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Stirling Economics Discussion Paper 2012-16

July 2012

Online at

http://www.management.stir.ac.uk/research/economics/working-papers

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This version 6 June 2012

Keywords: Genuine Savings, National accounts, Fossil Fuels, Carbon Dioxide, Global Warming, Economic History, Britain

JEL: Q01, Q51, Q54, N53, N54

Please do not cite without approval.

Abstract

In this paper, we examine means to incorporate the environmental effects of fossil fuel use into national accounts and genuine savings estimates. The main focus is on the rationales for the inclusion of carbon dioxide, and its appropriate price tag. We do this in the context of the pricing of historic carbon emissions in United Kingdom over the long run (from the onset of the industrial revolution to the present). Furthermore, we examine the reasonableness of taking into account other greenhouse gases than carbon dioxide. The global effects of carbon dioxide are compared to the local detrimental effects of the production and consumption of coal in the UK.

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We thank the Leverhulme Trust for funding this research under the project "History and the Future". We also thank the participants in the the 7th Sound Economic History Workshop in Tampere, Finland, May 19-20, 2012 for helpful comments.

Introduction

Conventional measures of national income and wealth can provide misleading signals about long-run economic possibilities of a country (Vincent 2001). To correct for this, various methods for Green (or Greened) National Accounting extend conventional national product measures to take account of the depletion of natural resources and the deterioration of environmental functions (Daly & Cobb 1989, Repetto et al. 1989, United Nations 1993/2003).

One major challenge is to take into account the various effects from the use of fossil fuels. Depletion costs are perhaps the most straightforward and will not be further discussed within this paper (see World Bank, 2011). The environmental costs of the use of fossil fuels, on the other hand, take various scales both in time and space affecting both human health and vital environmental services. In other words, pollution from fossil fuels has both flow and cumulative effects, and has effects on a local, regional and global scale.

Furthermore, some of the effects are captured by other measures in the accounts, which cause a danger of double accounting. For example, Kirk Hamilton and Michael Clemens (1999, 341) argue that: “The effects of pollution on output (damaged crops, lost production owing to morbidity) are usually not broken out explicitly, but because they are reflected implicitly in the standard national accounts, there is no need to adjust savings measures in this regard.”

In other words, we do not have to worry about valuing damages which are priced by markets, only those not reflected in market prices. In the end, the only pollutant Hamilton and Clemens consider in their genuine savings estimate is carbon dioxide. As a measure of the global marginal social cost of a metric ton of carbon they assume a constant $20 in 1990, taken from Fankhauser (1994). They charge global damages on the assumption that the property right to a clean environment lies with the pollute: “for example, we are assuming that the Comoros Islands have the right not be inundated as a result of CO_2 emissions elsewhere” (Hamilton and Clemens 1999, 342). They provide no further rationale for including damage caused by carbon; neither does the subsequent Manual for Calculating Adjusted Net Savings (Bolt, Matete and Clemens, 2002). This manual suggests using a $20 constant damage in 1995 for CO_2, deflated for other years using the U.S.A GDP deflator.

Neither Hamilton and Clemens (1999) nor Bolt, Matete and Clemens (2002) provides any rationale for using a constant damage for CO_2 as well as for the assumed price tag for this damage. This paper will provide further rationales for the inclusion of carbon dioxide, furthermore, will critically assess the constant damage function used and the appropriate price tag. We do this in the context of the pricing of historic carbon emissions in United Kingdom over the long run (from the onset of the industrial revolution to the present). Furthermore, we examine the reasonableness of taking into account other greenhouse gases than carbon dioxide.

Bolt, Matete and Clemens (2002) argues that ideally, the numbers subtracted from national “assets” would reflect marginal damages from the entire range of air pollutants emitted. As a first approximation they use, however, only the damage from carbon dioxide emissions. Following their advice, since 2003, the World Development Indicators –report also subtracts the damage costs of particulates in the air, calculated as willingness to pay to avoid mortality attributable to particulate emissions (World Bank 2003, 177). Here carbon dioxide represents emissions with global effects, while the effects of particulate matters are local. Damage from particulate matter is, however, only reported from 1990 onwards. In this paper, we are able to compare the global and local effects from the use of coal in the UK from the onset of the industrial revolution using an insightful dataset compiled by Fouquet (2011). This comparison gives new insights on how to include the local and global effects of fossil fuel use into the national accounts.

Time and space effects

The scale of pollution problems has major implications for national wealth. Some pollutants have effects, which are rather more "domestic" than others – for example, particulates impose a cost on the citizens of the country that emits them, as happens with low-level ozone from NO_x. In many cases, however, it is possible to externalize the pollution problem onto neighbor countries, for example by building higher smokestacks. Thus, for example, United Kingdom´s emissions of SO_2 pollute lakes in Norway. As long as the Norwegian government is not able to fine the UK for these emissions affecting Norway, only the damage costs of the part of the pollution affecting the UK has implications for the national wealth of UK. The question here, however, is which damages should a country count in its national accounts? We argue that one should only count damages that impact on the national well-being of the country doing the accounting. For example, Norway would show the cost of acidification from exported UK emissions in its national accounts, but UK would not.[1]

The effect of global emissions, like carbon dioxide, is in a way a combination of the effects of domestic and regional emissions. The long delay between emissions and effect make carbon dioxide particularly problematic. The initial effect is for the emissions of individual countries to be diluted into the major global Commons, showing no visible effects on the atmosphere. Carbon dioxide is both non-visible and non-toxic. Thus, the noticeable effects of the carbon dioxide emissions of a

[1] See See Atkinson and Hamilton (2007) for a longer discussion on this issue.

single country are similar to those of externalized regional emissions, like sulphur dioxide, in the short run.

In the long run, however, the combined carbon dioxide emissions of all individual countries are problematic, as the concentrations of carbon dioxide and other greenhouse gases exceed critical thresholds e.g., 350 parts per million ("ppm") is generally considered a “safe” upper level. The often mentioned 450 ppm target is however, more a political compromise between safety and the costs of emission reductions. Many cost cost-benefit analyses of emission reduction use an even higher concentration. For example, Eyre et al. (1999), Price, Thornton and Nelson (2007), and Interagency Working Group on Social Cost of Carbon (2010) assume a doubling of greenhouse gases from a preindustrial level to 550 ppm CO_{2e}, which would require a stabilization of CO_2-only concentrations at around 425–484 ppm. The current level in the atmosphere is, around 392 ppm, thus the ‘safe’ level has already been surpassed. The 450 ppm level can still be considered as a moderate risk, with the risks increasing at an escalating pace beyond that level. In economic terms, we can describe different targets as different levels of risk tolerance from risk-aversion through risk-tolerance to risk loving. In ethical terms, it can be described as a gamble on the future of future generations.

