Technological innovation, energy efficient design and the rebound effect

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Abstract

Does technological innovation to improve the efficiency of energy-using products and systems lead to lower energy consumption and hence reduced environmental impacts? The answer given by economists since the mid nineteenth century is 'no'. This is because there are direct 'rebound' or 'take-back' effects caused by energy efficiency improvements that lower the implicit price of energy, often leading to greater consumption. Also there are secondary or indirect effects of reducing energy costs through efficiency in that consumers may buy more products and/or choose, larger, more powerful, more feature laden models. Thus just promoting technical innovation to increase energy efficiency is unlikely to lead to reduced energy consumption and emissions. Other policies such as taxation or regulation are required.

As well as setting the theoretical arguments concerning innovation and energy efficiency the paper outlines results from an empirical research project, 'People-centred eco-design', which seeks to identify the key influencing factors on consumer adoption and effective use of energy efficient products and systems. In particular it aims to identify how consumers may avoid (or mitigate) rebound effects and how manufacturers, service providers and government might design and promote such products to achieve their optimal environmental benefits.

Keywords: technological innovation, energy efficiency, rebound effect, eco-design, environmental economics.

1. Introduction

Does technological innovation to improve the efficiency of energy-using products and systems lead to lower energy consumption and reduced environmental impacts? This debate, ultimately about the impact of technological change upon economic growth, stretches back to the mid 19th century. Then Stanley Jevons in his famous work *The Coal Question* of 1865 argued that improved efficiency in coal use would lead not to a reduction in national coal consumption, but rather to an increase (Alcott, 2005). As Jevons said:

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> It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth….Every improvement of the engine, when effected, does but accelerate anew the consumption of coal.

Similar arguments are heard today: that improved energy efficiency will lead to lower national energy consumption and is thus a way to reduce carbon emissions. So can technical innovation help to reduce energy consumption and tackle climate change?

The UK government believes so and has set a challenging long-term target of reducing the UK's carbon emissions by 60% from their 1990 levels by 2050 and it is committed under the Kyoto Protocol to a 12.5% reduction in greenhouse gas (mainly carbon dioxide) emissions between 2008 and 2012 (DTI, 2003). A key element of the carbon reduction strategy of the government is the innovation and diffusion of energy efficient lights and appliances, together with improving the energy efficiency of existing dwellings and the construction of innovative 'low' and 'zero carbon' new homes (DEFRA, 2004). This strategy uses the concepts of 'resource productivity' or 'eco-efficiency' to encapsulate the idea of 'doing more with less'. Thus the policy is to use competitive markets to stimulate innovation that will reduce the amount of environmental resources and damage needed to maintain our comfortable material lifestyles. This belief that improving the energy efficiency of goods and services will lead to a reduction in energy consumption has also been heavily publicised in books and papers promoting the so called 'Factor Four' revolution – allowing a doubling in wealth, while halving resource use (Weizsacker, et al., 1997).

This paper questions this belief and instead argues, drawing on the work of energy economists and others, that innovation to increase energy efficiency at the microeconomic level while leading to a reduction of energy use at this level, leads (in the long term) not to a reduction, but instead to an increase in energy use, at the national, or macroeconomic level (Herring, 2005). This argument has been supported by the historical record for most of the last century, of increasing levels of both energy efficiency and energy consumption.

Thus this paper concludes that energy efficiency may not be as 'environmentally friendly' as many claim and its promotion will not necessarily lead to a reduction in energy consumption and hence reduced carbon emissions. It will however save consumers money, promote a more efficient and prosperous economy, and thus could allow the financing of the move towards fossil-free energy future.

1.1. Definitions

Historically there have been two strategies used to reduce energy consumption in times of fuel shortage: 'energy conservation' and 'energy efficiency'. These terms have often been used interchangeably in policy discussions but they do have very different meanings (Herring, 1996). Energy conservation is generally considered to mean reduced energy consumption through lower quality of energy services, for example: lower home heating temperatures; vehicle speed limits; capacity or consumption limits for appliances, often set by standards.

Often it means doing with less, or even without, to save money or energy. It is strongly influenced by regulation, consumer behaviour and lifestyle changes.

Energy efficiency is simply the ratio of energy services out to energy input. It means getting the most out of every unit of energy produced or consumed. It is mainly a technological (and historic) process caused by stock turnover where old equipment is replaced by newer, more efficient technologies and designs. It is generally a by-product of other social goals: productivity, comfort, monetary savings, or fuel competition. Measuring energy efficiency, particularly on a macro scale, is fraught with methodological problems and is very hard to quantify over time, and between countries or sectors.

