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# Assessing the costs and benefits of reducing emissions of greenhouse gases

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# Assessing the costs and benefits of reducing emissions of greenhouse gases

The problem of global warming and associated climate change, arising from human activities (primarily increased emissions of carbon dioxide and other greenhouse gases) is the most serious environmental problem facing the world. Stablising the global climate over the next century will require drastic reductions in emissions of greenhouse gases, along with changes in land use, and other policies. The government of the United Kingdom, for example, has set a target of reducing emissions by 60 per cent by the year 2050.

A number of commentators have asserted that such policies would be 'economically ruinous' (Hayward, Gordon, Illarionov). Indeed, such descriptions have frequently been applied to the very modest reductions in emissions proposed under the Kyoto protocol.

In this submission, it is argued that the cost of substantial reductions in emissions implemented over a long period is likely to of the order of 3 per cent of national income or about one year's economic growth. On the other hand, the potential costs of failure to mitigate global warming may be much greater than this.

## Approaches to estimating costs

Two main approaches have been taken to estimating the costs of reducing emissions of greenhouse gases. One approach, exemplified by IPCC Working Group III (1999) has been based on analysis of the cost-effectiveness of various technical measures aimed at increasing energy efficiency, sequestering or offsetting emissions and so on. This approach provides useful inputs to an assessment of the costs of stabilising climate, but does not provide a direct estimate of likely responses to market-based policy instruments

The other main approach has been based on the use of general equilibrium models such as the RICE/DICE model (Nordhaus and Boyer …). Although these models are quite elaborate, and allow for specification of a range of policies in various countries and regions, the core of the analysis is the representation of the demand for energy and this is usually quite simple.

In the RICE-DICE model, demand for energy is derived from a constant returns to scale Cobb-Douglas technology, where the relevant coefficient is $\beta j$ the elasticity of output with respect to energy services. The calibration of the model means that the relevant parameters of the production technology are derived from estimates of the elasticity of demand for energy. Variations in the estimated elasticity produce substantial changes in the estimated cost of mitigation.

In this section, it is argued, based on international comparisons, and a disaggregated treatment of the generation of emissions, that the elasticity of demand for energy is likely to be higher than is commonly supposed, and the cost of reducing emissions correspondingly lower.

*The elasticity of demand for energy and emissions*

Nordhaus and Boyer use an estimate of -0.7 for the OECD (and -0.84 for non-OECD countries) derived from a range of studies. This estimate is broadly consistent with that derived from other surveys of the literature. However, there are good reasons to question its applicability to policies designed to reduce emissions (and therefore energy use) substantially.

The main problem is that the term 'long-run' in studies of energy demand typically refers to a period of five to ten years, and the parameter estimates are derived from demand studies incorporating lag structures considerably shorter than this.

In this paper, a disaggregated approach is used to suggest that the long-run elasticity of demand for energy in private transportation is likely to be considerably higher than would be expected on the basis of elasticity estimates like those cited above.

Begin with the observation that, prior to the increase in oil prices of the past few years, petrol prices in Europe were typically around 1-1.2 euros/litre, while prices in the United States were around $1.50/gallon, or about 0.35 euros/

litre at a PPP rate of 1.1 $/euro. On the other hand, US consumption per person was about five times as great as in Europe and nearly four times the level in wealthy European countries (World Resources Institute 2005)..

Allowing for a unit income elasticity, this suggests that the long-run price elasticity of demand is at least 1, and probably higher.

*A first-order approximation to the estimation of mitigation costs*

A standard estimate of the welfare loss associated with a reduction in energy demand driven by an increase in the shadow price may be obtained from the consumer surplus associated with a constant-elasticity demand curve. We have

$$\Delta = (-1+m^{(1/k-1)})/((k-1)(1-m^{\wedge(1/k)})) \qquad k\neq 1$$

$$\Delta = \log(m) \qquad \text{k=1}$$

where

$\Delta$ is the welfare loss, expressed as a proportion of initial expenditure

m is the desired proportional reduction

k is the elasticity of demand

For the purposes of assessing the proposed emissions target for the UK, consider the change required to reduce energy demand by 50 per cent. This is based on an implicit assumption that technological change exogenous to the UK, along with induced changes in the emission-intensity of efficiency use will yield emissions reductions sufficient to offset the effects of income growth and reduce emissions by a further 20 per cent, thereby yielding a total reduction of 60 per cent.

For values of $k$ in the range 1 to 2, $\Delta$ ranges from 0.7 down to 0.3. Assuming energy accounts for 6 per cent of GDP, the implied welfare loss is between 1.8 and 4.2 per cent of GDP, with a median estimate of 3 per cent of GDP, approximately equivalent to one year's economic growth.