These 350/450 ppm levels could be interpreted as a natural resource, the carrying capacity of the atmosphere. If the concentrations are increasing, the level of this resource is decreasing. We have less of the resource available regardless of whether we are over or under the assumed safety level. More emissions are a disinvestment, as it reduces the room for future emissions. In a similar fashion, Partha Dasgupta and Karl-Göran Mäler (2001) argue that when a country adds to the atmosphere’s carbon content, it reduces the value of this common property resource. They suggest two possibilities to calculate the value of the change in the country’s capital assets:

- Firstly, to attribute to each country the fraction of Earth’s atmosphere that reflects the country’s size relative to the world as a whole, using population as a means of comparison, or GNP, or whatever.
- Secondly, regard the global common as every country’s asset. In that case, the entire cost of global warming inflicted by a country would be regarded as that country’s loss.

A third way to calculate the cost of climate change for a country would be to estimate only the cost caused directly to that country, the costs due to drying climate, more storm damage, etc. in that country alone (Ackerman et al. 2008).

Our main argument in support of the second approach – to regard the global common as every country's asset - is the fact that in the case of a global phenomenon such as human induced climate change, there is in the long run no possibility for a single country to isolate itself. Let us briefly return to the sulphur dioxide example. Let us assume, by way of example, that Norway would be the major source of timber for the UK, and that the forest would be destroyed by acid rain. This would have welfare implications if Norway was the only source of timber for the UK. The UK, however, could go to Sweden or Finland for new sources of timber of the same quality and price. In the case of a global pollutant with global effects, the possibility for such isolation from the effects is not possible. There is, for example, no way for a single country to isolate itself from increases in food prices as climate change has negative impacts on *global* food production. Net exporters of food might, in the short run, receive some benefits from such developments, but at the expense of consumers.

Countries that are less affected by climate change will also have difficulty isolating themselves (except by increasing border control expenditures) from people leaving areas that are becoming uninhabitable due to climate change or conflicts induced by climate change. Oli Brown (2008) argues that the commonly cited estimate by Myers (2005) of 200 million people displaced by climate change by 2050 could 'easily be exceeded'. Even this estimate would mean a ten-fold increase over today's entire documented refugee and internally displaced populations. Ethically speaking, the use of a single damage cost indicates a belief that we are all in the same lifeboat when it comes to the long run effects of climate change.

Our second argument for the global damage approach is practical. Using one single carbon cost per ton for all countries, makes international comparisons easier.

Our argument for the inclusion of the costs of carbon dioxide emissions in national accounts is consistent with ideas discussed above: 1) No country will in the long run be able to isolate its economy from climate change and the costs it will inflict. 2) Avoiding the worst outcomes of climate change will require significant emission reductions worldwide. In the long run, free-riding by a single country will not be possible, at least not without potential diplomatic or local consequences e.g., consumer boycotts, which would eventually have direct effects on the economy.

3) The emission reductions needed are to a great deal cause by past emissions, thus past emissions cause costs in the future.

Criticism of the constant damage function

We have three major arguments against using a constant damage function for the emissions of carbon dioxide as suggested by Hamilton and Clemens (1999), and Bolt, Matete and Clemens (2002). The first one comes from a general feature of stock pollutants. One unit of a stock pollutant added to an already large stock is likely to cause a higher damage than a unit emitted under a low concentration level.

The second is intuitive; if we accept that the social costs of carbon (SCC) emissions rise as we move through time, it seems odd to keep it constant when moving backwards. Price, Thornton and Nelson (2007, 9) argue that: ”As time goes on, the damage comes closer, and is discounted less heavily; so its present value rises, increasing the SCC." Similarly, as we go back in time, the damage is further away, which should also be reflected in the damage cost.

The third argument relies on the claim that human induced climate change was initially a positive thing. Ruddiman (2005, see also 2003) claims that: "…Earth should have undergone a large natural cooling during the last several thousand years, and that at least a small glaciation would have begun several millennia ago had it not been for greenhouse-gas releases from early human activities" (p. 105). The human activities he refers to are the slow rise CO_2 concentrations that started 8,000 years ago when humans began to cut and burn forests in China and the rise of methane concentrations that began 5,000 years ago when human began to irrigate land for rice farming and tend livestock in unprecedented numbers. Ruddiman (2005, 105) further argues, that "…next glaciation is not "imminent'; it is overdue." Indeed, climate scientists at the turn of the 20th century were more worried about a new ice age than global warming. For example, Svante Arrhenius wrote in 1908 that with increased CO_2 "…we may hope to enjoy ages with more equable and better climates, especially as regards the colder regions of the earth, ages when the Earth will bring forth much more abundant crops than at present for the benefit of rapidly propagating mankind." This statement is interesting as he is often wrongly mentioned as the first one to warn about global warming.

Arrhenius (1896) calculated that a doubling of CO_2 in the atmosphere increases global surface temperature by an average of five to six degrees Celsius, but he did not consider this a problem.

The first to warn that an increase in the global temperature could be something to worry about was Gilbert Plass in 1956: "...the temperature from this cause may be so large in several centuries that it will present a serious problem to future generations." It would take several decades, however, until some kind of scientific consensus arose that global warming would be something bad for humankind in the long run (Kunnas 2010 & Vanderheiden 2008). Finally, in 1990 the Intergovernmental Panel on Climate Change stated in its First Assessment Report that the threat of climate change was real, and a global treaty was needed to deal with it (IPCC, 2004). As a response to this rising awareness, in 1992 a number of countries signed *The United Nations Framework Convention on Climate Change,* which sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change (UNFCCC 1992).

How does this discussion relate to national income accounts and Genuine Savings? As long as global warming is; good thing; emissions of greenhouse gases can be seen as an investment towards a 'better climate', and only thereafter as a disinvestment. The relevant turning point though is not the time of the recognition of the fact that global warming might be detrimental for humankind, but the 'actual' turning point, otherwise ignorance would be regarded as a good thing.

