Unclassified **ENV/EPOC/WPNEP(2002)7/FINAL**

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

29-Nov-2002

English - Or. English

ENV/EPOC/WPNEP(2002)7/FINAL
Unclassified

ENVIRONMENT DIRECTORATE
ENVIRONMENT POLICY COMMITTEE

Working Party on National Environmental Policy

Decision-Making and Environmental Policy Design for Consumer Durables

Nick Johnstone: Email - Nick.Johnstone@oecd.org; Tel. 33-1 45247922

JT00136027

Document complet disponible sur OLIS dans son format d'origine
Complete document available on OLIS in its original format

English - Or. English

FOREWORD

This report was prepared as part of the OECD project on Sustainable Consumption. It was drafted by Nick Johnstone, Nadia Caïd, and Ysé Serret under the supervision of the Working Party on National Environmental Policies (WPNEP). It benefited from extensive comments provided by Jean-Philippe Barde as well as delegates to the WPNEP. The paper is published under the responsibility of the Secretary-General of the OECD.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Energy-using consumer durables such as motor vehicles, household appliances, and electronic equipment often have significant environmental impacts. These arise at all stages in the production process, from resource extraction, through to production, use and finally disposal. Local, regional and global air pollutants from are perhaps the most obvious examples of the potential impacts on the environment. However, other issues such as water pollution can be equally important for specific kinds of consumer durables. In addition, many energy-using consumer durables generate non-hazardous and hazardous solid waste generation at the end-of-life phase. Natural resource use associated with consumer durables - principally water and energy - may also have adverse environmental impacts.

Moreover, these different types of impact can be related in complicated ways. In some cases, efforts to mitigate one type of environmental impact at one stage of production may have positive consequences at other stages of production. In other cases, efforts to reduce one type of impact will increase other types of impact. However, there may also be trade-offs, with reduced impacts associated with one stage of production resulting in increased impacts elsewhere in the production chain, or increased impacts of a different type altogether. The need to ensure that policy measures reflect this interdependence poses an exceedingly complicated challenge to policymakers.

This is further complicated by the fact that decision-making by firms and households with respect to the design, production, use and disposal of consumer durables is not well understood. This is due in part to their long-lived nature, resulting in long response lags and significant volatility in demand. Issues such as the date of replacement of the existing stock of consumer durables, as well as the diffusion rates for new types of consumer durables, are only imperfectly understood. Indeed, improving predictions concerning cycles in household consumer expenditures on consumer durables remains a significant challenge for empirical economists.

However, it is also due to the complexity of design and manufacture. Signals concerning different product attributes - including those related to the environment - are not always transmitted up and down the supply chain in an efficient manner. In particular, there may be information failures, missing markets or other types of market failure which result in the imperfect transmission of incentives for product design and manufacture.

As such, it is of significant environmental importance to know how consumers and firms make their decisions regarding consumer durables. Do the choices made by households reflect an optimal balance between the costs and benefits of investment in resource-efficient technologies? Do firms have sufficient incentives to develop newer, less environmentally-damaging consumer durables? What are the incentives for firms and households to design and use more recyclable or less polluting types of consumer durables?

All of these questions need to be addressed if policymakers are to introduce appropriate policies to reduce environmental impacts from durable design, production, use and disposal. This scoping report reviews some of the challenges facing policymakers as they seek to design environmentally effective and economically efficient environmental policies in this area, by looking at two broad sets of issues:

- Firstly, household decision-making concerning the choice between alternative consumer durables, the timing of replacement and the nature of use; and,

- Secondly, firm-level decision-making concerning the design and manufacture of consumer durables.

On the basis of an understanding of the review of analyses of these two sets of issues, principles for policy design are drawn. These principles can be summarised as the need to ensure that policies are:

- *Targeted* as closely as is administratively feasible (at reasonable cost) to the environmental damage which is to be mitigated;

- *Flexible* enough to allow different households and firms to respond efficiently to the policy measure;

- *Coordinated* across instruments which are designed to address different environmental impacts, but which are related either technologically or environmentally;

- *Integrated* up and down the product life-cycle from resource extraction through production and use, to disposal; and,

- *Responsive* to the conditions which prevail in different markets for consumer durables, including market barriers and failures.

Perhaps most importantly, given the important dynamic issues associated with decision-making concerning consumer durables, policies should also provide the degree of certainty needed for households and firms to respond optimally over lengthy planning horizons.

DECISION-MAKING AND ENVIRONMENTAL POLICY DESIGN FOR CONSUMER DURABLES

INTRODUCTION

Consumer durables can be defined as those household goods which provide continuous or repeated use over a period of at least one year. For the purposes of this report, they will also be defined such as to refer only to goods with engines, motors or which are powered by electricity or a primary fuel. They include household appliances (i.e. washing machines, refrigerators), consumer electronic equipment[1], motor vehicles, etc.

Energy-using consumer durables often have significant environmental impacts. These can arise in resource extraction, production, use and disposal. Local, regional and global air pollutants from are perhaps the most obvious examples of the potential impacts on the environment. However, other issues such as water pollution can be equally important for specific kinds of durables. In addition, many energy-using consumer durables generate non-hazardous and hazardous solid waste generation at the end-of-life phase. Natural resource use associated with consumer durables - principally water and energy - may also have adverse environmental impacts.

Moreover, these different types of impact can be related in complicated ways. In some cases, efforts to mitigate one type of environmental impact may have positive consequences for other types of environmental impact. In other cases, there will be trade-offs. The need to ensure that policy measures reflect the interdependence of these environmental impacts presents an exceedingly complicated challenge to policymakers.

This is further complicated by the fact that decision-making by firms and households with respect to the design, production, use and disposal of consumer durables is not well-understood. This is due in part to their long-lived nature, resulting in long response lags and significant volatility in demand. However, it is also due to the complexity of design and manufacture. Signals concerning different product attributes are not always transmitted up and down the supply chain in an efficient manner.

As such, it is of significant environmental importance to know how consumers and firms make their decisions regarding consumer durables. Do the choices made by households reflect an optimal balance between the costs and benefits of investment in resource-efficient technologies? Do firms have sufficient incentives to develop newer, less environmentally-damaging consumer durables? What are the incentives for firms and households to design and use more recyclable consumer durables?

All of these questions need to be addressed if policymakers are to introduce appropriate policies to reduce environmental impacts from durable design, production, use and disposal. This scoping report

1. Consumer electronics includes televisions and associated equipment, audio equipment, home computers and home office equipment such as faxes or printers.

will review some of the challenges facing policymakers as they seek to design environmentally effective and economically efficient environmental policies in this area. The report builds on the work undertaken in the context of the project on “Sustainable Consumption”. It does not review existing environmental policy in Member countries with respect to consumer energy-using durables, but merely draws attention to some of the important issues which need to be addressed in designing such policies.

This will be explored by looking at two broad sets of issues:

- Firstly, household decision-making concerning the choice between alternative consumer durables, the timing of replacement and the nature of use; and,

- Secondly, firm-level decision-making concerning the design and manufacture of consumer durables.

On the basis of an understanding of the review of analyses of these two sets of issues, policy implications are drawn. However, before proceeding to a review of household and firm-level decision-making with respect to consumer durables, it is important to first look at their environmental implications.

ENVIRONMENTAL IMPACTS OF CONSUMER DURABLES

The production, use and disposal of consumer energy-using durables represents a significant proportion of households' total impact on the environment. This is significant since not all of these impacts are effectively internalised through environmental policy measures. As such, consumers and producers do not always face appropriate incentives to reduce such impacts.

Consumer durable use is responsible for a large portion of total household electricity and fuel use. As such, the use of durables contributes significantly to CO_2 emissions, as well as emissions of other regional and local air pollutants. The precise contributions will, of course, depend upon fuel choice in motor vehicles and heating appliances, as well as the fuel mix used by the electricity supply industry. However, in most countries, the contribution is substantial. In addition, consumer durables have an environmental impact through water extraction and water pollution either directly with water-using durables (washing machines and dishwashers) or indirectly with the growing use of water for energy generation purposes (see OECD, 2001*a*).

Impacts from motor vehicle production and use are well-known. In Table 1 the relative importance of transport emissions in total economy-wide emissions for four different air pollutants is shown. Car use alone is responsible for approximately 90% of carbon monoxide emissions from mobile sources, and somewhat less for the other pollutants (80% for hydrocarbons, and 50% for nitrogen oxides) (see OECD, 1995). In 1990 car use was responsible for approximately 1,800 million metric tonnes of carbon dioxide (see OECD, 1995). However, it must be emphasised that by no means all car use is undertaken by households.

Air pollution emissions from “non-road” engines can also be significant. In the United States there are approximately 12 million marine engines. In addition, snowmobiles, lawnmowers, and off-road motorcycles can be significant sources of air pollution. The EPA has estimated that altogether emissions from these engines equal 11% of hydrocarbons, 9% of carbon monoxide, and 3% of oxides of nitrogen emission from mobile sources (see EPA, 2000).

Table 1. Transport and household-related emissions of air pollutants in the OECD in 1997

Pollutant	Household emissions (% of total economy-wide emissions)	Transport emissions (% of total economy-wide emissions)
CO	11%	85%
SO_x	6%	4%
NO_x	5%	52%
VOC	5%	44%

Source: OECD (2001)c.

However, for other energy-using durables, such as kitchen appliances, electronic equipment can also make significant contributions to environmental degradation. (Table 1 provides data for the same four air pollutants.) Residential electricity use is one of the fastest growing sectors of energy use in the OECD. From 1990 to 1998 demand grew from 1911 TWh to 2171 TWh, representing an average annual growth rate of 1.6 per cent. The associated CO_2 emissions grew from 1070Mt in 1990 to 1129Mt in 1998 (see IEA, 2002).

The share of residential electricity used by consumer durables (household appliances and consumer electronics) has grown significantly over recent years as shown in the estimated consumption by end use for the OECD countries from 1990 to 2000 (see IEA, 2002). Energy consumption associated with clothes dryers is estimated at 71 TWh in 2000, up 32 per cent from 1990. Dishwashing energy consumption rose by 26.7 per cent over the same period. Energy consumption for space cooling was estimated to be 156 TWh in 2000, up 15.6 per cent from 1990.

Among consumer electronics, televisions have the highest overall energy use. Television electricity consumption increased by 17.2 per cent between 1990 and 2000. By itself, "standby power"[2] of appliances and other electrical equipment in the residential sector of OECD Member countries is estimated to be responsible for 1.5 per cent of total electricity consumption and to contribute 0.6 per cent (68 million tonnes) of CO_2 emissions from the electricity sector. This represents annual CO_2 emissions of 24 million European-type cars (IEA, 2000).

The trend for increased energy used by durables is going to be fuelled by the penetration of ICT applications. According to some estimates (Aebischer, 2000), electricity consumption for a typical home multimedia platform may grow from around 350 kWh a year in 2000 to 1400 kWh a year per household in 2020. This represents an average annual increase of just over 7%. The implications for greenhouse gas emissions are significant with a possible extra 220 million metric tonnes of CO_2 from OECD countries in 2020 (see IEA, 2002).