It may seem at first contradictory to expect increased consumption to come from improved efficiency. But it is readily accepted in other areas of life that an improvement in efficiency (of a product) causes the (implicit) price of that product to fall, and hence stimulates consumption. For instance, more efficient aircraft and booking systems allow cheaper air fares, which results in a rise in air travel. The same is true for many domestic appliances, despite two decades of attempts through energy labelling and minimum efficiency standards to cut consumption. As Brenda Boardman, a leading UK advocate for greater energy efficiency in homes, commented (Boardman, 2004: 14):

> The substantial improvements in energy efficiency have been absorbed into more and larger products. At some stage, society needs to recognise that ever-higher standards of living are threatening our ability to limit climate change and, therefore, reducing our future quality of life.

Also with domestic electrical and electronic equipment; while it is getting more efficient we own many more of these products (e.g. several wide-screen TVs per household), so total energy consumption rises. In fact between 1972 and 2002, electricity consumed in the UK by domestic appliances and home electronics has doubled (EST, 2006).

2. The Rebound effect

The 'rebound effect' (or take-back effect) is the term used to describe the effect that the lower costs of energy services, due to increased energy efficiency, has on consumer behaviour both individually and nationally (Frondel, 2004; Herring, 2004). Put simply the rebound effect is the extent of the energy saving produced by an efficiency investment that is taken back by consumers in the form of higher consumption, either in the form of more hours of use or a higher quality of energy service. For instance when we replace a 75W incandescent bulb with an 18W compact fluorescent bulb (CFL)—a reduction in (wattage) power of about 75% - we could expect over time a 75% energy saving. However this seldom happens. Many consumers, realising that the light now costs less to run, are less concerned about switching it off, indeed they may leave it on all night, for example for increased safety or security. Thus they 'take back' some of the energy savings in the form of higher levels of energy service (more hours of light). This is particularly the case in households that suffer from 'fuel poverty' where the past level of energy services, such as space heating, are, or were considered, inadequate. Some or all of the energy savings from efficiency improvements, such as increased levels of insulation or a more efficient heating system, may then be spent on higher heating standards - the consumer benefits by getting a warmer home for the same or lower cost than previously. Such rebound effects are not theoretical; they have been observed or measured in empirical studies (e.g. Hong et al, 2006; Caird and Roy, 2006).

Similarly with cars, since the 1970s their efficiency has improved greatly through the use of a number of technologies, such as lightweight materials, lean burn engines, fuel injection, and aerodynamics. But the tendency of consumers to buy larger, less fuel efficient cars has wiped out the improvement in fuel efficiency, so the net effect is that over the past twenty years there has been virtually no improvement in the fuel economy of cars in Britain or in Europe. Professor Stephen Potter, a transport analyst remarks (2005: 172):

> Regulation and voluntary agreements have led to improvements in new car fuel economy, but these have made remarkably little difference to the actual 'on the road' fuel economy of the UK car fleet. 'Rebound effects' have emerged, such as changes in drivers' and car buyers' behaviour, compensating for the vehicle improvement.

2.1. Types of rebound effect

Rebound effects are due to the increased use of energy services caused by the reduction in their effective price due to greater efficiency and can be divided into three categories of effects (Dimitropoulos and Sorrell 2006):

1. **direct** effects due to the desire of consumers to use more of any product or service due to its lower price;
2. **indirect** effects due to the fact that, with lower energy price, more income is available to spend on other products and services, such as holidays, which involves consuming energy;
3. **Economy wide** effects due to long term changes in the economy caused by technological innovation, changes in consumer preferences and/or social institutions bought about by the substitution of energy for other factors of production.

2.1.1 The direct rebound effect

The effect of perceived lower costs on energy use is termed 'price elasticity' - the ratio of the percentage change in energy use to percentage change in energy price. Price elasticities vary by commodity and over time, depending on the ability of consumers to respond to price changes, either through changes in behaviour, substitution of alternatives or technological change. It is important to distinguish price induced efficiency gains from non-priced induced gains, as the former are caused by factor substitution e.g. substituting machines for labour, and may involve costs to the economy (such as was caused by the oil prices rises in the early 1970s and may result from the imposition of energy taxes). Non-priced induced gains are due to technological improvements and the rebound effects from them are the cause of most concern to energy analysts.

Much of the evidence on the magnitude of the (direct) rebound effect comes from US transportation studies where there is good statistical data on travel miles per vehicle and petrol consumption The results indicate that the number of vehicle miles travelled will increase (or rebound) by between 10% and 30% as a result in improvement in fuel efficiency. Similar results are obtained in the US for domestic energy services (see Table 1).