There are a number of economic papers on this issue, where the 'good' aspects: e.g., longer growth periods, carbon dioxide fertilization, less need for heating, etc. has been weighted against the 'bads': drought, extreme weathers, more need for air conditioning, etc. For example, Richard S. J. Tol (2011) argues that: "Most rich and poor countries benefitted from climate change until 1980, but after that the trend is negative for poor countries and positive for rich countries." The biggest positive of climate change in his calculations comes from agriculture, and is entirely due to carbon dioxide fertilization, which makes crops grow faster and more water efficient. Frank Ackerman et al. (2008, 17), however, argues that recent research has cast doubts on any agricultural benefits of climate change: "More realistic, outdoor studies exposing plants to elevated levels of carbon dioxide have not always confirmed the optimistic results of earlier greenhouse experiments."

Locating the point in time where climate change stops being a good thing and turns into a bad thing is, however, not enough. Another question is the long lifetime of greenhouse gases, especially carbon dioxide, which means that emission emitted before climate change became bad both in our thoughts and in reality, is still warming the climate. David Archer (2005) suggests 300 years and a 25 percent tail that lasts forever as the best approximation for the lifetime of fossil-fuel CO_2.

Over the past 200 years oceans have absorbed about a half of total anthropogenic carbon dioxide emissions (Sabine et al., 2004). However, not without costs as when carbon dioxide dissolves in seawater, it forms a weak acid called carbonic acid. Because of this chemical process, the average pH of the oceans has decreased by 0.1 units from pre-industrial levels, and an exponential decrease of nearly 0.8 pH unit is forecasted by 2300. This could have major effects on calcifying marine biota, such as calcareous plankton and coral reef communities. (Royal Society, 2005; Caldeira and Wickett, 2003; Orr et al. 2005). It also means that the global common, the buffer for future emissions has been significantly reduced.

Different price tags and their development in time

If we were to agree that 1980, for example, is the turning point where climate change would be a good thing before that date and bad thereafter, then we would have to count three hundred years backwards to find the point in time where the emissions of carbon dioxide would not cause any damage in the future. In other words, emissions emitted before 1681 would in this case be considered harmless. In this case, all the emissions during our time period under scrutiny, starting from 1750 would be considered as harmful, and should be deducted. We could then calculate the damage of the emissions in any year in a similar fashion to the lifetime labour income approach used by Trinh Le et al. (2006), but in this case with the three hundred years lifetime of carbon dioxide in the atmosphere, instead of the considerably shorter lifetime of humans. Thus, the cost of the emissions in 1681 would equal its relative share of the climate change the damage in 1981, the cost of the emissions in 1682 would equal its relative share of the damage in 1981+1982 and so forth. Furthermore, we would need to add the value of the buffer for future emission used-up as half of the emissions have been absorbed by the oceans. Thus, we would need the value of the damage caused by climate change for each year since the cut off year and 300 years forwards in time.

As a first approximation we could assume a constant damage cost, as suggested by Hamilton and Clemens (1999) and Bolt, Matete and Clemens (2002), and then take into account the change from climate change being a ‘’good thing’ into it being a ‘bad thing’ by setting the damage cost of carbon dioxide at zero 300 years ago from the turning point and letting it grow to the full value in 300 years.

As mentioned previously, Hamilton and Clemens (1999) and Bolt, Matete and Clemens (2002) use the constant marginal social cost of a metric ton of carbon emitted of $20 (12.66 £/tC) in 1995 taken from Fankhauser (1994). In 2002 that might have been a reasonable assumption, however, the advances in climate science suggest that a twenty year old figure can hardly be supported. It should also be noted that Fankhauser actually proposed a cost that rises over time: 20.3 $/tC (12.85 £/tC) for 1991—2000, 22.8 $/tC for 2001—2010, 25.3 $/tC for 2011—2020 and 27.8 $/tC for 2021—2030. In other words, the damage costs are increasing by 2.5 $/tC per decade. [2]

A rising estimate over time, also acts to support decreasing costs as we move backwards in time. Should we perhaps, deduct the same 2.5 $/tC per decade as we move backwards? This approach would make the cost of carbon change sign between 1913 and 1914, giving a negative damage cost implying benefits of climate change for carbon in years before that. Considering the different timescales of the positive and negative impacts of climate change – the positive effects of global warming, e.g., increased agricultural yields that have already been realized, will have been captured in the national accounts, however, the negative effects, which are the discounted values of future negative impacts, will not. It, therefore, makes sense to set the negative values (positive impacts) to zero.

Alternatively, we could set the damage cost of carbon at zero in 1680 as suggested above, rising to 20.3 $/tC in 1995. 20.3 $/tC) divided by 315 years gives an 0.0644$/tC increase per year. These different back-counting approaches have been depicted in Figure 1 below. The rapidly increasing estimates for the years after 2010 are based on the mid year of the estimates of Fankhauser with a linear interpolation for the years in-between.

[2] We have converted dollars to pounds by dividing with the 1995 exchange rate 1.58 $/£ (Officer 2011).

