The economics of climate change

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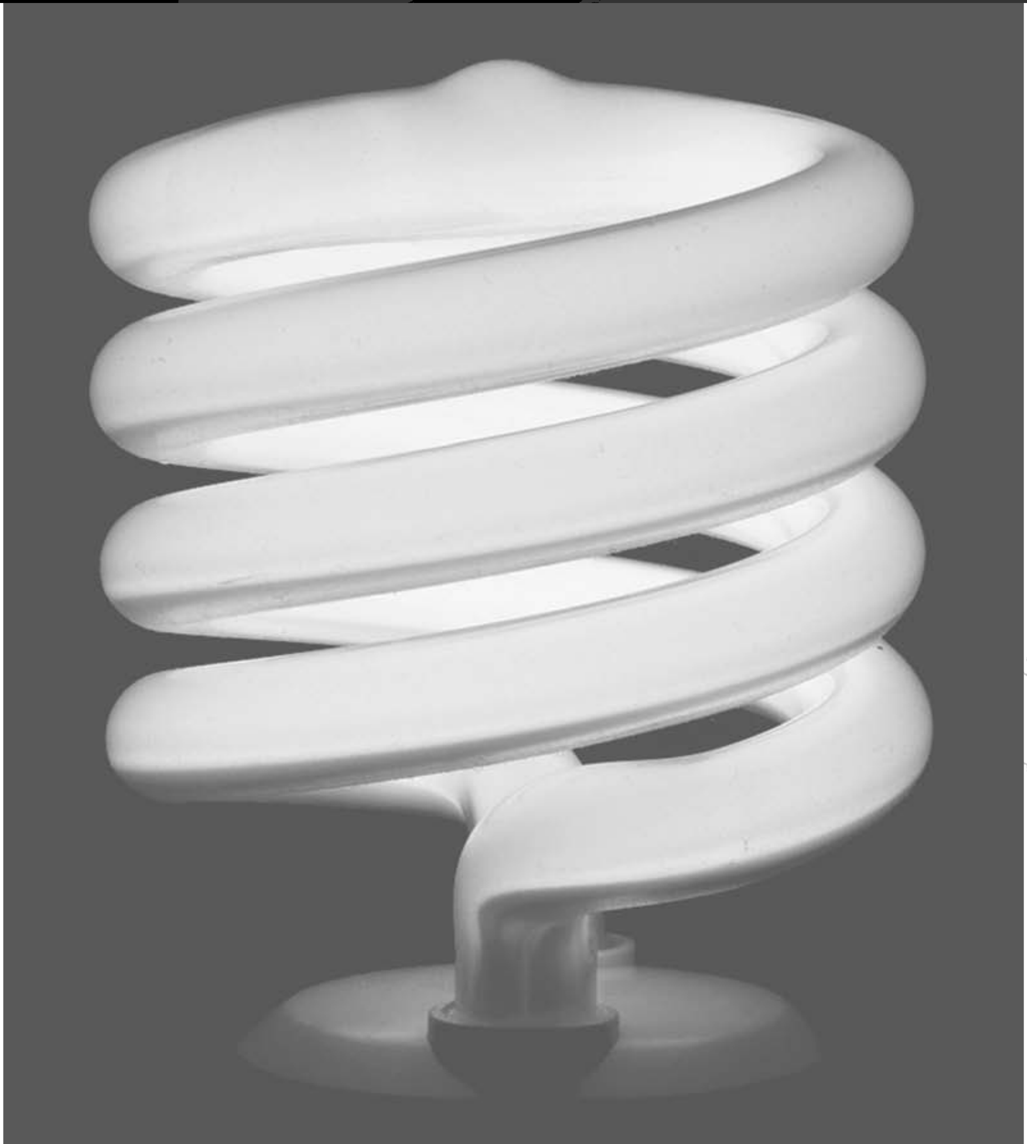

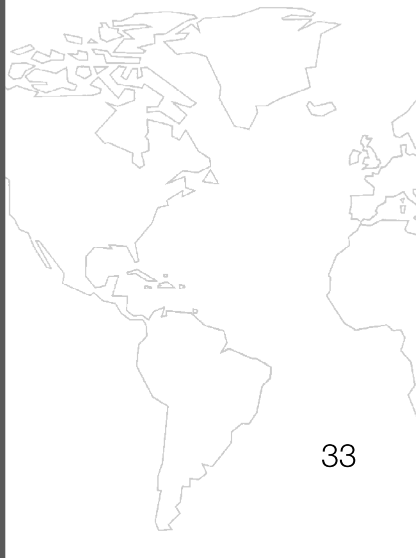

GDP and cost codes may not have the immediate appeal of melting glaciers and polar bears, but it is the process of economic growth and industrialization that has actually created the challenge of climate change. So it is important to think about the economics of climate change in order to find a path to mitigation that will be acceptable to people and at a reasonable cost. I am therefore going to concentrate primarily on economics, but I want to start with one or two quick comments on the science.