Some data on environmental impacts are available for personal computers, although it is difficult to distinguish between household use and other use. Nonetheless, Table 2 summarises some of the main impacts from both computer manufacturing sectors. [It is important to note that this includes both direct and indirect (i.e. supply chain) impacts, an issue discussed at greater length below. See EIO-LCA, 2001.]

2. Standby power use depends on the product. At a minimum, standby power includes power used while the product is performing no function. For many products, standby power is the lowest power used while performing at least one function (see IEA, 2001).

Table 2. Overall comparison of computer manufacturing and services

	Computers
Effects	1997
Total Supply Chain Purchases ($ million)	271,000
Electricity Used (Mkw-hr)	42,785
Conventional Pollutants Released (metric tonnes)	671,000
Fatalities	49
GHG's Released (million metric tonnes CO_2 equivalents)	57
Ores Used (million metric tonnes)	20
RCRA Waste Generated (million metric tonnes)	3.8
External Costs Incurred (median, $ million)	1,600
Toxic Releases and Transfers (metric tonnes)	92,000
Weighted Toxic Releases and Transfers (metric tonnes)	757,000

One report (Atlantic Consulting, 1998) estimated that 70% of all effects in a computer's life cycle occur during the use phase. In a study of personal computers in the European Union, use phase effects for a personal computer were estimated to be 0.45 tonnes of CO_2 equivalents and 10 GJ of energy (presumably mostly via electricity). (For more detailed information on the direct, indirect and use-phase impacts of personal computers please see OECD, 2001*b*.)

Energy-using consumer durables can also be significant contributors to hazardous and non-hazardous solid waste generation. For instance, it has been estimated that approximately 500,000 refrigerators are discarded every year in the Netherlands, with an average mass of 36 kg. (see Lambert *et. al*., 2001). While this does not represent a large proportion of the total solid waste flow, given the presence of CFC's, PCB's and other potentially harmful elements in refrigerators the nature of solid waste management and materials recovery is important.

As of 1998, there were 6 million tonnes of “Waste from Electrical and Electronic Equipment” (WEEE) (4% of municipal waste) per year in the EU (CEC, 2000). When electronic products are placed in landfills, the materials have the potential to leach into the environment. For example, lead has historically been used in cathode ray tubes for computer monitors. A University of Florida study in 1998 showed that leachate levels of lead from computer monitors are up to three times higher than leachate standards in the United States (see OECD, 2001*b*).

Environmental Impacts Across the Product Cycle

Analysis of the environmental effects associated with particular products has usually focused upon their direct emissions and resource requirements. This product-specific analysis is useful. However, increasingly, environmental concerns focus on a broader question: What are the life cycle effects of a product, considering both the direct effects in use, as well as the indirect effects upstream in production and downstream at the post-consumption phase?

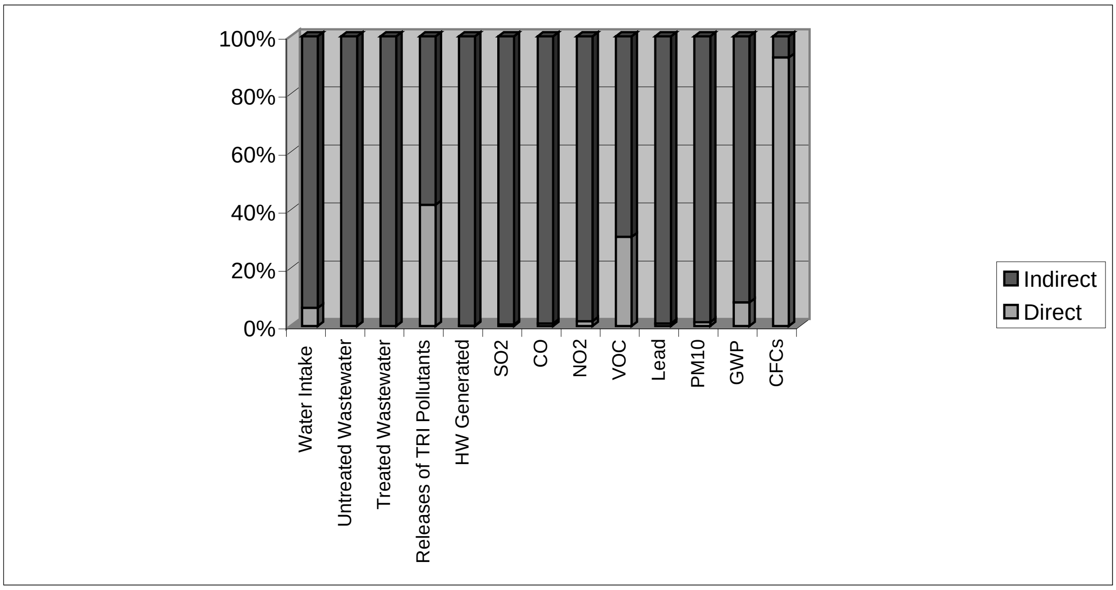
Thus, in recent years there has been a growth in interest in looking at the environmental impacts of products, from the “cradle to the grave”. Life Cycle Assessment (LCA) is a method for systematically assessing the environmental burdens associated with a product throughout its entire life cycle (SETAC, 1993). The assessment encompasses extraction and processing of raw materials; manufacturing; transportation and distribution; use, re-use, and maintenance; recycling; and final disposal.

Although many variations exist, the methodological framework for LCA following the Society of Environmental Toxicology and Chemistry (SETAC) guidelines has been internationally recognised and generally agreed upon (Sousa *et. al.* 1999). Despite continuing problems and current development and debate, a number of traditional manufacturing companies are now attempting to apply LCA within their existing business culture. In the first instance, most are beginning work in this field by avoiding the complexities of a full LCA. Instead, they are attempting to complete 'restricted' studies, with clearly defined limits and boundaries. Thus, much work is being carried out at different levels: levels of completeness, commitment of resources and levels of detail (Hook, 1995).

A less cumbersome means of examining environmental impacts over the lifecycle involves the use of environmentally-augmented economic input-output tables. Since such measures draw upon data for the country as a whole, anomalous firm-specific and location-specific is less of a concern. However, use effects must be treated separately since input-output tables do not provide information on the consumption of durables. Fortunately, there is usually more reliable data readily available for such effects.

Figure 1 shows the direct and indirect impacts from the production of household refrigerators and freezers.[3] Volatile organic compounds, toxic releases, and (not surprisingly) cholorofluorocarbons all have significant direct impacts, in excess of 20% of total impacts. Conversely, in the case of computer manufacturing, there is no simple environmental impact (of those listed) for which direct production contributes more than 5% of total impacts. Part of this is attributable to the slightly higher proportion of the value indirect inputs in total value of shipments in the computer industry. However, even with this caveat it is clear that the different balance between direct and indirect impacts for different types of consumer durable should be borne in mind.

Figure 1. Relative weight of direct and indirect environmental impacts from the production of household refrigerators and freezers



Environmental Impacts Across Pollutants and Media

Significantly, there is also potential for "shifting" of environmental burdens between different types of emissions and even between environmental media at particular points in the product chain. Depending upon substitution possibilities in production and consumption, constraining emissions (or resource use) at one point in the life cycle may result in increased emissions (or resource use) of another sort. There may even be shifting of impacts between media.

3. Data calculated from the Economic Input-Output Life Cycle Assessment (EIO-LCA) model, developed at Carnegie Mellon University. See Lave *et al*. (1995) and Hendrickson *et al*. (1998) for descriptions of the model.

Motor vehicles provide interesting examples of potential substitution. For instance, measures to improve fuel-efficiency (and thus reduce CO_2) lead to higher combustion temperatures and thus higher NO_x emissions (see Albrecht, 2001, for a discussion and some evidence). To find an optimum for controlling pollutants, the trade-off between CO_2 and NO_x controls had to be managed.

When catalytic converters were introduced this problem disappeared, as overall reductions of more than 80% of all pollutants and air toxic were achieved. However, there was a slight reduction of fuel-efficiency (and thus increase in CO_2 emissions) of a few percentage points. In addition, nitrous oxide (N_2O) emissions were 3 to 5 times higher compared to vehicles without catalysts. However, it is worth noting that this increase is of minor importance, as transport contributes only 3% to total N_2O emissions (primarily from agriculture), and is less than 1% of total greenhouse gas emissions (ECMT, 2001).

Another area in which such substitution can occur relates to materials recycling. In many cases the recycling of metals and other valuable materials from end-of-life consumer durables will result in other ancillary benefits such as reduced hazardous waste generation or air pollution, in addition to reduced resource use. However, this is not necessarily always the case. Lambert *et al*. (2001) discuss the conditions under which increased recycling could conceivably result in increased direct energy use and CO_2 emissions. However, once the upstream energy savings from reduced primary metal extraction are included, the ancillary benefits are positive.

HOUSEHOLD DECISION-MAKING WITH RESPECT TO DURABLE CHOICE, REPLACEMENT AND USE

Demand for consumer durables is not well understood. This is due in part to the demand for most consumer durables is only one contributor toward overall demand for the underlying service (i.e. dwelling warmth, personal mobility, etc.). As such, it is complementary with - and substitutable for - demand for a number of other related goods and services. Moreover, the services are provided by goods with economic and technical lives of uncertain length. In addition, the services are provided jointly by the durable with complementary inputs (i.e. energy and water). As such, the factors driving demand for the goods are difficult to understand precisely.

In this section we will explore some of the issues involved in household decision-making with respect to durable choice, replacement and use which have important environmental implications. However, the focus is on private costs and benefits (i.e. financial costs and savings from energy-efficient refrigerators), rather than on private demand for non-financial public environmental goods (i.e. reduced ozone depletion from CFC-free refrigerators). The latter set of issues have been discussed previously (see OECD, 2001*e*).

Decisions Concerning the Choice between Alternative Durables

Households choose between alternative durables which fulfil the same function on the basis of a variety of factors, including relative price and qualitative characteristics. For instance, a number of empirical studies have been conducted using “hedonic” methodologies to determine which factors are important in the household's choice of motor vehicle (see Witt, 1994; Mannering and Winston, 1985; and Berry *et al*., 1996, for examples.). More generally, a number of studies have show that psychological, social and cultural factors play a significant role in the consumer’s eventual choice (Erasmus 1998).

However, a central feature of recent policy debates, particularly those concerning efforts to reduce carbon dioxide emissions, has been the observation that households (and firms) often do not invest in a variety of technologies which appear to be cost-effective on the basis of simple financial appraisal analyses. For instance, a study by the National Academy of Sciences (1991) concluded that energy-related carbon dioxide emissions could be reduced by 37% in the United States through implementing cost-effective technologies. Numerous other studies have reached similar conclusions (see Table 3).