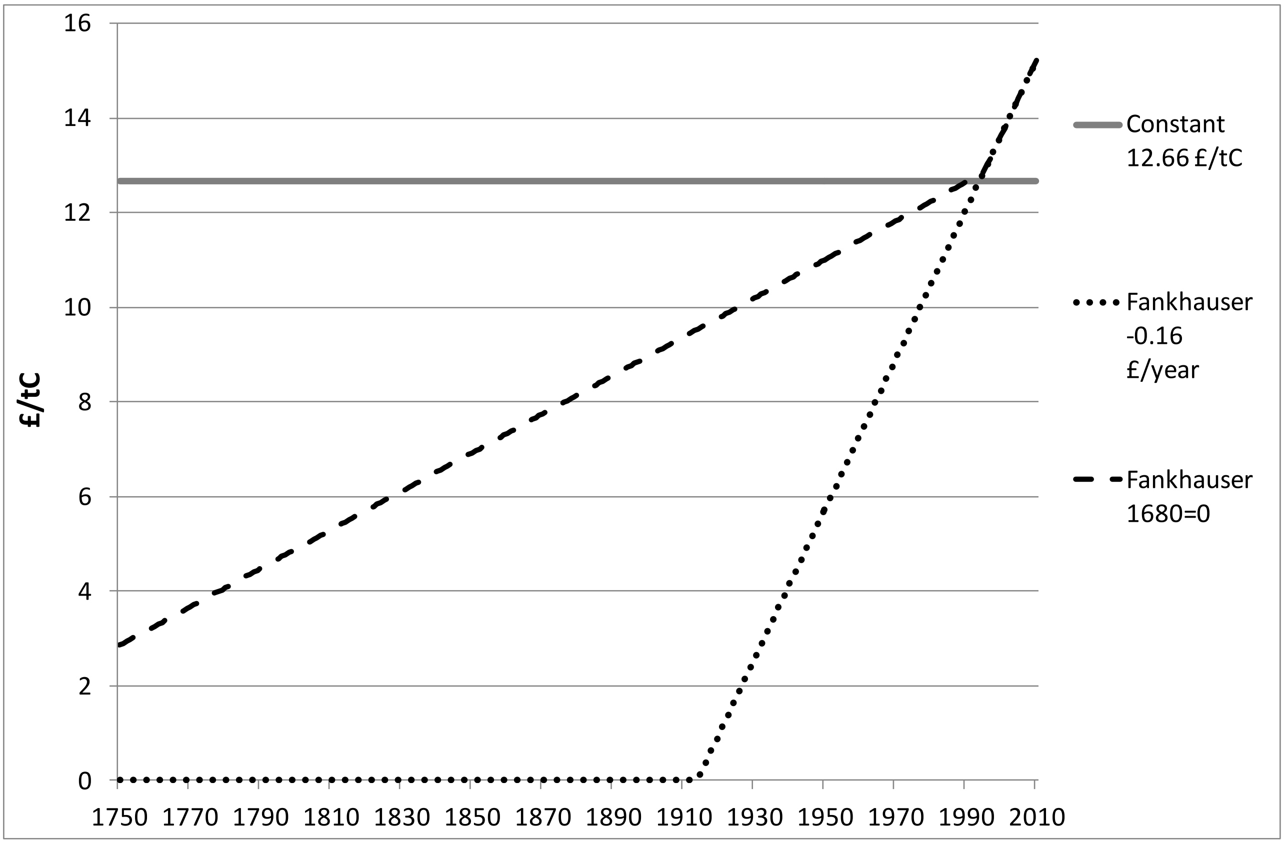

Figure 1. Carbon cost £/tC (1995 price level) constant vs. Fankhauser with -0.6 £/year deduction and going to zero by 1680

A more recent estimate was undertaken by a U.S. government working group (Interagency Working Group on Social Cost of Carbon 2010). For the costs in 2010, they produced a wide range of estimates ranging from 4.7 to 64.9 $ per metric ton of carbon dioxide (in 2007 dollars). See Table 1 below. The first three estimates are based on the average social costs of carbon (SCC) across models and socio-economic and emission's scenarios at the 5 %, 3 % and 2.5 % discount rates. The analysis is based on projected costs and benefits extending 300 years into the future, thus as we can see from the table, the discount rate is crucial for the outcome. The fourth value, the 95th percentile, is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. The central value is the average SCC across models at the 3 percent discount rate, which is, for example, 21.4 $ per metric ton of carbon dioxide in 2010.

Table 1 Estimate by the Interagency Working Group on Social Cost of Carbon 2010

Year	5 %	3 %	2.5 %	3 %
	Avg.	Avg.	Avg.	95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109,7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

To present this as cost per metric ton of carbon as in Fankhauser, we must divide with 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67). Thus, we end up in a range of 1.3 to 17.7 $ per metric ton of carbon in 2010. The central value would be 5.83 $/tC. Thus, we produce a lower social cost than those proposed by Fankhauser, despite the gloomier prognosis by climate scientists. A partial explanation for this is that the Fankhauser estimate is about global costs, and those by the U.S. government working group relate only to the U.S., which is estimated to be among the countries with lower than average costs of climate change.

Furthermore, Ackerman and Stanton (2011) argue that the U.S. government's estimate omits many of the largest risks associated with climate change, and downplays the impact of our current emissions on future generations. Their re-analysis explores the effects of uncertainty about climate sensitivity, the shape of the damage function, and the discount rate and estimates that costs are much higher.. In their worst case scenario, with a high climate sensitivity (the long-term temperature increase expected from a doubling of the concentration of carbon dioxide in the atmosphere) and a 1.5 percent discount rate, costs were as high as 893 $ (243 $/tC) in 2010, rising to $1,550 (422 $/tC) in 2050. (The 2007 exchange rate is $2 per pound).

Interestingly the Interagency Working Group provides the lowest carbon cost of all the articles considered in this paper, while Ackerman and Stanton provide the highest figure, although they are both using the same modified DICE model. This highlights the importance of the assumptions used in such models.

A review of the literature on the social cost of carbon, compiled by DEFRA, the Department for Environment, Food and Rural Affairs, suggests using, a point estimate for the social cost of carbon emissions of £70/tC for policy design in United Kingdom, with an associated sensitivity range giving a lower bound of £35 and an upper bound of £140, for emissions in 2000 (Clarkson & Deyes 2002). They argue that the point estimate should then be raised by £1 for each subsequent year. These costs are taken from Eyre et al (1999). Their choice of the Eyre estimates is based on their assumption that it is the most sophisticated study to date, as the method used is based on equity weighting instead of using individual regions. The weightings are based on both EU and non EU figures and removes the problems of eventual underestimation based solely upon US estimates, as argued above.

A periodic review of the Defra paper was undertaken in 2005. It suggested using both the shadow costs of carbon and social costs of carbon. The social costs of carbon suggested were slightly lower than those in the preceeding paper, £56/tC in 2000-2010, increasing by £1.2/tC per year and an increasing growth rate thereafter as shown in Table 2 below taken from Watkiss et al. (2005).

Table 2 SCC Values from the Defra 2005 Study

Year of emission	**Central guidance**	**Lower central guidance**	**Upper central guidance**
2000	56	35	220
2010	68	43	270
2020	81	51	350
2030	99	62	365
2040	112	71	410
2050	143	90	500

Finally, a DEFRA paper published in 2007 suggested using the shadow price of carbon (SPC) instead of the social costs of carbon (Price, Thornton and Nelson 2007). The SPC is based on the SCC for a given stabilisation goal, but can be adjusted to reflect:

- estimates of the marginal abatement cost required to take the world onto the stabilisation path.

- other factors that may affect the UK's willingness to pay for reductions in carbon emissions, such as a political desire to show leadership in tackling climate change.