Table 1

A study of the manufacturing sector in the USA revealed significant direct rebound effects, at about 24%, as increases in fuel efficiency led not only to lower product prices but also to a substitution process where other input factors (capital and labour) were replaced by energy (Bentzen, 2004). Research in Norway indicates similar results: a direct rebound effect of about 40% for households and 10% for commerce (Haugland, 1996). In industry the extent of the direct rebound depends on the possibilities for substitution of inputs: it is higher in industries (such as metals) with limited substitution possibilities than in industries (such as chemical and mineral products) which have greater opportunities to adjust inputs (Grepperud and Rasmussen, 2004).

Expansion of service demand can also take the form of consumer preference for higher levels of quality, comfort and performance. For instance, the oil prices rises of the 1970s stimulated R&D on more efficient car engines giving cars with high fuel economy; so when oil prices fell in the late 1980s car manufacturers could offer consumers more powerful and better equipped cars (like the sports utility vehicle or SUV – luxury 4-wheel-drive, air conditioned jeeps) with the same fuel costs per mile. Here consumers appear to take the possible savings in the form of higher levels of performance or quality. Another area where consumers 'trade up' is substituting energy for time: driving faster cars, using aircraft instead of trains, buying labour-saving domestic appliances, eating fast food and substituting private for public transport.

An important impact of the effect of higher efficiency, and consequent lower cost of energy services, is on marginal consumers - those who could not previously afford the service. The appliance market, such as for air conditioning, will expand as the cost of this energy service falls, the magnitude depending on the elasticity of service demand. This is because consumers' choice of equipment depends on factor costs, and more efficient equipment will increase the demand for the service because of lower marginal costs per unit of service. However, the direct rebound effects are generally less than 50%, although empirical research has shown that it can be nearly 100% for those suffering from 'fuel poverty', such as pensioners and low income families, as better insulation and more efficient heating systems give them the ability to heat their homes to a level which previously they could not afford (Hong et al 2006).

2.1.2. Indirect effect

The second effect of the lower effective price of the energy service is changes in the demand for other goods and services. For example, the cost savings obtained from a more efficient central heating system may be spent on an overseas holiday, with a consequent increase in aircraft fuel consumption. It is difficult to determine empirically these indirect effects, but it is argued they are small, since only 5 to15% of income saved is re-spent on indirect energy use—with air travel at the high end (Schipper and Grubb, 2000).

Similarly for producers, efficiency improvements lead to changes in demand for other factors of production. At the same time, the lower cost of outputs from one sector may lower the cost of inputs to another sector and thereby increase both production and consumption throughout the economy. For example, energy efficiency improvements in steel production may reduce the price of steel, which in turn may reduce the price of cars, increase the demand for cars and thereby increase the demand for gasoline. However, the impact of energy efficiency on long-run economic growth is the hardest to examine both theoretically and empirically, and is thus the area where the greatest dispute lies.

2.1.3 Economy wide effects

Most probably the greatest effect (in the long term) of lower costs of energy services is on the direction and pace of technological innovation and consumption in the economy. New products and services will be created or purchased to exploit markets opened up by lower costs thus creating an overall increase in energy consumption. For instance the range of uses for electric lighting has expanded greatly, as we explain below. The large increases in lamp efficiency and hence lower running costs have, for example, stimulated the market for security and outdoor lighting. Manufacturers continually seek innovations in order to lower consumer costs and create new markets. Only if energy efficiency is congruent with these objectives is it an important driver for innovation (Luiten et al., 2006). In conjunction with this, energy utilities have sought efficiency improvements to lower the cost of their product: considering it more profitable, for example, to sell much electricity at a low margin than little at a high margin. The result is a growing market for electricity and the continual development of new electrical and electronic products and services: electric lighting in the 1900s, domestic refrigeration in the 1930s; TV in the1950s; microwaves and videos in the 1980s, computers and the internet in the 1990s, digital TV and home cinema in the early 21st Century resulting in an overall historical increase in energy consumption.

2.2. Seven centuries of Lighting

For lighting it is possible to track changes in efficiency and consumption over seven centuries, as has been done in a fascinating study by Roger Fouquet and Peter Pearson (2006) for the UK. There they trace the evolution of demand for lighting as technology of lighting progress through medieval candles, 18th C oil lamps, 19th Century gas lights and finally 20th century electric lamps. Every time a new technology is introduced efficiency is improved and consumption increases dramatically. Our modern electric lights are 700 times more efficient than the oil lamps of 1800, and our consumption – measured in lumens-hours per capita – is over 6,500 times greater. Even in the era of the electric light, over the past 50 years, there has been a doubling of efficiency but a four fold increase in per consumption (See Table 2).