I want to look at the correlation over time between the two categories of greenhouse gas – carbon dioxide and methane – and global temperatures. Ice core records for the last 450,000 years show almost identical patterns of rise and fall in greenhouse gases and temperatures, with surges followed by more gradual stepped declines. But, as climate change sceptics legitimately point out, they are not quite simultaneous: temperature starts to rise just before the CO_2 and methane concentrations. What sets off the rise is almost certainly variations in the intensity of solar radiation due to certain features of our orbit around the sun, and the sceptics use these data to dismiss theorists who say that carbon levels drive temperature change.

The fact that the almost simultaneous growth pattern in CO_2 and temperature is started by a shift in temperature should not, however, be a cause for reassurance. Movements in both temperature and greenhouse gas emissions are far larger than can be explained by the original stimulus of variations in radiation. What is actually going on is that a small exogenous stimulus is then being amplified by a set of effects which are internal to the climate process, with hugely magnified results.

Over the last century or so, a large exogenous anthropogenic input has pushed levels of atmospheric greenhouse gases way beyond the historical pattern. We are not just on the edge but beyond it, breaking out of at least half a million years of historical variation.

Indeed we are going back to levels of CO_2 and greenhouse gases that have not been seen for 10 or 20 million years. What is really interesting in the long-term paleoclimatology record is that if you go back 60 million years, the levels of CO_2 in the atmosphere are massively higher than they are at the moment. There seems to have been a process spanning 50 million years when atmospheric CO_2 essentially left the atmosphere and ended up as fossil fuel.

What we are now doing is putting fossilized carbon back into the atmosphere as CO_2. If we continue with business as usual and release all the stored carbon that we know to exist, in particular the coal, we will release about 5,000 gigatonnes of carbon, which could easily drive total concentrations of CO_2 in the atmosphere not just to 600 or 700 parts per million (ppm) but way up to 1,500 or 2,000. It would take us a couple more hundred years to get there, but that gives us an idea of the scale of what we are doing. Its impact on temperature would probably take thousands of years to work through rather than just centuries. We would return to a dramatically different climate.

There have been very big temperature declines over the past 50 million years, in the region of 8 or 10°C. When all that carbon was in the atmosphere rather than in fossil fuels there were no polar ice sheets. The sceptics are absolutely right to say that the historical record does not show a stable climate, but it is precisely the variability of the past climate that should worry us when we think about the future. One of the complexities of the science and economics of climate change is that we frankly do not know how they will play out once the feedback loops have produced an effect.

Depending on where we are in the range of scenarios laid out by the Intergovernmental Panel on Climate Change (IPCC), our burning of fossil fuels could take the global average temperature to somewhere between 2 and 6 degrees higher than the pre-industrial level by the end of the century. As Professor John P. Holdren at Harvard University has said, ‘continuation of recent trends… leads by 2100 to temperatures not reached since the Eocene (25-35 million years ago), when sea level was 20 to 30 metres higher.

Now because of the inertia in the system, it takes an extremely long time for sea levels to adjust to atmospheric temperature increases. So it is reasonable to say that if we take a long approach to this – rather than that of my colleagues in the financial services industry who consider the long term as about a year – we have an environment on the edge.

So what has all this to do with economics and growth? Does it mean that we have to give up the idea of material prosperity, growth and consumption? Is the crisis such that there is no point in running fancy economic models? I do not think so, either in terms of the economic analysis or in terms of the implications for growth. Firstly, economics has quite a lot to tell us about how we should respond and the most cost-effective ways of doing so. Secondly, I do not actually believe that significantly mitigating climate change will require us to give up the benefits of material prosperity. The sacrifice needed is in fact quite slight.