The partial equilibrium consumer surplus measure does not take account of income effects and other general equilibrium effects. However, these general equilibrium effects are normally second-order. That is, if, as will be argued below, the cost of reducing emissions is likely to be small in relation to aggregate income (say, less than 10 per cent), the error associated with neglecting GE effects is likely to be negligible by comparison with other sources of uncertainty and error.

*A disaggregated approach*

One way of bounding the cost of reducing emissions is to consider a series of adjustments that, taken together, would yield the desired reduction. The cost of these adjustments provides an upper bound to the cost of achieving the desired reduction.

The disaggregated approach may be illustrated by consideration of emissions arising from personal transport. We have

$$E = V*F*I$$

where
$E$ is emissions (tonnes CO2).
$V$ is vehicle-kilometres travelled ('000km)
$F$ is fuel consumption (litres/km)
and
$I$ is emission-intensity (kg CO2/litre).

We may further write

$$V = N*T*L/P$$

where
$N$ is the population size
$T$ is the number of trips/person
$L$ is the average trip length (km) and
$P$ is the average number of persons/vehicle

Now consider changes over twenty years, a period long enough for the vehicle fleet to turn over, and for people and firm to make adjustments to home and work locations, commuting and shopping patterns, and so on.

First, some shift towards alternative fuels could be anticipated, reducing $I$. While radical alternatives such as ethanol and hydrogen and alternatives to internal combustion such as electric cars have so far proved disappointing, an increase in the effective cost of petrol would encourage greater use of existing alternatives such as LPG and diesel, which are more efficient in terms of carbon emission. Natural gas yields 0.64 tonnes carbon per tonne oil equivalent compared to 0.85 for oil.

Next, consider possible changes in $F$. A significant reduction could be achieved simply by improvements in the technical efficiency of fuel use. The motor vehicle industry, although technologically mature, still exhibits steady improvements in the efficiency of engines and other aspects of vehicle design. When fuel prices are low, much of the effort is allocated to improving performance.

When fuel prices are high, and policy is oriented towards reducing energy use, innovations that improve fuel economy are favoured. Over 20 years, and with support from publicly funded research, it seems reasonable to anticipate a 20 per cent improvement in fuel economy, for all types of vehicles, relative to the 'business as usual' trend.

Yet further improvements could be achieved with measures to reduce traffic congestion, including purely technical innovations such as more sophisticated management of traffic lights and market innovations such as congestion charges.

Next, the mix of vehicles in the fleet would change over time. The gain from this source can be illustrated by a simplified example. Suppose that half of fleet uses 10l/100km, and half uses 5l/100km, yielding an average of 7.5l/100km. If the proportions changed to 25:75, the average would fall to 6.25,and fuel use would fall by 15 per cent. Most of this change would arise as a result of consumer responses to changing prices. However, existing policies that favour the use of large, inefficient vehicles (such as the special treatment of SUVs in US fuel economy regulations) should be scrapped, and replaced by policies pointing in the opposite direction.

A small further saving in $F$ could be achieved through discretionary decisions on which vehicle to use for a given trip. Given high fuel prices, a household with a small car and a large SUV might be more inclined to use the small car for local trips.

A similar small change, say a 5 per cent reduction in fuel use, could be achieved through improved driving habits. These include stricter adherence to speed limits on open roads, and avoiding excessive acceleration and braking in urban areas.

The adjustments considered so far involve no change at all in travel patterns (with the exception of congestion pricing, which would actually improve things), and only marginal adjustments in lifestyle. The biggest single change, in the fleet mix, would do little more than restore the mix prevailing in, say, 1980. Yet taken together, these changes would be sufficient to reduce energy use by between 30 and 40 per cent and CO2 emissions by an even larger amount.

Now consider some changes in travel patterns. The most important single variable is the distance travelled by each person, given by $T*L$. To get an idea of feasible magnitudes consider a 20 per cent reduction in distance travelled. For commuting, the biggest single use of time, this could be achieved if people chose to live a little closer to work, to rearrange schedules to allow a four-day week, or to telecommute one day each week. Similar savings could be made on shopping and leisure travel with only modest costs. Further reductions in motor vehicle travel could be delivered by alternatives to cars like bicycles and walking

Total vehicle-kilometres travelled also depend on the extent to which people share cars, given by $P$. The average occupancy of cars has declined steadily reaching about 1.1 persons per vehicle for commuting trips in the US in 2000, and about 1.5 persons per vehicle for all trips. A partial reversal of this trend, raising occupancy to 1.65 persons would reduce fuel use by 10 per cent for a given number of person-km travelled.