Many of the investments required to achieve such gains have high initial capital costs, but lower operating costs. Thus, whether or not such investments are truly cost-effective depends upon the discount rate applied by households. The discount rates used by consumers indicate the extent to which they will invest in energy conservation measures which may be costly in the short-term, but which result in financial savings in the medium-term and long-term. It is a key element in predicting the sales of energy-efficient appliances, and thus the demand for energy itself.

Implicitly, all households apply a discount rate, ideally reflecting their rate of time preference (i.e. the extent to which they prefer equal benefits received this year relative to next year) and the opportunity cost of capital (i.e. the relevant prevailing interest rate). A number of empirical studies have been undertaken to determine precisely what this discount rate is for investments in energy-efficient consumer durables.[4] In general, it is found that households would have to have discount rates well in excess of 20% in order to explain why they choose less energy-efficient durables in favour of more efficient alternatives. (Results from specific studies are summarised in Table 3.)

Table 3. Estimates of implied discount rates for various consumer durables

Source	Appliances	Estimate
Dubin and McFadden (1984)	Space Heating and Water Heating	20%-30%
Gately (1980)	Refrigerators	> 45%
Ruderman et al (1987)	Heating & Cooling Equipment and Residential Appliances	> 20%
Verboven (1999)	Motor Vehicles	5%-13%
Train (1985)	Refrigerators	40%->100%
Hausman (1979)	Air Conditioners	25%
Meier and Whittier (1983)	Refrigerators	58%

Thus, it is of primary importance to understand the reason why households have such a high discount rate revealed in their purchase of appliances and durable goods. This could contribute to a great extent to the understanding of the most efficient means to encourage improvement of energy efficiency and reduction of pollution effects associated with the use of consumer durables. Indeed, the very notion of whether consumers behave rationally when making decisions regarding energy use and energy technologies has been a question of some debate: Economists say “generally yes” while engineering-based researchers say “definitely not”.

Technology analysts point to the observed efficiency gap – the difference between the level of energy efficiency actually achieved and the level judged cost-effective by standard financial criteria – as clear evidence that consumers are not behaving rationally. At this point, it is easy to extend this argument with the one which recommends governments to intervene with equipment performance standards, demand side management programs and related policy measure (Carlsmith *et al*. 1990).

4. The concept of implicit discount rates is a test criterion used to evaluate the effectiveness of individual decisions or observed market outcomes. The analyst computes the discount rate required to explain observed behaviour. If market participants maximise utility in accordance with standard economic theory, implicit discount rates will equate with the rate of return available on alternative investments of comparable risk. The theory assumes that observed decisions are consistent with cost minimisation.

However, economists often dispute this claim and assert that the application of simple financial appraisal methods may be misleading. The interaction of producers and consumers in competitive markets should lead to the implementation of all energy-efficient technologies that are truly cost-effective and the perceived "efficiency gap" may be based on the mis-measurement of true costs and benefits at the level of the individual household (Sutherland, 1991). Many of the "market barriers" identified by technology analysts may be understood as market failures generated by problems of imperfect information and transaction costs. Thus, the existence of the efficiency gap may be reconciled with the hypothesis that consumers make energy-related decisions in a fully rational manner (Sanstad and Howarth, 1994; Jaffe and Stavins, 1994).

One important factor, which is often overlooked in simple financial analyses, is the heterogeneity of users. A technology may be cost-effective for some parts of the population but uneconomic for others (Golove and Eto, 1996). Although an analysis based on average users may demonstrate the cost effectiveness of a particular technology, in practice we may observe low rates of adoption stemming from the heterogeneity in respect of the population. Only those households above the mean rate of return will adopt the technology (and they will do so only once), while all those below the mean rate of return will not do so. Thus, the more heterogeneous the population, the greater the variation in rates of return, the lower the rate of adoption.[5]

This is significant since a population is generally heterogeneous with respect to the returns it obtains from the energy it uses. A good example is provided by the evaluation of the benefits of replacing an incandescent light bulb with a compact fluorescent lamp (CFL). Depending upon assumptions made about the average hours the bulb will be used, some segments of the population will not be net beneficiaries from the investment, even if on average the investment appears to be cost-effective. The same would, of course, be true of households, which use their motor vehicles infrequently.

Perhaps most importantly, households will differ with respect to access to household savings and credit. Not surprisingly higher lower-income households tend to have implicit discount rates than higher-income households, as revealed in purchases of energy-using consumer durables (see Dubin and McFadden, 1994; and Brill *et al*., 1999, for discussions). While this can be explained as "efficient" behaviour, there may also be market failures at play such as imperfect markets for household credit. (These issues are taken up below.)

The functional attributes of the alternatives also need to be properly understood. Qualitative choice analysis takes into account not only prices and operating cost but also qualitative factors associated with the durable that affect consumer's willingness to pay for energy efficiency. Using the same example as above, if the quality of light provided by a compact fluorescent lamp (CFL) is less desirable than that provided by an incandescent bulb, this reduction in benefit (or additional cost) must also be included in the analysis. Such findings are consistent with a range of research using discounted cash flow models that compare the present value cost of energy-efficient equipment against equipment that currently is producing equivalent energy services.

There may be other costs as well, such as the acquisition of information about newer energy-saving technologies. In the case that manufacturers supply energy-efficient technologies that would provide clear *ex post* benefits to buyers, it is of primary importance that characteristics of the product are readily observed by the consumer in the course of market transactions. Economic theory suggests that firms would have an incentive to engage in advertising and other strategies to improve the information held by consumers provided that the benefits exceeded the costs (Howarth and Sanstad, 1995).

5. Assuming unbiased distributions in the rate of return.

There can also be externalities associated with the adoption of new consumer durables. Many of these relate to the “public good” nature of information. For instance, investment in a particular product by one household can generate valuable information (i.e. performance reliability, financial viability, etc.) for other potential adopters (see Howarth *et al*., 2000). These “consumption externalities” can be pervasive, particularly for products, which are particularly innovative. Unless a threshold level of adoption is achieved, information concerning its reliability and viability will not be diffused throughout the economy.

In general, consumers appear to be poorly informed concerning the net financial benefits of energy efficiency. Behavioural studies suggest that people use “rules of thumb” which deviate from the norms of substantive rationality, and thus bias their decisions against energy-efficient technologies (Kempton and Montgomery 1982; Kempton and Layne, 1994; and Stanstad and Howarth, 1994*a*). Some studies find that consumers systematically apply incorrect and incomplete information (Stern 1986). It is for such reasons that consumer education and product labelling programmes are often promoted by policymakers. (This is discussed below.)

Recent developments in investment theory may provide an alternative explanation for such high revealed discount rates. When investments are irreversible, uncertain and flexible in time, the new theory shows that a more cautious approach to undertaking the investment is optimal. (Metcalf and Rosenthal, 1995). If an investment is irreversible it cannot be undone regardless of the return that ultimately is realised. Thus, if prices rise then the investment will *ex post* turn out to be profitable and if prices fall, the investment will be unprofitable *ex post*. Uncertainty refers to the possibility of different future returns from this investment that *ex post* may provide a low (possibly negative) rate of return. Flexibility means that investors have some choice about the timing of the investment, and thus can postpone the investment to see if more information comes along helping in determining if the investment will provide a high rate of return ex post. Investment in consumer durables is notoriously cyclical, indicating the very important degree of flexibility, which exists. (Attansio, 1998.)

Thus, uncertainty about future energy prices, and therefore the actual savings from the use of more energy-efficient technologies, combined with the irreversible and flexible nature of the investment, make the appropriate discount rate for analysing the net present value of energy savings significantly greater than is typically used in the calculations that suggest the existence of market failure (Jaffe and Stavins, 1994). In effect, the greater the degree of uncertainty about future energy prices, the greater the risk for the household of investing in more expensive energy-saving durables. High discount rates may be explained by the fact that consumers considering energy efficiency investments demand high rates of return because of the perceived risks of such investments. Therefore, uncertainty concerning energy prices might rationally explain the prevalence of high implicit discount rates.

Decisions Concerning Durable Stocks, Longevity and Replacement

Rising income levels, and electronic and other innovations have contributed over the years to an increasing inventory of durable goods. For instance, income elasticities for motor vehicles are often in excess of 1, meaning that vehicle sales rise more than proportionately with income. For instance, Jørgensen and Wentzel-Larsen (1990) estimated an income elasticity of 1.1 for Norway. McCarthy (1995) estimated an income elasticity of 1.7 for the United States. (For estimates from Finland see Suoniemi and Sullström, 1995.)

Growth in the stock of durables is also related to technological change. For instance, in the area of information and communications technologies, more and more products will become obsolete. Existing studies indicate that the majority of such equipment is stored in warehouses or in households. Regardless, the ultimate sink of such efforts continues to be landfills. As the volumes of ICT equipment purchases grow, useful lives of products decrease, and technological changes force upgrades, the volume of equipment going to landfills will increase. Some particular concerns are the expected transition to digital television, mobile telephones, and portable digital assistants. Digital television broadcast standard phase-ins will abruptly create hundreds of millions of old televisions in the United States. (OECD, 2001*b*).

Thus, with growing economies and technological change there are larger stocks of durables in many OECD countries. Table 4 gives data on household appliance ownership in 1973 and 1997 in selected OECD Member countries. The high penetration of such goods has led current sales to consist mostly of replacement purchases (Fernandez, 2001). For instance, in 1994 approximately 75% of appliance sales were accounted for by replacements. Thus, it is important to examine the longevity of goods, or more specifically the determinants of the point at which households replace their current possessions with new ones.

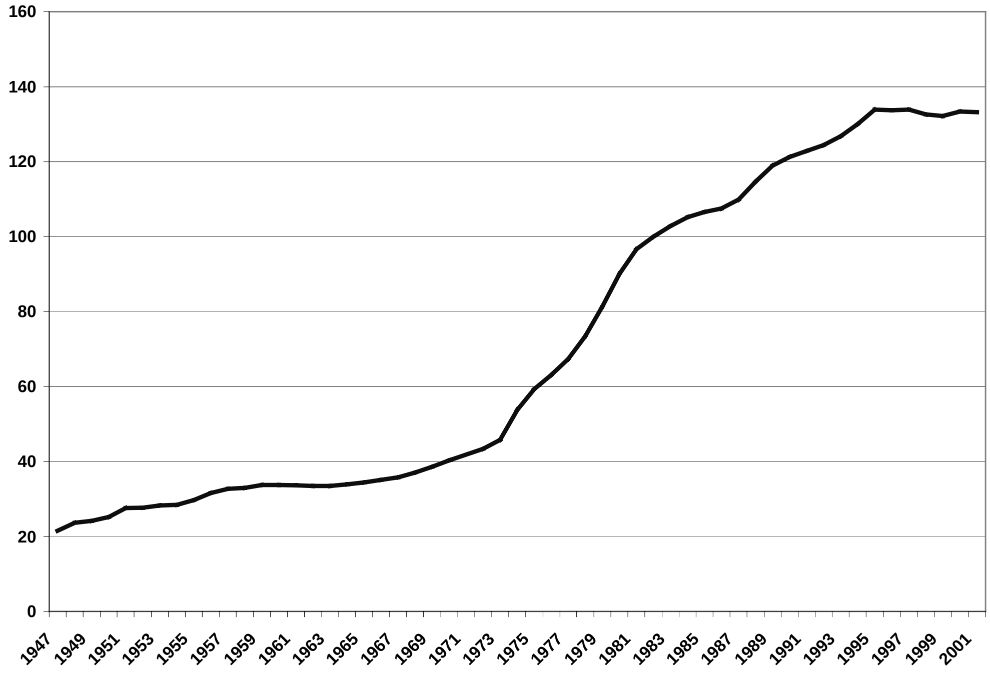
Table 4. Household appliance ownership for selected OECD countries, 1973-1997 (units per 100 households)

		Refrigerators & combination units	Freezers	Clothes washers	Clothes dryers	Dish-washers	Air conditioners
US	1973	100	34	70	38	25	47
	1997	115	36	79	55	50	86
JAPAN	1973	104	na	101	na	na	15
	1997	120	na	107	23	na	191
UK	1973	73	8	68	4	3	Na
	1997	104	42	92	51	21	Na
DENMARK	1973	97	42	41	1	6	Na
	1997	107	65	72	30	35	Na
NORWAY	1973	89	57	72	15	3	Na
	1997	141	92	92	35	47	Na

Source: IEA (2000) in OECD Environmental Outlook, 2001.