"Therefore, whereas the SCC is determined purely by our understanding of the damage caused and the way we value it, the SPC can adjust to reflect the policy."

They conclude that a social cost of carbon consistent with the damage experienced under an emission's scenario which leads to stabilization at 550ppm CO_{2e} should be adopted:

"The Stern Review calculates that this implies a social cost of carbon of \$30/tCO_{2e} in 2000, equivalent to £19/tCO_{2e}. This is therefore the number we believe should be adopted as the basis for a shadow price of carbon (SPC) profile for use in policy and investment appraisals across government in the UK. Using the uprating conventions set out below [uprated each year by 2 percent a year reflecting the Stern Review's assessment of the rising incremental damage of each unit of carbon as temperatures rise], we adopt an SPC in 2007 of £25/tCO_{2e}."

Table 3: Shadow price of carbon (SPC) £/tCO2e suggested in Defra 2007

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
SPC	18.6	19.3	20.1	21.2	22.2	23.3	24.3	25.5	26.0	26.5	27.0	27.6	28.1

All values in 2007 prices except 2000-2006 where the price level is the same as the year

Based on these different starting points, we can, construct new estimates that allow changes over time. In Figure 2, we have set the carbon price in 1680 to zero 1680, and alternatively allowed the carbon costs to diminish with the same 3 percent a year, as Eyre et al., use to produce the £70/tC suggested in the first Defra report. The Defra estimates have been named by the year of the report, to show how the Defra estimates have declined over the years. It should also be noted that the 2007 Defra price tag is a 'shadow price' instead of a social cost of carbon, as provided by the rest of the estimates presented. In practice, however, there is little difference between them, as the SPC is based on the SCC. For comparison's sake, we have also included the 12.85 £/tC constant, which deflated to the 2000 price level as 14.1 £/tC. We can clearly see how all the estimates with the 3 percent yearly deduction, drops below this constant by the mid 1940s. The estimates using a carbon price going to zero by 1860, again exhibits a distinctive kink, causing some suspicions about the appropriateness of this method.

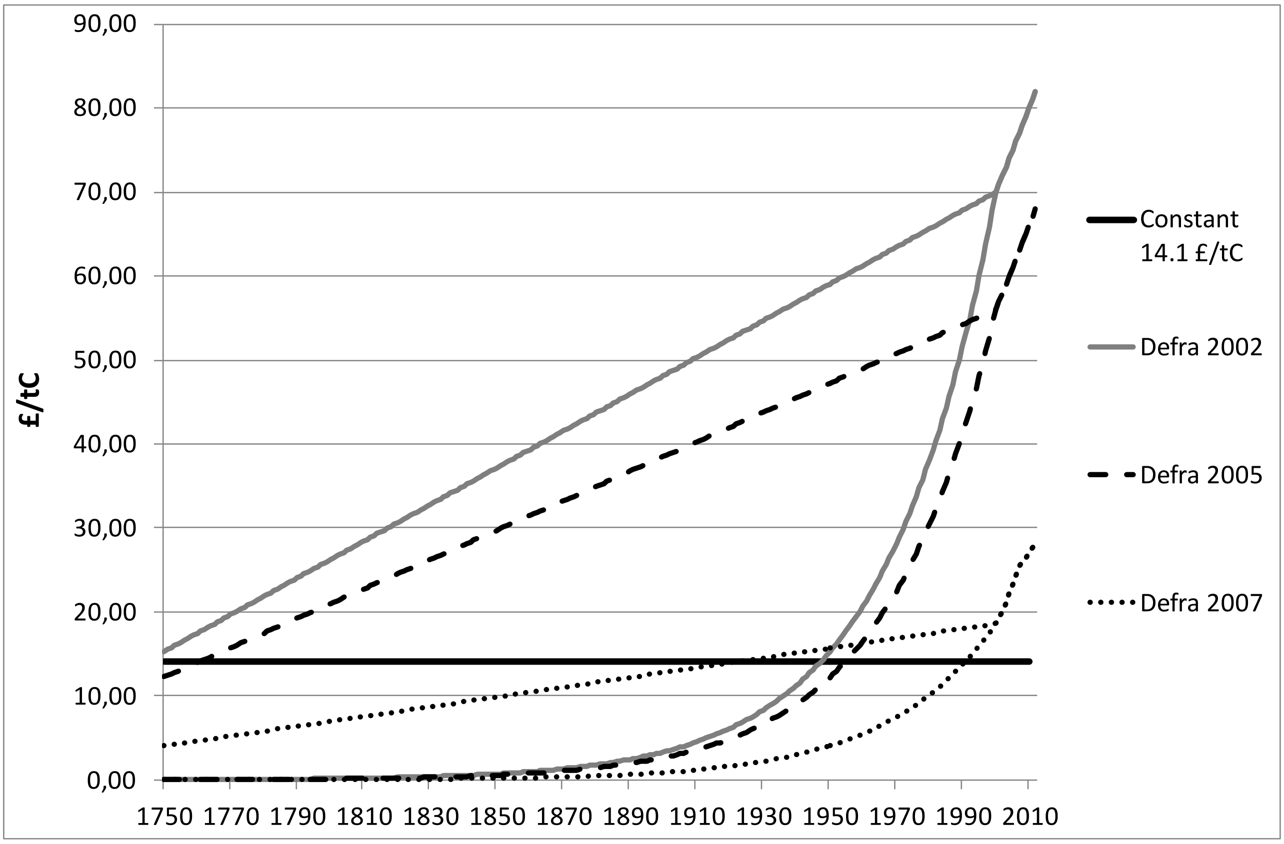

Figure 2. Carbon cost £/tC (2000 price level) constant vs. Defra 2002, 2005 and 2007 with 3 percent annual deduction

This is just a first snapshot of some of the estimates of the costs of carbon dioxide emissions. Richard S.J. Tol (2005) gathered 103 estimates from 28 published studies, and combined them to form a probability density function. He found the range of estimates strongly right-skewed: the mode of all studies combined was $2/tC (1995 US$), the median was $14/tC, the mean $93/tC and the 95th percentile $350/tC. He concluded though that: "Using standard assumptions about discounting and aggregation, the marginal damage costs of carbon dioxide emissions are unlikely to exceed $50/tC, and probably much smaller." Using the 1995 exchange rate of 1.58 $ per £ gives 31.6 £/tC for the latest.