An effective increase in $P$ could also be achieved through greater use of public transport. Doubling the share of these would reduce the number of vehicle trips by around 10 per cent, though the reduction in fuel use would be smaller since mostly short trips would be avoided.

Adding all of these modest changes together would yield a reduction in fuel use of more than 50 per cent Some of these changes would be imperceptible, others would require marginal adjustments over a couple of decades. Taken all together, they would be barely noticeable relative to the changes in lifestyle that most people experience over such a period. It follows that the welfare cost of adjustment must be modest, and conversely that the long-run responsiveness of emissions to prices must be elastic.

*Oil shocks*

The idea that reductions in energy consumption would involve prohibitive costs to the economy draws much of its intuitive support from a misinterpretation of recent economic history, and particularly of oil 'shocks. The oil price increases of 1973, 1981 and 1991 all coincided with recessions in the United States, and some similar predictions have been made with respect to the increase in prices over the past five years.

In reality, however, the significance of the relationship between oil prices and macroeconomic activity has been overstated. The importance of oil to the economy was always overstated in popular accounts, and is now quite modest, around three per cent of GDP assuming a price of $50/barrel. Even the energy sector as a whole is of modest importance, accounting for six to eight per cent of GDP. Even a large shock to such a sector is not going to reduce GDP by more than a few percentage points, less than the impact of a moderate recession.

More importantly, causality mostly runs from the macroeconomy to oil prices rather than *vice versa*. The responsiveness of oil prices to macroeconomic shocks is clear in the case of the original 1973 oil shock. An inflationary upsurge was well under way by the time OPEC oil ministers met in October 1973. Wage and price controls had been imposed in the United States in 1971, but had broken down by early 1973—the oil shock merely administered the coup de grace, leading to the final abandonment of controls. Prices of all kinds of commodities were skyrocketing, and monetary policy was being tightened in response, making a decline into recession inevitable. Because of the cartelised nature of the oil market, oil prices responded with a lag, just as the world economy was beginning its downturn.

Similarly the 1981 recession was caused by the Volcker credit squeeze, when interest rates were increased sharply, with the objective of ending an inflationary spiral of which rising oil prices were a symptom rather than a cause. The 1991 shock, only a blip in downward trend, also occurred when a recession was already under way.

A very similar analysis applies to the current period. Although the limits to supplies of oil imply that prices must increase in the medium term, the fivefold increase in prices from $13/barrel to $65/barrel over the past five years cannot be explained in this way. Rather the increase is the product of booming demand in the United States and China, which can in turn be attributed to the expansionary monetary policy adopted by the US Federal Reserve in response to the recession of 2000 and 2001.

In this context, recent Japanese experience is particularly worthy of consideration. Japan is heavily reliant on imported energy and has experienced weak demand for more than a decade. For Japan, unlike the US, the increase in oil prices may be treated as a purely exogenous shock. Yet Japan has experienced a strong economic recovery during 2005 and this recovery seems to be gathering strength. Japan's experience is a good illustration of the modest economic significance of changes in energy prices.

An increase in the price of oil from $30 to $60 is equivalent in its effects to a carbon tax of around $200/tonne of carbon (a ton of oil is around 8 barrels, depending on density, and yields about 0.85 tonnes of carbon). Since the increase in oil prices is a response to growth in demand, we would not expect to observe substantial quantity responses in the short term. Nevertheless, it does appear that adjustments are taking place, most notably in the United States, where the relative increase in prices has been greatest. Demand for fuel-inefficient 'sports utility vehicles', which had been growing strongly, has declined sharply. As discussed below, long-run adjustments of this kind, rather than short term changes in demand for transport services, are the most important factor to be considered in assessing the likely effects of mitigation policies.

## The cost of doing nothing

A notable feature of the RICE/DICE model is that it incorporates estimates of the cost of global warming, and therefore generates optimal adjustment paths. For the most commonly-used parameter values, the RICE/ DICE model suggests that only modest mitigation of climate change is justified. This finding has been widely quoted, usually in exaggerated form, by writers such as Lomborg (2001).

Yet the estimates of the cost of doing nothing are by far the weakest part of the RICE/DICE model. In part these assessments reflect the outcome of Nordhaus' earlier work on US agriculture, which found only modest effects, many of which were positive (Mendelsohn, Nordhaus and Shaw 1994). The usefulness of these estimates is vitiated by the failure to take appropriate account of adjustment costs (Quiggin and Horowitz 1999).

*Species extinction and biodiversity loss*

Far more important, however, is the treatment of species extinction and o. This is almost certainly the most serious single cost of global warming for developed countries, but Nordhaus and Boyer use trivially low estimates: $2.5 billion per year for the United States, and $1 billion for Europe. The latter sum also includes damage to cultural sites such as possible flooding in Venice.