It has been suggested that modern cookers, vacuum cleaners, kettles and irons are less durable than in the past (Cooper, 1994). Unfortunately detailed data on the average age of different classes of durables is not readily available. However, in order to calculate producer and consumer price indices in Member countries, government statistical agencies have to estimate economic obsolescence. Figure 2 shows the estimated trend for commodities produced by "durable" manufacturing sectors in the United States since 1947 (indexed on 1982). While there was rapid increase in economic durability in the 1970's and 1980's, this seems to have become more or less constant in recent years. This is perhaps due to the increasing weight of information and communications technology in the index.

Figure 2. Index (1982=100) of Estimated Economic Life of Durable Products in the United States[6]



At a more disaggregated level, Figure 3 gives data on the average age of appliances discarded in the UK in 1998. Whether these figures are rising or falling is not known with certainty. Perhaps more importantly, whether or not the relationship between some measure of "technological" obsolescence and "economic" obsolescence is changing is also not known.

In the US Department of Transport's *Nationwide Passenger Transportation Surveys*, there is clear evidence that the average age of vehicles is increasing (see Figure 4). However, it must be recognised that this is due in part to the growth in multi-vehicle households. For instance, the average number of vehicles per household grew from 1.59 to 1.78 in the same period. Moreover, the vehicle age data is somewhat misleading as an indicator of the average age of vehicles in use since households tend to drive older cars fewer miles. For instance, in an econometric model Pickrell and Schimeck (1999) found that, holding all other factors constant, vehicle miles travelled declined by 6% and 8% for each additional year of vehicle age.

6 . Data obtained from United States Department of Labour, Producer Price Indices (www.bls.gov/servlet).

Figure 3. Average age of appliances discarded in the UK in 1998

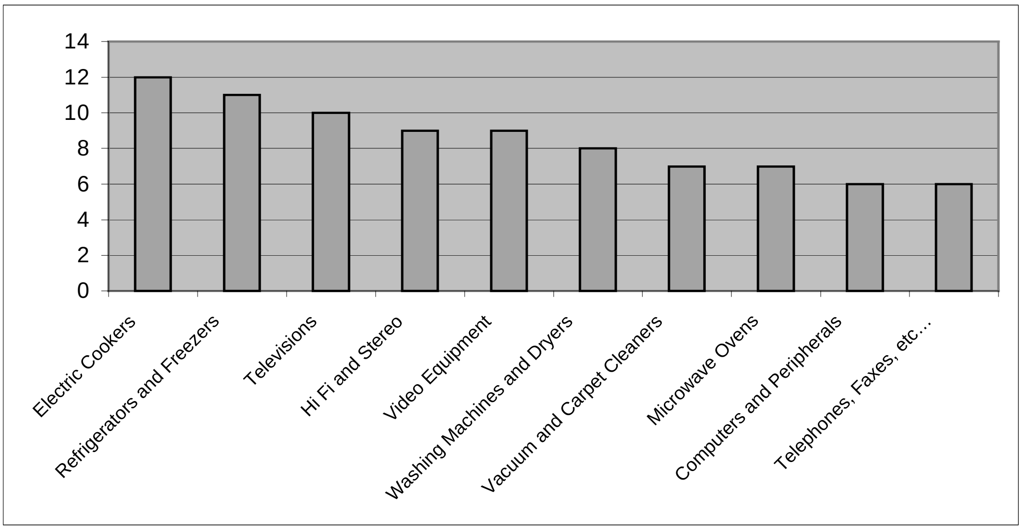
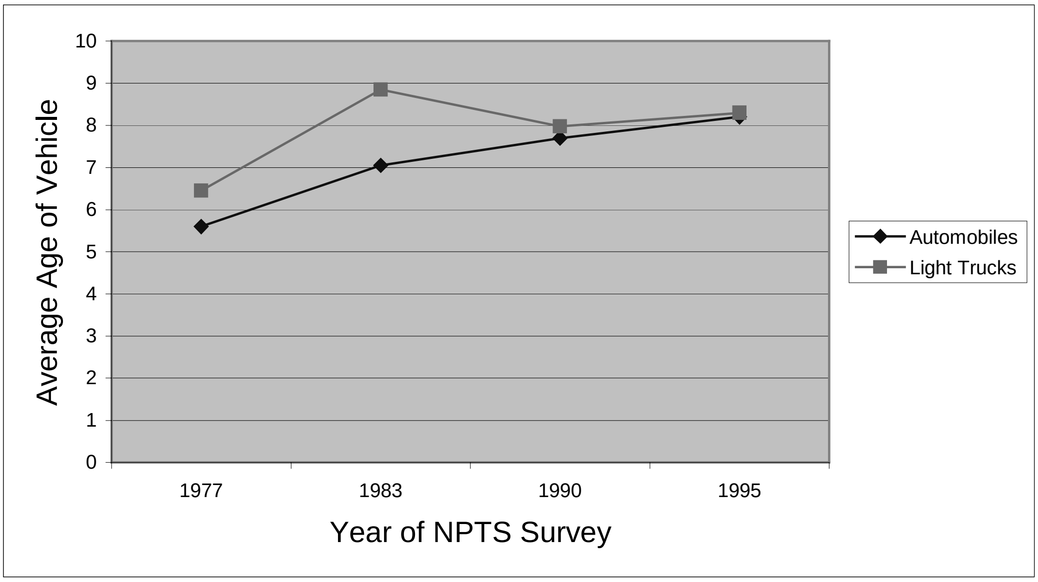


Figure 4. Average age of vehicle stock in the United States



The frequency of replacement decisions can be environmentally significant since it determines the rate of technological change in the economy. An understanding of the process of technological change is important for the economic analysis of environmental issues, because environmental impacts of social and economic activity are greatly affected by the rate and direction of technological change (Jaffe et. al., 2000). This linkage occurs because new technologies may either create or mitigate pollution and because many environmental problems and policy responses are evaluated over timeframes in which the cumulative impacts of technological changes are likely to be large.

In a sense, environmental impacts from the production and use of consumer durables have to be understood in terms of stock-flow relations. The links between the rate of innovation for new products and the speed with which these products replace the existing stock is key. With long-lived products (such as durables), the existing stock is never at the technological frontier. Moreover, even if newer products are less environmentally damaging in use, it is unlikely to be environmentally beneficial to be at the frontier. (See Kletzan *et al*., 2002, for simulations which explore some of these issues in the Austrian context.)

On the one hand, the “dematerialisation” literature makes frequent reference to the desirability of increasing the longevity of the capital stock and consumer durables. It is often argued that by “fixing” (or embedding) resources (principally metals, construction materials, plastics derived from oil) into longer-lived capital equipment and consumer durables, environmental impacts would be reduced. These benefits would arise from both slower rates of resource extraction upstream and reduced waste generation downstream (see Berkhout, 1999; Hinterberger and Seifert, 1997; and Ayres, 1998).

On the other hand, faster turnover may reduce other kinds of environmental impacts. For instance, there is empirical evidence to support the view that newer products are generally less environment-intensive (see Johnstone, 2001*a*). As such, increasing down the rate of turnover may reduce some types of environmental damages. One graphic illustration of this is the fact that many OECD governments have introduced “scrappage” policies to try and get older more-polluting (and durable) vehicles off the road. (See Alberini, 1998; Albrecht, 2001; and Kahn, 1996, for empirical estimates of the impact.) Germany instituted a similar programme, in order to encourage the replacement of less efficient heating equipment with more efficient models. [7]

Despite the dominant role of replacement purchases in many consumer durable categories, the research on the determinants for replacing home appliances has not been extensive. There are several factors that make the statistical analysis of the demand for durable goods complex. First, the element of timing involved in the acquisition and replacement of durable goods does not arise in typical demand studies. Second, due to their longevity, consumers generally replace durable goods infrequently, leading to some data-driven difficulties of analysis durable goods acquisition with conventional statistical tools (see Raymond *et al*., 1993 for a discussion).

A survey conducted by the US Department of Energy which provides information on energy consumption within the USA residential sector, has been taken as a basis for a study focusing on the replacement of electric space heaters and air conditioners (Fernandez 2001). The main objective of the study, which is based on a duration model that allows for unobserved heterogeneity across households, is to determine the determinants of replacement of home appliances.

An important conclusion of this survey is that the age of the head of the household as well as the age of the durable are statistically significant indicators of replacement. In particular, the older the head of the household, the less likely that the durable will be replaced. Economic factors such as monthly income, household credit ratings and operating costs of the appliance tended to be of the expected sign, but were not always statistically significant.

In a study of heating equipment in Alabama, Raymond *et al*. (1993) also found that age of the head of household was important in the replacement decision. One possible interpretation is that older households may have higher implicit discount rates since their planning horizon is shorter. A higher income is associated with a higher probability of replacement. A 10-year increase in the age of the head of the household reduces the probability of replacement within 20 years by 11%. By contrast, a $1 increase in monthly operation costs leads to an increase of 7.3% in the probability of replacement within 20 years.

7. Personal Communication, Harald Neitzel, Bundesministerium für Umwelt, Naturshcutz und Reaktorsicherheit.

A study by Alberini *et. al* (1998) on the determinants of households' willingness to accept different "scrappage bounties" for vehicles, looked more closely at vehicle characteristics.[8] The result of the model used shows that the price which a household is willing to accept to scrap a vehicle is negatively related to vehicle age, mileage, and positively related to the assessment of the vehicle's condition and money spent on repairs. Thus, scrappage programmes will tend to get the oldest and least-maintained vehicles off the road first.