Table 2

Over the last two centuries the cost per capita for lighting per hour has only doubled – measured by the increase in the price (0.03%) times the consumption growth (6641x) – while GDP has gone up by a factor of 15. So lighting has become much more affordable and, as we highly value illumination as an energy service, it is not surprising that we consume so much more light.

2.3. The academic debate

The rebound effect is the focus of a long-running dispute between energy efficiency proponents and energy economics since the early 1980s. The debate grew more intense in the early 1990s, spurred by concerns about climate change. It was conducted most in the pages of academic journals, but also spread to the pages of *The New York Times* in late 1994 and the leading UK science magazine *New Scientist* in 1998 (Pearce, 1998). It culminated in two special issues of journals devoted to aspects of the rebound effect; edited by Schipper (2000) and by one of this paper's authors (Herring, 2000), to which many of the protagonists in this debate contributed. Then in 2005 the UK House of Lords Science and Technology Committee gave a sympathetic hearing to the economist Len Brookes, the leading UK critic of the proposition that increased energy efficiency would lead to a reduction in national energy use (a view termed the 'Khazzoom-Brookes' postulate). In its report the Committee said (HoL, 2005: Para.7):

> The Government's proposition that improvements in energy efficiency can lead to significant reductions in energy demand and hence in greenhouse gas emissions remains the subject of debate among economists. The "Khazzoom-Brookes postulate", while not proven, offers at least a plausible explanation of why in recent years improvements in "energy intensity" at the macroeconomic level have stubbornly refused to be translated into reductions in overall energy demand.

Following this criticism the government asked the UK Energy Research Centre (UKERC) to undertake a systematic review entitled 'The Evidence for a Rebound Effect from Improved Energy Efficiency' and a final report is expected in early 2007 (UKERC, 2006). In conjunction with this work, The UK Department of Environment, Food & Rural Affairs (DEFRA) has commissioned research to model the macroeconomic impacts for the UK of the rebound effect (DEFRA, 2006). There is no dispute that the rebound effect exists, what is at the core of the conflict is its magnitude, and the two opposing positions can be summarized as:

1. Energy use is higher than if there had been no efficiency response - a position maintained by Len Brookes, and under some circumstances by Harry Saunders (2000).
2. Energy use is lower than if there had been no efficiency response - a position maintained by Lee Schipper and his colleagues (Schipper & Grubb 2000)

Each side has supported its case with a mix of theoretical argument and empirical observations, based on historical data on energy use. A key problem in resolving the two positions is that it is not possible to run 'control' experiments to see whether energy use is higher or lower than if there had been no efficiency improvements - there is after all only one past. Attempts to estimate the overall magnitude of the rebound effect, using theoretical economic models based on neoclassical growth theory, have again proved inconclusive with the results dependent on assumptions about the elasticity of substitution of energy for other factors of production - the greater the elasticity (see below) the greater the rebound. A further problem is that the rebound effect differs by energy end use and sector of the economy, and also the response at the micro-economic level (the consumer) is different to that at the macro-economic (the national economy). Also the rebound effect can vary between countries, depending on the energy costs and unmet demand for energy services; thus it may be considerably higher in developing countries than in the UK or USA.

However all agree that the rebound effect is closely linked to the elasticity of substitution, which is a component of the widely measurable phenomenon of price elasticity. The higher the observed price elasticity of energy services, the greater is the rebound effect. This leads to the paradoxical position than any imposition of energy or carbon taxes, in the hope of reducing energy use, would have its impact severely blunted by the rebound effect, if consumers have a high price elasticity, i.e. are willing to pay more for energy they perceive they need or want.

3. Innovation, efficiency and economic growth

Historically there has been an unending race of technological innovation and energy efficiency versus economic growth over the last two centuries. If economic (or GDP) growth is faster than the rate of efficiency increase (as it has been historically) then total energy consumption increases. For instance in the UK over the last 35 years energy efficiency (as expressed by energy intensity – a rough proxy) doubled; a Factor 2 improvement. However GDP more than doubled, so total energy consumption rose by about 15%. Thus at current rates of efficiency improvement, it is perfectly feasible for there to be a Factor 4 improvement in efficiency during the 21st century. But as the Royal Commission on Environmental Pollution (RCEP) comments (2000: 6.139):

> There will continue to be very large gains in energy and resource efficiency but on current trends we find no reason to believe that these improvements can counteract the tendency for energy consumption to grow. Even if energy consumed per unit of output were reduced by three-quarters or Factor Four, half a century of economic growth at 3% a year (slightly less than the global trend for the past quarter century) would more than quadruple output, leaving overall energy consumption unchanged.