In his most recent paper Tol (2012) used a vote-counting procedure to estimate the probability density function of the total economic impact as a parabolic function of global warming. From the available 14 estimates of the total impact of climate change, he calculated an expected value of the social cost of carbon of approximately $29/tC in 2015, rising 1.99% per year. Counting back with 3

% as in the previous example, would give a carbon cost of $18.4/tC in 2000, or 12.1 £/tC.[3] A 1.99 percent annual deduction returns $ 21.4/tC in 2000, or 14.1 £/tC. The latter is the same as the constant used by Hamilton and Clemens (1999) and Bolt, Matete and Clemens (2002). After that point, both decline rapidly below the constant, as can be seen from Figure 3.

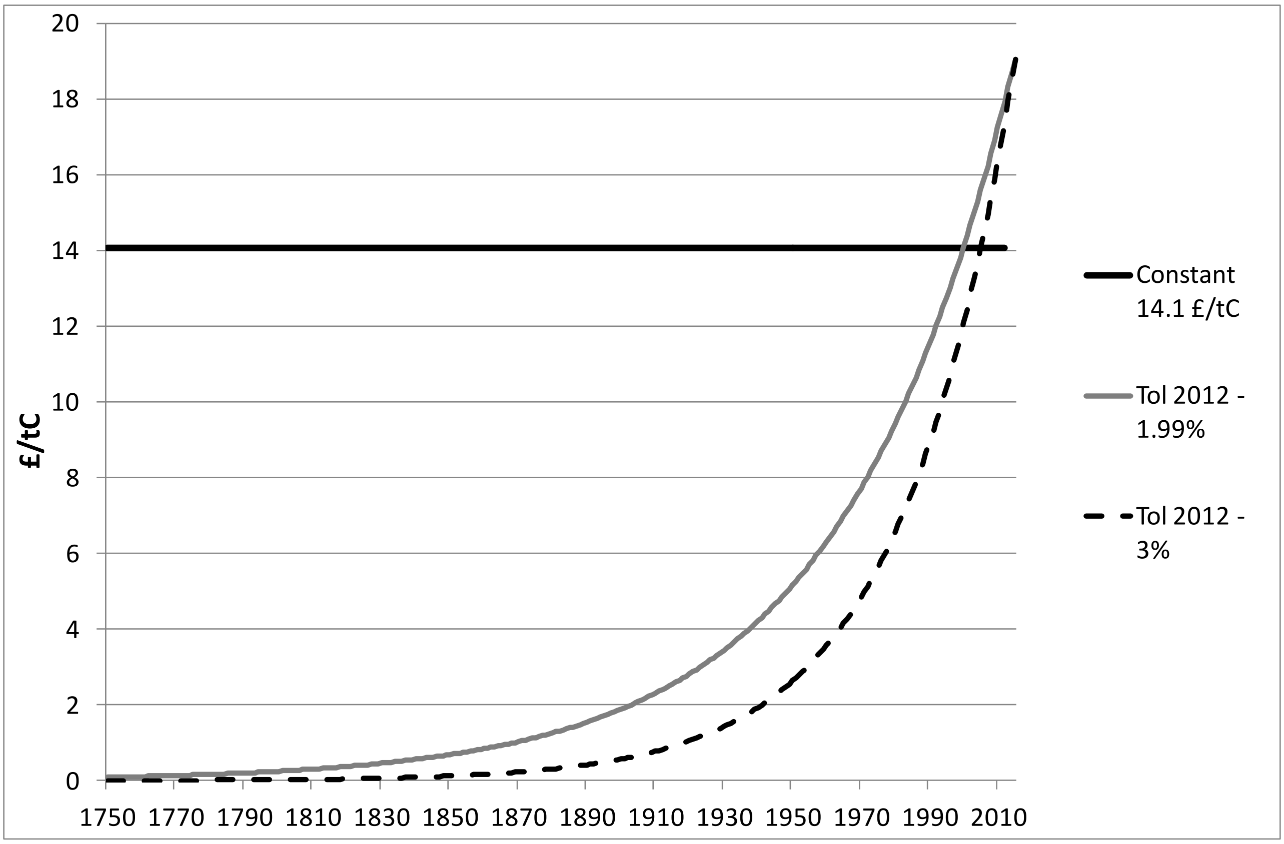

Figure 3. Carbon cost £/tC (2000 price level) constant vs. Tol (2012) with 1.99 and 3 percent annual deduction

The importance of the price tag

Before proceeding to the other costs of the use of fossil fuels, we will take a brief look at the importance of the chosen price tag. In Figure 4 below we have multiplied a selection of price tags for the cost of carbon with UK emissions of carbon taken from McLaughlin et al. (2012). As we are using emission data from the UK, we are omitting the 'U.S. only' estimates. The Defra estimates have been calculated with 3 percent discounting and for Fankhauser (1994), we have used both a price declining to zero by 1860 and a constant yearly deduction of 0.16 £. For Tol (2012), we have used both 3 percent and 1.99 discounting. Unsurprisingly, the highest peak costs are with the Defra estimates, peaking in 2006 at 11,388 M£, 9,291 M£ and 3,641 million pounds, as their starting price

[3] We have converted dollars to pounds by dividing with the 2000 exchange rate 1.52 $/£ (Officer 2011)

tags are the highest. The importance of the decision to use a constant or a diminishing cost as we move back in time, is shown by the constant price having the fourth highest peak, peaking at 2,541million £ in 1971, when the UK carbon dioxide emissions where at their highest peak. The lowest costs come from the Tol (2012) estimate with a 3 % discount; while the Fankhauser (1994) estimate with a yearly 0.16 £ deduction and Tol (2012) with a 1.99 % discount provides trajectories closer to each other.