It is almost impossible now to stop the world's climate going up by 2°C, maybe even 2.5°C. We have released such quantities of a number of greenhouse gases that there is no reverse gear. The debate now is about what action we can take to ensure that temperatures do not rise by 4 or 5°C. The economics of climate change really matters.

What exactly is the economics of climate change? An economist would summarize it thus: compare through time the economic and social cost of climate change and assign an economic value to its adverse consequences; identify the costs of mitigating climate change; identify the costs of adapting to climate change because we might choose to adapt rather than mitigate; and, of course, maximize net present value. We maximize the net present value of human welfare by taking into account the changing pattern of costs through time and using an appropriate discount rate to compare the value of different people's welfare at different points in time. That is the economics of climate change, which turns out to be a rather difficult thing to do.

There are many economists who have tried to cover all sides of the problem using what are called integrated assessment models. These take all the different costs at different periods of time and plug in discount rates, and come up with a result. One of the problems with this type of modelling is that it is so complicated that it's hard to know how to respond to the results. There are so many assumptions written into every line of the model that you cannot actually get a handle on whether the assumptions are sufficiently robust to be meaningful. It is a very complex challenge.

First you have to establish what our emissions of greenhouse gases will be as we go into the future. For this, you have to estimate GDP growth, the energy intensity of GDP growth, and the carbon intensity of energy. These are the scenarios for emissions and this is where economists play an important role. Then you have to turn emissions into stocks of greenhouse gases in the atmosphere, which is actually one of the easiest steps because it involves the straightforward physics of the dissipation of gases in the atmosphere. What is really tricky is working out whether 350ppm of atmospheric carbon – or 400 or 500ppm – relates to a particular temperature level. That theory has huge uncertainties.

Then you need to go from the average global temperature to regional climates and anticipate what is going to happen to temperatures and rainfall in particular areas. That is even trickier, but you need to get to that point in the calculations before you can begin to identify the economic and social consequences. What does it mean for crop yields, for peoples' health or for their way of life?

The relationships between atmospheric carbon and global temperature are non-linear, and we do not currently have – I suspect never shall have – absolute certainty about exactly what level of cumulative atmospheric carbon will produce what global temperature. What we do have is uncertain probability. The best the scientists can do is give us probability distributions of the likely concentration of CO_2 at which we must stabilize if we are to avoid going above a certain rise in temperature. The Hadley Centre has calculated that if we stabilize at 550ppm we have a 99 per cent probability of a temperature increase greater than 2°C but only a 24 per cent probability of an increase greater than 4°C.

We have to realize that we are always going to be dealing with a famous distinction made by Frank Knight, the well-known economist, between uncertainty and risk. We are not dealing with a precisely modellable risk where we can say definitively that the probability distribution results are XYZ. What we have is an uncertain judgement as to what a probability distribution is, and that is a tricky thing to deal with when you are trying to optimize your course of action. In terms of anthropogenic greenhouse gas emissions, it means that the effect on temperature can only ever be uncertain.

One thing we can be fairly sure of is that due to amplifications within the science (such as ice-melt reducing the planet's albedo, which in turn increases ice-melt), there are feedback loops which make the relationship between our emissions and the climate's response non-linear. But we are never going to know precisely what that non-linear function is.

When we think about the adverse social consequences of climate change we have a problem in that they come in many different categories. Some are quite easy to work out, at least conceptually, in terms of GDP equivalent – for example the cost of building a flood defence system, the economic losses associated with changes in crop yield, or the cost of three times the usual number of hurricanes. Others, however, require a value judgement – for example the value of human welfare when it comes to heat waves, the spread of tropical diseases or coastal zones going under water. It is the conceptually 'containable' effects that can be – and have been – put through integrated assessment models by economists. The bigger impacts are much harder to assess.

Then there are what are called contingent effects, which are incredibly difficult to value. If the regional effect of global warming is to lead to a sudden movement in the Sahara desert, producing lower agricultural yields in places like Niger, then you have increased poverty. The net overall effect of that both on measured GDP and on human welfare could be massively higher than what you would anticipate simply looking at agricultural yields.

Finally, you have entirely subjective judgements such as the aesthetic or spiritual value of species and the landscape itself. One of the reasons why economists produce hugely varying estimates when trying to work out the costs of climate change (Sir Nicholas Stern said as much as 20 per cent of GDP; William Nordhaus said as low as 1 or 2 per cent), is the difficulty of where the cut-off point lies across these different categories of effects. Once again, we have non-linearity. A 4°C temperature increase would be far more than twice as bad as a 2°C temperature increase. But at what point does the ability to adapt break down, and of what and for whom? If you want to put non-linearity into a model you have to turn it into some sort of equation. Frankly, we are just guessing at what kind of equation can express non-linearity.

