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The Implications of the Economic Slowdown for Greenhouse Gas Emissions and Targets

A report by
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Key points

- The current global economic downturn is unusually severe. Global GDP and many energy prices have fallen and financial intermediation has been impaired around the world.
- Carbon dioxide emissions from fossil-fuel combustion are correlated with GDP across countries and through time, so the adverse impact of the recession on incomes is likely to reduce annual emissions.
- The responsiveness of fossil-fuel-related emissions to increases in income is probably higher in developing countries than in industrial economies, but probably still positive in the latter (contrary to some suggestions in the literature), especially in the short term. The adverse shock to incomes has been broadly similar in the two groups of countries, with wide variations across individual countries.
- But energy production, and hence CO_2 emissions, respond to energy prices as well as to incomes. The responsiveness in the long run is probably greater than many studies have suggested. Because the slowdown has led to falls in many energy prices, it may have led firms to substitute energy for other inputs to production.
- The downturn is also reducing investment and hence the embodiment of more energy-efficient technologies. And the pace of low-carbon investment and innovation is likely to have slowed. These developments will tend to moderate the fall in emissions. But the recession may also have weeded out some of the most energy-inefficient firms and avoided some lock-in of high-carbon technologies in new plant and equipment.
- The severity of the recession and past patterns of growth suggest that the underlying rate of trend growth may be adversely affected even after slack in the global economy is taken up. That will tend to reduce emissions growth over the medium term.
- We estimate that if periods of low global GDP growth per head (<1% per year) since 1950 had not occurred, global CO_2 emissions from fossil fuel use would be about 50% higher at present.
- Using a very simple modelling approach broadly consistent with the lessons of the economic literature, we calculate that fossil-fuel-related global CO_2 emissions will be around 9% lower in 2012 in a scenario consistent with the IMF's current GDP projections, but 23% lower in a '1930s style' depression. Some factors suggest that that may be an over-estimate of the size of the fall; but if trend growth is adversely affected, it could be an under-estimate.
- For the UK, using NIESR economic forecasts and the optimistic prediction that the long term downward trend in carbon intensities will continue through the recession, we predict that UK emissions will be at most 9% lower in 2012 than they would have been without the recession
- Critically, however, we predict that under 'business as usual' with no policies to promote climate-change mitigation, the recession will delay the point at which the world experiences a 2℃ global temperature rise (with respect to pre-industrial levels) by only around 21 months in the IMF recession scenario, and five years in the '1930s-style' recession scenario.
- The underlying assumption that the trend in the energy intensity of output would be unaffected by the recession is examined by carrying out an empirical study of UK businesses' energy use, relating it to the age of their capital stock. It concludes that firms with more recently installed capital tend to use less energy per unit of output, so that a recession that slows investment is likely to raise energy intensity compared with the no-recession case. That will tend to offset in part the direct impact of a lower path for GDP on greenhouse gas emissions.
- This microeconomic study draws attention to the contrasting behaviour of UK energy demand in the downturns of the 1970s and 80s on the one hand and the early 1990s on the other. The fall in energy prices in the latter case may have helped sustain demand and hence emissions. The current recession is more like that of the early 1990s than the earlier ones.
- The recession, while making it easier to meet Kyoto Protocol targets for near-term reductions in annual emissions, is no substitute for global collective action to combat human-induced climate change. It would warrant reducing any long-term greenhouse gas concentration target set before the recession, but by less than 50 ppm CO_2e even in the extreme case of a 1930s style recession, and by less than 20 ppm CO_2e if the IMF's current projections turn out to be correct.

Introduction

The current global economic downturn is unusually severe. According to the IMF, writing in April 2009, "By any measure, this downturn represents by far the deepest global recession since the Great Depression" (IMF, 2009). It surprised forecasters. As late as July 2008, the IMF was forecasting that world GDP would grow by 3.9% in 2009 (see Table 1). By July 2009, it was predicting that world GDP would contract by 1.4% – a downward revision of over five percentage points in only a year. Even after some better news more recently, the latest (October) forecast remains very low. By comparison, the slowdown of 2001-02, while a surprise, was less of a shock (Table 2). Between May 2001 and December 2001, the IMF revised down its forecast for world growth in 2002, but only by 1.4 percentage points. This downturn, while particularly acute in Europe, has been worldwide (in contrast to the slowdown earlier in the decade, when China's growth, for example, was little altered). Unlike most of the downturns in developed economies since the Second World War, it has not been triggered by adverse supply-side shocks such as a sudden rise in oil prices, nor by deliberate anti-inflationary policies by governments. Oil and other commodity prices, which had in general been rising quite sharply up until the summer of 2008, have fallen sharply, and energy costs for several fuel types have fallen (see Figure 1 for the inflation-adjusted oil price over the longer term and Tables 3 and 4 for changes in UK industrial energy prices in the past two years). Financial intermediation has been severely disrupted by asset price falls and the liquidity and insolvency problems afflicting banking sectors.

Table 1: IMF Global Growth Projections for 2009 (Real GDP %)

Region/ country	April 2008	July* 2008	Oct 2008	Nov* 2008	Jan* 2009	April 2009	July* 2009	Oct 2009
World	3.8	3.9	3.0	2.2	0.5	-1.3	-1.4	-1.1
Advanced economies	1.3	1.4	0.5	-0.3	-2.0	-3.8	-3.8	-3.4
Euro area	1.2	1.2	0.2	-0.5	-2.0	-4.2	-4.8	-4.2
US	0.6	0.8	0.1	-0.7	-1.6	-2.8	-2.6	-2.7
UK	1.6	1.7	-0.1	-1.3	-2.8	-4.1	-4.2	-4.4
Developing economies	6.6	6.7	6.1	5.1	3.3	1.6	1.5	1.7
China	9.5	9.8	9.3	8.5	6.7	6.5	7.5	8.5

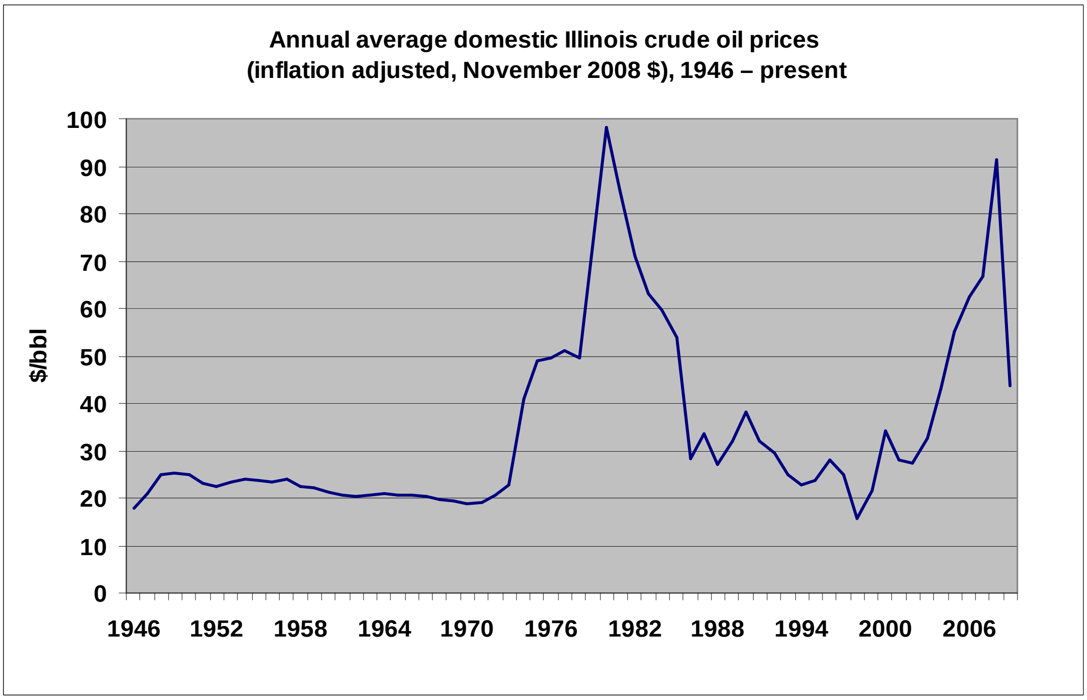
Source: IMF World economic Outlooks (various) *WEO Update Report

Table 2: IMF Global Growth Projections for 2002 (Real GDP %)

Region/country	May 2001	October 2001	December 2001	April 2002	September 2002
World	3.9	3.5	2.4	2.8	2.8
Advanced economies	2.7	2.1	0.8	1.7	1.7
Euro area	2.8	2.2	1.2	1.4	0.9
US	2.5	2.2	0.7	2.3	2.2
UK	2.8	2.4	1.8	2.0	1.7
Developing economies	5.6	5.3	4.4	4.3	4.2
China	7.1	7.1	6.8	7.0	7.5

Source: IMF World economic Outlooks (various)

Figure 1: The (inflation-adjusted) price of oil



Source: Financial Trend Forecaster, InflationData.com

Table 3: Changes in UK industrial energy prices

Energy type	2009 Q2 over 2008 Q2	2008 Q2 over 2007 Q2
Coal	9.2%	23.3%
Heavy fuel oil	-4.3%	57.7%
Gas oil	-30.5%	72.2%
Electricity	17.0%	22.8%
Gas	-12.4%	63.9%

Source: ONS

Table 4: Changes in UK retail petroleum product prices and crude oil prices

Product type	Aug 09 over Aug 08	Aug 08 over Aug 07
Super unleaded	-6.9%	16.4%
Premium unleaded	-7.4%	17.1%
Diesel	-15.9%	28.4%
Standard grade burning oil	-33.0%	60.5%
Gas oil	-28.0%	58.9%
Crude oil acquired by refineries	-27.7%	67.7%

Source: ONS

The global recession coincides with both the 2008–2012 commitment period for the Kyoto Protocol and the negotiations for its successor at Copenhagen in December. This has led to many articles in the world's press and statements by world leaders that portray the recession as either a threat to or an opportunity for these negotiations[1]. But how might these economic developments affect greenhouse gas emissions, given the importance of economic activities in generating the latter? Do they make it easier to achieve the goals of policies to combat human-induced climate change? Should the goals be amended in the light of the crisis?

This report investigates these questions as follows. In Part (1), the key implications of the economic literature for understanding the possible impact on greenhouse gas emissions are drawn out. In Part (2), the quantitative implications are illustrated for the world and for the United Kingdom, using a very simple modelling approach that nevertheless we think is broadly consistent with the lessons of the economic literature. The main message is that even though the global recession may permanently and significantly lower the trajectory for annual world greenhouse gas emissions under 'business as usual', the time at which the world broke through the widely proposed ceiling of a 2℃ increase in global mean temperatures[2] would be delayed by a trivial amount. In Part (3), the underlying assumption that the trend in the energy intensity of output would be unaffected by the recession is examined by carrying out an empirical study of UK businesses' energy use, relating it to the age of their capital stock. It concludes that firms with more recently installed capital tend to use less energy per unit of output, so that a recession that slows investment is likely to raise energy intensity compared with the no-recession case. That will tend to offset in part the direct impact of a lower path for GDP on greenhouse gas emissions. The study illustrates the benefits of understanding better the economic responses of greenhouse gas emitters to changes in the economy as a whole. In Part (4), some of the implications of the report's findings for climate-change policy targets are explored.

[1] See, for example, the news stories from around the world (accessed July 21, 2009): http://www.washingtonpost.com/wp-dyn/content/article/2009/07/09/AR2009070902021.html
http://www.guardian.co.uk/business/2009/feb/23/carbon-trading-economy-downturn
http://news.xinhuanet.com/english/2009-03/11/content_10987237.htm
http://www.usnews.com/articles/news/energy/2009/03/06/will-the-recession-derail-obamas-alternative-energy-plans.html?PageNr=1
http://www.theaustralian.news.com.au/story/0,25197,25250439-5013404,00.html

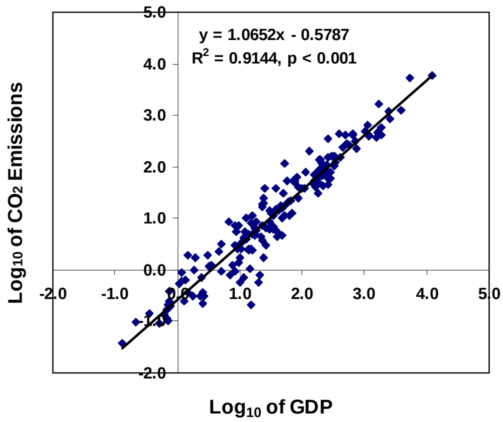
[2] Relative to pre-industrial times.

Part 1: Themes from the economic literature

Through what channels might the slowdown affect greenhouse gas emissions?

Global average temperature is predicted to increase by between 1.1 and 6.4℃ by 2100 if action is not taken to reduce the emissions of four long-lived greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halocarbons. Of these, CO_2 is the most important greenhouse gas, accounting for 77% of all global anthropogenic greenhouse gas emissions in 2004, including those from land use change (IPCC, 2007). The single largest source of CO_2 emissions is the burning of fossil fuels, which accounts for three quarters of CO_2 emissions, and roughly 60% of all greenhouse gas emissions (WRI, 2009). Given that modern economies rely heavily on fossil fuel energy sources, there is a strong relationship between the size of a country's economy (as measured by Gross Domestic Product, or GDP) and its fossil fuel CO_2 emissions, as Figure 2 illustrates.

Figure 2: The correlation between fossil fuel CO_2 emissions (Mt/year) and GDP (billions of 2005 PPP$) for 173 nations in 2005



Major efforts have been devoted to developing projections of greenhouse gas emissions and to considering how climate-change policies might reduce them. Working Group III's contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) included an extensive discussion of the main drivers of emissions in the large-scale models used in climate-change mitigation studies. In general, such models use parameters from engineering and economic studies of parts of the energy, industry and land-use systems rather than being directly estimated from past data. Population growth, changes in GDP per head, the pace of innovation and the choice of production techniques are all important. There have also been several smaller-scale reduced-form econometric studies of emissions across countries and time, such as Neumayer (2004), and studies that have concentrated on the relationship of emissions per head and income per head (e.g. Holtsmark, 2006).

Many of the explanatory variables in such models, such as long-run population growth and the availability of natural renewable energy resources, are unlikely to be affected by the global slowdown. But the slowdown has had a significant effect on some key variables. In particular, the growth rates of global and national income per head have slowed sharply and energy demand has slowed. Investment has been particularly hard hit; while it is common for investment to be more volatile than output as a whole, the crisis in financial intermediation in this recession has led to a sharp tightening in credit conditions that is exacerbating the downturn in capital accumulation. That could affect the supply capacity of economies in the future, the type of plant and equipment used, decisions about land use and the pace of innovation. Energy prices have fallen sharply, which is likely to have affected the demand for energy at any given level of income and hence the energy intensity and carbon intensity of output. It may also have reduced the incentives to look for energy-saving innovations. These issues are discussed further below.