The fact that economic growth tends to be very closely correlated with energy consumption, at least for short periods does not mean that energy consumption is the cause of the growth. Indeed, standard growth models assume exactly the opposite: that economic growth (due to the accumulation of capital, and labour, plus technical progress) is responsible for increasing energy and natural resource consumption.

However in a recent paper the industrial ecologists Robert Ayres and Benjamin Warr argue, on the contrary, that declining resource prices can have a direct impact on growth, via a positive feedback loop (Ayres & Warr 2005). Thus efficiency improvements lower resource prices which encourages higher demand, the wages of labour tend to increase as output rises, and this further stimulates substitution of natural resources, especially fossil fuels, for other inputs From their analysis they identify electrification as perhaps the single most important source of power for production of goods and services, and the most important single driver of economic growth during the twentieth century.

Nevertheless, the role of energy efficiency in promoting economic growth is well appreciated by many environmental economists and sociologists concerned with resource consumption (e.g. Hukkinen 2001, Levett 2004). Some argue that increased efficiency bought about by long term technological innovation enables society to consume more resources—a rebound of greater than 1. For instance Mathias Wackernagel and William Rees in their pioneering book *Our Ecological Footprint* concluded (Wackernagel & Rees, 1997):

> Ironically then, it is precisely the economic gains from improved technical efficiency that increase the rate of resource throughput. Micro-economic reality demands that these efficiency gains be used to short-term economic advantage. Far from conserving natural capital or decreasing ecological footprints, this leads to higher consumption.

Thus, as noted earlier, promoting energy efficiency may not necessarily the best way to save energy or reduce emissions. For it may actually encourage energy consumption by conveying the message that consuming increasing amounts of energy is acceptable as long as the energy is consumed by technologies that have been deemed efficient (Moezzi, 2000).

3.1. Policy implications

Society has generally preferred technical or economic solutions over lifestyle changes, and scientists and engineers have therefore emphasised the technical possibilities of a shift to less resource intensive types of consumption. One solution is the concept of 'service efficiency' which may be defined as providing a maximum of useful end-services to consumers using the minimum of materials and energy use (Roy, 2000). There is an extensive literature on this concept and there exist new types of product-service system that deliver energy services using innovative combinations of market goods and services and labour. For example, Demand Side Management (DSM) programmes operated by US and Canadian electricity utilities, as well as offering conventional energy efficiency measures such as subsidised energy efficient products to their customers, may have an energy service company (ESCO) that sells heat, light and power rather than electricity and thereby have an incentive to install the most energy efficient equipment in customers' homes or businesses (Curtis and Khare, 2004: 399).

However, despite the energy efficiency gains possible with such schemes, service efficiency in itself is not a panacea for sustainable consumption as the gains are easily offset by an increase in the number and variety of products consumed. Also as researchers into the cultural aspects of consumption have shown, it is necessary to understand how and why we consume (Jackson, 2006).

This is why innovations that are meant to be efficient, and to reduce the need for resources, often have the opposite effect. As F.-J. Radermacher, a German sociologist remarked (quoted in Hilty & Ruddy 2000):

> The trap that we have fallen into again and again over the course of technical progress consists of our always using progress on top of whatever went before (the rebound effect). This effect predicts that market forces and humanity's apparently unlimited capacity for consumption will use new technology to convert more and more resources into more and more activities, functions, services and products.

Thus if technical innovation is the driver of economic growth, greater energy efficiency will only stimulate economic growth and result in higher energy consumption. Can the link between the two be broken? Perhaps we could 'dematerialize' our economy: that is get rich while minimising use of resources.

3.2. Dematerialization and time

There is a continuing trend in industrialized countries to 'dematerialization' of the economy, due to the structural shift in the economy from energy-intensive manufacturing to energy-frugal services - the so called Factor 4 revolution. One innovation proposed is that the 'digital' economy (otherwise known as the 'new', 'weightless' or 'knowledge' economy), will bring forth dematerialization. It is often argued that information technologies, such as computers, will reduce material and energy consumption through substituting 'virtual' for real experiences and physical products. However after the 'dotcom' euphoria of the early 2000s there is no hard evidence that this innovation will automatically or necessarily be good for the environment. As Finnish sociologists Heiskanen & Pantzar (1997) ask:

> Will the information super-highway do away with the urge to travel?...Will consumers actually substitute one good for another, or will they want to have it all: the television on, the newspaper on the table, and electronic news pointlessly self-scanning as the consumer of all this information dozes on the couch?