We also have a great debate about discount rates. This is a somewhat esoteric issue. The range of debate, which is between a discount rate of 2 per cent and one of 4 per cent, may not sound very big. But the thing about compound interest is that pursued over 150 years the difference between 2 per cent and 4 per cent is transformational. What value should you place today on a £1,000 detriment in 2150? With a 4 per cent real discount it is worth £3.67 today, but with a 2 per cent discount it is worth £59.00 today. So how you trade off the value of the future versus the costs of the present depends very much on the discount rate. Discount rates really are quite fundamental, and it is not surprising that they have been debated.

Finally, in amongst the layers of complexity already outlined, there is a problem in that the impact of climate change almost certainly varies very significantly in different parts of the world. The IPCC's

Working Group II Report, which sets out the impact of climate change on ecosystems and human life, tells very different stories for different regions. For Africa there are projected reductions in crop yield of – in some countries – as much as 50 per cent by 2020, and crop net revenues falling by as much as 90 per cent by 2100. The population at risk of increased water stress is projected to be between 350 and 600 million by the 2050s. In Europe, however, all we need to worry about is the likelihood that winter floods will increase in coastal zones and that flash floods will increase throughout the region. And winter tourism in mountain regions is expected to face reduced snow cover. Well, we have seen some flooding already and can probably adapt and deal with it. So we are really talking about the trade-off between our skiing holidays being disrupted and quite a lot of people in Africa dying.

If you look at the IPCC's figures for the additional population at risk of hunger in the next 50 years, they expect there to be tens or even hundreds of millions of people at risk in Africa, but none in northwest Europe because even if we had to deal with considerable climate change, we are a rich developed society with some capacity. There are two things going on here. First, the hotter countries are more vulnerable to slight increases in heat. If the temperature in the United Kingdom went up by 3°C it would be a different climate but it would not be an impossible one. In parts of India or Africa another 3°C makes it quite unsuitable for human life.

This means that the economics of climate change is heavily influenced by ethical issues of what relative weight you attach to harm in one country or in another, or indeed to sacrifices that the developed world may have to make versus the harm that the developing world could face.

Sir Nicholas Stern's report concluded that if we do not act, the overall costs and risks of climate change will be equivalent to losing at least 5 per cent of global GDP each year, now and forever. If a wider range of risks and impacts are taken into account, the loss could rise to 20 per cent. In contrast, the cost of actions to reduce greenhouse gas emissions to avoid the worst impacts of climate change are around 1 per cent per annum. I have read Nick's report, and been involved and debated it, and concluded that for all the uncertainties, its overall conclusion is completely robust. A reasonable assessment of the potential damage says it is really very big. Nick's own figures concur that it is inherently difficult to decide whether you place a value of 5 or 20 per cent on the costs of inaction. Either way, it is much bigger than the cost of mitigation, and at least we have a higher degree of certainty regarding the cost of mitigation – I would argue that a reasonable estimate is around 1 to 2 per cent of GDP.

So, why did Nick Stern conclude that it could be limited to 1 per cent of GDP and, indeed, why is that the figure that most economists who have looked at the challenge come up with? It seems surprisingly small when you think about the scale of the changes that we need to bring about.

If we are to have a chance of stabilizing greenhouse gas concentrations at something like 500 to 550ppm (versus 380 today and 280 in the pre-industrial era), then an appropriate abatement scenario would see emissions peaking in around 2020 and then declining by something like 20 or 30 per cent relative to current levels by 2050. This is 60 to 70 per cent lower than what we might expect in a ‘business-as-usual’ scenario. Of course these are global figures, so the developed world will have to make even greater emissions cuts to allow – at least for a while – for some growth in the developing world.

China’s per capita emissions are currently about half of European levels and about a fifth of US levels. India’s are still only an eighth of European levels. The International Energy Agency estimates that China’s per capita emissions will double by 2050 to reach current European levels. If we assume that poorer economies are necessarily going to increase their emissions as they grow richer, the challenge for the developed world in any reasonable abatement scenario is to cut its emissions by something like 60 to 80 per cent against the current level. Indeed, in 2000, the UK Royal Commission on Environmental Pollution recommended cutting emissions by 60 per cent by 2050.