Emissions and income

The long-run relationship between emissions and GDP has been the focus of attention because it is crucial to an understanding of how economic development around the world will affect the stock of greenhouse gases in the atmosphere. The following Figures 3 and 4 show the correlation between changes in GDP and CO_2 emissions from fossil fuels in world as a whole and in the United States. The picture is similar for the United Kingdom, but the correlation is not as strong and the implied impact of a change in GDP on emissions is smaller.

Figure 3: Change in global fossil fuel CO_2 emissions in response to change in global GDP (1990 PPP$), 1950–2006

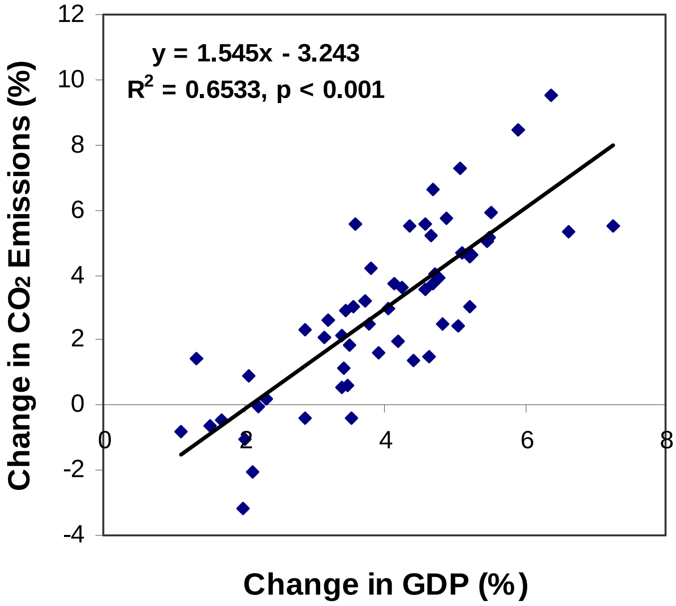
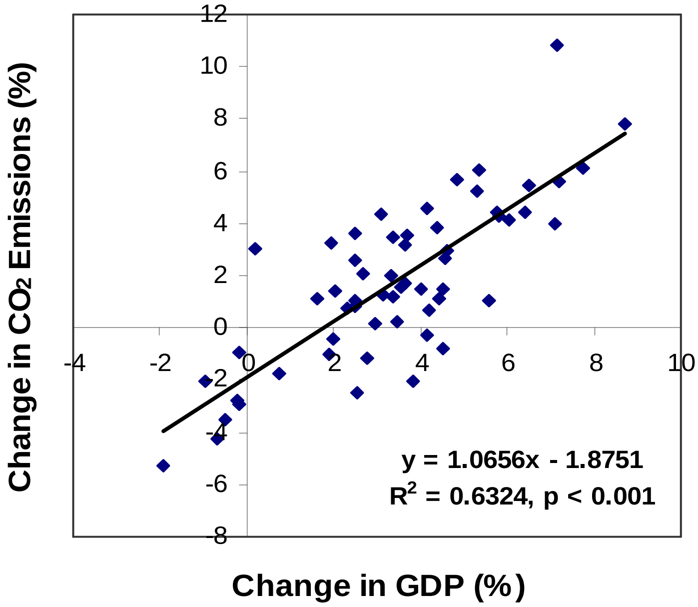


Figure 4: Change in fossil fuel CO_2 emissions in response to change in GDP (chained 2000 dollars) for the United States, 1950–2007



Several observers have noted that the sensitivity of emissions per head to variations in income per head appears to be lower in countries with higher per capita incomes. Holtz-Eakin and Selden (1995), using a global panel data set, found a diminishing marginal propensity to emit carbon dioxide as GDP per capita rises. In Neumayer's cross-country study, extrapolating the estimated equation for emissions suggested that CO_2 emissions would start to fall with income at income levels between $55000 and $90000 – but the maximum income level observed in the data was $41354. In another panel-data investigation of emissions, Schmalensee et al (1998) found clear evidence of an 'inverse U' relationship between CO_2 emissions per head and income per head. The 'inverse U' shape has given rise to debate about whether the so-called 'environmental Kuznets curve' is applicable in the case of greenhouse gas emissions[3]. Energy use per head, which is highly correlated with CO_2 emissions per head from the energy sector, also appears to increase less with income per head at higher income levels (eg. Schmalensee et al, op cit; Judson, Schmalensee and Stoker, 1999; and, for US states, Aldy, 2007).

Such results suggested that, as countries' incomes per head rise, the structure of demand might change towards less energy-intensive activities (these shifting to less developed economies) and energy supply might be shifted away from carbon-intensive technologies as the local pollution associated with them became less acceptable. However, the direct evidence for these propositions is not strong. For example, Sue Wing and Eckaus (2007) showed that changes in US industrial structure since 1980 had had little effect on energy intensity. Liu and Ang (2007) found that trends in aggregate energy intensity in the industrial sector in the past 30 years had been influenced more by changes in energy intensity within sectors than by structural change. And it is not clear that the demand for environmental improvements increases more than in proportion to increases in income (i.e. that environmental improvements are income-elastic; see Kristom and Riera (1996) who argue the contrary).

The validity of the environmental Kuznets curve in the case of CO_2 emissions has also been brought into doubt by some more recent studies that have drawn attention to the econometric challenges of estimating the relationship between emissions per head and income per head from panel data (e.g. Lee and Lee, 2009; Muller-Furstenberger and Wagner, 2007)[4]. The hypothesis that emissions per head will eventually decline as income per head rises sufficiently high is generally rejected, although there is evidence that emissions per head may converge towards the levels in the most industrially developed countries.

Studies that attempt to control for exogenous technological shifts (e.g. Lanne and Liski, 2004) suggest that shifts such as the decline in the use of steam power, the spread of the internal combustion engine and electrification can mask the impact of income on emissions. Huntington (2005) estimated that, over the long term, a 1% rise in GDP per head leads to a 0.9% increase in emissions per head in the United States, holding other explanatory variables constant. That fits well with Neumayer's observation that, across 163 countries, from 1960 to 1999, the correlation between CO_2 emissions per head and GDP per head (both measured in logarithmic terms) was nearly 0.9. Martinez-Zarzoso (2009), in a study of 121 countries over 1975-2003, and controlling for countries' energy intensity, industrial structure and urbanisation, generally rejects the environmental Kuznets curve hypothesis (the 'inverted U') once country heterogeneity is allowed for. The share of industrial activity in the economy is positively related to emissions per head for non-OECD countries but not the OECD – the most developed economies. The elasticity of CO_2 emissions per head with respect to GDP per head is 1.5 for countries at average levels of income and energy efficiency, but lower for higher-income countries.

What are the implications for the impact of the current slowdown on greenhouse gas emissions? A given fall in income per head is likely to reduce energy-related emissions more in poorer countries than richer ones. But studies of emissions per head and income per head in the long run may

[3] The analogy is with the 'inverse U' shape of the relationship between income inequality and the level of income per head across countries observed by Kuznets (1955).
[4] These studies also bring into question the studies of income per head and emissions per head over time that do not exploit the cross-sectional properties of data sets. That is relevant in interpreting McKitrick and Strazicich (2005), who argue that global emissions per head are stationary in the statistical sense and without an upward trend.

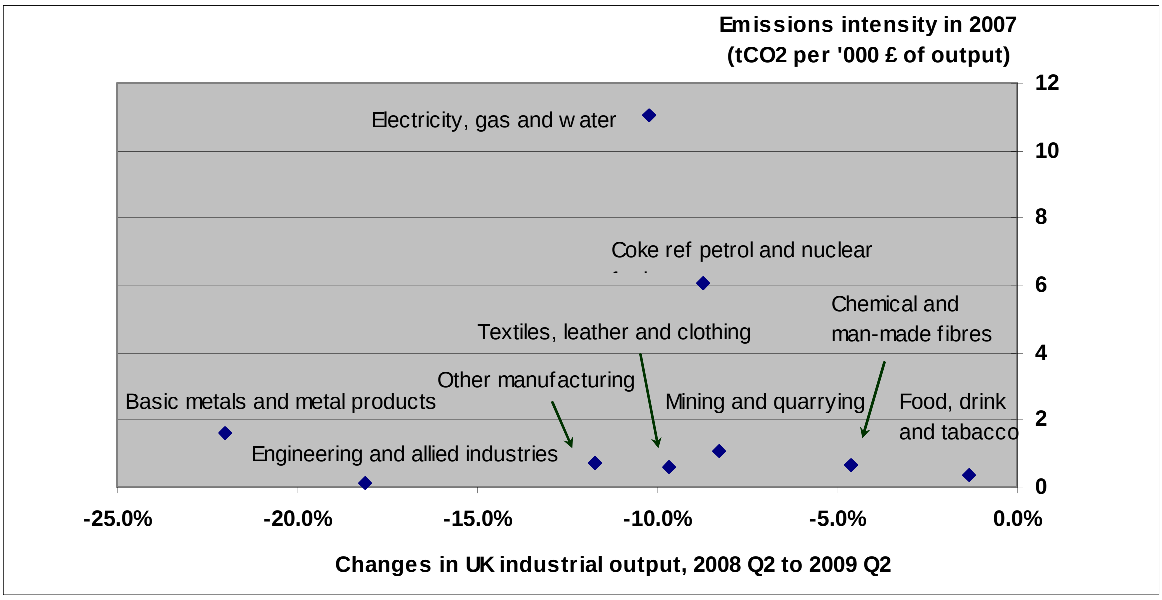
underestimate the relationship in rich countries if they do not take into account other factors, in particular the choice of energy technologies. In the short run, the capacity to vary the choice of technology or to change the industrial structure of the economy is limited, because both require extensive investment. And it is not clear that a rich country would in any case want a more energy-intensive industrial structure after an adverse income shock. Hence a temporary fall in incomes is unlikely to lead to the adoption of a more energy-intensive industrial structure (which would otherwise tend to offset in part the impact of lower incomes on emissions).

However, most studies of emissions and income have focused on the long run, because their authors have been concerned with the long-run accumulation of greenhouse gases in the atmosphere. To investigate the possible impacts of recession, it is helpful to consider studies that have paid more attention to short-run dynamics. While this has not been the focus of work on emissions, it has been more common in studies of energy demand, which is closely related to emissions from the energy sector. Such studies have also investigated the impact of energy prices on demand, another potentially important factor in this downturn, given the fall in oil prices and the carbon quota price in the EU Emissions Trading System.

The income and price elasticities of energy demand

Energy demand has proved surprisingly difficult to model. Adeyemi and Hunt (2007) conclude from their review of the literature that “there is no consensus on how to estimate industrial energy demand, in particular how the effect of technical change (and possible other exogenous factors) is captured.” Technical change may be autonomous or stimulated by rising relative prices of energy sources. Switching between fuel types may entail switching between production structures with very different responses to income and price shocks. Focusing on inter-fuel substitution and substitution among different factors of demand (e.g. capital, energy and labour) may be very useful in understanding the behaviour of the energy sector given the overall macroeconomic environment but less useful for understanding the impact of macroeconomic shocks. Economic downturns affect different industries differently, in ways that vary in part according to what triggered the specific downturn in the first place. In the United Kingdom, there has been no strong correlation between the carbon intensity of output by industry and the size of changes in output in the current recession (Figure 5).

Figure 5: Production industry emissions intensity and the impact of recession



Source: ONS

In this report, we concentrate on Adeyemi and Hunt's results for OECD countries and Agnolucci's (2009) for the British and German industrial sectors. The two articles contain extensive commentary on other studies of energy demand. Both take the view that single-equation approaches with constant elasticities of demand are to be preferred to the complex equations with cross-equation restrictions that are derived if complex production functions are assumed; as Adeyemi and Hunt argue (following Pesaran et al, 1998), they are simpler to implement, have more limited data requirements, are more straightforward to interpret and generally outperform more complex specifications.

As far as the response of energy demand to changes in income is concerned, Adeyemi and Hunt estimate a long-run elasticity of OECD industrial energy demand with respect to income of 0.8 in their preferred specification – not far from Huntington's elasticity of emissions with respect to income per capita of 0.9. Agnolucci derives an estimate of 0.52 for the long-run elasticity of energy demand with respect to economic activity, which he suggests is broadly consistent with past studies.

Turning to the price elasticity of energy demand, both studies conclude that energy demand is more sensitive to prices than many earlier estimates suggested. Agnolucci finds a long-run price elasticity of demand of -0.64 (i.e. a 10% fall in price, other things equal, leads in the long run to an increase in energy demand of 6.4%). Adeyemi and Hunt find some support for the hypothesis that the response of energy demand to a price change is asymmetric: it depends whether the price increases or decreases. They estimate that the price elasticity of demand for a price increase above its previous maximum is -0.5; for a price increase below its previous maximum -0.6; and for a price decrease -0.3. That is consistent with the hypothesis put forward by Gately and Huntington (2002) and Huntington (2006), that price increases induce technological improvements designed to economise on the now more expensive energy inputs; if the price falls subsequently, the producer does not usually find it profitable to return to using their previous technology, so energy demand does not increase as much as it fell in the first place.

The lack of consensus about income and price elasticities is reflected in the variety of assumptions made in energy-demand models used by official bodies. The International Energy Agency's (IEA's) 2006 World Economic Outlook discussed the IEA's assumptions in some detail. With respect to income elasticities, that Outlook reported a weighted average income elasticity worldwide of crude oil demand of 0.09 in the short run and 0.48 in the long run. Average income elasticities of demand for electricity (using GDP per capita) ranged from 0.4 to 1.3, and were generally higher in non-OECD countries. These figures are not directly comparable with the ones for industrial demand reported above, but seem on the low side; the share of energy demand from industry tends to be broadly constant in developed countries (with the share from the transport sector increasing with income and the share from the domestic sector falling with income), so that one might expect long-run income elasticities for industrial sectors to be similar to the income elasticities for countries as a whole.

In contrast, the overall elasticity of energy demand with respect to industrial output in the energy demand model used by the UK government is, at 1.1, significantly higher. A review of the model for the UK Committee on Climate Change (Oxford Economics, 2008) noted that industry energy demand in the model is more sensitive to changes in sector output and much less sensitive to energy prices than the models of Oxford Economics and Cambridge Econometrics. Outside the industry sector, the income elasticity assumptions are rather odd. A 1% increase in income *reduces* domestic gas demand by 0.03% and *reduces* car fuel demand by 0.4% (including the offset via slightly increased car ownership). The suspicion arises that the impacts of increases in income are being conflated with increases in energy efficiency over time.