Decisions Concerning Durable Use

The environmental effects from durable use are determined in part at the point of purchase. By buying more efficient appliances, the same level of service provision can be provided with fewer impacts. However, they are also a function of the nature of durable use.[9] Households display considerable variation in average use of all types of durables, from motor vehicles to small kitchen appliances. These differences are partly a function of demographic and spatial factors [see ENV/EPOC/WPNEP(2001)15].

However, they are also a function of economic factors, with prices playing a key role. It has been estimated that the price elasticity of demand for petrol use is approximately -0.2 to -0.3 in the short-run and between -0.6 to over -1.0 in the longer run. (See Dahl and Sterner, 1991, for a review of the empirical literature.) This indicates that a 10% increase in the price of petrol will, in the long run, result in as much as a 10% decrease in petrol use.

The distinction between the short-run and long-run impacts is a function of the extent and nature of adjustments which can take place. This can be illustrated with reference to the use of motor vehicles. In the first instance the household's only means of response is to drive less by cutting out discretionary and non-essential trips. However, in the medium-run issues such as vehicle choice and change of usual travel modes become important. Ultimately, in the longer-run choice of location of residence and/or employment will become important.

Unfortunately, detailed estimates of price elasticities for electricity use for other kinds of durables are less readily available, since electricity consumption is not differentiated by appliance type. Similarly in the case of water consumption it is difficult to distinguish between water use for different purposes, some of which are not related to durable ownership. However, similar issues are likely to be at work, with increased opportunities for substitution with increased time lags.

One countervailing factor which has received considerable attention in recent years is the "rebound effect". As energy (or water) prices rise, the relative efficiency of energy-using durables would be expected to rise as well. As such, the "cost" of using the durable is likely to fall by rather less than is implied by the increase in the cost of energy, encouraging increased use rates. In a study of American motor vehicle use, Greene (1992) estimated "rebound rates" of approximately 5%-15% for motor vehicle use. A more recent study by Greene et al. (1999) estimated rates of approximately 20% in the long run.

In some cases, use is largely or partly non-discretionary. For instance, the issue of "standby power" has received growing attention in recent years. Appliances and other electrical equipment tend to consume increasing power when switched off or not performing their primary function. Without pulling the plug from the socket or switching the power off at the wall, televisions, computers, and many other appliances consume energy 24 hours a day even when they are not being used. For some devices, the

8. Household characteristics were also included but they were not found to be statistically significant.

9. In effect, the appliance choice and use decisions are partly simultaneous, as discussed above.

standby mode has about the same power consumption per hour as the active mode. Depending upon use patterns, standby energy use can be several times the active energy use over the lifetime of the appliance.

Recent field studies indicate that about 10 per cent of residential energy use in OECD Member countries can be attributed to standby power consumption. This amount is projected to expand rapidly in the future with the growing number electronic devices and the trend to purchase networked products with high standby power requirements for use in homes and offices (see IEA, 2001). In such cases "use" is largely determined at the point of purchase, and not on a continuous basis. The environmental effects from this non-discretionary use can be reduced at the purchasing stage by choosing products with optimised power management.

FIRM-LEVEL DECISION-MAKING CONCERNING DURABLE DESIGN AND MANUFACTURING

One of the keys to the reduction of environmental impacts from households is the design and manufacture of less environmentally damaging consumer durables. Clearly the environmental policy framework is key in determining such issues since it will determine the incentives which firms face in the development of new products. Product standards, material input bans, labelling schemes and other policies will play an important role in determining the extent to which firms invest in the design of consumer durables which are less environmentally-damaging. Less directly, policies which affect the cost of use (energy taxes) and disposal (waste fees) will provide incentives for designs which save on the environmental factor targeted. (These issues are discussed below.)

Indeed, many firms attach considerable importance to energy-efficiency in their marketing and advertising campaigns, sometimes supported by public information campaigns (see below). In a related vein, the financial benefits of extended product life and ease of recyclability in terms of reduced waste disposal costs are also often important in firms' efforts to capture market share. More generally, public environmental benefits which do not translate directly into private financial (or other) benefits are often used to differentiate firms and their products.

However, it is also important to look at more general issues concerning firm-level decision-making with respect to the design and manufacture of consumer durables, since environmental effects are often "incidental" to the primary motivation for product innovation (see Johnstone, 2001*b*). Some of the most important environmental gains in recent years have come about through more general trends in product development and technological change, rather than dedicated efforts to reduce specific impacts.

Table 5 provides estimates of the relative importance of different factors in explaining the change in the energy efficiency of models of selected appliances offered for sale in the United States (see Newell *et al*., 1999). As can be seen in the case of air conditioners the role of autonomous technological change is key. Irrespective of relative prices and regulatory standards, technology was moving in an environment-saving direction. Conversely, for water heaters, technology was moving in an environment-using direction, and regulations and prices had to "work against" this trend.

Table 5. Change in energy efficiency of appliances attributable to different factors

	Room Air Conditioners	Central Air Conditioners	Water Heaters
Price-Induced (%)	28	27	46
Standards-Induced (%)	24	-	68
Autonomous Change (%)	43	62	-10

As noted above, in a competitive environment there are clearly strong incentives for firms to develop and market new products, which meet the demands of consumers. For instance, Berry et al. (1996) found that there was a significant relationship between prices of petrol and the rate at which firms applied for patents related to energy-saving devices for motor vehicles. (More generally, see Kautto et al 2001 for a discussion on consumer demand and incentives for environmentally-beneficial product development in five firms in Finland.)

However, it is generally argued that due to the pervasiveness of positive externalities in technology development and diffusion, market forces will not generally provide the optimal rate of innovation in the absence of government intervention (see Jaffe and Stavins, 1995). In effect, the "feedback loops" are not always sufficiently strong between consumers and product designers. This is as true of the market for consumer durables as it is for other parts of the economy. Indeed, given the long lead-times required for, and the degree of uncertainty involved in, the development of many consumer durables, such problems may be particularly important.

These externalities arise due to the "spillovers" which exist in technological development. Due to the difficulty of excluding others from the benefits of applied research and product development, firms will not have sufficient incentive to undertake the necessary investments (see Jaffe *et al*., 2000). These effects can be exacerbated by other factors. For instance, it is commonly argued that financial markets do not tend to assess low-probability high-return investments - such as those in research and development of new products – appropriately (see Scherer *et al*., 2000).

There may also be learning effects and economies of scale. For instance, the cost of production of a new durable may fall over time as firms "learn" how to manufacture the good more inexpensively. Similarly, as the scale of production expands, this may allow for the realisation of economies of scale. Together these two factors indicate the vital importance of overcoming initial market barriers to the development of new products. Once these barriers have been overcome, there should be widespread diffusion amongst households (see Johnstone, 2001*b*).

Due to such factors it has been commonly argued that the social rate of return for industrial research and development and technological innovation exceeds the private rate of return. Indeed, it has been estimated that the average social rate of return for research and development is seven times the private return.[10] (Fagerberg 1994). Since industrial research and development and innovation is (at least partly) a public good, the private generation of technological innovations will not be equal to the social optimum in the absence of public intervention.

These technological externalities can coexist with (and exacerbate) environmental externalities. Indeed, to the extent that innovation in product design is "sub-optimal" it has been argued that environmental damages will likely increase in the presence of technological externalities, since product innovation is often (but not always) environmentally-beneficial, even in the absence of price and regulatory incentives. The importance of this for energy efficiency is shown in Table 5. (See also Johnstone, 2001*b*, for a discussion.)

Technological externalities and missing markets may have other effects as well. A study by Eichner and Runkel (2000) shows that if there are not "indirect markets" for durability, then the lifespan of products will be sub-optimal -- i.e. firms will underinvest in the development of products which are durable. Similarly if there are not "indirect markets" for recyclability then firms will underinvest in the development of products with attributes which make this more feasible. Hence, this analysis shows that,

10. Although, it must be emphasised that this is a notoriously difficult area to derive reliable estimates.

besides environmental externalities, there are further sources for inefficiency which can have adverse impacts on the environment, namely, missing markets for product design.

In addition, the recycling and reuse of durables or parts of durables can result in substantial environmental benefits where it replaces manufacturing of new products or components when the replacement decision is taken (see Ayres, 1998). However, incentives for firms are often inadequate. "Technical externalities" are pervasive in the markets for used appliances and parts of appliances. Upstream product designers and manufacturers are not encouraged to design for recycling since downstream users may not face appropriate financial incentives to recycle the products. The end result is that the benefits of particular types of design may be less than the costs, but there is no way for this information (and appropriate incentives) to be transmitted to product designers.

One study (Cooper and Mayers, 2000), investigated the purchase, use and disposal of household appliances in the UK, and more specifically the use and disposal of waste of electric and electronic equipment. Some of its major conclusions are that recycling and disposal of household appliances are more complex than other wastes, such products tend to pass in and out of use, following a cascade of use. Another significant factor is the increased prevalence of complex products composed of composite materials in product design. This can complicate recycling and reuse.

CONCLUSIONS AND POLICY IMPLICATIONS

Policy measures related to energy-using consumer durables must target at least the following areas:

- Product design;
- Product manufacture;
- Product choice;
- Product use; and,
- Product reuse, recycling and disposal.

Some measures will cover many of these elements. For instance, a carbon tax should affect product design, product choice and product use. Similarly, an extended-producer responsibility scheme should affect product design, product choice and reuse, recycling and disposal. However, getting the policy mix right requires careful evaluation. There are four broad sets of policy recommendations which emerge from this review of the impacts and markets for consumer durables:

- The need to target policies effectively and ensure coherence;
- The need to remove market failures;
- The need to introduce policies which reduce uncertainty; and,
- The need to tailor instrument choice to the characteristics of the market.

These four closely related sets of issues will be discussed in turn.

Policy Targeting and Coherence

The discussion of environmental impacts above illustrates the complexity of environmental impacts from consumer durables, with potential for shifting up and down the product cycle and across types of environmental impact. In seeking to address a number of these inter-related environmental impacts of individual products, policymakers have sought to develop more coherent policy frameworks than those which arise from more discrete measures targeted at different points in the product chain and at different types of environmental impact. There are clearly benefits to be obtained from increased policy coherence between policies targeted at different types of impacts, and even different environmental media.

If environmental impacts are targeted discretely in an uncoordinated manner this raises the potential for significant perverse effects. For instance, targeting CO_2 emissions from motor vehicles in an uncoordinated manner may increase other environmental impacts (i.e. airborne particulate matter from the use of diesel fuel). With the potential for technology "lock-in", the costs of subsequently addressing these other impacts may be much higher than would have been the case if all impacts had been considered initially. This is, of course, a very significant policy challenge.

As one response to this complexity, the "product" has become the focus of much environmental policy. The product has become the target of environmental policies designed not only to mitigate impacts from use, but also impacts upstream in production and downstream in disposal. The EU's Integrated Product Policy is perhaps the most visible expression of this tendency (CEC 2001). Thus in some sense, product has become the "umbrella" through which policy coherence is to be achieved (up and down the product lifecycle) and horizontally (across environmental media).