Propaganda here, like that for the earlier 'paperless' office, has outstripped evidence, and some research shows that ICT can increase consumption, particularly if it stimulates personal travel, internet buying and selling and associated freight traffic (see Rejeski, 2003).

The internet by facilitating communications between people can increase the desire for travel and meetings, and has certainly aided the development of low cost airlines which has greatly stimulated short breaks tourism. Its effect is similar to previous revolutions in communications (newspapers, the telegraph, the telephone, radio, TV) over the last 150 years. The knowledge that these technologies bring stimulates transport growth though opening up new commercial possibilities and the desire to travel to new 'exotic' places. Thus we had the railway in tandem with the telegraph, the automobile with the phone, the aeroplane with radio, and now mass global tourism with the TV and internet.

What has been happening is that we are substituting energy for time. So the energy savings resulting from energy efficiency equipment depend crucially on our time management, on whether we are time-poor or time-rich. For time scarcity drives consumption decisions and therefore influences energy consumption in many ways, mostly to increase it (Dimitropoulos 2006). As Mathias Binswanger argues (2000: 131):

> Time saving devices usually require more energy as is most evident from transport where an increase in the efficiency of time use (faster modes of transport) tends to be associated with a larger input of energy …the overall effect of time-saving technological progress will be an increase in energy use.

This is happening in the competitive global market where firms strive to make the most efficient use of all their factors of production (capital, labour, resources, and time). This emphasis on total factor productivity (in manufacturing, services and agriculture) need not lead to greater environmental resource productivity or energy efficiency. For example, one empirical study of attempts to introduce energy efficient process technologies into the paper and steel industries through government R&D support showed that the development and commercialisation of innovations by these industries was motivated by concerns about reducing capital investment and increasing capacity rather than energy efficiency (Luiten et al., 2006: 1033-1035). It may be most cost effective for firms to substitute resources and energy to reduce labour costs or to save time. Hence the transfer of manufacturing from western countries to China, the import of fresh flowers and vegetables by air freight from Africa or South America. So how can we transform technical eco-efficiency into reduced environmental impacts? Is it possible to develop low (or even zero) emissions products and services, and should we now concentrate more on consumption rather than production (Throne-Holst, et al, 2006).

4. Open University research projects

So are low emissions products and services feasible? Can 'dematerialization' become a reality? For advocates of 'dematerialization' of the economy perhaps the most talked about is the internet, with its potential to transform the way information and services (like insurance, education, recreation and entertainment) are delivered to consumers. The UK Open University (OU) – which provides higher education through distance learning and electronic delivery methods – has a keen interest in this debate. Recently its Design Innovation Group (DIG) conducted research that throws light on claims that internet delivered services reduce energy consumption and associated carbon dioxide emissions.

4.1. Factor 10 Visions Higher Education project

This project, part of a broader OU Factor 10 Visions programme, examined the potential for up to Factor 10 (90%) reductions in resource consumption and emissions (notably carbon dioxide) in several sectors. In the higher education sector study, the relative impacts of three systems – conventional campus-based teaching, print- based and internet-based distance learning – were examined.

Survey results showed that on average, the production and provision of the distance learning courses consumed nearly 90% less energy and produced 85% fewer carbon emissions (per student credit) than the conventional campus-based university courses. The much lower impacts of distance learning compared to campus-based courses is mainly due to a major reduction in the amount of student travel, economies of scale in utilisation of the campus site, and the elimination of much of the energy consumption of housing for students living away from home. However, courses delivered mainly via the internet appear to offer only a small reduction in energy consumption and carbon emissions (20% and 12% respectively) when compared to mainly print-based distance learning courses. This is due to high student use of networked computing, consumption of paper for printing off internet-based material, and additional home heating, probably for night-time internet access. (Roy, et al, 2004)

Thus, the paperless office had definitely not arrived for students who often printed out internet based material; although this was more than offset by the savings in not having printed course books. However, it is the indirect effects of doing the internet-based course that may have the big impact. For many students the course acted as a catalyst, giving them basic internet literacy. As such, some felt that the course had reduced the amount they travelled— they could now shop or obtain information via the internet, work from home, or communicate with friends using e-mail. For others the same internet literacy had stimulated increased travel, for example by giving access to low cost flights or new contacts (Yarrow, et. al., 2002).