Overall, energy demand modelling suggests that greenhouse gas emissions from the energy sectors of OECD countries are likely to be sensitive to income and hence fall in a recession, but there is considerable doubt about the precise strength of the relationship. Energy demand adjusts gradually, so long-run impacts are likely to be greater than short-run effects. There is less evidence for the impact of changes of income outside the industrial sectors of developed countries.

Emissions are also likely to be sensitive to the relative prices of energy, with some scope in the longer run to substitute labour for capital and energy in general. In the shorter run, there is also some flexibility in some sectors, especially power generation, to switch fuel type in response to relative fuel prices, so the impact of recession on the prices of fuels with different carbon contents is worthy of further exploration.

'Green' investment

Investment is particularly sensitive to variations in aggregate demand, an observation that underlies the 'accelerator' theory of investment. In the United Kingdom, business investment as a whole fell by nearly 22% between 2008 Q2 and 2009 Q2, as did investment in the manufacturing sector alone. That is likely to reduce the pace at which the capital stock in industry is modernised, as Part (3) of this report demonstrates. As older capital tends to be more energy-intensive, that will moderate somewhat the pace of energy efficiency gains and offset in part the decline in emissions growth brought about by slower income growth in the global downturn.

The slowdown in investment will also tend to slow the pace at which low-carbon technologies are embedded in the capital stock. According to a recent report sponsored by the United Nations Environment Programme (UNEP/SEFI/NEF, 2009), investment in sustainable energy slowed sharply in 2008 and 2009 after very rapid rates of growth earlier in the decade (e.g. 59% in 2007 over 2006). In the first quarter of 2009, new financial investment fell by 53% compared with the same period a year earlier. Large-scale investment in the energy infrastructure is required to reduce dependence on fossil fuels, via changes in how electricity is generated and distributed. Such investments have tended to rely heavily on project financing mechanisms, which have been particularly hard-hit by the crisis in financial intermediation. This crisis has also slowed cross-border investments sharply[5]. However, the decline in investment also avoids locking in more carbon-intensive techniques of production in industry. If carbon pricing and other climate-change mitigation policies are strengthened before investment picks up again, there is some possibility of a faster transformation of the economy in the recovery than would have been achieved without the intervening downturn.

Pace of innovation

The decline in energy prices since the onset of the global slowdown is likely to discourage innovations to improve energy efficiency. So is the slowdown in investment, necessary to embody new ideas in actual production processes. The discussion above about the price elasticity of energy demand suggested that responses to price changes are asymmetric. Price rises stimulate inventions but price falls do not induce technological regression. Nevertheless, the price falls of the last year are likely to slow the pace of innovation that would have been encouraged by the price rises earlier in the decade. It is important to note in this context the growing significance of induced technical change in proposals for the long-term mitigation of climate change (see, for example, the special issue of *The Energy Journal* in April 2006 on endogenous technical change). Empirical research on US data has confirmed the importance of energy prices as well as the quality of the existing stock of knowledge in influencing the volume of patenting activity in connection with energy-efficient innovations (Popp, 2002). Hence, as with the slowdown in investment, the near-term impact of the decline in the relative prices of energy is likely to offset in part the impact of the slowdown on emissions via income.

How fast will the world economy recover?

There is great uncertainty about the speed with which the global economy will recover from the current downturn, as illustrated by the size of the revisions to IMF forecasts referred to above and in the UK by, for example, the increased width of the GDP projection fan-charts in the Bank of

[5] The challenges of promoting private finance for climate-change mitigation in the developing countries are discussed further in a recent paper from the Grantham Research Institute: see http://www.lse.ac.uk/collections/granthamInstitute/MeetingtheClimateChallenge.htm

England's *Inflation Reports*. The increases in unemployment and decreases in capacity utilisation in industrial countries confirm that there is a large cyclical element to the downturn. In principle, that means that growth should rebound temporarily to a rate above its long-run trend when that spare capacity in the labour market and in firms is absorbed. However, the recession is likely to have slowed the accumulation of physical capital and led to accelerated scrapping of equipment and erosion of the human capital of the unemployed, all of which is likely to reduce the supply capacity of economies. Hence the global economy is unlikely to bounce back all the way to the GDP trajectory obtained by extrapolating the pre-recession trend in output.

The slowdown in growth may also have a permanent adverse impact on productivity growth, through, for example, slowing productivity growth in the financial services sector. A prolonged shrinking of firms' and households' balance sheets may hold back demand and investment growth for an extended period of time. The downturn is likely to discourage the entry of less efficient firms (Lee and Mukoyama, 2008), stimulating aggregate productivity growth compared with booms, although there is some controversy about whether recessions have a 'cleansing' or 'sullying ' effect (contrast Caballero and Hammour, 1994, and Barlevy, 2002). In general, output growth after a shock to GDP does not appear to revert to a time-invariant trend rate in most countries, although there is a debate about whether the reversion may just be very slow and whether the United States differs in this respect from other nations (see, among others, Nelson and Plosser, 1982; Cochrane, 1988; Cogley, 1990). Webster et al (2008) investigate the role of uncertainty about GDP growth in long-run climate-change modelling and are critical of the tendency to assume a fixed trend rate of GDP growth for each region in a model; instead they assume that, in the jargon of statistical time series, GDP growth follows a random walk with drift. That introduces the possibility of long-lasting booms and busts in regional growth.

In the current context, the implication of this discussion is that the global downturn is likely to have pushed the world economy on to an output trajectory permanently below what it would have been in the absence of the downturn. And, further, the slope of that trajectory may be lower than before. In other words, the downturn may have slowed the underlying growth rate of the world economy, especially if it reflects in part a slowing of underlying productivity growth (e.g. in the financial sector) or perceptions of such a slowdown.

Table 5: Recession and greenhouse gas emissions: summary

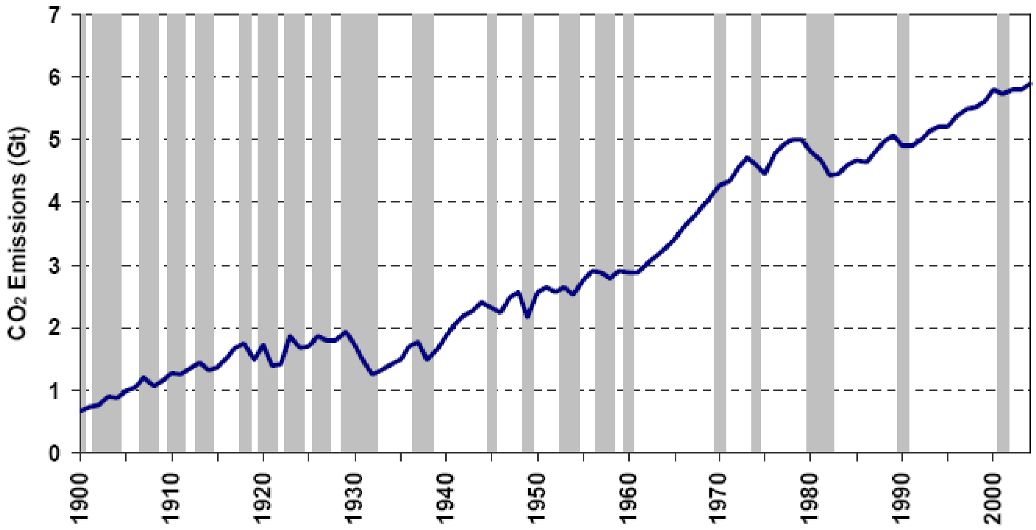
Aspect of the slowdown	**Likely direction of short-run impact on emissions**	**Likely direction of long-run impact on emissions**
Fall in incomes and output	⇩	⇩
Fall in energy prices	⇧	⇧
Fall in investment (given output)	? ⇧	?
Fall in pace of innovation	?	⇧
Fall in trend growth rate		⇩

Part 2: How the recession helps to secure Kyoto emission reductions and gives the world a head start on greenhouse gas mitigation

Introduction

As individual economies grow or shrink over time, their CO_2 emissions tend to increase or decrease as well, in close relation to changes in GDP. Periods of recession, which are generally characterised by zero or negative GDP growth, have historically been accompanied by sharp drops in CO_2 emissions (for the example of the USA, see Figure 6.

Figure 6: Fossil fuel CO_2 emissions in the United States (grey shading denotes periods of recession)



Figures 7 and 8 below show the paths of emissions for the United States and the United Kingdom under the counterfactual assumption of no past recessions. If recessions in the United States since 1950 had not occurred, and had long term growth rates not been affected by the business cycle, we calculate that US CO_2 emissions from fossil fuel use would have been over 3 Gt/year, or ~50% higher, in 2007. Furthermore, although there is no commonly accepted definition of what constitutes a global recession, we estimate that if periods of low global GDP growth per head (<1% per year) since 1950 had not occurred, global CO_2 emissions from fossil fuel use would also be about 50% higher at present.

Figure 7: Fossil fuel CO_2 emissions in the USA for the period 1950–2007 (blue line), in comparison with fossil fuel CO_2 emissions predicted if post-1950 recessions had not occurred (red line)

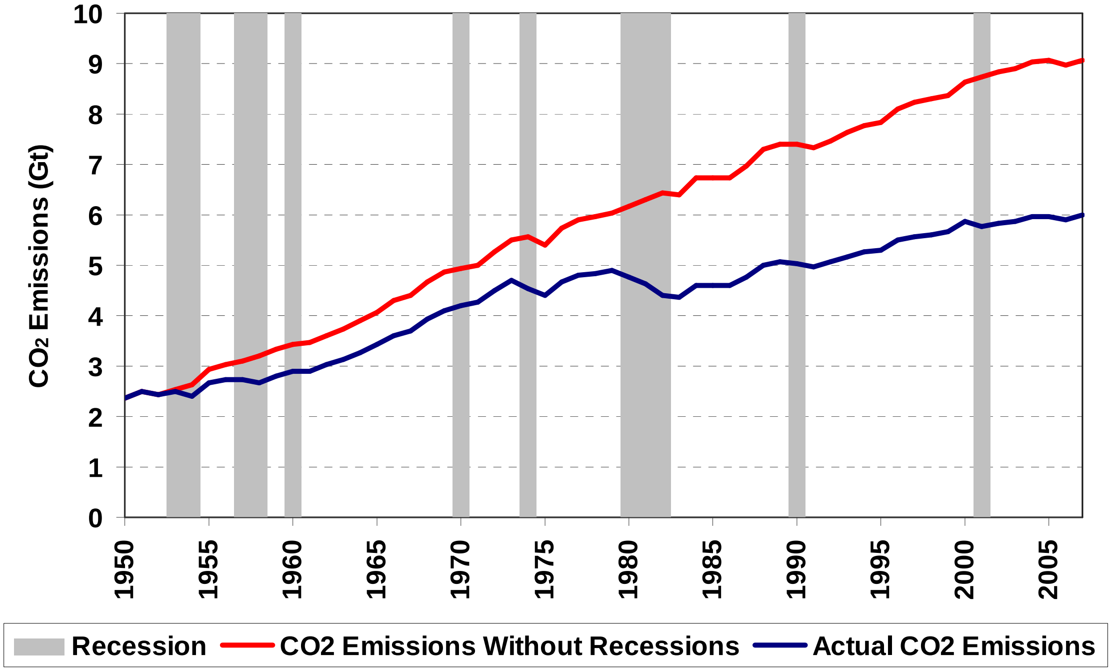
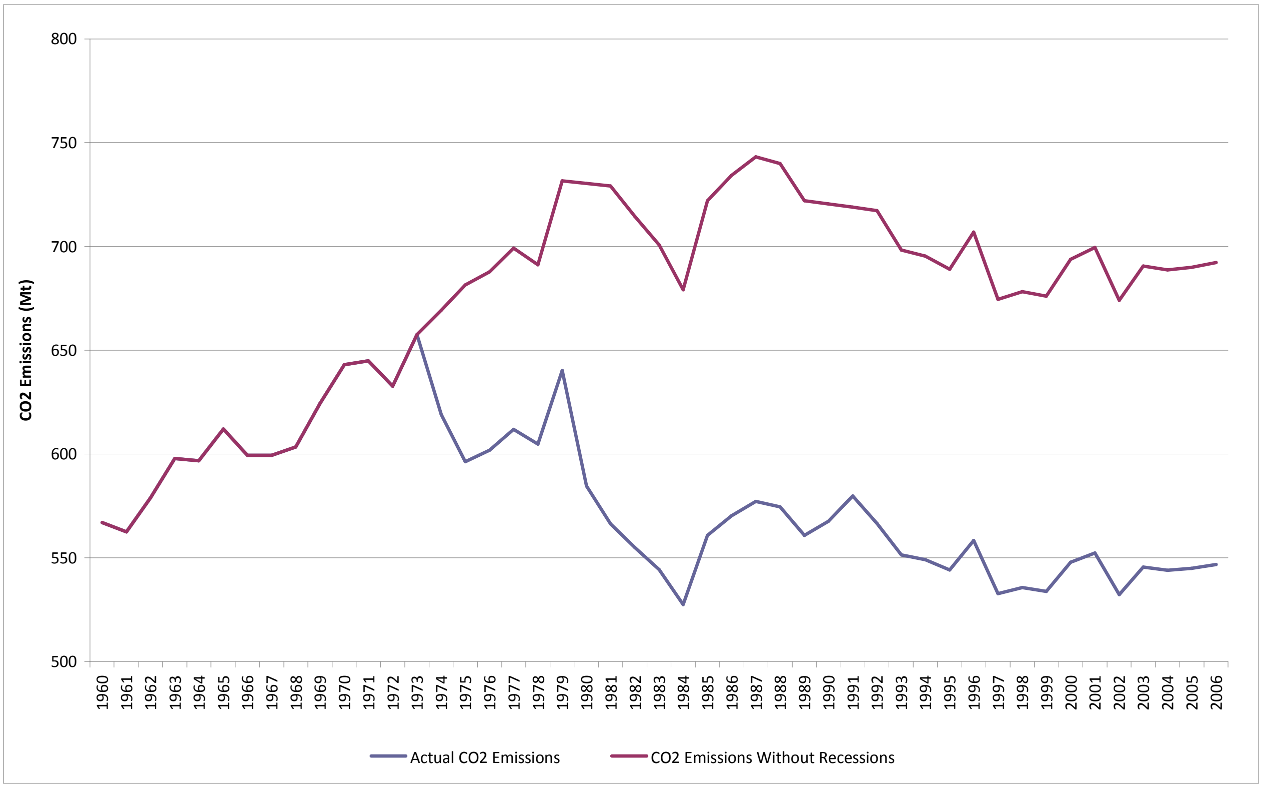


