETR will have varying effects on the prices of different sorts of products and services. Material or carbon taxes increase the prices of product groups according to their direct and indirect material and carbon content. The recycling mechanism reduces

Figure 3.7 Total primary energy supply in 2020 under scenario S2H — deviation from the baseline (BH)

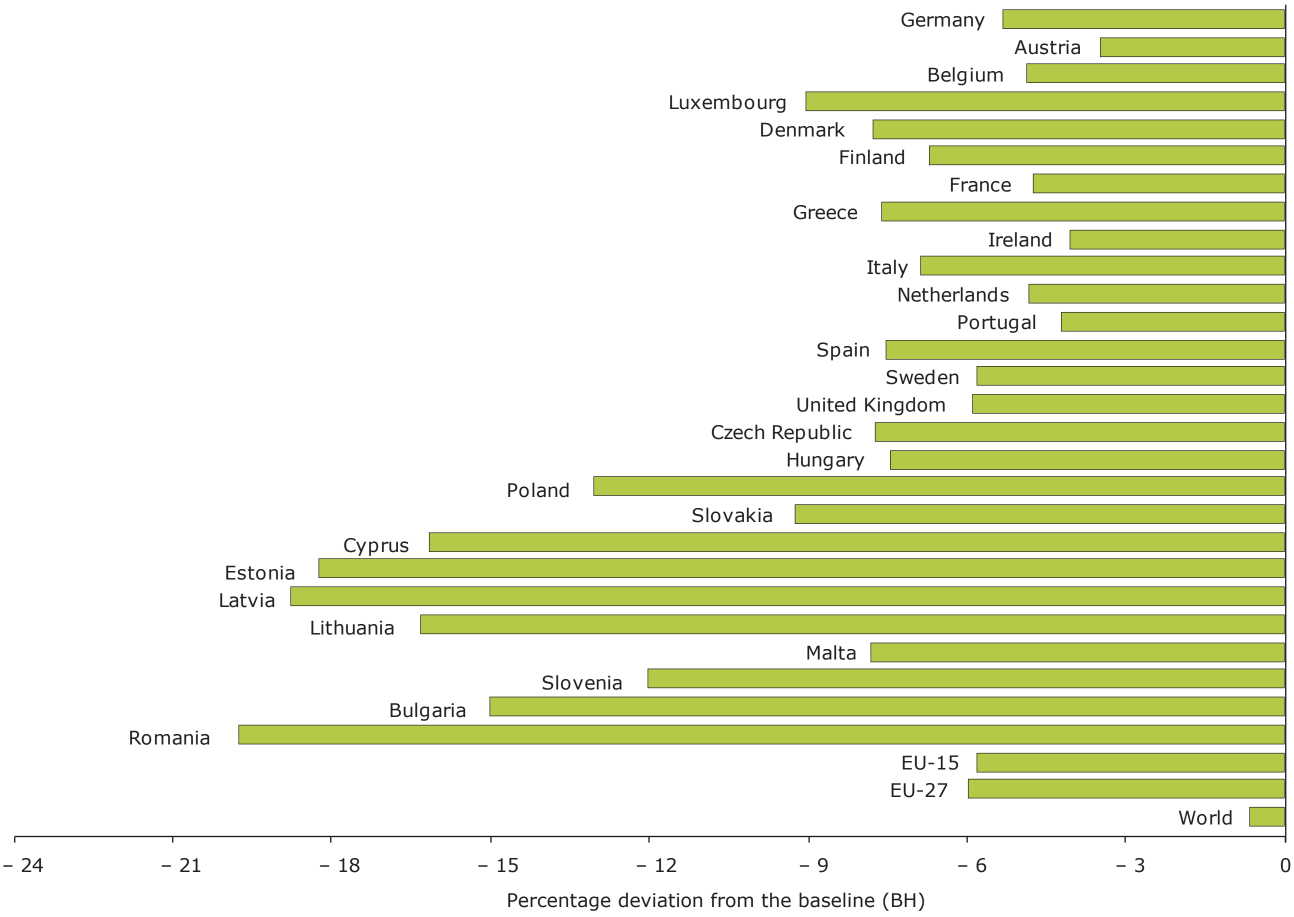


Table 3.2 Additional ETS and environmental tax revenues in 2020 (% of GPD)