4.2. People-centred eco-design project

This project by the same OU research group surveyed the factors influencing consumer adoption – and non-adoption – of conventional energy efficiency measures and of innovative micro-generation energy technologies—collectively termed low and zero carbon technologies (LZC). This research is based on the hypothesis that an important factor in the slow take-up by consumers of many LZC products – ranging from compact fluorescent lamps and condensing central heating boilers to hybrid petrol-electric cars and solar water heating systems – is that often they have been designed without taking sufficient account of users' requirements – functional, economic and symbolic (Roy, et al, 2007). The research also examined how consumers who adopted them used their LZC products and systems. This is important because even if people adopt LZC technologies, they may not use them in an energy saving manner. There may be rebound effects, such as leaving energy efficient heating and lighting on for longer, installing extra lighting in the home or garden or driving further in a fuel efficient car. They may open windows or doors in mechanically ventilated dwellings, or electrically heat conservatories designed to gather solar energy (Oreszczyn, 2004). As Boardman comments (2004: 3):

> In reality, many consumers choose …a mixture of a higher standard of living and energy conservation. That is why the level of energy that will be conserved as a result of an energy efficiency improvement requires careful analysis if it is to be successfully predicted. Such predictions, however, are very difficult to make given that little is known how people actually use low carbon products after they have adopted them.

Other empirical research into how and why consumers use energy in their households shows the importance of understanding consumer lifestyles and aspirations, particularly with items that have fashion and aesthetic as well as utilitarian functions, such as lighting (Stokes et al, 2006).

4.2.1 Results

In the People-centred eco-design project the research team conducted some 90 telephone interviews of UK consumers who adopted, or considered getting, one or more established technologies of loft insulation, heating controls, condensing boilers, energy efficient lighting and solar water heating. An on-line survey linked to a 2006 BBC TV programme on climate change produced nearly 400 responses from consumers who had adopted – or seriously considered but rejected – one or more of the above established technologies and/or innovative micro-generation technologies, including micro-CHP, domestic photovoltaics (PV) and micro-wind turbines, plus biomass (wood-fuelled) stoves. Finally we have obtained the views of 50 energy professionals, such as local authority housing officers, architects and energy consultants, via an on-line energy newsletter.

The main reason given by the consumers for the adoption of LZC technologies is to reduce fuel bills and/or save energy. Another important reason given by the people who responded to the on-line survey is environmental concern (especially climate change and nature conservation), but this reflects the 'greener' attitudes of this self-selected sub-sample (Roy and Caird, 2006).

The majority (58%) of adopters of loft insulation said the main benefit of loft insulation was a warmer house, while nearly a third said they also had lower fuel bills (29%) and/or energy consumption (31%). There is thus, not unexpectedly, empirical evidence from this study of a rebound effect for loft insulation, with at a small minority (4%) saying they took the entire benefit in higher room temperatures, heating more of the house or heating the house for longer periods rather than lower energy consumption. Energy efficient lighting also appears to involve a rebound effect, as about a third of users choose to leave CFLs switched on longer than incandescent lamps and/or have installed additional CFL lighting in the home, in the garden or for security. Improved heating controls, when used properly, and condensing boilers appear to have a smaller rebound effect with about a half of adopters of these energy efficiency products noticing reductions in fuel bills and/or energy consumption as well as a warmer house, and only about 10% saying they took the main benefit in heating more of their house, for longer, or to higher temperatures. This study suggests that while there is clearly a rebound effect with energy efficiency measures, the level varies with the technology concerned.

The reasons for non-adoption vary widely depending on the technology concerned and go beyond the well-known financial issues. Even for loft insulation, which is one of the most cost-effective energy efficiency measures, concerns about irritant fibres in loft insulation materials, the need to clear the loft, and loss of loft storage space when installing the recommended thickness of insulation, prevented adoption. Reasons given for non-adoption of other mainstream LZC technologies varied widely. For condensing boilers its was its reputation among installers and consumers for unreliability and shorter life; for compact fluorescent lamps their size and perceived ugliness followed by their cost, incompatibility with existing fittings and dimmers, and their light quality– barriers of interconnectedness and symbolism. For micro-generation technologies the main barrier to installation was cost (about 50% for micro-CHP and wind), rising to 85% for PV, a very expensive technology. But other important barriers were the uncertain performance and reliability of these technologies, no suitable location for the unit, especially micro-wind turbines, and interconnectedness issues of integrating with existing electricity and/or heating systems.