Figure 8: Fossil fuel CO_2 emissions in the UK for the period 1960–2006 (blue line), in comparison with fossil fuel CO_2 emissions predicted if post-1970 recessions had not occurred (red line)

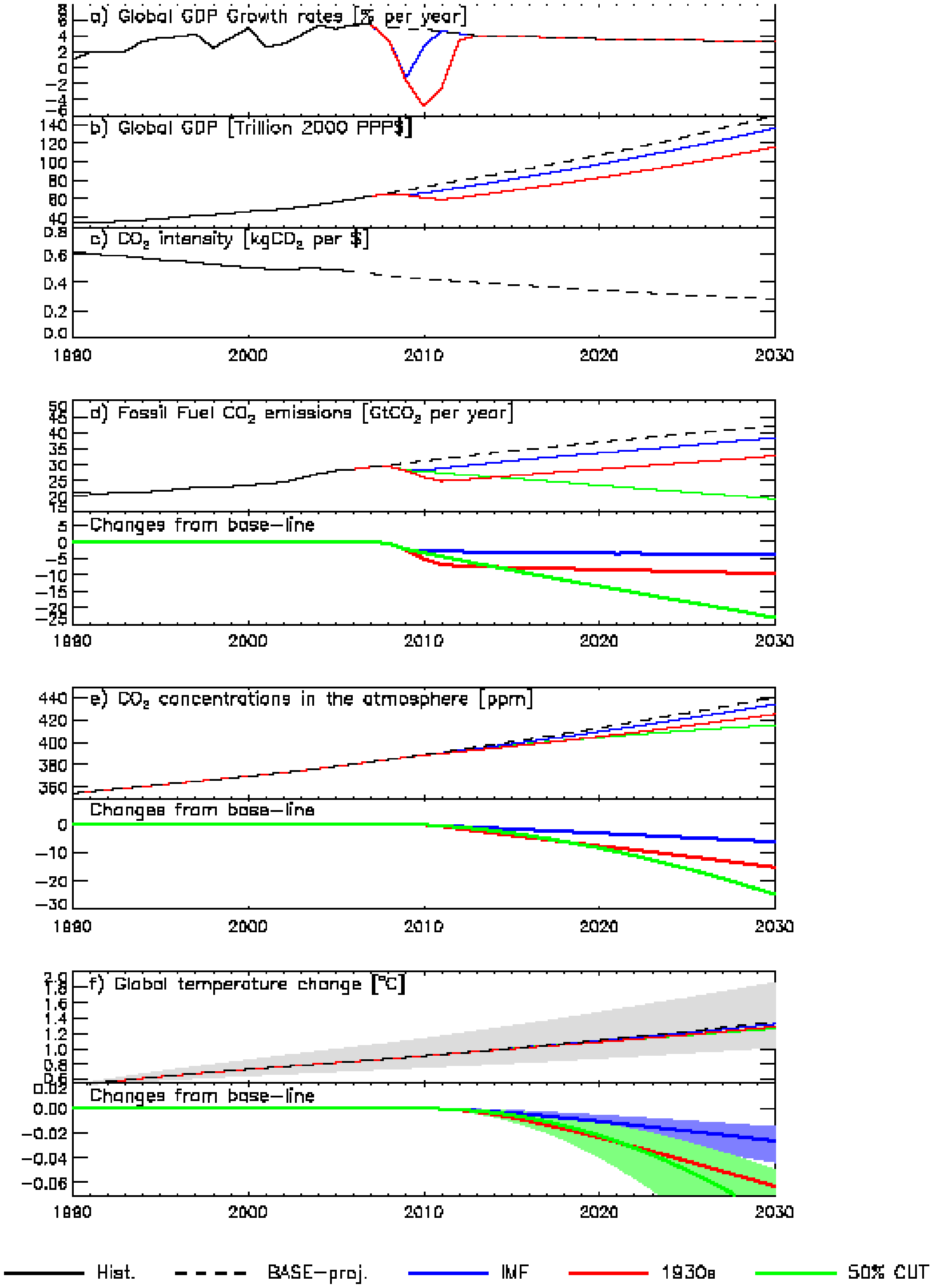


The impact of the recession on global emissions

In December 2007, the United States officially entered its most recent recession (NBER, 2008). The downturn is now affecting the global economy as a whole, with countries representing three quarters of the global economy expected to experience a decline in per capita GDP (IMF, 2009a).

To estimate the effect of the global recession on CO_2 emissions from fossil fuel use, and then global climate, we construct two recession scenarios for the period 2007–2030. The first scenario is for a mild recession, based on forecasts made by the International Monetary Fund (IMF) in July 2009 (IMF, 2009b). In this scenario, world GDP is projected to contract by 1.4% in 2009, increase by a modest 2.5% in 2010, and resume growing at long-term average rates (~3.6%) in 2011. The second scenario is for a deeper '1930s-style' recession, based on rates of GDP growth that occurred in Europe during the Great Depression. That would be more in keeping with the possibility that the trend rate of growth will be reduced, at least temporarily, as discussed in Part (1). In this scenario, world GDP is expected to continue contracting for longer – falling by as much as 4.9% in 2010, and not growing at long-term average rates again until 2013 (Figs. 9a and 9b).

Figure 9a: Economic scenarios and their effect on global CO_2 emissions climate response



(In the above Figure, the black solid lines show historical data, black dashed lines show the results for the baseline projection, blue lines show the results for a ‘mild’ recession based on the latest IMF forecast, and red lines shows the results for a deeper ‘1930s-style’ recession. The green lines illustrate a mitigation scenario with a 50% emissions reduction in 2050. The Figure has six main panels: (a) global GDP growth rates, (b) global GDP, (c) global carbon intensity, (d) global CO_2 emissions showing absolute values (top) and differences from the baseline scenario (bottom), (e) atmospheric CO_2 concentration showing absolute values (top) and differences from baseline (bottom), and (f) CO_2-induced global temperature change relative to preindustrial levels showing absolute values (top) and differences from baseline (bottom). The shading on (f) gives the uncertainty range based on the uncertainties in climate sensitivity and ocean heat uptake.)

Low or negative rates of GDP growth, such as those arising from the global recession, could have an influence on carbon intensities. The discussion in Part (1) reviewed some of the possible mechanisms. For example, on the one hand, declining GDP could result in smaller annual decreases in carbon intensities, because less money is spent on research and the development of low-carbon technologies (but see Margolis and Kammen, 1999). Slower investment results in an older, less energy-efficient capital stock than otherwise. Emissions tend to vary less than one-for-one with output or GDP. On the other hand, falling GDP could result in greater annual decreases in carbon intensities as consumers cut back on carbon-intensive activities like flying, and less efficient firms are forced out of business by the 'cleansing effect' of the recession (Caballero and Hammour, 1994).

In order to investigate these two possibilities, we analyse historical GDP and carbon intensity data for the world, for the period 1950–2006. We find a weak positive correlation ($R^2 = 0.197$, $p < 0.001$) between change in global GDP and change in global carbon intensity. In other words, we find that lower rates of global GDP growth have historically been accompanied by greater decreases in carbon intensity, in support of the second hypothesis above, and in agreement with a previous analysis for high-income countries (Victor, 2008), but contrary to the implications of much of the literature on the income elasticity of emissions reviewed above. For the United Kingdom alone, the correlation is very weakly negative.

Given the weak statistical correlation between the two quantities and the conflict with some of the literature on income elasticities, we decided not to adjust the projected carbon intensity data from the EIA, but instead use the same set of carbon intensities for the recession scenarios as the baseline scenario. We apply the carbon intensities to our economic scenarios to produce projections of fossil fuel CO_2 emissions for the period 2007–2030. Following the end of the recession in each scenario, we assume that GDP growth rates (and CO_2 growth rates) recover to the long-term averages used in the baseline scenario. A carbon cycle model and a climate model are then applied in turn to convert these emission scenarios into changes in atmospheric CO_2 concentration and global temperature.

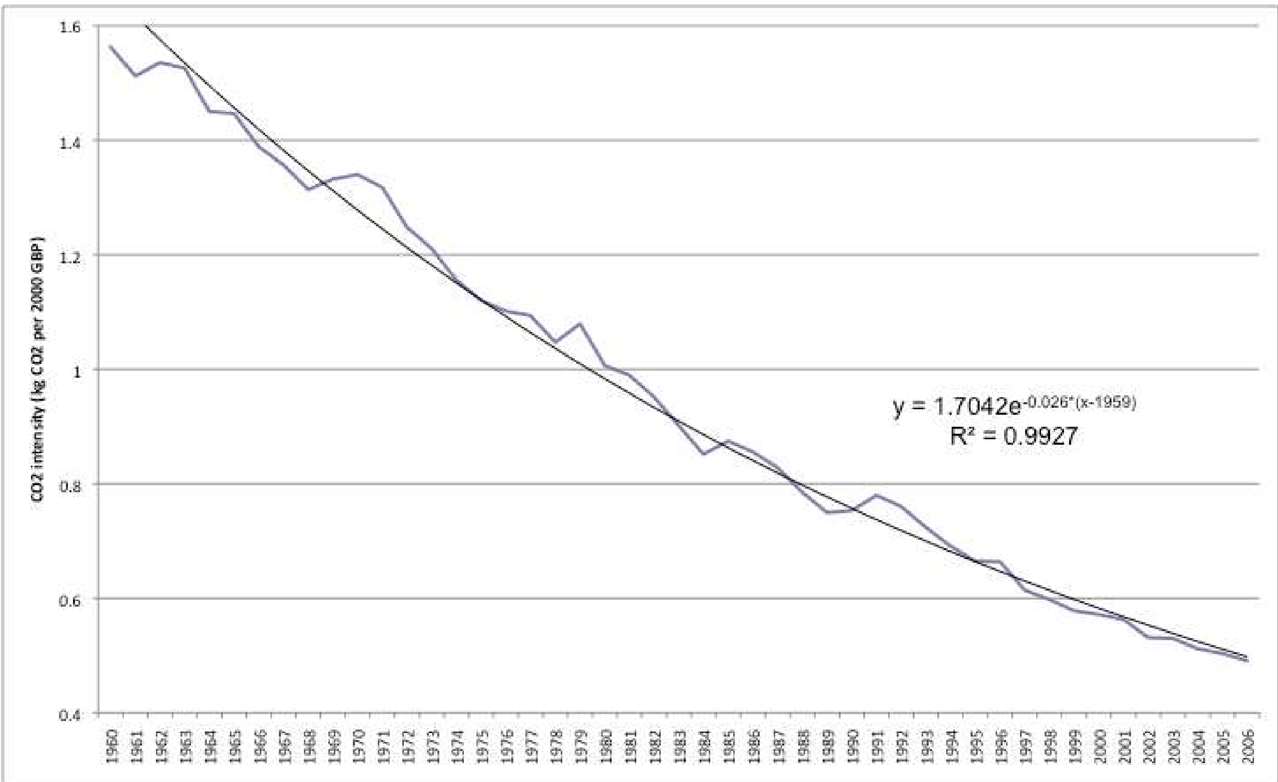
At the global scale, our results (Fig. 9d) show that a 'mild' recession[6], as predicted by the IMF, would cause global CO_2 emissions to fall by 1.1 Gt (or 4%) between 2008 and 2010, with emissions remaining below their 2008 levels for four years, or until 2012. Thus, CO_2 emissions would be 3.0 Gt (or 9%) lower in 2012 – the final year of the Kyoto Protocol commitment period – than if the recession had not occurred. A deeper 1930s-style recession would cause global CO_2 emissions to fall by 4.6 Gt (or 16%) between 2008 and 2011, with emissions remaining below their 2008 levels for fourteen years, or until 2022. CO_2 emissions would be 7.4 Gt (or 23%) lower in 2012 than if the recession had not occurred.

For the UK more specifically, although there are reasons to expect investments in low carbon technologies to slow in a recession (see IEA, 2009) historically there seems to be no statistically significant relationship between recessions and trends in carbon intensity. Accepting that it generates an optimistic forecast of the reduction in CO2 emissions, for the UK analysis we extrapolate (exponentially) past trends in carbon intensity and apply these to the longer term economic forecasts made by the NIESR both before (i.e. April 2008) and during/after (i.e. October 2009) the recession (NIESR, 2008; 2009). As is shown in Figure 9b, we forecast that even with a continuing downward trend in carbon intensities, something that is by no means guaranteed, UK emissions will be at most 9% lower in 2012 than they would have been without the recession.

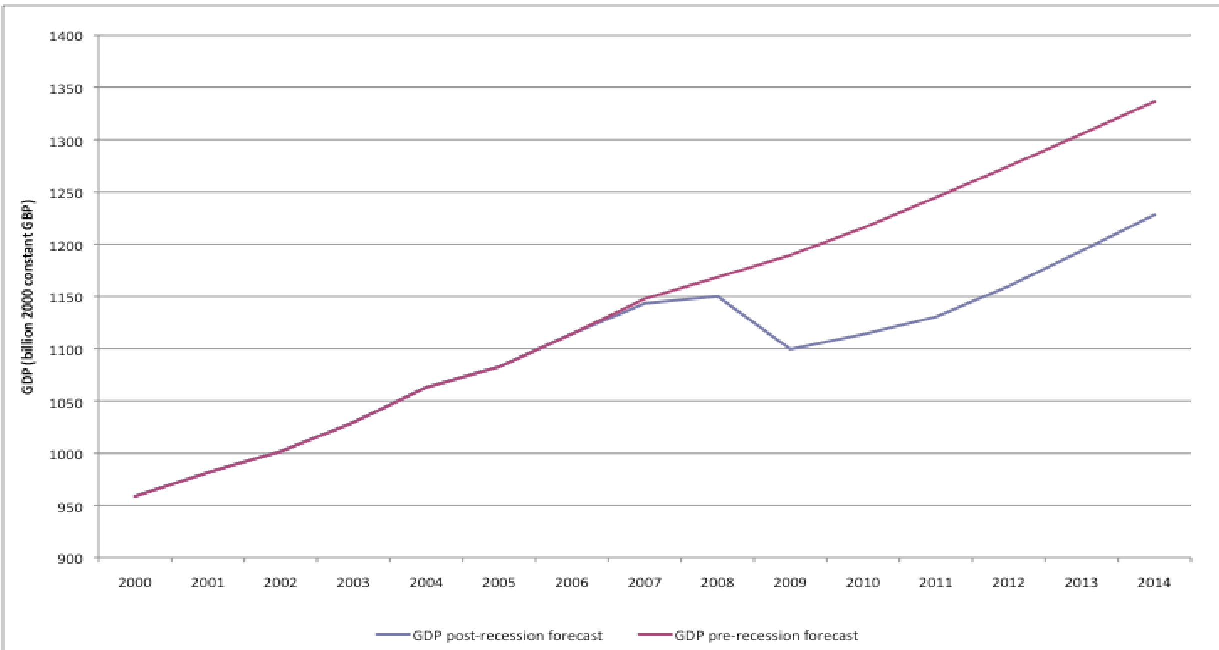
[6] 'Mild' only relative to the second scenario.