This target is also written into the Climate Change Bill set up by the Climate Change Committee, though one of the Committee’s current tasks is to report by December 2008 on whether that target should be not 60 per cent but 80 per cent. Some people would say 90 per cent. Either way, running our economy on upwards of 60 per cent less carbon and other greenhouse gases than we currently do sounds like an impossible challenge. But there are good reasons to believe not only that it is technologically feasible, but that it can be done at a manageable economic cost.

One way to think about technological feasibility is a rather useful analysis presented by Professor Socolow at Princeton University. It is well known as the ‘Socolow Wedges’. Total annual carbon emissions are around 7 gigatonnes (around 25 gigatonnes as carbon dioxide). Under current trends this will rise to 14 gigatonnes by mid-century. To flatten the slope over the coming decades would require removing 7 gigatonnes from the trajectory. But flattening it is not enough; emissions need to begin a downward trend. How can this be made manageable? What Socolow and his team came up with was the idea of imagining every gigatonne on the 50-year trajectory as ‘a wedge’ – which, indeed, is what it looks like on a simple line graph. They asked what would have to be done to take out a wedge of 1 gigatonne, and compiled a list of actions, each of which can remove a 1-gigatonne wedge using technologies which are not gleams in the eye of scientists in the lab, but – with some exceptions – exist at some cost today:

- Increase fuel economy for 2 billion cars from 30 to 60mpg.
- Decrease travel for 2 billion 30mpg cars from 10,000 to 5,000 miles per year.
- Cut carbon emissions from buildings and appliances by 25 per cent.
- Double the existing capacity of nuclear power.
- Switch natural gas for coal for 1,400 gigawatts of electricity generation.
- Introduce carbon capture and storage (CCS) at 800 gigawatt coal stations.
- Introduce CCS at fossil-based hydrogen plants while increasing capacity 10-fold.
- Introduce CCS at coal-to-synfuels plants producing 30 million barrels per day.
- Increase wind-power capacity 50-fold.
- Increase solar photovoltaic capacity 700-fold.
- Increase the 2004 Brazilian ethanol production 100-fold.
- Reduce deforestation to zero, plus reforestation, afforestation and new plantations.
- Apply conservation tillage to all cropland.

I shall comment on a few of them.

With regard to vehicle fuel efficiency, the middle of this century will see something like 2 billion cars in the world. The business-as-usual assumption is that they will run at around 30mpg. If every single one of them – or the average of all of them – could achieve 60mpg, that would represent a 1-gigatonne emissions saving. This is not impossible. You can buy cars today that with careful driving give you that sort of fuel consumption. One of the great effects of the Toyota Prius – amongst other modern cars – is that it gives you a continual count of your fuel consumption, and drivers with counters tend to have a little game with themselves to increase their mpg. With technological progress over the next few years, an average of 60mpg for all cars is an achievable target.

Halving the distances we travel in private vehicles is probably a bit more difficult. But rising fuel costs will have an impact, and urban design focused on efficient mass transport systems brings it into the realms of the possible.

The nuclear issue is probably controversial, but if we triple the present capacity to 1,050 gigawatts, that is another gigatonne of carbon emissions saved. Gas for coal substitution is feasible, at least until we can get real renewables up and running.

Coal is a much dirtier fuel than gas in CO_2 terms, so carbon capture and storage is an absolutely vital technology. Whether we like it or not, the Chinese are building huge numbers of coal-fired power stations, so unless we develop and make economic the technology to capture that carbon and store it in geological strata, we are not going to succeed.

We need 50 times as much wind power as at present. That is a huge task, but not impossible. This is true of pretty well all of the actions suggested above.

I think that there are two main conclusions to draw from this list. First of all, it is feasible. Second, it has to be a combination of these things: you cannot just bank on one.

You might be in favour of nuclear power and happy to treble current capacity, but you cannot multiply that up to solve the problem because you will run out of uranium. As stated, 50 times as much wind power is doable, but try covering all our energy needs with wind power and you will run out of places to put windmills. Biomass may have a contribution to make, but if you try to do the whole thing with biofuel – unless we get real breakthroughs in technology that allow us to grow biomass in desert areas or new ways of producing it in laboratories – it will be at the expense of food production. Indeed, half of what is going on in food prices at the moment throughout the world is the competition from bioethanol, unfortunately produced in an incredibly environmentally unsustainable fashion as a result of the American subsidy regime. This may have started as an environmental proposition, but it has turned into yet another way to make Iowan farmers significantly richer. Iowa, of course, has a rather large role in the American electoral system because it holds its caucases before anyone else.