S2H	Germany	United Kingdom	EU-27
ETS revenues	0.83	0.64	0.59
Carbon tax (industry)	0.52	0.44	0.54
Carbon tax (households)	0.33	0.41	0.36
Material tax	0.41	0.29	0.56
Sum	2.09	1.78	2.05

Figure 3.8 Output price impacts of scenario S2H in Germany in 2020 — deviations from the baseline (BH)

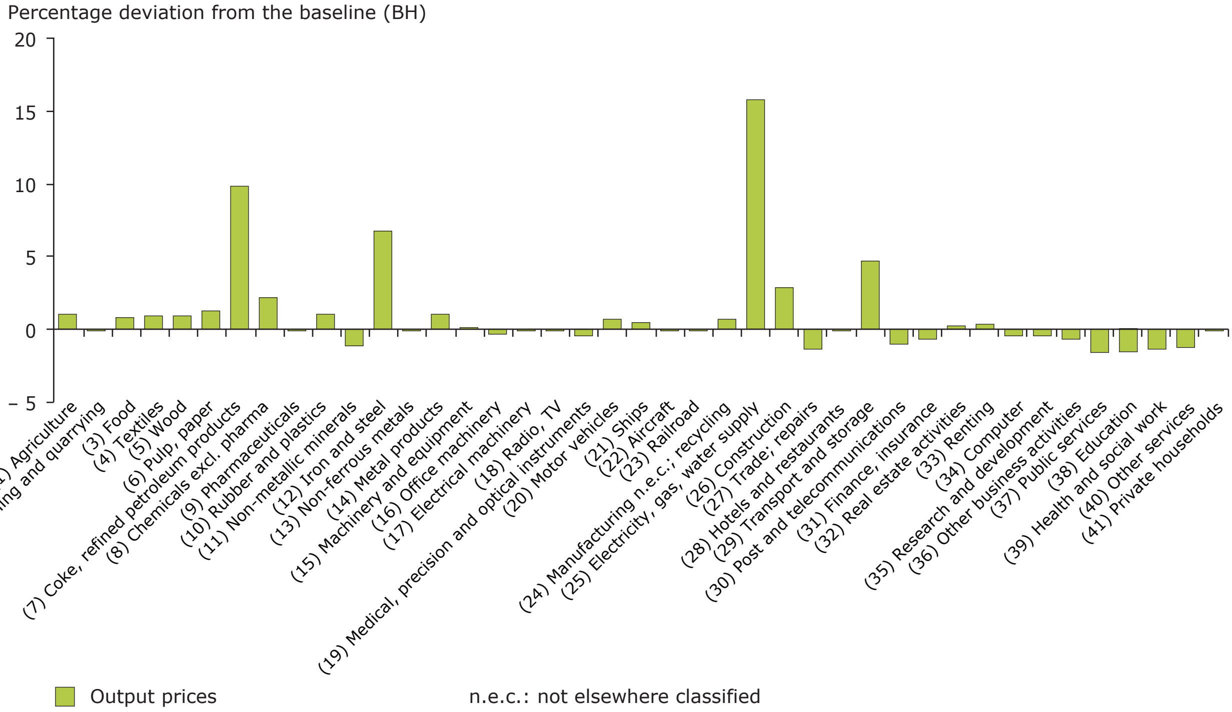
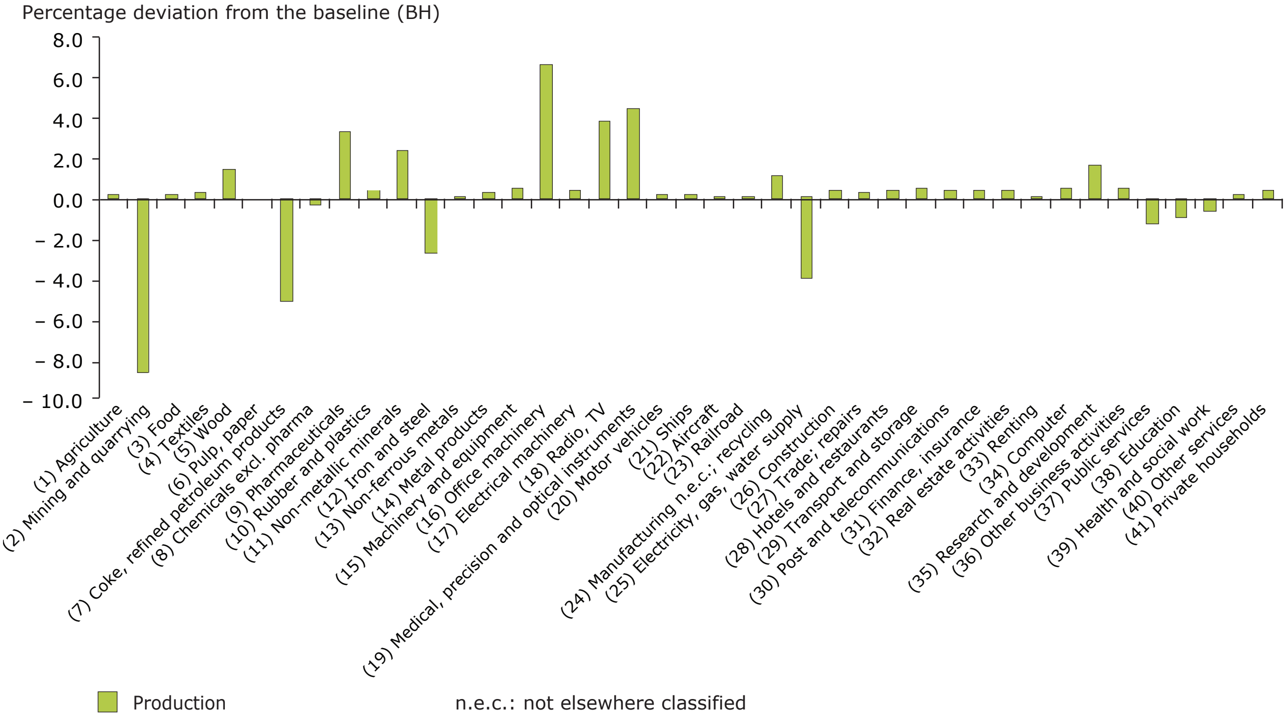