Figure 9b: Economic Scenarios and Effects of UK CO2 Emissions

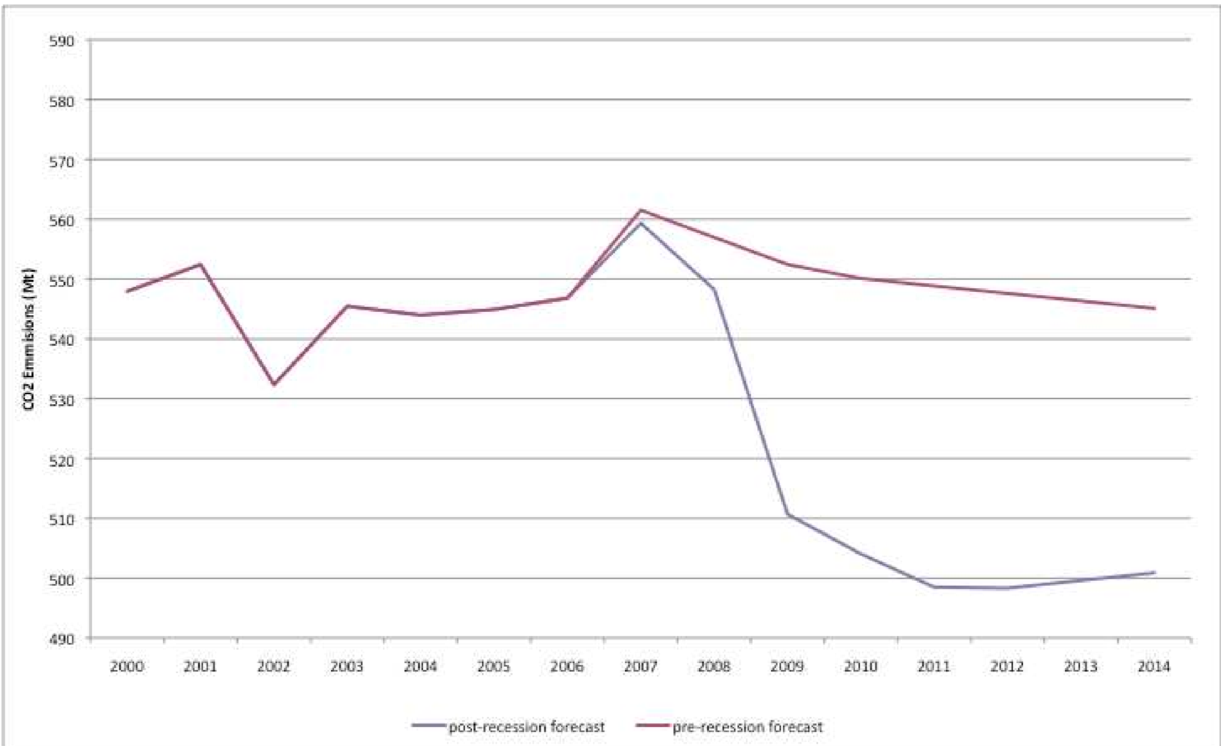
i) Long Term Trends in UK Carbon Intensity



ii) NIESR UK Growth Forecasts Pre- and Post-Recession



iii) Impacts of Recession on UK CO2 Emissions



Although recession may therefore be associated with up to 9% reductions in emissions in 2012 both at the global scale and for the UK, CO_2 concentrations in the atmosphere and the global mean temperature will continue to rise during and after the recession, albeit at a slower rate, if business is allowed to continue as usual (see Figure 9a). Compared with the expected increases in atmospheric CO_2 and temperature rise in the baseline business-as-usual scenario, the IMF recession would reduce the predicted increase in atmospheric CO_2 concentration between now and 2030 by 6 ppm (or 10%), and reduce the predicted increase in global mean temperature by 0.03℃ (or 6%). A deeper 1930s-style depression wo uld reduce these increases by 25 pmm (45%) and 0.1°C (20%). As a result, the recession will delay the point at which the world passes through a 2℃ global temperature rise (with respect to pre- industrial levels) by approximately 21 months in the IMF recession scenario, and five years in the 1930s-style depression scenario. Hence it would seem that any effects of the recession on climate change, in the absence of further mitigation measures, are likely to be small.

Box: further detail on methods used for global level analysis

Baseline scenario

A variety of agencies, including the U.S. Energy Information Administration (EIA), the International Energy Agency (IEA), and the Intergovernmental Panel on Climate Change (IPCC) have published projections of CO_2 emissions for the coming decades (e.g. IPCC, 2000; EIA, 2008, 2009; IEA, 2008). In order to construct a baseline of fossil fuel CO_2 emissions in the absence of the current recession, for the period 2007–2030, we used data from the 'reference scenario' of the EIA's *International Energy Outlook 2008* (EIA, 2008). We chose the 2008 EIA data over the other sources for two main reasons. First, although these data were published recently (September 2008), they do not take the global recession into account, making them ideal for constructing a 'recession-free' baseline. The same does not apply for more recent publications, such as EIA (2009) and IEA (2008), which incorporate the effect of the recession to a limited extent. Second, the EIA reference scenario data include explicit annual predictions of GDP, CO_2 emissions, and carbon intensities from 2007 until 2030, as well as historical data back to 1990 (the baseline year for the Kyoto Protocol).

Recession scenarios

To evaluate the effect of the current recession on CO_2 emissions, two scenarios were constructed and compared against the EIA reference scenario (or 'baseline'). The first scenario is for a 'mild' recession, based on predictions made by the International Monetary Fund (IMF) – mild only in comparison with the second scenario. The IMF produces a biannual report, entitled the *World Economic Outlook*, with GDP growth predictions for the next six years, as well as periodic updates to this report with GDP growth predictions for the next two years. The GDP growth predictions from the July 2009 update were used to construct the mild recession scenario. This latest update has world GDP contracting by 1.4% in 2009, and then growing by a modest 2.5% in 2010.

The global GDP growth predictions published by the IMF are based on 2005 purchasing-power-parity (PPP) weights, while the GDP growth predictions produced by the EIA are based on 2000 PPP weights. Statistics published using the more recent 2005 PPP values assign less weight to economic activity in developing countries such as China and India, where economic growth has been quite high in recent years. The result is that global growth rates calculated using 2005 PPPs are generally lower than growth rates calculating using 2000 PPPs. Between 1990 and 2005, the global economy grew by an average of 3.48% per year according to historical EIA data calculated using 2000 PPPs, but only 3.24% according to historical IMF data calculated using 2005 PPPs. To allow the IMF's projections to be compared to the EIA reference scenario, the IMF projections were therefore adjusted upward by the difference (0.24%).

The second scenario is for a deeper '1930s-style' recession, based on the rates of GDP growth that occurred during the Great Depression. Because of the structure of the world economy at that time, the only economies significantly affected by the Great Depression were the USA and Canada in North America and a number of European countries. The USA and Canada recorded growth rates between -12.9% and -2.4% during the four-year period from 1930 to 1933 (Maddison, 2008). We believe it would be unrealistic to assume such low growth rates for the world economy in the current recession. However, the growth rates experienced by a number of Western European countries between 1929 and 1933 could represent a pessimistic but possible scenario for the current global recession. The average annual growth rates experienced in the combined economies of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom, were 3.1% in 1929, -1.7% in 1930, -4.9% in 1931, -2.6% in 1932 and 3.4% in 1933 (Maddison, 2008). The source data for these values were calculated using 1990 PPP weights. A comparison of global GDP growth rates in 1990 PPP$ with global growth rates in 2000 PPP$ for the period 1990–2005 revealed no significant difference, so the historical growth rates were not adjusted.

The GDP growth rates for the two scenarios were applied to the last year of historical GDP data, to generate GDP predictions from 2008 onwards. GDP growth rates from the reference scenario were used after the end of the recession in each scenario to generate the remaining values out to 2030. Projected carbon intensity values from the reference scenario (in kg of CO_2 per $), were then applied to the GDP values to calculate CO_2 emissions from 2007 to 2030. The carbon intensity values that were used ranged from 0.464 kg/$ in 2007 to 0.282 kg/$ in 2030, a decrease of 2% per year on average, reflecting the EIA assumptions about the pace of improvements in energy efficiency and changes in industrial structure.

Mitigation scenario

To compare the magnitude of the current recession to initiatives intended to reduce CO_2 emissions, a mitigation policy scenario was constructed. This scenario estimates the level of global fossil fuel CO_2 emissions that would be emitted if all countries were to begin actively reducing their emissions in 2010, with the goal of a 50% reduction in global CO_2 emissions by 2050 (relative to 1990 levels). The scenario assumes that global CO_2 emissions follow the IMF Recession Scenario until the end of 2009, and that after this emissions will decrease by a constant amount each year until 2050. In Annex I countries, emissions are assumed to decrease by 0.284 Gt/year, and in Non-Annex I countries they are assumed to decrease by 0.145 Gt/year. Under this scenario, emissions in Annex I countries would be 20% lower in 2020, and 80% lower in 2050 (with respect to 1990 levels). This scenario is based on targets suggested at the recent G8 Summit in L'Aquila, Italy, and represents the ambitious level of global emissions reductions that would need to be agreed at the upcoming climate negotiations in Copenhagen if the average global temperature increase is to be limited to 2 ℃.

Atmospheric CO_2 concentrations and global temperature change
To determine scenarios of atmospheric CO_2 concentrations from 2006 onwards (Fig. 9e), a simple carbon cycle model (Joos et al, 1996) was used with parameters tuned to match the Bern Carbon cycle model used in IPCC's 4th Assessment Report, Working Group 1, Chapter 2 (Forster et al, 2007). Emission inventories for 1751–2006 were taken from the Carbon Dioxide Information Analysis Center (CDIAC) (Boden et al, 2009) for cement production and land-use change. For fossil fuel emissions, data from the CDIAC were used for the 1751–1989 period, while data from the EIA were used for 1990 onwards (EIA, 2008).

Radiative forcings for these concentrations were given by the simple formula

$$\text{Radiative forcing} = 5.35 \ln(C/C_o),$$

where C is the present-day concentration and C_o the preindustrial concentration of 278 ppm. Radiative forcings for the non-CO_2 greenhouse gases and for other drivers of climate change were taken from IPCC's 4th Assessment Report (Forster et al, 2007) and IPCC SRES scenario A1B scenario (IPCC, 2000), as employed by Gregory and Forster (2008). These were then combined with the CO_2 only radiative forcings to create a radiative forcing scenario for each of the baseline and recession cases. Anthropogenic aerosols forcings were included. However, natural forcings of volcanic and solar activity were excluded from these scenarios. For the purposes of this study, the non CO_2 forcings were all assumed to be unaffected by the recession.

A simple two-layer climate model, comprising an ocean mixed layer and deep ocean layer (Forster, 2006 ; Shine et al, 2005), was used to estimate the global mean temperature change from 1751 for the radiative forcing scenarios. The free parameters in the model are the climate sensitivity and ocean mixed layer depth. These were varied within realistic ranges based on Randall et al (2007) (2℃ to 4.5℃ for the equilibrium climate sensitivi ty and 20 m to 200 m for the mixed layer ocean depth) to determine a range of projected temperature change shown by the shading on Figure 9f.

For the baseline radiative forcing case the predicted temperature change in 2009 from anthropogenic causes varied between 0.7℃ and 0.9℃ depending on the choice of ocean heat capacity and climate sensitivity. A mid-range equilibrium sensitivity of 3.0℃ and mixed layer ocean depth of 100 m gave a warming of 1.3℃ in 200 9. The shading in the bottom panel on Fig. 9f represents the uncertainty in the climate change since 2009 caused by uncertainty in model parameters; this uncertainty is therefore zero in 2009. Note that radiative forcing uncertainty and particularly the role of aerosol forcing uncertainty (Houghton, 2008) was not included and this could significantly affect these ranges of predicted temperature change, but an analysis of this is beyond the scope of this Report.

To estimate when each scenario crossed the 2℃ thre shold the emission scenarios were extended beyond 2030, keeping their rate of emission change in 2030 constant. Depending on model parameters, the crossing date of the 2℃ threshold ranged between 2035 and 2062. Nevertheless, the relative time of crossing comparing recession and non-recession cases was robust for crossing dates after 2025, after the Earth's temperature had had enough time to respond to the drop in emissions caused the by recession. Using this approach we found that, compared to the baseline scenario, an IMF-style recession delayed crossing the 2℃ threshold by 21 months, and a 1930s-style recession delayed crossing this threshold by five years.

Part 3: The recession, investment and energy use

Introduction

The current slowdown may encourage companies (and governments) not to implement or to postpone investment projects that could have facilitated further emission reductions. This could be because they are cash strapped or have difficulty getting access to necessary credit or because the general uncertainty warrants a wait and see approach (Bloom, 2009). Figure 11 illustrates the relevance of such considerations. It shows the growth rate of industrial energy consumption in the UK from 1970 to 2008 thus covering three major recessions (1973, 1980, 1991). Whereas the 1973 and 1980 recession clearly lead to a dip in energy consumption as well, it is harder to detect such an association in 1991. In conjunction with GDP growth rates shown in figure 10 it becomes clear that there is not always a simple linear relationship between energy consumption and economic activity.

To understand better factors which might lead recessions to increase energy intensity of production, this Part of the Report examines to what extent industrial energy intensity in the UK is connected to investment and how investment is affected by recessions. We use firm level data on energy intensity and investment to examine the extent of embodiedness of energy intensity improvements in capital investments. Hence, we examine to what extent improvements in energy intensity require investment by firms. To understand the issue, consider the case of light bulbs. Some firms might require a lot of energy for lighting simply because employees tend not to switch off unneeded lighting. Thus energy could be reduced simply by educating staff or linking pay to energy usage; i.e. energy intensity would reduce without further investment. On the other hand, firms might introduce a new, less energy intensive, lighting system with sensors that switch off lights automatically when not needed, which would require further investment and would therefore be a technological change that is embodied in capital.