The basis for the Nordhaus-Boyer is the assumption that the ecosystem damage associated with climate change is equivalent to a 50 per cent reduction in the capital value of National Parks.

However, National Parks represent only a small proportion of US public policy actions designed to protect natural ecosystems. Most obviously, the Endangered Species Act restricts a variety of development actions potentially harmful to endangered species. Although only a small number of species are protected, relative to those that would be endangered by climate change, and only a small range of economic activity is affected, the economic cost of the Endangered Species Act has been estimated (admittedly by critics) at $3.5 billion per year.

Other legislation, including the Wetlands Protection Act, involves substantial public expenditure and economically costly restrictions on development. Even developmentalist legislation such as the Water Resources Development Act of 1986 involves substantial direct allocations of resources to the preservation of biodiversity, and even larger indirect costs associated with design requirements dictated by concerns about environmental impacts.

In quantitative terms, the economic impact of more general environmental protection laws, including the Clean Air Act and Clean Water Act, is substantially greater than that of measures specifically directed at preserving species. The Clean Water Act, in particular, goes well beyond requirements to protect human health, which could be addressed more cheaply by water treatment.

Although it is hard to assess the total cost of environmental protection, it seems clear that it is substantial in relation to GDP. Assessments of the productivity slowdown of the 1970s have frequently pointed to environmental regulation as a significant contributor to the slowdown in measured productivity growth (in economic terms, of course, it would be more correct to state that the failure to take account of environmental externalities led to an overestimation of output and growth in the period before regulation).

An alternative approach to deriving estimates of the welfare loss associated with large-scale biodiversity loss would be through the use of stated preference methods such as contingent valuation and choice modelling. Examination of the results of studies of individual sites suggests that the aggregate willingness to pay for preventing such biodiversity loss would be substantial: of the order of 1 to 5 per cent of income compared to the value of 0.025 used by Nordhaus and Boyer.

Stated preference methods are, ultimately, a proxy for political processes and the strong public support for costly environmental preservation measures is an indication that the Nordhaus-Boyer valuation is a serious underestimate.

Much more work is needed before realistic monetary values can be placed on the environmental damage likely under a ‘business as usual’ policy and on the environmental benefits of deep cuts in emissions. Nevertheless, it seems reasonable to assert that the benefits are likely to be of the same order of magnitude (say 1 to 5 per cent of national income) as the costs of emissions reductions. That is, mitigation of environmental damage alone is sufficient to justify a substantial program aimed at reducing emissions.

*Catastrophe*

The treatment of the possibility of catastrophe in the Nordhaus-Boyer model is deficient in a number of respects. The approach is to estimate the probability of a single catastrophic possibility, equivalent to a permanent loss of 25 per cent of income, and evaluate a certainty equivalent assuming a coefficient of relative risk aversion equal to 4. The estimated certainty equivalent is around 1 per cent of income for a median scenario involving warming of 2.5 C and 6 per cent for a warming of 6 C

There are a number of problems. First, the estimated probabilities, derived by adjusting the median value from a panel of experts in 1994, are conservative (1.2 per cent for a 2.5 C warming and 6.8 per cent for a 6 C warming).

Second, the risk aversion measure is lower than that implied by observations on the risk premium for equity. The risk premium for euqity reflects the market price of systematic risk, associated with much smaller fluctuations.

Third, the analysis fails to take appropriate account of low-probability events with losses more substantial than those considered in the scenario. Even occurring with probability 0.1 a possible loss of 50 per cent of income would add substantially to the estimated damage. And even a very small possibility of a truly catastrophic outcome, such as runaway warming would be associated with a substantial risk premium.

Finally the modelling fails to take appopriate account of the convexity of the damage function and the implications of uncertainty. Consider a model run where the best estimate of warming is 2.5 C but suppose this arises from a probability distribution where there is a 30 per cent probability of no warming, a

50 per cent probability of 2.5 C warming and a 20 per cent probability of 6 C warming. The mean is unchanged, but the expected loss associated with catastrophe risk, using the estimates cited above is now nearly 2 per cent.

## Concluding comments

It has frequently been claimed that adoption of the Kyoto protocol, let alone deep long-term cuts in emissions would be economically catastrophic. The analysis presented in this paper shows that even large cuts in emissions, implemented over a long period, would have modest economic costs. These estimates are quite robust, reflecting the fact that energy makes up a small proportion of national income and there are many margins on which energy use can be adjusted.

By contrast, a failure to act carries with it both a small, but economically significant, possibility of catastrophic loss and the certainty of massive damage to natural ecosystems. Hence, action to mitigate global warming will yield positive expected net benefits.

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