Figure 3.9 Impacts of scenario S2H on industrial output in 2020 in Germany — deviations from the baseline (BH)



social security contributions and lowers labour costs according to the direct and indirect labour content of sector output. The ETR therefore reduces output prices in labour-intensive service sectors and increases prices in carbon- and material-intensive industry sectors.

The example of Germany shows insignificant impacts in the trade-intensive sectors of machinery (15–17), motor vehicles (20) and other transport equipment (21–23) (Figure 3.8). Iron and steel (12) and chemicals without pharmaceuticals (8) face the highest price increases of trade-intensive sectors. As the German iron and steel industry primarily delivers high quality steel to the German car industry and increasingly to the German windmill industry, negative competitiveness impacts will be limited. Exchange rate variations against non-EU competitors have been much higher in the past.

The higher prices of carbon- and material-intensive products will reduce price competitiveness on export markets and increase the market share for imports in domestic markets. This loss of price competitiveness is based on an assumption of limited market development of energy efficiency and RES technologies in other part of the world. It will be offset by gains in labour-intensive sectors if the ETR causes real wage costs per unit of output to fall as a result of using recycled revenues to reduce employer social security contributions.

Any improvement in non-price competitiveness will also raise exports. The extra employment will raise incomes, raising consumption and output.

The overall impact on sector output depends on countervailing effects, which are negative for iron and steel and a few service sectors and positive for a few industry sectors. For most industries, the output effect is insignificant (Figure 3.9). The greatest impact is felt by producers of fossil fuels, who must obviously reduce production due to lower demand for their products.

Under scenario S2H, employment impacts are positive for most sectors relative to the baseline as labour productivity decreases and wage rates fall in relation to consumer prices (CPI) and output prices (Table 3.3). The relative costs of labour are lower than in the baseline without the ETR reform. Only around a quarter of the employment increase takes place in industry.

Concerning the wage rate, two countervailing effects have to be considered. First, when the labour market is characterised in terms of the 'real wage bargaining' model, as in E3ME and GINFORS, with market power on both sides (employers and trade unions), consumer price increases will lead to wage increases (the econometrically estimated factor is 0.85 for Germany). Second, labour productivity is another important factor for wage bargaining. The estimated elasticity for Germany is 0.63, meaning that a 1 % increase of labour productivity leads to wage increases of 0.63 %. Higher labour demand due to lower labour costs thus reduces the wage increase. In the end, the German economy is more labour intensive than without the ETR, partly due to the structural change towards labour-intensive industries.