The list is feasible, but it does not tell us anything about the costs. Do all these carbon savings cost far too much for the economy to absorb? Actually, the answer is no. All the best analyses say that doing a mix of these or other actions is much more likely to be 1 or 2 per cent of GDP than 5, 6, 7 or 8. I would argue that even if it were 5, 6, 7 or 8 – or even 20 – we should still do it. Fortunately, that does not seem to be necessary.

To put 1 to 2 per cent of UK GDP in context, it is somewhere in the region of £14 to 28 billion. Over the next 50 years, on the UK Treasury's medium forecast, the country's per capita GDP is likely to go up by about 2.4 times. The cost of a 60 per cent emissions cut is only around 0.3 to 2 per cent of GDP. Now in terms of our rising living standards, this means that rather than achieving the rise we might expect in January 2050 with no emissions cuts, we will have to wait until November of that year. This does not seem a major threat to our material prosperity.

But is it believable? What does it actually mean for people's way of life? Of course lifestyles will have to change, but some of these are at no real cost at all. In fact they might even be positive. Here in the United Kingdom, as well as on my business travels, I continually find that buildings are either overheated or air-conditioned to the point of necessitating an extra layer of clothing. But the choice to standardize temperatures at 18, 20 or 22 degrees is completely arbitrary. Turning down the heating in winter and raising the temperature in summer by a couple of degrees is easy to adapt to, but can have a huge impact on the carbon emissions figures.

Similarly, if people can be persuaded to get out of their cars and take public transport or bike to work there is nil cost. GDP does not go down; incomes do not go down. What happens is that people have more money to spend on other things, and their overall well-being may well go up. Quite apart from the potential benefits to health and fitness, there is a considerable benefit to be enjoyed from the 'smugness factor'. A cyclist cannot help but feel superior as he or she cycles past people stuck in a traffic jam in their SUVs. There is a consumer value in smug superiority.

There are lots of ways in which we can change our lifestyle that have no measurable effect on GDP but can save a lot of carbon. How many of them we are actually willing to do is one of those tricky questions that cannot really be answered. We on the Climate Change Committee will have to think about what assumptions we can make and how we can model them in.

Moving on from nil-cost emissions savings to nil- to low-cost ones, actual numbers become a bit more accessible. There is a whole set of opportunities in households and companies to improve energy efficiency, such as improving insulation, which might cost a little bit up front, but gives a positive rate of return. The Carbon Trust has estimated that in UK manufacturing, about 10 to 20 per cent of emissions can be cut while giving a return of more than 15 per cent – and of course we can do this at home.

Fluorescent light bulbs may cost four times as much as incandescent ones, but at 11 watts rather than 60, they produce the same amount of lumens while using 80 per cent less electricity. And of course they last much longer, so over three or four years of use there is a positive net value. Now it might seem a bit 'nerdish' to spend the evenings calculating the value of investments in light bulbs, but it is only when we do the calculations that we see the opportunities – and there are plenty. One of the things that has to be worked out by the Climate Change Committee is to identify those opportunities, figure out how reliable they are and how they can be achieved.

There are also things that will cost us money. Pretty well all renewable energies that we know about do have a cost penalty over fossil fuels, but for many of them we are talking about a cost penalty of an additional 30 or 40 per cent, not 300 or 400 per cent. It is not prohibitive.

Just look at this simple calculation (sometimes in economics, simple calculations tell you more than complicated integrated assessment models). Total energy costs as a percentage of GDP are now about 4 or 5 per cent. In a business-as-usual scenario, putting aside any impact that energy efficiency measures might have, that will probably fall to 2 or 3 per cent by 2050. Now suppose that energy in a renewable form might cost 50 per cent more, that extra 50 per cent on the cost is actually only an extra 1.5 per cent of GDP. That kind of order-of-magnitude calculation tells us that even if we pursue carbon emissions in a relatively inefficient fashion, it still won't cost all that much.