Somewhat more formally, we can express the issues at hand as follows: We want to assess the impact on energy consumption – and thus GHG emissions – of a recession. Hence we need to assess energy consumption during a recessionary state at time t, relative to a counterfactual control case of no recession at time t

$$E_{tR} - E_{tCF} = \rho_{tR} Q_{tR} - \rho_{tCF} Q_{tCF} \qquad (1)$$

where Q denotes output quantity and ρ is the energy (or GHG) intensity of output. Thus in a recession there is no doubt about output going down ($Q_{tR} - Q_{tCF} < \mathbf{0}$). However, because of the increased ageing of capital, intensity might go up relative to the counterfactual case ($\rho_{tR} - \rho_{tCF} > \mathbf{0}$).

Econometric approach

In our approach, we follow closely the method adopted in the literature to measure the embodiedness of productivity (total factor productivity or TFP) improvements in capital (Mairesse, 1978). This suggests measuring embodiedness by the extent to which productivity depends on the average age of the capital stock. The idea is that, if the productivity of firms systematically varies with the age of their capital stock, then productivity improvements require investment to materialise (embodied technological progress). Alternatively, there is no reason why firms should forego an opportunity to increase their productivity. Translating this idea to energy intensity, we run regressions of the following form:

$$\frac{EE}{GO}_{it} = \beta_{age}AGE_{it} + \beta_{kage}KAGE_{it} + \beta_k lnK_{it} + \alpha_I + \alpha_t + \varepsilon_{it} \quad (2)$$

where $\frac{EE}{GO}$ is energy intensity measured as energy expenditure as a fraction of gross output (Revenue), AGE is the age of a firm and $KAGE$ is an index of the age of the capital stock. α_I and α_t represent (three digit) sector and year dummies. ε is an error term assumed iid. Hence β_{kage} measures the embodiedness of energy intensity changes in capital. Below we also regress a version of equation (2) with energy expenditure as a fraction of operating costs as dependent variable ($\frac{EE}{VCOST}$). This addresses the concern that differences in $\frac{EE}{GO}$ could be driven by differences in the price of output which we cannot control for in our data.[7]

For comparison with the existing literature we also report similar regressions of output

$$GO_{it} = \beta_{age}AGE_{it} + \beta_{kage}KAGE_{it}\beta_k lnK_{it} + \beta_M lnM_{it} + \beta_L lnL_{it} + \beta_{EE} lnEE_{it} + \alpha_I + \alpha_t + \varepsilon_{it}$$

where we include further controls for material inputs (M), labour (L) and energy (EE) so that β_{kage} measures the degree of embodiedness in capital of TFP improvements.

As an index of the age of the capital stock we use the share of capital that was added in the last three years.[8]

$$KAGE_{it} = \frac{I_{it} + (1-\delta)I_{it-1} + (1-\delta)^2 I_{it-2}}{K_{it}}$$

This is slightly different from Mairesse (1978), who uses the average age of the capital stock. Compared with his, our measure simplifies dealing with left censoring; i.e. determining the age of capital that was added before the start of the sample.

Basic regression results

Table 6 reports regression results for a sample covering the whole of manufacturing. Column (1) reports results using energy expenditure over gross output as dependent variable. Note first that firms with higher levels of either buildings or plant and machinery capital stocks are significantly more energy intensive (rows (1) and (2)). On the other hand, if a larger fraction of either buildings or machinery capital is only recently installed, energy intensity is significantly lower. The figures imply that a 1% larger fraction of new (less than three year old equipment) capital is associated[9] with a 0.32 percentage points lower energy intensity in the case of buildings and 0.26 percentage point lower energy intensity for machinery. Columns (2) and (3) repeat the exercise first for energy expenditure as dependent variable and second for energy intensity measured as energy expenditure over variable costs. This leads to the same qualitative conclusions. Column (4) reports a productivity regression on the same sample. This confirms that newer capital is strongly correlated with higher total factor productivity (TFP); e.g. a one percentage point higher share of three year old machinery is associated with 10% higher TFP.

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7 Martin (2008)

8 We also experimented with share of capital added in the last 2 years without much change in the results.

9 We have to keep in mind that any values reported on the basis of simple OLS regressions have to be interpreted as mere correlations.

Quantifying the impact of the capital age effect

The previous sub-section showed that the energy intensity of firms is strongly related to the age of their capital stock. This could explain why, in aggregate, recessions do not necessarily lead to large reductions in energy usage: recessions may lead to a decline in investment activity, so that the age of the capital stock declines relative to a counterfactual state without recession. Again, there is no necessity that this should be the case. Firms could indeed see recessions as an ideal time to install new equipment. Figure 14 examines this by plotting changes in our capital age variables over time (KAGEpm and KAGEb). The available data allow us to look at only one – the 199! – recession. For machinery, there is indeed an episode of a declining share of new capital, so that on average the capital stock becomes increasingly old. An econometric test shows that this is also a statistically significant deviation. There is no discernible deviation for building capital. Interestingly, the period of ageing capital stock from 1991 to 1993 seems to be followed by a period of increased activity after 1993. Combining our regression results from table 6 with the deviation found in Figure 14 allows us to make a quantitative assessment of this effect. The values underlying Figure 14 suggest that, post-recession, the new machinery share is about one percentage point lower. Taking the coefficient of -0.256 from Table 6 and considering that average energy intensity in UK manufacturing is about 2%[10], we can estimate the capital age effect of a (1991) recession on energy intensity as about 0.1%. Considering that the negative effect of a recession on output is about 2%, while economically meaningful, this is surely not sufficient to explain why energy consumption did not drop more in the 1991 recession.

Sectoral results

Tables 7 to 9 repeat the regressions in table 6 separately for various manufacturing industry groups. In most sectors, this reproduces the qualitative finding from the overall regressions earlier of a negative and often significant relationship between capital novelty and energy intensity. There are, however, important quantitative differences between the sectors. Notably, manufacture of metals and fabricated metal products (DJ) has an estimate more than five times higher for the impact of new capital on lower energy intensity.

Conclusion

Looking at previous recessions, it is not clear that an output contraction necessarily leads to a contraction of energy consumption and thereby GHG gas emissions. It is interesting to contrast the early 80s recession, which led to an energy consumption reduction in proportion with the output contraction, with the early 90s recession, which did not.

Using micro data, we examine one possible explanation, the increasing age of capital due to lower capital replacement during recessions. While we find economically meaningful effects, they are not large enough to counter the decline in output. This leaves the door open for other explanations. A key difference between the 80s and 90s recession was what happened to oil and energy prices. The 80s recession was in part caused by an oil price shock, while the 90s recession was not. Rather, the 90s recession led to or coincided with a decline in energy prices. In qualitative terms, the 90s recession is therefore not unlike the current one (Figure 16). This suggests that we should be cautious about expecting dramatic emissions reductions from the current recession.