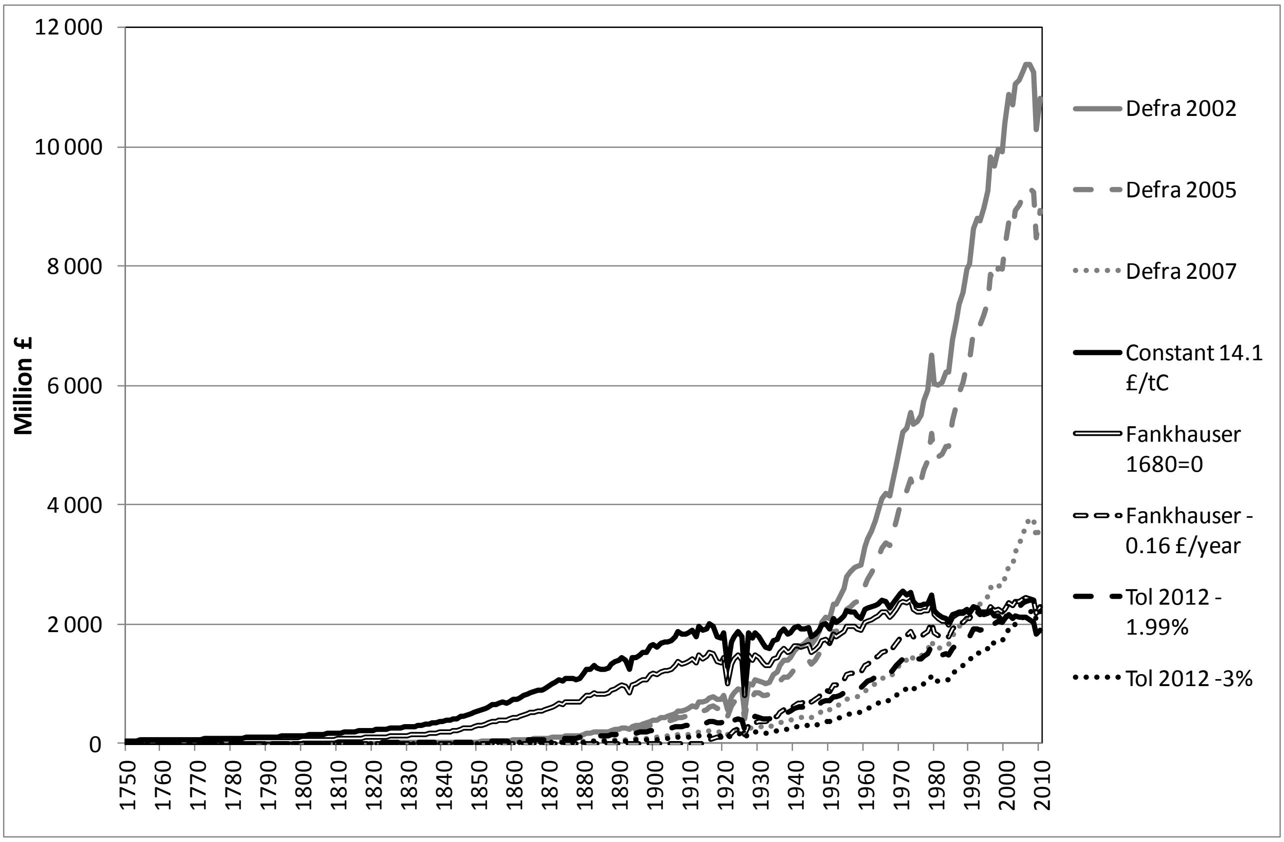

Figure 4. Costs of Carbon emissions, Million £ in 2000 price level, 1750-2010

It might be more instructive, however, to show the costs of carbon dioxide emissions as a share of GDP. That is done in Figure 5, below. This changes the outcome considerably, with the highest percentage at the peak with the constant carbon cost of 1.5 percent in 1873. Otherwise the order remains affectvely unaltered, with the next highest peaks with Defra 2002 and 2005 assumptions in 1992 at 1.2 and 1 percent; followed by Fankhauser going to zero by 1860, peaking at 0.96 percent in 1908. The rest of the estimates' peak between 0.2 and 0.4 percent of GDP.

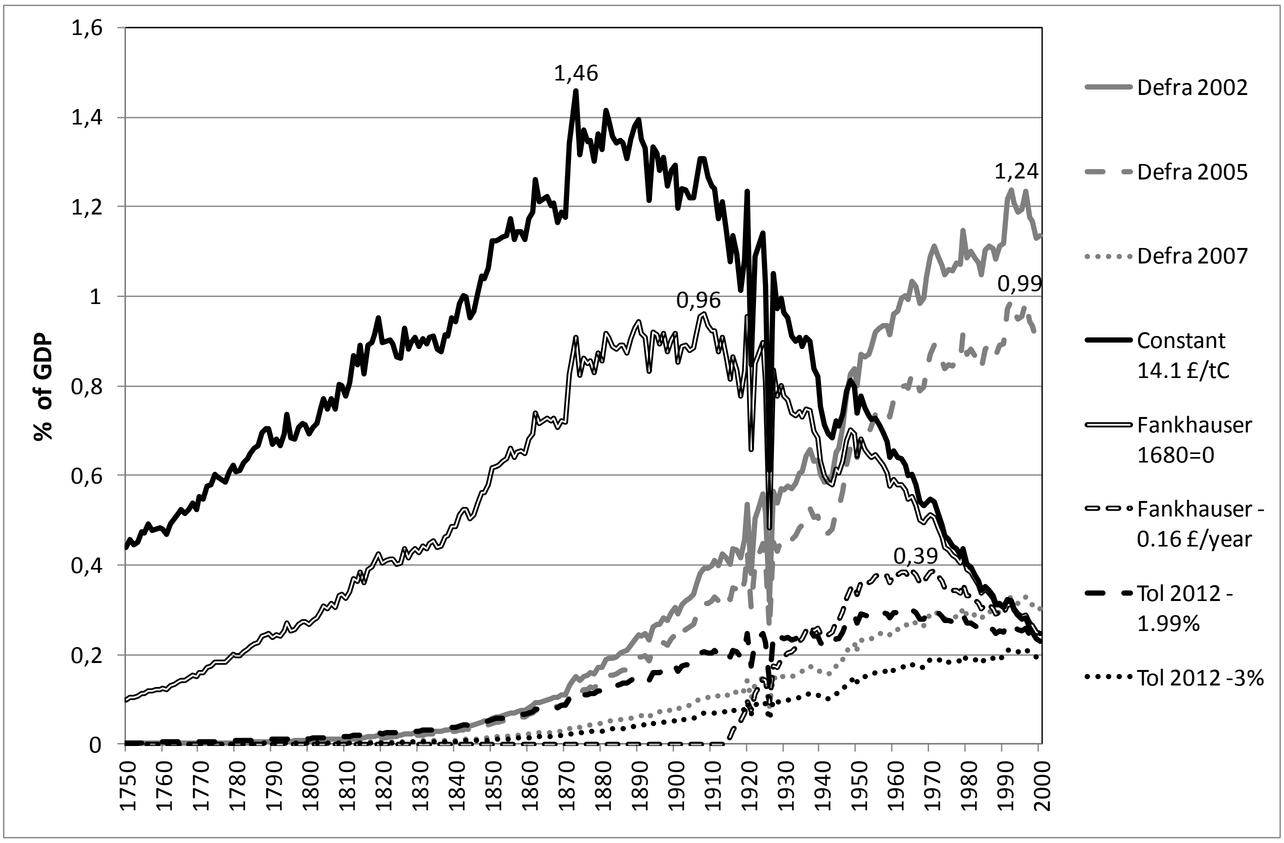

Figure 5: Carbon costs compared to GDP, 1750-2000

Which carbon cost estimate to use?