To run it another way, we can produce gas electricity or nuclear electricity at 3p per kilowatt hour, and onshore wind at around 6p per kilowatt hour. So there is a cost penalty of 3p per kilowatt hour. Our total electricity consumption in the United Kingdom is about 300 to 350 terawatt hours or 300 billion kilowatt hours. Multiply the 3p cost penalty by 300 billion terawatt hours and you get a cost penalty of £9 billion. Expressed as billions of pounds it sounds like an enormous cost, but it is actually only 0.6 per cent of GDP, so not such a great sacrifice of material prosperity.

Overall, I am optimistic that this is doable at reasonable cost, but there is a huge amount of work if the Climate Change Committee and government are actually to deliver it. I have set out an optimistic picture of the economic feasibility; pulling the policy levers to make it happen is a bit more complicated.

I have already mentioned emissions mitigation measures that economists have worked out to be at zero net cost, such as additional insulation in buildings, low fuel consumption vehicles and the like – all of which are basically energy efficiency measures. These are things that fall below the x axis on a cost curve. They don't need carbon tax incentives, because they are enough of an incentive in themselves. But if they are positive NPV (net present value) projects, why have they not been done already?

It was once said that if an economist sees a £10 note on the street, he/she will not pick it up because if it were genuine it would have been picked up already. These projects have not been grasped because there is a hidden cost in actually thinking about them. Thinking about them is in itself a cost. If, for example, you are refurbishing your house, you might want to install energy-efficient light bulbs or additional insulation or triple glazing, but your builder will probably roll his eyes at you because it's not what he usually does. So you don't get round to it.

There is a paradox here in that one of the biggest problems is just how cheap energy is. The main reason that people replace incandescents with fluorescents is not that they have done the calculations; it is because they feel that it is better for the environment. It is an ethical decision. Energy is so cheap that we are not forced to count every penny that we spend on it and figure out how to make savings. For those of middle income and above, electricity consumption is not a big part of the household budget, and small savings are of little interest. You might as well just have a glass of wine and a relaxed evening rather than do the calculations.

This is also true of the commercial sector. If you are running a large commercial building like an office site in Central London, the energy inputs to running the business are 4 per cent or even less of your total costs. In some industries, like chemicals, steel or aluminium, energy inputs are such a large proportion of the total cost of production that professional managers will have seized all the opportunities to squeeze out extra energy efficiency. Even then, they will have concentrated on the production process, not on the relatively very small costs of running their offices. There are plenty of commercial businesses, both large and small, with so many other things to worry about that positive NPV energy projects get ignored amongst the general pressures.

In terms of the complexities of switching to renewable energy, one of the challenges here is to work out the cost penalty, and the key difficulty is that the cost penalty is not an exogenous given. It is in itself an endogenous given affected by public policies. The cost of moving, for instance, to wind power – whether onshore or offshore – or tidal power is crucially dependant on how fast we choose to make the change, because the costs are determined by a different form of cost curve. It is a 'decline with experience' curve, where in many technologies the more that you produce of something the more the costs come down. That creates an interesting challenge for policy makers. Do we simply wait for these things to happen? Do we believe that by choosing to go further and faster in the direction of renewables we will automatically affect the cost penalty and bring it down?

The key thing is that just as we need many technology levers, we also need many policy levers. One of the policy levers that people talk about – and again it is of immediate interest to economists – is carbon pricing, either through a taxation regime or through a trading regime such as the European Commission's Carbon Trading Scheme. This involves creating a charge for emitting carbon, and some people think that's as much as we should do: setting a carbon track and trade system and allowing it to do the work. In some sectors – particularly energy-intensive ones – it will work. If we face a steel mill plant not only with the cost of fuel but also with a charge for emitting carbon, we will intensify yet further the search for energy efficiency. But we can only rely on the market to work in that case because the costs are large and there are professional managers focusing on it. Similarly, we may – albeit debatably – affect transport demand through crisis. And we will certainly affect renewable energy development if we increase the cost of burning fossil fuels – the relative cost of building a wind farm goes down as the relative cost of burning fossil fuels goes up. But without a dramatic increase in the cost of electricity, it wouldn't make a blind bit of difference to people's decisions about light bulbs or insulation, whether at home or in business. That means that there is a significant role to play in policy and regulation.