Table 3.3 Employment impacts of scenario S2H in Germany — deviations from scenario S2H in 2020

Employment in 2020	Deviation from S2H (%)	Deviation from S2H absolute (1 000s)
Agriculture, forestry	2.4	9.0
Industry	0.9	65.3
Non-metallic minerals	2.4	6.2
Iron and steel	– 2.8	– 3.7
Machinery and equipment	0.5	5.6
Electrical machinery	0.4	1.8
Construction	3.7	44.9
Trade and transport	1.0	82.9
Business services	1.7	76.7
Other services	– 0.2	– 21.6
Total	0.7	250.6

Table 3.4 Employment impacts of scenario S2HE in 2020 in Germany — deviations from scenario S2H

Employment in 2020	Deviation from S2H (%)	Deviation from S2H absolute (1 000s)
Agriculture, forestry	– 0.1	– 0.2
Industry	0.3	19.4
Non-metallic minerals	0.2	0.5
Iron and steel	0.4	0.5
Machinery and equipment	1.3	13.0
Electrical machinery	2.4	11.7
Construction	0.1	1.8
Trade and transport	0.0	2.6
Business services	0.7	30.8
Other services	0.1	10.7
Total	0.2	63.4

Table 3.5 Employment impacts of scenario S2HI in 2020 in Germany — deviations from scenario S2H

Employment in 2020	Deviation from S2H (%)	Deviation from S2H absolute (1 000s)
Agriculture, forestry	– 0.1	– 0.2
Industry	0.0	0.0
Non-metallic minerals	2.5	6.5
Iron and steel	– 2.7	– 3.6
Machinery and equipment	0.8	7.8
Electrical machinery	0.4	1.9
Construction	– 0.0	– 0.4
Trade and transport	0.0	0.7
Business services	0.2	11.5
Other services	0.	5.6
Total	0.0	16.7

Additional exports under scenario S2HE mainly create new jobs in machinery and related business services (Table 3.4). Under scenario S2HI, a shift in the input structure of the energy sector leads to a shift in the industry structure and creates a few jobs in the service sector (Table 3.5).

3.4 Conclusions of the scenario assessment

The foregoing analysis used the GINFORS model to assess economic and environmental impacts of using the ETS and ETR to reach the EU's 2020 GHG targets. In general, the results show positive employment effects and only small negative impacts on GDP in EU-27 Member States. The economic impacts depend on the levels of international energy prices, the mechanism used to recycle revenues, and country specifics such as carbon and energy intensity and the structure of energy consumption.

Although there is significant evidence that eco-innovation is positively driven by higher energy prices, quantification is difficult. The present study included simulations of possible impacts of a shift in the industry structure towards renewable energy in the electricity sector and an overall increase of EU exports due to higher global demand for renewable energy. The main results can be summarised as follows:

- environmental tax reform, shifting taxes from labour to energy and resources will create additional jobs and trigger eco-innovation;
- impacts of eco-innovation in the form of additional EU exports or shifts in industry structures will have a slight positive influence on GDP and create a smaller number of additional jobs.

These findings correspond to results from the EmployRES study (Fraunhofer ISI et al., 2009). As ETR is directly aimed at reducing labour costs, it will create additional jobs in the short and medium term. In the longer term, the cost reduction and new technologies arising from eco-innovation will play a larger role.

Like all fiscal reforms, a major ETR in Europe will create winners and losers. At the sector level, carbon- and material-intensive industries will face economic losses. At the country level, the carbon-intensity and overall flexibility of economies is important. Clearly, structural change away from carbon-intensive industries, together with technological change, is inherent in any successful climate mitigation policy.

On the other hand, several factors can smooth these structural adjustments. International cooperation will reduce economic pressure on countries and sectors. In addition, ETR together with auctioning of ETS allowances can be a major source of revenues for EU Member States in the future, even if part of the revenues will have to be earmarked for adaptation and mitigation measures in developing countries. Indeed, future debate on grandfathering or auctioning ETS allowances should reflect the important point that giving allowances away for free denies countries the money to ease structural change and invest in low-carbon technologies.