10 Author's calculations based on ARD.

Figure 10: Growth rates of GDP in the UK

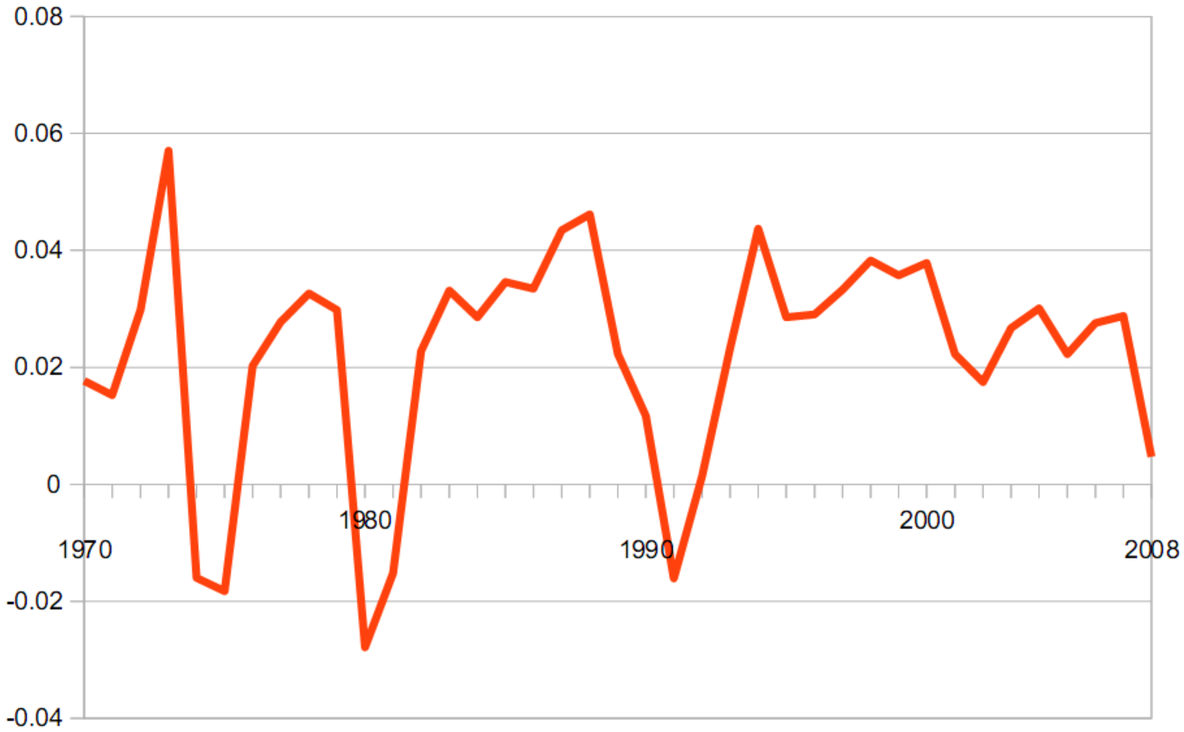


Figure 11: Growth rates of industrial energy consumption in the UK

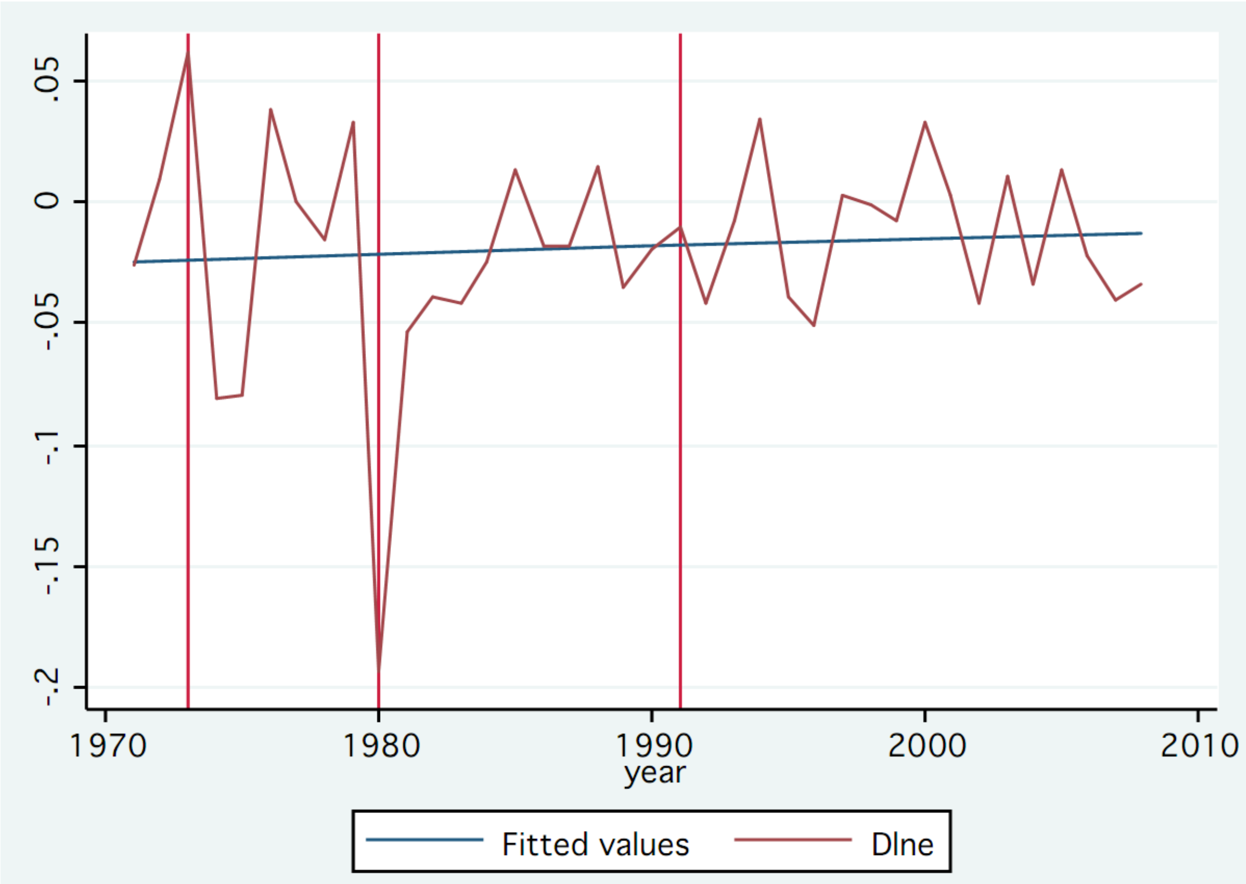


Figure 12: Growth rates of industrial energy consumption in the USA

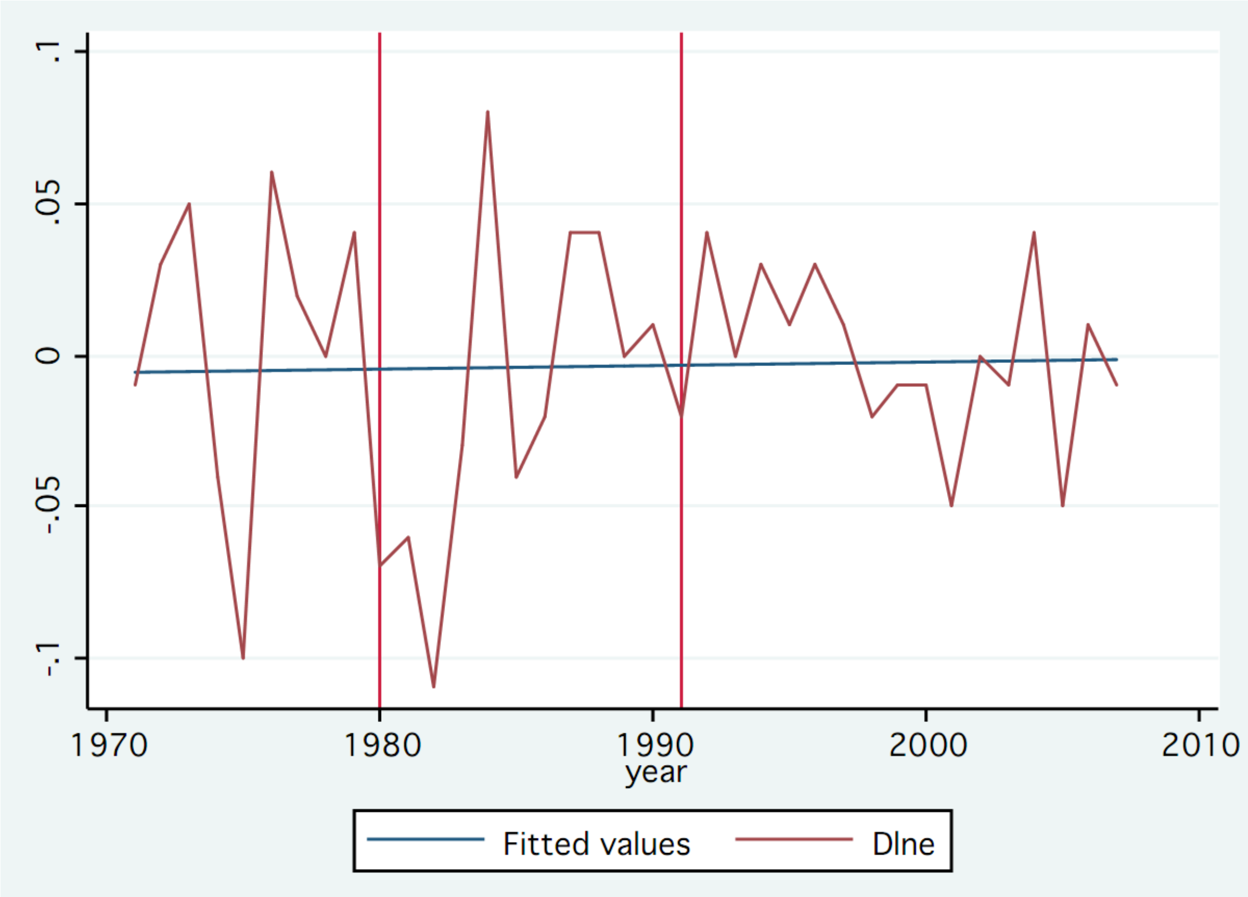
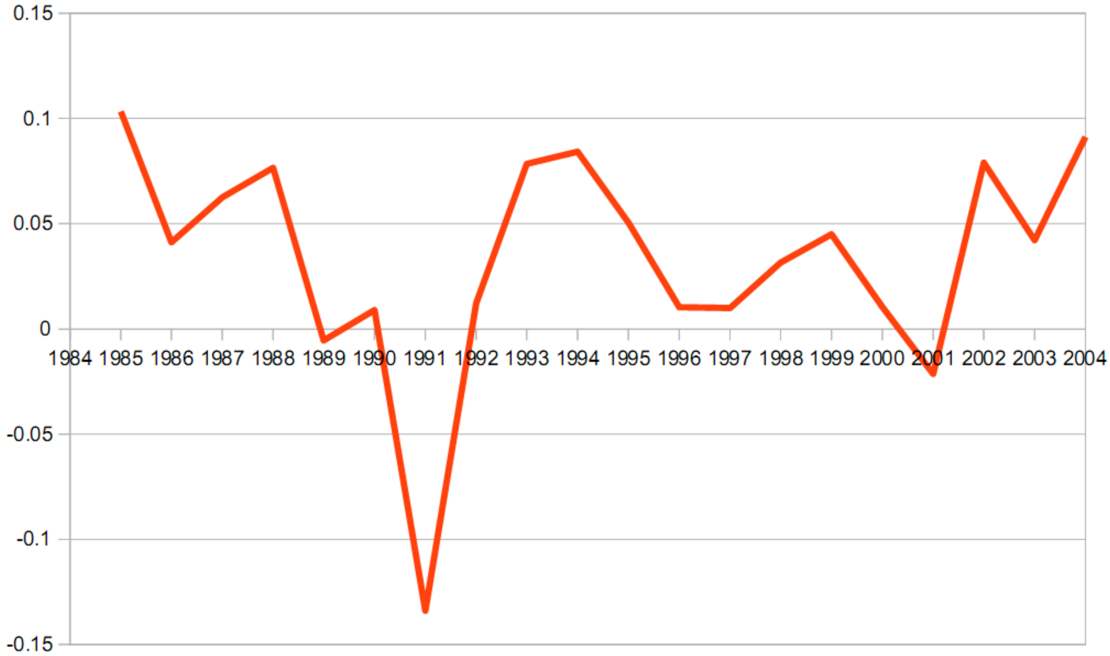


Table 6: Embodied technical change – regressions for the whole economy

	(1)	(2)	(3)	(4)
Dep.Var.	EE/GO X 100	lnEE	EE/VCOST X 100	lnGO
Buildings Capital	0.052***	0.047***	-0.01	0.019***
lnKb	(0.010)	(0.006)	(0.012)	(0.003)
Plant and Machinery	0.204***	0.139***	0.148***	0.100***
lnKpm	(0.011)	(0.007)	(0.013)	(0.004)
Share of 3 year old Buildings	-0.323***	-0.204***	-0.211***	0.246***
KAGEb	(0.050)	(0.030)	(0.056)	(0.015)
Share of 3 year old plant and machinery	-0.256***	-0.089**	-0.116*	0.100***
KAGEpm	(0.061)	(0.037)	(0.070)	(0.019)
Output	-0.289***	0.786***	-0.222***	
lnGO	(0.011)	(0.007)	(0.012)	
AGE	0.007***	0.005***	0.004***	0.004***
	(0.001)	(0.000)	(0.001)	(0.000)
Energy				0.109***
lnEE				(0.004)
Materials				0.668***
lnM				(0.005)
Sector dummies (3 digit)	yes	yes	yes	yes
Year dummies	yes	yes	yes	yes
Obs	50597	50597	50597	50597
Firms	25905	25905	25905	25905

Notes: All regressions report robust standard errors with clustering at the firm level.

Figure 13: Growth of value added per employee for UK manufacturing, based on ARD sample



Notes: Figure shows growth of value added per employee for the manufacturing sector computed directly from the ARD sample.

Figure 14: Changes in the share of new capital over time

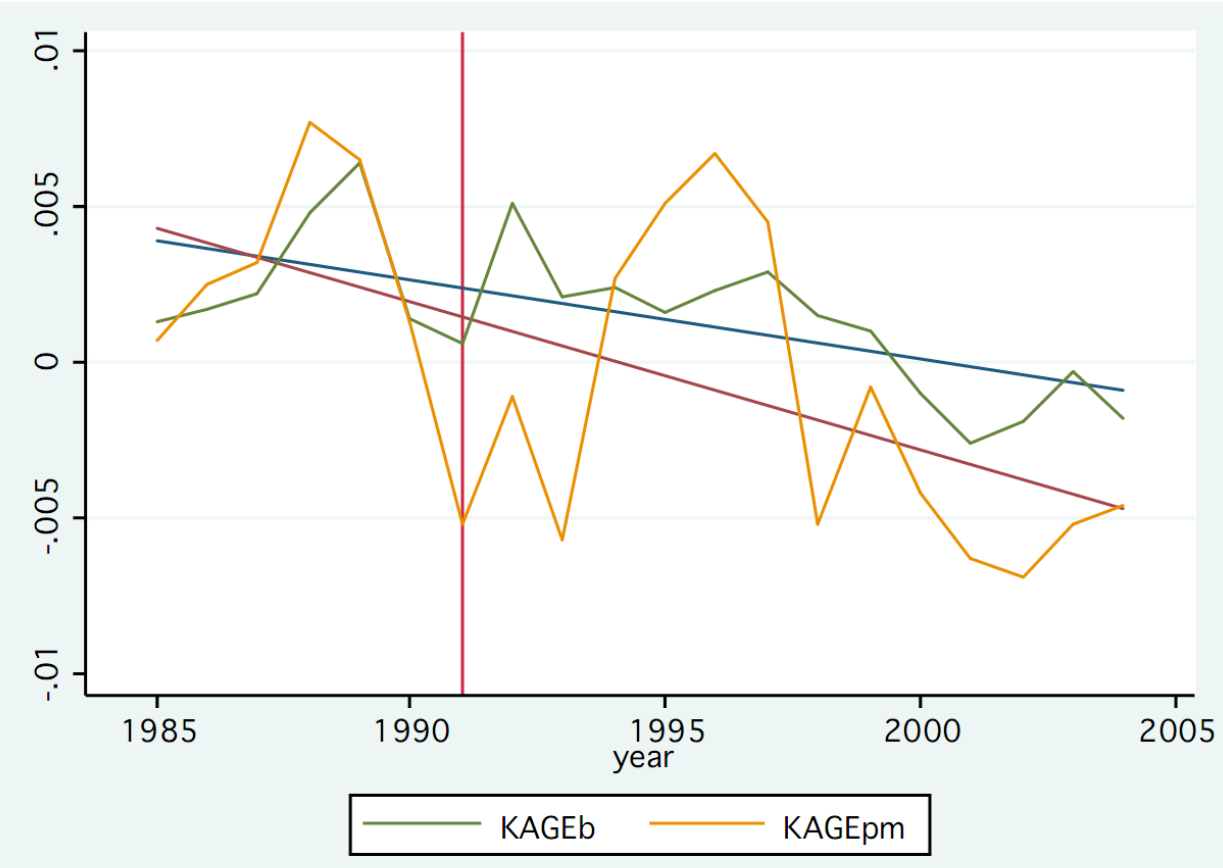


Figure 15: Oil price index for the UK 1980-2005

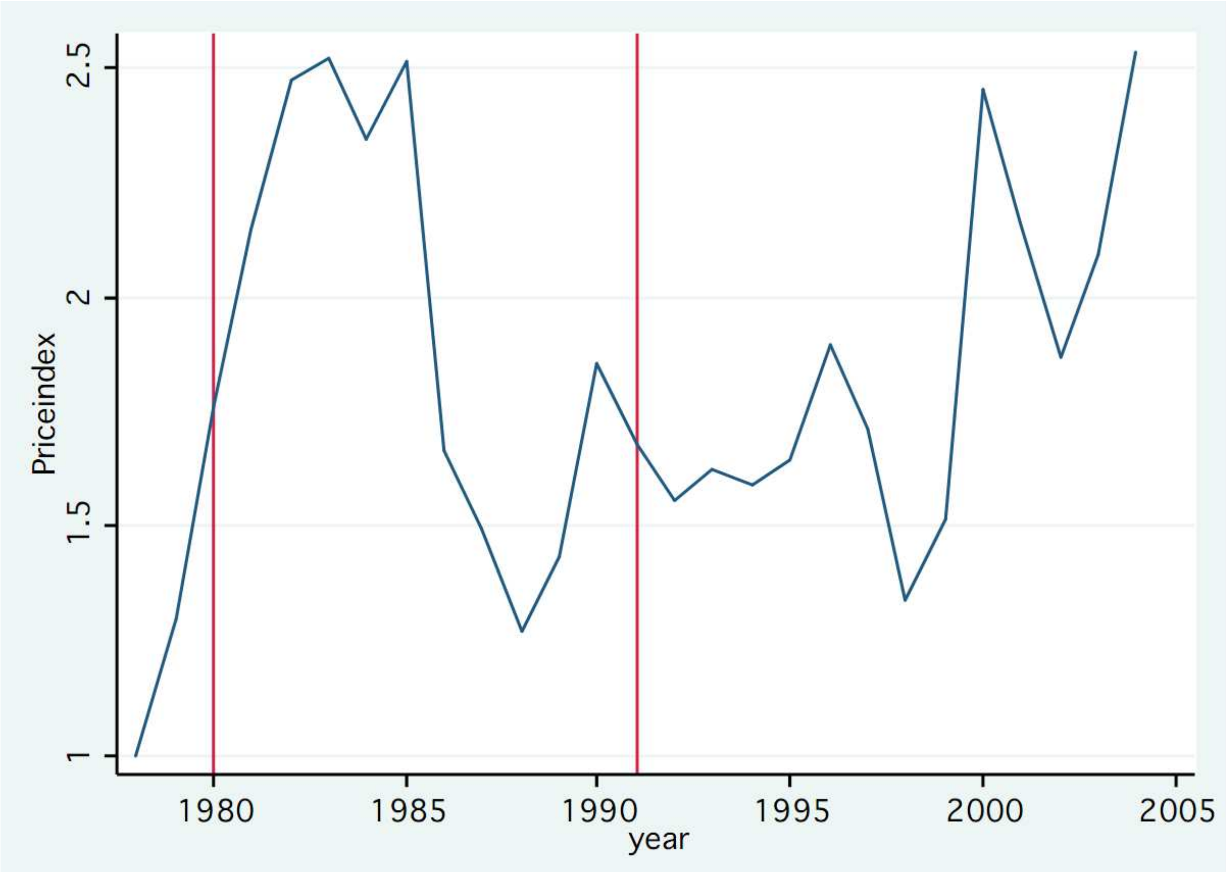


Figure 16: Oil price index for the UK 2005-2009

Table 7: Embodied technical change – regressions for the industry sub-sectors DA, DB, DC, DD, DH and DN

		(1)	(2)	(3)	(4)
	Dep.Var.	EE/GO X 100	lnEE	EE/VCOST X 100	lnGO
Manufacture of food products, beverages and tobacco (DA)	Buildings Capital	-0.08	-0.04	-0.190***	0.075***
	lnKb	(0.058)	(0.033)	(0.069)	(0.017)
	Plant and Machinery	0.328***	0.199***	0.261***	0.081***
	lnKpm	(0.058)	(0.032)	(0.070)	(0.016)
	Share of 3 year old Buildings	-0.489**	-0.242**	-0.632**	0.236***
	KAGEb	(0.220)	(0.118)	(0.258)	(0.053)
	Share of 3 year old plant and machinery	0.1	0.14	0.534*	0.05
	KAGEpm	(0.257)	(0.151)	(0.293)	(0.070)
	Output	-0.397***	0.758***	-0.287***	
	lnGO	(0.046)	(0.027)	(0.050)	
	AGE	0.014***	0.008***	0.016***	0.003***
		(0.003)	(0.002)	(0.004)	(0.001)
	Energy				0.092***
	lnEE				(0.011)
	Materials				0.677***
	lnM				(0.016)
	Obs	4962	4962	4962	4962
	Firms	2146	2146	2146	2146
Manufacture of textile and leather products (DB,DC)	Buildings Capital	0.087*	0.068**	-0.01	-0.01
	lnKb	(0.049)	(0.030)	(0.055)	(0.016)
	Plant and Machinery	0.209***	0.147***	0.133**	0.127***
	lnKpm	(0.049)	(0.028)	(0.053)	(0.016)
	Share of 3 year old Buildings	-0.16	-0.04	-0.04	0.531***
	KAGEb	(0.259)	(0.163)	(0.291)	(0.072)
	Share of 3 year old plant and machinery	0.08	0.23	0.11	0.17
	KAGEpm	(0.375)	(0.271)	(0.426)	(0.152)
	Output	-0.308***	0.779***	-0.157***	
	lnGO	(0.043)	(0.025)	(0.050)	
	AGE	0.014***	0.009***	0.01	0.005***
		(0.004)	(0.002)	(0.004)	(0.001)
	Energy				0.143***
	lnEE				(0.013)
	Materials				0.627***
	lnM				(0.018)
	Obs	3856	3856	3856	3856
	Firms	2004	2004	2004	2004
Manufacture of Wood and plastic products, NEC (DD,DH, DN)	Buildings Capital	0.01	0.01	-0.02	0.019***
	lnKb	(0.022)	(0.013)	(0.025)	(0.007)
	Plant and Machinery	0.298***	0.198***	0.223***	0.111***
	lnKpm	(0.027)	(0.017)	(0.031)	(0.010)
	Share of 3 year old Buildings	-0.372***	-0.280***	-0.07	0.154***
	KAGEb	(0.128)	(0.071)	(0.139)	(0.038)
	Share of 3 year old plant and machinery	-0.228**	-0.115*	-0.17	0.104***
	KAGEpm	(0.109)	(0.061)	(0.123)	(0.031)
	Output	-0.317***	0.785***	-0.278***	
	lnGO	(0.026)	(0.017)	(0.028)	
	AGE	0.006***	0.005***	0	0.006***
		(0.002)	(0.001)	(0.002)	(0.001)
	Energy				0.086***
	lnEE				(0.009)
	Materials				0.675***
	lnM				(0.011)
	Obs	8108	8108	8108	8108
	Firms	4600	4600	4600	4600

Notes: All regressions include 3 digit sector controls, year dummies and report robust standard errors that cluster at the level of firms.