I don't think we are going to make the shift from incandescents to fluorescents and then to lighting-emitting diodes (LEDs, which produce the same amount of lumens with 1 watt as an incandescent does with 11 watts) through a carbon price. We can only achieve that sort of switch through regulation, by saying there is a date beyond which it is illegal to sell an incandescent bulb. Similarly, building regulations are key drivers of whether or not people will insulate buildings. Automotive emissions probably have to be driven down by agreements with the car industry on the average fuel economies of the corporate car fleet – which do exist on the European level. Consumer information alone is not enough.

Finally, we may also have to pull a price deal on technology support and subsidy. If the cost of technology comes down as a result of the volume of its production, we may want to intervene in two ways: driving the technology out of the research lab and into development by pump priming the research, or deliberately subsidizing it over the hump to get it up to a scale whereby the cost comes down.

Let me finally talk about what the United Kingdom is doing and whether it's doing enough. The UK has now made a set of target commitments which are in international agreements or in stated government policy, and some are now legally binding within the Climate Change Bill. Under the Kyoto Protocol the country made a legally binding commitment to reduce average annual greenhouse gas emissions (including carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) by 12.5 per cent relative to 1990 levels during the period 2008-2012. We already have a domestic CO_2 goal of 20 per cent below 1990 levels by 2010, and under the Climate Change Bill, we have also written into law a 60 per cent domestic reduction by 2050. The Bill also requires the government to set five-year carbon budgets. The third carbon budget, for the period 2018-2022, must see carbon emissions in the range of 26 to 32 per cent below 1990 levels.

So in terms of legal commitments we are doing quite well. These are quite stretching commitments and we have a set of policies, taxes and trading schemes in place, including a fuel duty escalator and a climate change levy, the EU Emission Trading Scheme and renewable obligation certificates. In terms of regulatory and voluntary commitments, we have building regulations and European appliance labelling, automotive voluntary commitments and supplier obligation. In fact, we have a panoply of measures set out in the government climate change programme.

In terms of the Kyoto Protocol we will more than meet the target that we committed to on reducing greenhouse gases. We did a reasonable job of reducing our non-CO_2 greenhouse gas emissions – in particular major reductions in methane from landfill sites – and we reduced our CO_2 emissions in the 1990s as we switched from coal to natural gas. But CO_2 reductions have since flattened out, and we are now way off target for any of our stated targets.

So we need to do more, and there is more in the climate change programme – in the areas of taxes and trading, appliance and building regulation, information and technology support – that the government says will take out 23.4 to 33 million further tonnes of emissions from the present annual level. However, even if it achieves the higher end of that range – 33 rather than 23.4 – we will only just achieve the lower end of the target. So even with the higher end of the policy levers that we are now pulling we can only achieve a 26 per cent reduction, not the 32 per cent reduction considered necessary. We clearly need to do *much* more.

The world is now at the potentially fruitful stage of making a raft of declarative and, in some cases, legal commitments. The European Union has committed to a 20 per cent unilateral cut in greenhouse gases by 2020, rising to 30 per cent if others can agree during negotiations, and has committed to a 20 per cent renewable energy target by 2020, which is actually very stretching. The leading presidential candidates of the United States of America are all committed to some category of cap and trade system. California has made quite strong legal commitments to a 25 per cent cut by 2020, and has an aspiration of 80 per cent by 2050. The French are talking about a 75 per cent cut by 2050. And with regard to the Kyoto Protocol, we now have the Bali agreement to negotiate follow-on commitments. So, we are making progress in terms of commitments, but so far this is not translating into the results that we need.

The abatement scenario that I mentioned earlier had the total level of global emissions beginning a downward trend from 2020 onwards. But the International Energy Agency's latest *World Energy Outlook* predicts an ongoing rise in emissions beyond 2020, even with all policy levers in place. It concludes that the number and strength of policies under consideration continues to grow faster than the number and strength of policies actually adopted, reflecting a growing concern but more talk than action.

In conclusion, we know that we can cut emissions at an acceptable cost to the economy, but we need to do much more with regard to policy, and we also need to bring in the most rapidly growing developing countries as well. The Chinese are taking steps on energy efficiency, but when you talk to them about emissions cuts they are still unwilling to enter into debate because, as they point out, their per capita emissions are still at half our level. The problem is that even if we manage to cut our own emissions by 2020, China may have overtaken us in per capita emissions, let alone in absolute emissions. There is an immensely important challenge to persuade the leading developing nations, above all China, that they also have a long-term interest.

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