All of this points to the issue of policy "incidence" and the need for policy coherence. When the inter-related environmental effects of different products are examined, it becomes clear that the point at which an environmental policy is applied is key. Indeed, precisely "where" policymakers target in the product lifecycle may be as important as the "type" of instrument which is applied. There are clearly benefits to policy coherence. However, depending upon how this coherence is achieved, there may also be costs. For instance, in some cases, policymakers may be using products as imperfect proxies for different types of environmental damages occurring upstream or downstream (see Fullerton, Hong and Metcalf, 1999).

As a general rule, where administratively feasible it is always preferable to target policies on environmental damages as closely as possible. If not, perverse substitution effects may arise as firms and households respond to the measure. (See Khazoom, 1995, for an empirical analysis of the long-run effects of the American CAFÉ regulations.) Moreover, it may be impossible to address different spatial effects which arise downstream and upstream. Targeting the product may be inappropriate for goods which have very different environmental impacts depending upon when and where they are used and disposed. And finally, the information requirements of targeting products rather than impacts may be much higher, since two types of information are required rather than just one (the nature of the impact and the optimal means of its amelioration).

However, administrative costs of targeting externalities directly and in a co-ordinated manner may be very high. Thus, a balance must be struck. Integrated and coordinated policy frameworks in which discrete environmental policies are targeted directly are likely to be preferable to blunter policy measures, which seek to meet multiple environmental objectives through single instruments. For instance, measures such as reduced tax rates for "environmentally preferable" products or detailed product standards are unlikely to be efficient means of addressing environmental impacts over the product's lifecycle. A much stronger case can be made for improved co-ordination of measures targeted at different points.

This issue is illustrated in a study based on the analysis of the upstream pollution and downstream waste disposal, a model of production and consumption has been developed that incorporates life-cycle environmental externalities (Walls and Palmer, 2000). The main conclusion of that study is that no single instrument can solve multiple environmental problems. Alternative instruments must correct for multiple externalities - e.g., upstream air or water pollution along with downstream waste disposal. However, it is critical that all externalities are considered simultaneously, but where possible that they are addressed through individual measures which target the damage as closely as possible.

Removal of Market Failures and Barriers

In setting policy, it is important to understand the functioning of the market. Introducing "environmental" policies in the presence of other types of market failures and barriers may be economically inefficient and environmentally ineffective. Thus, the economic reasons for the relatively slow development and adoption of more environmentally-friendly consumer durables needs to be understood, both from the supply side and the demand side.

One of the principal means of addressing externalities associated with technological innovation is through the intellectual property rights regime since this helps innovators to internalise the benefits from research and development. The general criteria for granting a patent to an innovation is to examine the following criteria: novelty, non-obviousness and usefulness. These criteria are largely neutral with respect to the direction of technological change. As such, it is argued by some (i.e. Hsu 1998), that the importance of "public goods" has not been adequately reflected in the "usefulness" criterium.

Many countries are also adopting strategies which are explicitly trying to bend the direction of technological change in an environmentally-benign manner. For instance, many governments encourage environment-related technological innovations through directed support for environment-related research and development. (See Honkasalo, 2001, for a discussion of the *Finnish Environmental Cluster Research Programme*.) In other cases, support may be provided to encourage the diffusion of particular kinds of environmentally-preferable consumer durables. Such measures place significant information requirements on governments.

Governments may also seek to play a role in promoting synergies between different agents in the private sphere. For this reason, many countries are promoting "clusters", whereby different firms are encouraged to collaborate in the development of environmentally-preferable products and technologies. In many cases this happens spontaneously, without any government intervention required. However, in other cases a government role may be necessary, helping to overcome potential institutional barriers and serving as an "honest broker". Such collaboration may occur between firms at similar stages in the product cycle, or between firms at different stages in the product cycle (see OECD, 1998*a* and 1998*b*.)

On the demand-side the slow adoption of environmentally-preferable consumer durables may be a reflection of factors such as heterogeneity of users or products. In such cases, there is little that can and should be done by policymakers. However, in other cases slow adoption by households may be primarily due to market failures related to information and search costs. In such cases, information-based labelling schemes should help to correct such problems (see OECD, 2001*e*). It is important to bear in mind that such measures have implications not only for household decision-making, but also for durable supply and design.

This is strikingly revealed in the aforementioned study of product innovations for energy-using household appliances. Looking at the energy-efficiency of air conditioners and water heaters offered for sale in the United States, Newell *et. al*. (1998) estimated the responsiveness of manufacturers to rising energy prices, before and after the introduction of an energy labelling scheme in 1975. The results indicate that the effects of energy price changes on the mean efficiency of appliances supplied by manufacturers rose appreciably (and became statistically significant) once appliances were labelled (see Table 6). Why would this be the case? Assuming that manufacturers were responding to household demand, it is clear that households did not have the information necessary to make informed decisions (or information was too costly to acquire) prior to the introduction of the labelling scheme. [11]

Table 6. Energy price-responsiveness of appliance manufacturers

	Air Conditioners (Room)	Gas Water Heaters
Pre-Labeling Price Elasticity	0.001	0.326
Post-Labeling Price Elasticity	1.175*	0.577*

Source: Newell et al. (1998). * indicates significance at 5% level.

There may be other types of particular market failures associated with specific segments of the population. For instance, if tenants face insufficient incentives to invest in appliances which are not "portable" (i.e. space heating equipment), then policymakers may seek to align incentives of the principal (the landlord) and the agent (the tenant). Similarly, if capital markets are inefficient with respect to the provision of credit for low-income households, then intervention in financial markets may be justified. (See Johnstone, 1996; and Brechling, Helm and Smith, 1991, for discussions and empirical evaluations of these issues.)

Policy Certainty and Length of Planning Horizons

From the household's perspective purchasing and replacement decisions for consumer durables is very complex. Some times these decisions can have long-lived environmental consequences. "Scrappage" policies are a graphic illustration of this fact. Such policies seek to "correct the failures" of previous policy frameworks and household decision-making. The technological gap between the oldest cars in the existing stock and new models is such that scrappage policies may be cost-effective as a transitional policy. However, they are best understood as complements to more forward-looking policies which give households the right incentives from the outset.

The importance of policymakers sending clear and unambiguous signals to households has long been recognised. This is particularly true of long-lived consumer durables since firms and households are making complex decisions over a long planning-horizon. A number of factors, many of which are only know imperfectly, have to weighed off against each other. One striking illustration of the practical importance of this facet of decision-making with respect to durable choice is the very significant difference between short-run and long-run price elasticities with respect to household energy use.

Analogously, in order for firms to redesign products in a way which is environmentally beneficial, they need clear and long-term incentives in place. In order for a firm to produce more environmentally-friendly products significant investments must be undertaken, including re-tooling and changing supply chains. This introduces lags in response rates, necessitating clear, unambiguous and long-term policy direction. Policies need to be in place for a sufficiently long period of time in order for the "long run" to actually come into being.

"New investment theory" highlights even more the need for environmental policies to have clear and discernible effects for households. Price uncertainty may be a more significant barrier to investment than the levels of prices themselves. As such, it is key that policy makers avoid protracted policy

11. It must be noted, however, that this is one area where information is likely to have a particularly strong impact since the public environmental objective (reduced greenhouse gas emissions) is almost perfectly correlated with the household's financial objective (reducing energy expenditures).

discussions which increase uncertainty in the market. In such cases households and firms are likely to delay investments until there is greater clarity about future developments over the planning horizon. Thus, policymakers should be aware of the three characteristics of investments on which this new theory hinges: irreversibility, uncertainty and the flexibility in the timing of investments. When these characteristics are present, careful analysis is needed before policies aimed at removing barriers to investment can be justified.

These insights may also have implications for instrument choice. For instance, it has been argued that an instrument which provides certainty of price (i.e. a tax) may be preferable to those which do not (i.e. a permit). By giving households more certainty over the course of the lifetime of their investment, tradable permits may provide stronger incentives for early investment. (See Pizer, 1997, for a recent discussion of differences between the effects of price-based and quantity-based environmental policies, and their implications for investment in the presence of uncertainty.)

Policy Objectives and Instrument Choice

The importance of the environmental regulatory framework in bringing about a technological trajectory which is less environmentally damaging has been noted. Indeed, as far back as the mid-1970s it was pointed out that “over the long haul, perhaps the most important single criterion on which to judge environmental policies is the extent to which they spur new technology towards the efficient conservation of environmental quality” (Kneese and Schultz, 1975). However, different policies will provide different signals to firms engaging in environment-related research and development, seeking to innovate, and adopting innovations.

While the case for market-based instruments (taxes, permits, deposit-refund schemes, etc.) relative to direct regulation (technology-based controls, performance standards, input bans, etc.) has usually been made in static terms, at the theoretical level it is thought that the case is even more convincing when the dynamic effects in terms of technological innovation are examined. In particular, the rate of change is more likely to be optimal since a greater proportion of benefits of development of environmentally-friendly consumer products are realised by the firm under market-based instruments, but this is not the case for many direct forms of regulation (see Johnstone, 2001*b*). Moreover, since market-based instruments are not “prescriptive” they are more likely than many types of direct regulation to ensure that the direction of technological change is cost-minimising with respect to the avoidance of damages (see Downing and White, 1986; Milliman and Prince, 1989; Kemp *et al*., 1992; Nentjes and Wiersma, 1987; and Jung *et al*., 1996).

However, it is important to remember that in many sectors and for many pollutants, the simple application of market-based instruments may not be sufficient to bring about the kinds of environmental improvements that are being sought. A mixture of policy interventions may be required. As noted above, while information-based measures are rarely likely to solve environmental problems by themselves, they can complement other policies very effectively, and may encourage environmentally-beneficial technological change. Similarly, supply-side policies which seek to address technological externalities which inhibit environmentally-friendly product development may be required as well.

One obvious example relates to the issue of “stand-by” power. If “use” is non-discretionary and there is reason to believe that households do not take such factors into account when choosing their appliances, there may be a case for the provision of information and performance standards since an energy or carbon tax would not result in the necessary behavioural changes (see IEA, 2001.)

More fundamentally, it may be necessary to introduce complementary policies to address the issue of “missing markets”, which can discourage the design of environmentally-preferable consumer durables. For instance, in order to encourage recycling, measures such as "extended producer responsibility" may be effective since they can differentiate waste by characteristic and are able to transmit signals back to designers and manufacturers. It may also be justifiable to restrict the incorporation of particular materials (or composite materials), which increase the complexity of recycling products.

