Executive Summary

Environmental policy has the potential to bend the direction of innovation towards less environmentally harmful impacts. It has long been recognised that the characteristics of any environmental policy framework can affect the rate and direction of innovation in environmental technologies. Environmental policies have the effect of changing relative input prices. In doing so, they encourage research on technologies which save on the use of the more expensive inputs. The research presented in this publication assesses the role of public policy in inducing environmental innovation in a wide variety of fields, including:

- General environmental management:
  - Air pollution abatement.
  - Water pollution abatement.
  - Solid waste management.
- Specific abatement technologies:
  - Regional air pollutants.
  - Motor vehicle pollution abatement (including alternative-fuelled vehicles).
  - Material recycling, solid waste incineration and landfilling.
  - "Green" chemistry.

Indicators of inventive activity and international technology transfer are constructed based on data extracted from the European Patent Office’s World Patent Statistical (PATSTAT) Database. It covers all important intellectual property offices worldwide, with data stretching back over several decades. Our development of indicators for environmental innovation across time and countries represents a significant step forward in our capacity to analyse the potential impacts of environmental policy on innovation. Selected patent-based indicators of environmental innovation are now available on OECD.Stat (http://stats.oecd.org/index.aspx?queryid=29068). (For further information see also www.oecd.org/environment/innovation/indicator.) While it must be emphasised that patents are an imperfect and incomplete measure of innovation, for the purposes of comparative policy analysis patent data have a number of important advantages relative to alternative measures.
Making a rigid distinction between market-based instruments and direct forms of regulation can be misleading.

Economists have long argued that directly changing the relative price of polluting inputs (or products) through market-based instruments, such as taxes or tradable permit schemes, is the most effective way to induce innovation. While there is no question that “pricing” pollution is a necessary condition for encouraging innovation, drawing a stark contrast between market-based instruments and direct forms of regulation can be misleading since there can be as much variation within policy types as across them. In this book, it is argued that it is more helpful to think in terms of the more general characteristics of different instruments, and what effect each individual characteristic has on innovation. The relevant characteristics include:

- **Stringency** – How ambitious is the environmental policy objective relative to business-as-usual?
- **Predictability** – What effect does the policy measure have on investor uncertainty; is the signal consistent, foreseeable, and credible?
- **Flexibility** – Does it let the innovator identify the best way to meet the objective (whatever that objective may be)?
- **Depth** – Are there incentives to further improve one’s performance regardless of the level of performance already achieved (down to zero emissions)?
- **Incidence** – Does the policy target directly the externality, or is the point of incidence a “proxy” for the pollutant?

While many taxes and tradable permit systems score well on most of these criteria, there is no hard and fast rule which allows for a unique mapping from instrument type (e.g. taxes, regulations) to each of these five characteristics. For this reason, **assessment of the effects of environmental policy on technological innovation requires a close analysis of both the characteristics of the environmental policy framework and the technological areas** which it is likely to affect. In this book, we report on research in which the policy framework is represented in a variety of different ways, and in a manner which is suitable for empirical analysis. This includes the results of surveys of business representatives, reviews of specific national regulations and directives, and the contents of international environmental agreements.

**Stringency of environmental policy is important but predictability and credibility of policies in the longer run matter as well.**

In the first part of this volume, the potential impacts of environmental policy on innovation are analysed in the context of general environmental management (covering a broad range of air, water, and waste management technologies). A number of key conclusions emerge from this work:

- Not surprisingly, it has been found that **policy stringency plays a significant role in inducing innovation**. More specifically, based on evidence from a broad cross-section of countries, it is found that the stringency of environmental policy has a positive impact...
on the likelihood of developing innovative means of mitigating environmental impacts (such as air and water pollution and managing solid waste). A more ambitious policy will provide greater incentives for polluters to search for ways to avoid the costs imposed by the policy. This finding is largely confirmed by the research presented on the more specific policy measures and technology fields assessed in the second part of this volume.

● However, it is not just the “level” of the price of polluting which matters. **Predictability and credibility of the price over the longer term are also important.** Signals that are difficult to predict over time encourage investors to postpone investments, including the risky investments which lead to innovation. In the face of unpredictability there is an advantage to “waiting” until the policy dust settles. By adding to the risk which investors face in the market, an “unpredictable” policy regime can serve as a “brake” on innovation, both in terms of technology invention and adoption. Frequently changing policy conditions impose a cost, and such instability should be avoided.

● In addition, the more **flexible** (or technology-neutral) a policy regime is, the more innovation takes place. Since future trajectories of technological change cannot be foreseen, it is important to give innovators the incentive to search across a wider “space” to identify the best means of complying with regulations. Flexibility unleashes efforts to search for new innovations, some of which may be only improvements on existing technologies. This implies that rather than prescribing certain abatement strategies (such as technology-based standards), wherever possible governments should give firms stronger incentives to seek out the best means to meet a given environmental objective.

> **Flexibility of policy regimes encourages innovation and ensures that markets are not fragmented across different countries.**

Research in other fields has identified **international technology transfer as an important means of bringing about improved welfare.** This is particularly true in the case of environmental technologies where many negative impacts cross borders. Based on results presented in this book, two environmental policy factors appear to have an influence on the flow of technologies internationally: A) the degree of flexibility of the domestic policy framework in both the source and the recipient countries; and B) the degree of international policy co-ordination. If environmental policy is prescriptive and uncoordinated this can result in fragmented technology markets, with the potential market for any innovations split across different policy jurisdictions.