Results from this project showed how important it is to research user requirements when developing such products and systems. LZC products and systems are often designed as purely functional goods without considering the many factors that influence consumer adoption. These factors include other aspects of utility such as health impacts (e.g. irritant insulation fibres) and ergonomics (e.g. harsh CFL lighting); interconnectedness with existing buildings and systems (e.g. solar water heating incompatibility with combination boilers and cold fill appliances), and symbolism (e.g. the perceived ugliness of CFLs). Price is an obvious barrier to adoption of these technologies, becoming increasingly significant as their cost increases from a £5 CFL or a £100 loft insulation job to a £4000 SHW system or a £15,000 PV roof. Subsidies have had a significant effect on adoption of lower cost systems, but in the UK have so far been insufficient to stimulate the market take-off of costly micro-generation systems; where the ability and willingness to adopt still relies on ‘green’ households with disposable wealth. Wider adoption of such systems probably requires innovative financing schemes e.g. council tax rebates, repayment loans through energy suppliers.

5. Conclusions

Does innovation to produce more energy-efficient products and systems lead to lower energy consumption? This depends upon the extent of the ‘rebound’ whose effect is difficult to measure on a national or macro scale. In recent decades there have been great strides in reducing some types of pollution—such as sulphur dioxide—generally as a consequence of legislation, often bought about by environmental activists, which has spurred the introduction of pollution control technologies. But reducing carbon emissions is far more difficult and eco-efficiency solutions are unlikely to be effective on their own. However, adopting more efficient (or greener) products without reducing the growth in consumption will not make a large difference in the long term. Research shows that while adopting energy efficient products and systems patterns can produce a reduction in energy consumption in the short term of 10% to 20%, these reductions are soon outpaced due to rising levels of consumption, caused by even modest growth (1% to 2% per annum) in income (Alfredsson, 2004).

For energy efficiency to expect it to do much better in the future calls for some explanation as to why the future should be markedly different from the past. Why should there suddenly now be a 'step change' in the rate that technical innovation leads to environmental savings. As Jackson and Michaelis remark (2003: 15):

> Historical data suggest there is very little evidence to suggest that resource productivity improvements as high as 5-8% per year could be maintained throughout the industrial world over a period of 30-50 years, as required by the Factor 10 goal. From the labour productivity data we can see that it is possible to maintain rates of improvement of 2-3% per year over the long term. But we should bear in mind that labour is the largest single cost in the economy, and both workers and employers have strong incentives to increase its productivity. Massive shifts in policy would be required to provide the incentives needed for sustained resource efficiency improvements.

What these 'massive shifts in policy' would entail is only now being investigated. They will surely involve changes in behaviour, and ultimately in our lifestyle. Our People-centred eco-design project has found that changing behaviour is often not simply a matter of regulatory sticks and financial carrots but understanding people's lifestyles. Somehow we need to combine innovative technology (embodying high levels of eco-efficiency) with a sustainable lifestyle to ensure a future economy with a high 'quality of life'.

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Tables and captions

Table 1

Estimates of the direct rebound effect by end use for the US residential sector.

End Use	*Rebound effect*	*Number of Studies*
Space heating	10-30%	26
Space cooling	0-50%	9
Water heating	<10-40%	5
Lighting	5-12%	4
Car transport	10-30%	22

Source: Greening et al. (2000)

Table 2

Changes in the price, efficiency and consumption of domestic lighting from 1800-2000.

	Price of lighting fuel	***Lighting efficacy***	***Price of light per lumen***	***Consumption – lumen-hours per capita***	***Real GDP per capita***
1800	100%	1	100%	1	1
1850	40%	4	26.8%	4	1
1900	26%	7	4.2%	86	3
1950	40%	331	0.15%	1,544	4
2000	18%	714	0.03%	6,641	15

Index 1800=1

Source: Fouquet & Pearson (2006)

Biographies

Horace Herring (1950) is a researcher at the Open University, UK, and has recently contributed material on sustainable consumption and design to the course *Innovation: designing for a sustainable future*. He has a varied range of interests, from energy efficiency to environmental history, and ecological economics to science fiction. His last book *From Energy Dreams to Nuclear Nightmares*, was on the history of opposition to nuclear power in Britain, and his forthcoming one is entitled *Energy Efficiency and Sustainable Consumption: Dealing with the rebound effect*.

Robin Roy (1946) is Professor of Design and Environment at the Open University with a background in mechanical engineering and a doctorate in design and planning. Since joining the Open University he has chaired and contributed to many distance teaching courses on design, technology and environment, including *Working with our environment*; *Design and designing*; and *Innovation: designing for a sustainable future*. He founded the Design Innovation Group to conduct research on the management of product design and technological innovation and on design for the environment. This paper includes results from two recent DIG research projects that he led; *Factor 10 Visions* and *People-centred eco-design*. He has held several major research grants and published many books and papers on design, innovation and environment.