Conclusions

In summary, the environmental policy challenges for governments are as complex as the decision-making procedures that households and firms must undertake when designing, manufacturing, buying, using and disposing of consumer durables. If environmental policy for consumer durables is to be environmentally effective and economically efficient, they must take into account the complexity of this decision-making. This implies that the "ideal" policy regime for consumer durables is one which is:

- *Targeted* as closely as is administratively feasible (at reasonable cost) to the environmental damage which is to be mitigated;

- *Flexible* enough to allow different households and firms to respond efficiently to the policy measure;

- *Coordinated* across instruments which are designed to address different environmental impacts, but which are related either technologically or environmentally;

- *Integrated* up and down the product life-cycle from resource extraction through production and use, to disposal;

- *Responsive* to the conditions which prevail in different markets, including important market failures or barriers.

While the ideal is never likely to be realised, such principles should be borne in mind when considering alternative policy frameworks for consumer durables.

REFERENCES

B. AEBISCHER (2000). “Electricité dans les services: déterminants de long terme” in J.-L. Bertholet *et al*. (eds.) *Quels systèmes énergétiques pour le XXIe siècle? Consommation et synthèse* No 3 in the publication series “Energie, Environnement et Société” du Centre Universtaire d'Etudes des Problèmes de l'Energie, Université de Genève, Genève.

ALBERINI, A. *et al*. (1998). “Fleet Turnover and Old Car Scrap Policies” Washington, DC: Resources for the Future, Discussion Paper No. 98-23.

ALBRECHT, J. (2001) “Tradable CO2 Permits for Cars and Trucks” in *Journal of Cleaner Production*, Vol. 9, pp. 179-189.

ATLANTIC CONSULTING (1998). “LCA Study of the Product Group Personal Computers in the EU Ecolabel Scheme” London: Atlantic Consulting, mimeo.

ATTANSIO, ORAZIO P. (1998) “Consumption Demand” Cambridge, MA: NBER Working Paper 6466.

AYRES, R.U. (1998). “Industrial Ecology: Depreciation, Waste and Pollution” Fontainebleau, France: INSEAD Centre for the Management of Environmental Resources, Working Paper 98/64/EPS.

BERKHOUT, F. (1999). “Trends in Aggregate Resource Efficiency: A Review of Evidence” Brigthon, UK: University of Sussex, mimeo.

BERRY, STEVEN, SAMUEL KORTUM AND ARIEL PARKS. (1996). “Environmental Change and Hedonic Cost Functions for Automobiles” Cambridge, MA: NBER Working Paper 5746.

BRECHLING, V. D. HELM and S. SMITH (1991). “Domestic Energy Conservation: Environmental Objectives and Market Failures” in D. Helm (ed.) *Economic Policy Towards the Environment* (Oxford: Blackwell).

BRILL, A. M. et al. (1999). “Household Energy Conservation Investment and the Uninformed Consumer Hypothesis” Medford, MA: Tufts University, Department of Economics Working Paper 99-18.

CALCOTT, P. and M. WALLS (2000). “Policies to Encourage Recycling and Design for Environment: What to Do When Markets are Missing” Washington, DC: Resources for the Future Discussion Paper 00-30.

CARLSMITH *et al.* (1990). “Energy Efficiency: How Far can we Go?” Oak Ridge, Tennessee: Oak Ridge National Laboratory, Discussion Paper.

CEC - COMMISSION OF THE EUROPEAN COMMUNITIES (2001) “Green Paper on Integrated Product Policy” Brussels: COM(2001)68/Final.

CEC - COMMISSION OF THE EUROPEAN COMMUNITIES (2000), "Draft Proposal for a European Parliament and Council Directive on Waste Electrical and Electronic Equipment", Brussels, Commission of the European Communities.

COOPER T, and MAYERS, K. (2000). "Prospects for Household Appliances" Sheffield, UK: Centre for Sustainable Consumption Discussion Paper, Sheffield Hallam University.

COOPER T. (1994). *Beyond Recycling, the Longer Life Option*. (London: New Economics Foundation).

DAHL, CAROL AND THOMAS STERNER (1991)."Analysing Gasoline Demand Elasticities: A Survey" in *Energy Economics*, Vol. 13, No. 3, pp. 203-210.

DIXIT, A.K., and PINDYCK R. S. (1994). *Investment Under Uncertainty*. (Princeton: Princeton University Press).

DOWNING, PAUL B. AND LAWRENCE J. WHITE (1986) 'Innovation in Pollution Control' in *Journal of Environmental Economics and Management*, Vol. 13, No. 1, pp. 18-29.

DUBIN, JEFFREY A & MCFADDEN, DANIEL L, 1984. "An Econometric Analysis of Residential Electric Appliance Holdings and Consumption" in *Econometrica* Vol. 52, No. 2, pp. 345-62.

ECMT (2001). "Vehicles Emission Reduction" (Paris: European Conference of Ministers of Transport).

EICHNER, T. and RUNKEL, M (2000). "Efficient and Sustainable Management of Product Durability and Recyclability" Siegen: Germany, Department of Economics Working Paper, University of Siegen.

EPA - ENVIRONMENTAL PROTECTION AGENCY (2000) "Emission Standards for new Nonroad Engines and Highway Motorcycles" (Washington D.C.: EPA420-F-00-046)

ERASMUS, A.C. (1998). "A Suggested Approach to Educating Consumers on the Purchase of Electrical Household Appliances" in *Journal of Family Ecology and Consumer Sciences*. Vol. 26, No1.

ERNST AND YOUNG (2000). "Developing the Foundation for Integrated Product Policy". Brussels: Report Prepared for DG Environment, European Commission.

FAGERBERG, JAN (1994). "Technology and International Differences in Growth Rates" in *Journal of Economic Literature*, Vol. 32, pp. 1147-1175.

FERNANDEZ, V. (2001). "Observable and Unobservable Determinants of Replacement of Home Appliances" in *Energy Economics*, Vol. 23, No. 3, pp. 305-323.

FREEMAN. C. and L. SOETE (1990). "Change and the Environment", in Freeman and Soete (eds.) *New Exploration in the Economics of Technical Change* (London: Pinter).

FULLERTON, D. and S. WEST (1999). "Can Taxes on Cars and on Gasoline Mimic an Unavailable Tax on Emissions", Cambridge, MA.: NBER Working Paper 7059.

FULLERTON, D., and W. WU (1996). "Policies for Green Design", Cambridge, MA: NBER Discussion Paper 5594.

FULLERTON, DON et al. (1999) "A Tax on Output of the Polluting Industry is not a Tax on Pollution: The Importance of Hitting the Target" *Paper Presented at the NBER-FEEM Conference on Distributional and Behavioural Impacts of Environmental Policy*, Milan, June 11th-12th.

GATELY, Dermot (1980). "Individual Discount Rates and the Purchase and Utilisation of Energy-Using Durables: Comment", Volume 11, No. 1, pp. 373-374.

GOETT, A.A. (1988). "Implicit Discount Rates in Residential Customer Choices, Vol. 1: Investments in Conservation Measures". Palo Alto, California: Electric Power Research Institute EM-5587 Project 2547-1, Final Report.

GOLDBERG, L., (1998). "The Advent of Green Computer Design" in *IEEE Computer* Vol.31, No.9, pp. 16-19.

GOLOVE, H. William, ETO H. Joseph (1996). "Market Barriers to Energy Efficiency: A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency" Berkeley, CA: Lawrence Berkeley National Laboratory. Report No. LBL-38059. March.

GRANBERG, B. (1999). "Understanding the Longevity of Consumer Durables" Stockholm: Department of Economic History, Stockolm University, Discussion Paper.

GREENE, DAVID L., JAMES KAHN and ROBERT GIBSON (1999) "Fuel Economy Rebound Effect for U.S. Household Vehicles" in *The Energy Journal*, Vol. 20, No. 3, pp. 1-31.

GREENE, DAVID (1992) "Vehicle Use and Fuel Economy: How Big is the Rebound Effect?" *The Energy Journal*, Vol. 13, No. 1, pp. 117-143

HASSETT, K.A. AND G.E. METCALF (1995). "Energy Tax Credits and Residential Conservation Investment" in *Journal of Public Economics*, Vol. 57, pp. 201-217

HAUSMAN, J.A. (1979) "Individual Discount Rates and the Purchase and Utilisation of Energy-Using Durables" in *Bell Journal of Economics*, Vol. 10, pp. 33-54.

HENDRICKSON, C.T., HORVATH, A., JOSHI, S. and LAVE, L.B. (1998), "Economic Input-Output Models for Environmental Life Cycle Assessment", *Environmental Science & Technology*, 32 (4), April, pp. 184A-191A.

HILL, L. J., D. B. HUNSAKER and T. R. CURLEE (1996). "The Principles of Life-Cycle Analysis", Oak Ridge: Oak Ridge National Laboratory, Discussion Paper ORNL/TM-13178/.

HINTERBERGER, F. and E.K. SEIFERT (1997). "Reducing Material Throughput: A Contribution to the Measurement of Dematerialisation and Sustainable Development" in: A. Tylecote and J. van der van der Straaten (eds.) *Environment, Technology and Economic Growth* (Cheltenham, UK, Edward Elgar).

HONKASALO, ANTERO (2000) "Eco-efficiency, Entrepreneurship and Co-operation: The Finnish Environmental Cluster Research Programme" in OECD *Innovation and the Environment* (Paris: OECD).

HOOK, E. (1995). "LCA - Help or Headache? A Review of Progress Towards Full Life Cycle Assessment", *The Interdisciplinary Journal of Design and Contextual Studies* (on-line journal available at http://www.co-design.co.uk)

HOWARTH, RICHARD AND ALAN SANSTAD (1995). “Discount Rates and Energy Efficiency”, *Contemporary Economic Policy*, Vol. XIII, No. 3, pp. 101-109.

HOWARTH, RICHARD *et al*. (2000). “Energy-Efficient Lighting: Market Data, Market Imperfections, and Policy Success”, in *Contemporary Economic Policy,* Vol. XIV, No. 3.

HSU, Mu-yen (1998). *Geen Patent: Linking Economic Development and Environmental Protection by Promoting Innovation for Environnement*, Taipei, Taiwan: National Yunlin University of Science and Technology, Discussion Paper.

IEA (2001). *Things that go Blip in the Night – Standby Power and How to Limit it* (Paris: International Energy Agency).

IEA (2002). *Taming the Terrible Toaster* (Paris: International Energy Agency).

JAFFE, A. B. AND R.N. STAVINS (1995). “Dynamic Incentives of Environmental Regulations: The Effects of Alternative Policy Instruments on Technology Diffusion” in *Journal of Environmental Economics and Management*, Vol. 29, pp. S43-S63.

JAFFE, A., and STAVINS, R. (1994). “The Energy Paradox and the Diffusion of Conservation Technology” *Resource and Energy Economics* Vol. 16, No. 2, pp. 91-122.

JAFFE, A., NEWELL, G., RICHARD, and STAVINS R. (2000). “Technological Change and the Environment” Washington DC: Resources for the Future, Discussion Paper 00-47.

JOHNSTONE, N, ECHEVERRIA, J., PORRAS, I. and MEJIAS, R. (2001). “The Environmental Consequences of Tax Differentiation by Vehicle Age in Costa Rica”, *Journal of Environmental Planning and Management*, Vol. 44, No. 6, pp. 803-814.