● The effect of the flexibility of national policy regimes on the international diffusion of environmental technologies has been assessed. The results confirm that **flexibility of policy regimes not only increases domestic rates of innovation, it also ensures that markets are not fragmented across different countries.** With prescriptive regimes the market will be fragmented into different regulatory silos. Given the risks associated with expenditures on research and development, and the economies of scale required to recover such expenditures, it is important that regulatory regimes in “source” countries not constrain the potential markets for any induced innovations. In addition, flexible policy regimes in “recipient” countries allow potential adopters of innovations to access a much wider range of technologies available on international markets.
We assessed the role of international policy co-ordination through adherence to multilateral environmental agreements. More specifically, we examined whether adherence to a series of international agreements on reducing SO\textsubscript{X} and NO\textsubscript{X} emissions (the Convention on Long-Range Transboundary Air Pollution (LRTAP), and the related Protocols) has induced the transfer of technologies between signatories. We argue that transfer of technology between signatories to an agreement can be a way of encouraging adherence, providing an inducement for upwind countries to participate. Some descriptive evidence is presented but more formal analysis might be addressed in future work.

While general policy conditions are clearly important factors driving the development and international diffusion of environmental technologies, a more precise assessment of the effects of policy on innovation requires an analysis of the effects of specific policy instruments. The second part of this volume includes detailed case studies of the potential impacts of environmental policy on innovation in specific fields (incl. regional air pollutants, motor vehicles, solid waste and recycling, green chemistry). A number of conclusions emerge from the different “sectoral” studies.

First, in follow-up work on the role of multilateral environmental agreements in inducing international technology transfer, we assessed the specific role of the LRTAP Protocols in encouraging transfer of air pollution abatement technologies between signatories. The major finding is that there is a positive effect on technology transfer between pairs of countries which have both joined the LRTAP Protocols. It must be emphasised, however, that while the Protocols place emphasis on co-operation across signatories, there are few explicit incentives. The finding presented may be due to the simple sharing of information on available abatement technologies through intensive co-operation – that is, through regular conferences and sharing of documentation. While on the face of it removing information gaps may seem relatively unimportant relative to other factors, improved information flows across borders might have been pivotal in introducing more ambitious national policies.

Appropriate sequencing of policy measures is important.

Second, in many cases different instruments are introduced in combination, sometimes with different but related environmental objectives. In this vein, work has been undertaken in the area of alternative-fuelled vehicles to assess the relative importance of fleet-level fuel-efficiency standards, after-tax fuel prices, and public support for R&D. Based on precise characterisations of the policy instruments implemented in different countries, the results indicate that relatively minor changes in a performance standard or automotive fuel prices would yield effects that are equivalent to a much greater proportional increase in public R&D budgets. However, there are significant differences between types of technologies – electric and hybrid vehicles. For example, in the case of electric vehicles the role of after-tax fuel prices is statistically insignificant, but standards play an important role. Conversely, for hybrid vehicles it is after-tax fuel prices which are statistically significant and not standards. R&D plays a much more important role for electric than hybrid vehicles.

These results may indicate the importance of the sequencing of policy measures. Relative prices may have a lesser role to play than ambitious performance standards or significant
public support for research the further a technology is from being directly competitive with
the incumbent technology (petrol- and diesel-driven technologies). While in theory a price
sufficient to induce an equal level of innovation for such technologies could be introduced,
such a measure would likely be politically infeasible in practice. Moreover, even if
introduced, it may not be perceived as credible over the longer-term.

For technologically mature sectors, behavioural
and organisational innovations are the most likely
responses to greater environmental stringency.

- Third, a case study of material recycling and waste management technologies has been
conducted through a descriptive analysis of the correlation between the introduction of
important policy measures and patent counts for different waste streams. The results
indicate the possibility that the first wave of policies (end of the 1980s, beginning of
the 1990s) has produced an innovation response, but their effect is now less pronounced.
This result is underlined in the analysis of specific waste streams (end-of-life vehicles,
packaging, composting), where there seems to be a strong and positive link between
policy action and innovation performance at the beginning of the 1990s, but this link is
less clear in the last fifteen years.

One possible explanation for this finding is that the sector is technologically mature,
relative to other areas of environmental innovation, a point which is reflected in the data
presented in the first chapter. Rates of innovation have been declining, with the exception
of some emerging economies. However, even there the rates are lower than for innovation
overall. Nonetheless, in many countries recycling rates have increased and waste
generation per unit of economic activity is beginning to fall. For mature sectors, responses
to environmental policy shocks may be reflected in behavioural and organisational
innovations, rather than in terms of technological inventions.

- The final case study focuses on “green” chemistry, which is different insofar as the
nature of the patent classification system did not allow for the identification of the
“population” of green chemistry patents. However, some specific fields were identified.
Among these, biochemical fuel cells and green plastics were the two areas that have
shown the most growth. Other areas are past their innovation peak: notably, totally
chlorine-free pulp and paper technology and biodegradable packaging. The trends in
selected areas of industrial biotechnology are interesting in that this is a cornerstone of
green chemistry, and it is hoped that many future green technologies will emerge from
this area. While patenting in industrial biotechnology has increased, it has not increased
more than the rate for the chemistry sector overall.

Qualitative review of the role of public policy indicates that innovation in this area
requires avoiding differentiated treatment of new versus existing chemicals. If producers
are allowed to continue relying on “grandfathered” existing chemicals, incentives for
development of new, less environmentally harmful substances will be undermined.
In addition, the frequent use of support measures (R&D support, public procurement,
grants, and awards) to encourage innovation in this area means that policy makers face a
difficult task in identifying particular technologies or activities to be supported in the face
of imperfect information and uncertainty over future trajectories. As with other areas, a
balance of policy flexibility and predictability is essential.