Caution is needed in relating the findings of this study to the EU policy debate. In the model simulations, the single carbon price is the only instrument used to reach the EU's 2020 GHG targets. In reality, of course, other renewable energy and efficiency policies will also contribute to carbon reduction and have to be taken into account when comparing the results (especially the high carbon prices) to other studies. Both reduce the potential revenues from fossil energy carriers and carbon emissions.

A variety of renewable energy and efficiency policies could enable the climate and energy targets to be met while securing even better economic prospects. The results of the present study clearly indicate that the discussion on market-based instruments should be intensified. Ultimately, however, the EU will need a rich mix of policies to reach its GHG targets while maximising prosperity.

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Annex 1
Classification of refereed journal articles

Reference	Type					Instrument						Area					Stage		
	Theoretical	Empirical	Case study	Review	Qualitative	Taxes	Permits	Subsidies	Voluntary	Command	Regulation	Energy	Air	Water	Other	General	Innovation	Diffusion	Relevance
Brunnermeier & Cohen (2003)		X									X					X	X		**
Buen (2006)					X			X	X			X					X	X	*
Christiansen & Skjaerseth (2005)			X			X			X			X					X	X	***
Fischer et al. (2003	X					X	X									X	X	X	***
Frondel et al. (2008)		X				X	X	X	X	X						X	(X)	(X)	***
Hemmelskamp (1997)				X		X	X	X		X				X	X		(X)		**
Hoglund Isaksson (2005)		X				X							X				(X)	(X)	***
Jaffe & Stavins (1995)	X	X				X1		X		X		X						X	***
Jaffe & Palmer (1997)		X									X					X	X		**
Jaffe et al. (2002)				X	X	X	X	X		X		X	X				X	X	***
Jung et al. (1996)	X					X	X	X		X						X	(X)	(X)	**
Kemp (1998)		X				X								X				X	***
Kerr & Newell (2001)		X					X			X			X					X	*
Klaassen et al. (2005)		X						X				X					X	X	**
Lanjouw & Mody (1996)		X									X	X	X	X			X	X	**
McGinty & de Vries (2009)	X							X								X		X	**
Mickwitz et al. (2008)			X			X		X		X		X	X	X			X	X	***
Milliman & Prince (1989)	X					X	X			X						X	X	X	***
Millock & Nauges (2006)	X	X				X		X					X					X	***
Montero (2002)	X					X	X			X							X		***
Newell et al. (1999)		X				X1				X		X					X		***
Norberg-Bohm (1999)					X	X	X		X	X					X		X		**
Popp (2002)		X				X1						X					X		***
Popp (2005)				X			X			X						X	X	X	**
Porter & van der Linde (1995)					X	X	X			X						X	X		**
Requate (2005)				X		X	X			X						X	X	X	***
Skjærseth & Christiansen (2005)			X			X		X	X	X		X	X				X	X	***
Snyder et al. (2003)		X								X			X	X				X	*

Annex 2
Classification of books and book chapters

	Type					Instrument						Area					Stage		
Reference	Theoretical	Empirical	Case study	Review	Qualitative	Taxes	Permits	Subsidies	Voluntary	Command	Regulation	Energy	Air	Water	Other	General	Innovation	Diffusion	Relevance
Johnstone (2005)					X	X	X			X			X				X	X	***
Johnstone & Hascic (2008)		X				X	X	X	X	X		X					X		***
Kemp (1997)	X	X		X		X	X	X	X	X		X	X	X			X	X	***
Kemp (2000)				X		X	X	X	X	X						X	X	X	**
de Vries & Medhi (2008)		X				X1				X			X				X		***

Annex 3
Classification of reports

	Type					**Instrument**						**Area**					**Stage**		
Reference	Theoretical	Empirical	Case study	Review	Qualitative	Taxes	Permits	Subsidies	Voluntary	Command	Regulation	Energy	Air	Water	Other	General	Innovation	Diffusion	Relevance
Görlach et al (2005)			X			X		X				X					X	X	***
Knigge & Görlach (2005)			X			X		X				X					X	X	***
Technopolis (2008)				X	X			X		X						X	X		*
Volleburgh (2007)				X		X		X	X	X		X	X	X	X		X	X	***

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