JOHNSTONE, N. (1996). “An Empirical Analysis of Air Pollution Emissions from the U.K. Residential Sector” in *Environmental and Resource Economics,* Vol. 8, No. 4, pp. 367-374.

JOHNSTONE, N. (2001*a*). “Resource Efficiency and The Environment”. Background document for the OECD *Environmental Outlook* (Paris: OECD).

JOHNSTONE, N. (2001*b*). “Technological Change, Public Policy and the Environment” Background document for the OECD *Environmental Outlook* (Paris: OECD)

JOHNSTONE, N. and KAROUSAKIS, K., (1999). “Economic Incentives to Reduce Pollution from Road Transport: the Case for Vehicle Characteristics Taxes” in *Transport Policy*, Vol. 6, No. 2, pp. 99-108.

JØRGENSEN, FINN AND TORE WENTZEL-LARSEN (1990) “Forecasting Car Holding, Scrappage and New Car Purchase in Norway” in *Journal of Transport Economics and Policy*, Vol. 24, No. 2, pp. 139-156.

JUNG, C. *et al.* (1996) “Incentives for Advanced Pollution Abatement Technology at the Industry Level” in *Journal of Environmental Economics and Management*, Vol. 30, pp. 95-111.

KAHN, M. (1996) “New Evidence on Trends in Vehicle Emissions” in *RAND Journal of Economics*, Vol. 27, No. 1, Spring, pp. 183-196.

KAUTTO, PETRUS et al. (2001) "Towards Greener Products: A Case Study of Five International Finnish Enterprises" Helsinki: Finnish Environment Institute, Finnish Environment. (Finnish, Summary in English).

KEMP, R. and L. SOETE (1990). "Inside the 'Green Box': on the Economics of Technological Change and the Environment" in: C. Freeman and L. Soete (eds.) *New Exploration in the Economics of Technical Change* (London).

KEMP, RENE ET AL. (1992) "Supply and Demand Factors of Cleaner Technologies" in *Environmental and Resource Economics*, Vol. 2, pp. 615-634.

KEMPTON, W and L. LAYNE (1982). "The Consumer's Energy Analysis Environment", *Energy Policy*, October, pp. 857-867.

KEMPTON, W. and L. MONTGOMERY (1982). "Folk Quantification of Energy", *Energy - The International Journal* Vol. 7, No. 10, pp. 817-828.

KHAZOOM, J. D., (1996). "An Econometric Model of the Regulated Emissions for Fuel-Efficient New Vehicles" in *Journal of Environmental Economics and Management* Vol. 28, pp. 190-204.

KLETZAN, DANIELA, et al. (2002) "Economic Modelling of Sustainable Structures in Private Consumption" Vienna, Austria: Austrian Institute of Economic Research Policy Paper.

KNEESE, A. and C. SCHULTZE. (1975). *Pollution, Prices and Public Policy* (Washington, D.C: Brookings Institute).

KOOPMAN, P. (1999). "Life Cycle Considerations", Pittsburgh, PA: Carnegie Mellon University, Working Paper, 18-849b.

LAMBERT, A.J.D. AND M.L.M. STOOP (2001) "Processing of Discarded Household Refrigerators: Lessons from the Dutch Example" in *Journal of Cleaner Production*, Vol. 9, pp. 243-252.

LAVE, L.B., COBAS, E., HENDRICKSON, C.T. and McMICHAEL, F. (1995), "Using Input-Output Analysis to Estimate Economy-Wide Discharges" in *Environmental Science & Technology*, Vol. 29, No. 9, pp. 420A-426A.

MANNERING and WINSTON (1985). "A Dynamic Empirical Analysis of Household Vehicle Ownership and Utilization" in *Rand Journal of Economics*, Vol. 16, No. 2, pp. 215-236.

MCCARTHY, PATRICK (1995) "Market Price and Income Elasticities of New Vehicle Demands" in *Review of Economics and Statistics*, Vol. 78, No. 3, pp. 543-547.

McMICHAEL, F., HENDRICKSON, C., HORVATH, A., and LAVE, L. (1998). "A Comparison of Direct and Indirect Environmental Effects of Critical Industries", Paper Presented at the A&WMA 91st Annual Meeting and Exhibition.

McNEILL, W.L. and D.L. WILKIE (1979). "Public Policy and Consumer Information: Impact of the New Energy Labels", *Journal of Consumer Research*, Vol. 6, No. 1.

MEIER, K. A., and J. WHITTIER (1983). "Consumer Discount Rates Implied by Purchases of Energy-Efficient Refrigerators", *Energy - The International Journal*, Vol. 8, No. 12, pp. 957-962.

METCALF, G.E. (1999) "Measuring the Energy Savings from Home Improvement Investments: Evidence from Monthly Billing Data" Medford, MA: Tufts University, Department of Economics Working Paper.

METCALF, G.E., and ROSENTHAL, D. (1995). "The New View of Investment Decisions and Public Policy Analysis: An Application to Green Lights and Cold Refrigerators", *Journal of Policy Analysis and Management*, Vol. 14, No. 4, pp. 517-531.

MILLIMAN, SCOTT R. AND RAYMOND PRINCE (1989). "Firm Incentives to Promote Technological Change in Pollution Control" in *Journal of Environmental Economics and Managemen*t, Vol. 17, pp 247-265.

NATIONAL ACADEMY OF SCIENCES (1991). "Policy Implications of Greenhouse Warming: Report of the Mitigation Panel" Washington, DC: National Academy Press.

NENTJES, A. and D. WIERSMA (1987) "Innovation and Pollution Control" in *International Journal of Social Economic*s, Vol. 15, pp. 51-71.

NEWELL, R. G. *et al.*. (1999). "The Induced Innovation Hypothesis and Energy-Saving Technological Change" in *Quarterly Journal of Economic*s, Vol. 114, No. 3, pages 941-75.

OECD (1982). *Product Durability and Product-Life Extension* (OECD: Paris).

OECD (2001*a*) "Towards Sustainable Consumption: Household Energy and Water Consumption and Waste Generation" (ENV/EPOC/WPNEP(2001)15).

OECD (2001*b*) "Environmental Impacts and Policy Implications of the Growth of the ICT Sector" (ENV/EPOC(2001)18).

OECD (2001*c*). *OECD Environmental Outlook* (OECD: Paris).

OECD (1995). *Motor Vehicle Pollutio: Reduction Strategies Beyond 2010* (OECD: Paris).

OECD (2001*e*). "Information and Consumer Decision-Making for Sustainable Consumption" (ENV/EPOC/WPNEP(2001)16).

OECD. (1998a). "Public/Private Partnerships for Developing Environmental Technology" (OECD DSTI/STP/TIP(98)3/REV1).

OECD. (1998b). "Government Programmes for Diffusing Environmental Technology" (Paris: OECD DSTI/STP/TIP(98)2.)

PICKRELL, DON AND PAUL SCHIMEK (1999) "Growth in Motor Vehicle Ownership and Use: Evidence from the Nationwide Personal Transportation Survey" *Journal of Transportation and Science*, May, pp. 1-17.

PIZER, WILLIAM A. (1997) "Prices vs. Quantities Revisited: The Case of Climate Change" Washington, DC: Resources for the Future, Discussion Paper 98/02.

RAYMOND, J., T.R. BEARD, and D. CROPPER (1993). "Modeling the Consumer's Decision to Replace Durable Goods; a Hazard Function Approach" in *Applied Economics* Vol. 25, No. 10, pp. 1287-92.

ROBINSON (1991). “The Proof of the Pudding: Making Energy Efficiency Work”, *Energy Policy*, September, pp. 631-645.

RUDERMAN, H., M.D. LEVINE AND W.J. VAUGHAN (1987) “The Behavior of the Market for Energy Efficiency in Residential Appliances Including Heating and Cooling Equipment” in *The Energy Journal*, Vol. 8, pp. 101-124.

RUNKEL, M. (1999). “Product Durability, Solid Waste Management and Market Structure”, Siegen, Germany: Department of Economics Working Paper 78-99, University of Siegen.

SANSTAD, H. A., and R. B. HOWARTH (1994). “Consumer Rationality and Energy Efficiency”, Paper Presented to the ACEEE Summer Study on Energy Efficiency in Buildings, Carmel, California.

SCHERER, F., D. HARHOFF, AND J. KUKIES (2000), “Uncertainty and the size distribution of rewards from technological innovation” in *Journal of Evolutionary Economics* Vol. 10, pp. 175-200.

SCHERER, F.M. AND D. HARHOFF (2000), “Technology Policy for a World of Skew-Distributed Outcomes” in *Research Policy* Vol. 29, pp. 559-566.

SETAC (Society of Environmental Toxicology and Chemistry) (1993*). Guidelines for life cycle assessment: A Code of Practice*, Pensacola, CA: Society of Environmental Toxicology and Chemistry Press.

SOUSA, I, D. WALLACE, N. BORLAND and J. DENIZ, (1999). “A Learning Surrogate LCA Model for Integrated Product Design” *Proceedings of the 6 th International Seminar on Life Cycle Engineering*. Kingston, Ontario, Canada: Queen's University, pp.209-219.

STERN, P.C. (1986). “Blind Spots in Policy Analysis: What Economics Doesn’t say about Energy Use”, *Journal of Policy Analysis and Management*, Vol. 5, No. 2, pp. 200-227.

STRAATEN, J. VAN DER (eds.) *Environment, Technology and Economic Growth*. (Cheltenham, UK, Edward Elgar).

SUONIEMI, ILPO AND RISTO SÜLLSTRÖM (1990). “The Structure of Household Consumption in Finland: 1966-1990” Helsinki: Valtion taloudellinen tutkimuskeskus (VATT), Research Report No. 27.

SUTHERLAND, R. J. (1991). “Market Barriers to Energy-Efficiency Investments”, *Energy Journal*, Vol. 12, No.3 , pp. 15-24.

SVENSSON, G. and EKVALL, T. LCA (1995). “A Fair and Cost Effective Way to Compare Two Products?” *Proceedings of the 1995 Total Life Cycle Conference, Land, Sea and Air Mobility. SAE International*, Vienna.

TRAIN, K., “Discount Rates in Consumers' Energy-Related Decisions,” Energy: The International Journal, Vol. 10, No. 12, 1985, pp. 1243-1253.

VERBOVEN, FRANK (1999). “Implicit Interest Rates in Consumer Durables Purchasing Decisions - Evidence from Automobiles” Tilburg, Netherlands: Tilburg University, Department of Economics Working Paper.

WALLS, MARGARAET AND KAREN PALMER (2001). “Upstream Pollution, Downstream Waste Disposal, and the Design of Comprehensive Environmental Policies”, in *Journal of Environmental Economics and Management*, Vol. 41, pp. 94-108.

WITT, R. (1994). “The Demand for Car Fuel Efficiency: An Hedonic Approach” Surrey, UK: Surrey Energy Economics Discussion Paper Series, No. 77.