Table 8: Embodied technical change – regressions for the industry sub-sectors DE, DG and DI

		(1)	(2)	(3)	(4)
	Dep.Var.	EE/GO X 100	lnEE	EE/VCOST X 100	lnGO
manufacture of pulp and paper (DE)	Buildings Capital	0.198***	0.166***	0.05	0.064***
	lnKb	(0.030)	(0.020)	(0.032)	(0.012)
	Plant and Machinery	0.105***	0.108***	0.061**	0.106***
	lnKpm	(0.024)	(0.016)	(0.028)	(0.010)
	Share of 3 year old Buildings	-0.311***	-0.265***	-0.281**	0.231***
	KAGEb	(0.098)	(0.070)	(0.110)	(0.042)
	Share of 3 year old plant and machinery	-0.457**	-0.26	-0.18	0.295***
	KAGEpm	(0.195)	(0.160)	(0.229)	(0.086)
	Output	-0.291***	0.737***	-0.125***	
	lnGO	(0.033)	(0.021)	(0.034)	
	AGE	0.007***	0.006***	0	0.004***
		(0.002)	(0.001)	(0.002)	(0.001)
	Energy				0.155***
	lnEE				(0.012)
	Materials				0.594***
	lnM				(0.016)
	Obs	6238	6238	6238	6238
	Firms	3454	3454	3454	3454
Manufacture of chemicals, chemical products and man-made fibres (DG)	Buildings Capital	0.05	0.048*	-0.03	0.035**
	lnKb	(0.048)	(0.025)	(0.059)	(0.016)
	Plant and Machinery	0.337***	0.225***	0.325***	0.093***
	lnKpm	(0.050)	(0.030)	(0.061)	(0.017)
	Share of 3 year old Buildings	-0.415*	-0.1	-0.477*	0.228***
	KAGEb	(0.227)	(0.131)	(0.262)	(0.061)
	Share of 3 year old plant and machinery	-0.27	-0.17	0.04	0.02
	KAGEpm	(0.266)	(0.140)	(0.307)	(0.078)
	Output	-0.391***	0.682***	-0.321***	
	lnGO	(0.059)	(0.036)	(0.072)	
	AGE	0.006*	0.006***	0.008*	0.004***
		(0.004)	(0.002)	(0.004)	(0.001)
	Energy				0.090***
	lnEE				(0.016)
	Materials				0.690***
	lnM				(0.026)
	Obs	2844	2844	2844	2844
	Firms	1119	1119	1119	1119
Manufacture of other non-metallic mineral products (DI)	Buildings Capital	-0.161**	-0.061**	-0.222***	0.02
	lnKb	(0.076)	(0.030)	(0.084)	(0.014)
	Plant and Machinery	0.537***	0.248***	0.470***	0.099***
	lnKpm	(0.098)	(0.039)	(0.114)	(0.022)
	Share of 3 year old Buildings	-0.37	-0.02	0.22	0.389***
	KAGEb	(0.381)	(0.151)	(0.459)	(0.086)
	Share of 3 year old plant and machinery	-0.13	-0.1	-0.24	0.02
	KAGEpm	(0.443)	(0.196)	(0.519)	(0.103)
	Output	-0.331***	0.835***	-0.211**	
	lnGO	(0.092)	(0.040)	(0.106)	
	AGE	0.024***	0.012***	0.014*	0.004***
		(0.007)	(0.003)	(0.007)	(0.001)
	Energy				0.129***
	lnEE				(0.015)
	Materials				0.639***
	lnM				(0.021)
	Obs	1918	1918	1918	1918
	Firms	900	900	900	900

Notes: All regressions include 3 digit sector controls, year dummies and report robust standard errors that cluster at the level of firms.

Table 9: Embodied technical change – regressions for the industry sub-sectors DJ, DK and DL

		(1)	(2)	(3)	(4)
	Dep.Var.	EE/GO X 100	lnEE	EE/VCOST X 100	lnGO
Manufacture of basic metals and fabricated metal products (DJ)	Buildings Capital	0.087***	0.078***	0.06	-0.015*
	lnKb	(0.030)	(0.015)	(0.034)	(0.008)
	Plant and Machinery	0.182***	0.089***	0.129***	0.106***
	lnKpm	(0.031)	(0.015)	(0.035)	(0.009)
	Share of 3 year old Buildings	-0.06	0	0.02	0.162***
	KAGEb	(0.156)	(0.078)	(0.172)	(0.040)
	Share of 3 year old plant and machinery	-1.569***	-0.758***	-1.400***	0.201***
	KAGEpm	(0.216)	(0.118)	(0.245)	(0.060)
	Output	-0.222***	0.857***	-0.217***	
	lnGO	(0.026)	(0.015)	(0.029)	
	AGE	0.008***	0.005***	0	0.004***
		(0.002)	(0.001)	(0.002)	(0.001)
	Energy				0.106***
	lnEE				(0.009)
	Materials				0.659***
	lnM				(0.011)
	Obs	8547	8547	8547	8547
	Firms	4841	4841	4841	4841
Manufacture of machinery and equipment (DK)	Buildings Capital	0.01	0.02	-0.01	0.01
	lnKb	(0.024)	(0.018)	(0.026)	(0.009)
	Plant and Machinery	0.174***	0.136***	0.088***	0.099***
	lnKpm	(0.028)	(0.021)	(0.032)	(0.011)
	Share of 3 year old Buildings	-0.343**	-0.273***	-0.22	0.266***
	KAGEb	(0.135)	(0.101)	(0.148)	(0.043)
	Share of 3 year old plant and machinery	0.09	0.02	0.24	0.07
	KAGEpm	(0.223)	(0.164)	(0.274)	(0.065)
	Output	-0.262***	0.791***	-0.208***	
	lnGO	(0.027)	(0.020)	(0.028)	
	AGE	0.005**	0.005***	0	0.005***
		(0.002)	(0.001)	(0.002)	(0.001)
	Energy				0.094***
	lnEE				(0.010)
	Materials				0.686***
	lnM				(0.011)
	Obs	5450	5450	5450	5450
	Firms	2908	2908	2908	2908
Manufacture of electrical and optical equipment (DL)	Buildings Capital	0.060***	0.048***	0.01	0.028***
	lnKb	(0.021)	(0.017)	(0.025)	(0.008)
	Plant and Machinery	0.147***	0.145***	0.085***	0.079***
	lnKpm	(0.023)	(0.018)	(0.026)	(0.010)
	Share of 3 year old Buildings	-0.245**	-0.230***	-0.185*	0.250***
	KAGEb	(0.097)	(0.083)	(0.107)	(0.042)
	Share of 3 year old plant and machinery	-0.09	-0.05	-0.02	0.129**
	KAGEpm	(0.136)	(0.109)	(0.171)	(0.059)
	Output	-0.284***	0.730***	-0.201***	
	lnGO	(0.027)	(0.019)	(0.027)	
	AGE	0	0	0	0.002***
		(0.002)	(0.002)	(0.002)	(0.001)
	Energy				0.109***
	lnEE				(0.011)
	Materials				0.682***
	lnM				(0.014)
	Obs	5815	5815	5815	5815
	Firms	2971	2971	2971	2971

Notes: All regressions include 3 digit sector controls, year dummies and report robust standard errors that cluster at the level of firms.

Part 4: The recession and climate-change policy targets

The recession versus agreements on climate-change mitigation

The Kyoto Protocol sets targets for 39 industrial countries and the European Community (the 'Annex I' parties) to reduce their greenhouse gas emissions by 2008-12. The targets are intended to achieve a 5% (or 0.9 Gt) reduction in greenhouse gas emissions in the Annex I countries, with respect to 1990 levels (UN, 1997). In 2006, the most recent year for which data are available, collective greenhouse gas emissions in Annex I countries were 4.5% (or 0.8 Gt) below 1990 levels. Although a number of individual countries are not currently on track to meet their Kyoto targets, the group of Annex I countries as a whole is relatively close. This overall compliance is largely the result of substantial reductions in CH_4 and N_2O emissions, in combination with relatively unchanged CO_2 emissions. CO_2 emissions are similar in 1990 and 2006 because (1) declining emissions in the former communist states have largely compensated for increasing emissions in a number of other Annex I countries; and (2) Annex 1 countries are net importers of CO_2 emissions from production of goods especially in China (Guan et al, 2009; Peters and Hertwich, 2008).

To achieve the overall 5% Kyoto reduction target, Annex I countries would need to reduce their total emissions by an additional 0.1 Gt – a small amount – but then maintain this level of reduced emissions throughout the 2008–2012 commitment period. Our baseline scenario suggests that, in the absence of the recession, fossil fuel CO_2 emissions in Annex I countries would probably increase by almost 0.7 Gt between 2006 and 2012. Therefore it seems unlikely that the Kyoto target could be achieved without the recession. However, the recession will result in a direct reduction in CO_2 emissions in Annex I countries, so that meeting this target becomes a real possibility. Moreover, the recession may cause *global* CO_2 emissions to begin falling during the 2008-12 commitment period (Figure 9 in Part (2)). The Kyoto Protocol alone would not have been able to achieve that, since it only targets emissions in industrial nations, while emissions in developing nations have continued to increase.

In order to limit the average global temperature increase to 2℃, leaders at the recent G8 Summit in Italy proposed a 50% reduction in global greenhouse gas emissions by 2050, with an 80% reduction in developed countries (G8 Summit, 2009). If climate negotiations in Copenhagen later this year agree to targets such as these, the reduction in global CO_2 emissions that would be required each year between 2010 and 2050 would be smaller than the annual CO_2 reductions that we predict will occur during the recession (Figure 9 in Part (2)).

We conclude that the impact of the recession on greenhouse gas emissions will be significant. At the end of the Kyoto commitment period, global fossil fuel CO_2 emissions may be between 9 and 23% lower than they would have been without the recession. The fall will be less to the extent that the capital ageing identified in Part (3) is significant worldwide and that income elasticities are lower than assumed in the exercise here. But it will be greater if the recession reflects and prolongs a period of lower productivity growth in the world economy. These reductions will have an impact on the longer term. The recession has therefore put the world on a path to achieve the ambitious targets that are being called for in Copenhagen before these negotiations have begun. But ambition is still needed to make the structural, technological and behavioural changes necessary to achieve a lower carbon economy – as our analysis shows that, without a strong climate-change mitigation regime, even the significant reductions in CO_2 emissions that will occur due to the recession will only delay the point at which the world passes through 2℃ of warming by a few years[11].

[11] This conclusion is reinforced by the recognition that several major developing countries have higher long-term growth aspirations than are embodied in past projections of emissions under business as usual. Blanford et al (2009) argue that model-based projections of business-as-usual emissions should be revised downwards because of the recession, but in many cases also need to be revised upwards to reflect the stronger-than-expected trend growth of India and China in recent years. It is not clear that, net, the overall impact should be a downward revision.

Implications for long-run stabilisation targets

Another way of putting the impact of the recession into perspective is as follows. The recession, by itself, warrants a lower long-run atmospheric stabilisation target in principle, because it offers the possibility of lower cumulative emissions than in its absence without any additional policy measures. But the warranted revision to any target contemplated before the slowdown is unlikely to be very large.

To illustrate the broad scale of the likely impact, consider the following simple calculation. Suppose policy-makers before the recession were considering an atmospheric stabilisation target for the concentration of the so-called Kyoto greenhouse gases in the atmosphere of 450 ppm CO_2e in 2100. But, because of the recession, annual emissions remain lower in each year from 2012 to 2100 than they would otherwise have been – let us assume by the same number of Gt as in 2012 (extrapolating to total emissions from the number obtained above for the percentage reduction in fossil-fuel-related CO_2 emissions). If the no-recession level of emissions in 2012 would have increased the atmospheric concentration of greenhouse gases by 2.5 ppm CO_2e a year (roughly the pre-recession rate of increase), a reduction of x% in emissions in 2012 due to the recession results in an increase in concentration of only (100-x)/100 times 2.5 ppm CO_2e[12]. By 2100, concentration rises by less than it would have done without the recession, by an amount 88 times x/100 times 2.5 ppm CO_2e (assuming no decay of the greenhouse gases emitted over the period, again for simplicity's sake). Then, if policy-makers undertake the same amount of mitigation activities that they had planned before the recession, the atmospheric concentration of greenhouse gases would be a little less than 50 ppm lower in 2100 than in the no-recession case.

But it would make sense to take advantage of the recession to reduce the costs of mitigation as well as to reduce climate-change impacts further. Hence in this simple example it would make sense for policy-makers to revise down their ultimate target by less than 50 ppm. Similarly, for the 'mild' recession case, where annual emissions are nearly 10% lower in 2012 than without the recession, it would make sense to cut the ultimate stabilisation target by less than 20 ppm.

[12] This assumes for simplicity's sake that the fraction of annual emissions that remains in the atmosphere is the same at the margin as on average.

The Implications of the Economic Slowdown for Greenhouse Gas Emissions and Targets

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