So far, we have shown that there are many alternatives for setting the price tag for carbon dioxide emissions in the past, and that the chosen price tag will have a major influence of the costs of carbon dioxide emissions in the past. Although no matter what value you use, historic damage costs are still very small compared to the GDP. The question of which damage cost estimate and back counting method we choose should choose, however, remains unanswered.

In attempting to answer this question, the first thing we do is drop the ‘U.S. only’ or any country specific estimates. Our main argument for this is the fact that in the case of a global phenomenon as human induced climate change, there is no possibility for a single country to isolate itself. Using one single carbon cost per ton for all countries also makes international comparisons easier. Furthermore, Ackerman and Stanton (2011) clearly show that the Interagency Working Group on Social Cost of Carbon (2010) estimates omit many of the largest risks associated with climate change, and downplays the impact of our current emissions on future generations. Their own worst case scenario cost, is used only to illustrate the effects of possible extremely dire consequences of climate change. This is relevant when looking forward, but perhaps not so when looking backwards, knowing that historical emissions have not led to any worst-case scenario – yet.

Next, we drop the constant carbon cost. If we accept that the costs of carbon emissions rise when moving forwards in time, it feels odd to keep it constant when going backwards. Against estimates set going to zero by 1680 or any other years, is the large effect on the assumed year when the negative effects of climate change overturn the positive effects. This problem is missing in estimates based on a percentual decrease for each year back in time, as they are moving asymptotically towards zero. Here the main problem is choosing the 'right' percentage.

Such assumptions as those made above still leave many other options for carbon cost estimates. Which if any, of the remaining estimates do we find most support for? Using this approach, we would suggest using the Tol's (2012) estimate. Interestingly, a 1.99 percent annual deduction of carbon costs returns $ 21.4/tC in 2000, or 14.1 £/tC which is the same as the constant used by Hamilton and Clemens (1999) and Bolt, Matete and Clemens (2002). Furthermore, as the Tol estimate itself is a combination of many independent estimates; it can be seen as a good compromise between different approaches to calculate the carbon costs.

Rabl (1996) argues that in the cost benefit perspective of future generations beyond the first generation should be discounted at the growth rate of the economy; any discount rate greater than the growth rate of the economy used for a sufficiently long time would cause the annual benefit becoming larger than the total economy. We argue that this conclusion holds as well when looking back into the past, as a particular point in time is the future of a more distant point. This notion would support using the rather low discount rate of 1.99 % used by Tol (2012) over the 3 % or higher discount rate in most of the other papers discussed. The 1.99 percent rate is close to the 1.8 percent growth for the UK economy from 1750 to 2000, and slightly below the post war 2 ½ percent growth rates.

An alternative would be to use the GDP growth rate of the economy itself. In an exercise like this, focusing on just one country choosing the appropriate discount rate, would not pose any significant problems. Choosing the right discount rate in international comparisons can, on the other hand, be tricky. Should we use the same discount rate, like the global GDP growth during the period of interest, or different discount rates, like the GDP growth rate of each country separately? This question will be discussed further in a subsequent paper dealing with international comparisons of the effect of the use of fossil fuels.

Should we take into account additional greenhouse gases?

Before proceeding further, we will briefly consider other greenhouse gases. The second most important greenhouse gas is methane (CH_4) arising from extraction of fossil fuels, cattle, sheep and other ruminant livestock, landfills, and rice cultivation. Other important greenhouse gases are nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). Of all total warming potential of global greenhouse-gas emissions in 2005, CO_2 contributed 77%, methane 14% and nitrous oxide 8% (Stern Review, 170). Richard Eyre et al. provide some estimates for the damages of both methane and nitrous oxide. As we can see from Table 4, there is again a large variation between the models used and especially the discount rate applied. Alternative estimates are provided by C. Hope (2006).

Table 4. Marginal damages of Methane and Nitrous Oxide Emissions in 1995—2005.

Greenhouse gas	Damage unit	Marginal damage from model			
		FUND		Open Framework	
		1 %	**3 %**	**1 %**	**3 %**
Methane	**€/t**	46	19	44	20
Nitrous Oxide	**€/t**	17 000	6 400	26 000	11 000

Source: Eyre, Nick et al. (1999) *Global Warming Damages*.

Methane is approximately 21 times more powerful at warming the atmosphere than carbon dioxide (CO_2) by weight, but its lifetime in the atmosphere is only approximately 12 years.[4] Thus, we would not need to make or find estimates of methane emissions going very far back in time, only 12 years earlier than the estimated turning point when climate change becomes a bad thing. The very same short lifetime in the atmosphere of methane speaks, on the other hand, against its inclusion in any estimate as we move further back in time. If we believe that climate change before the 1980s did not cause any harm, methane emissions prior to the 1970s would not cause any harm either. Thus, it would have no relevance for most of the period under investigation. Furthermore, Watkiss et al. (2005) argue that, "any extra methane emitted today will have disappeared before the most severe climate-change impacts occur."

[4] http://www.epa.gov/outreach/scientific.html

The atmospheric lifetime of nitrous oxide is considerably longer than that of methane, approximately 120 years and its heat trapping effects are approximately 310 times more powerful than carbon dioxide on a per molecule basis.[5] Arguments against the inclusion of nitrous oxide come from the fact that it was responsible for only 8% of the warming potential in 2005, compared to the 77% for CO_2. When the costs of carbon dioxide emissions were at most, only around one percent of GDP, the effect of nitrous oxide would be only around one-tenth of a percent at most. Thus, its inclusion would not make much difference.

Local effects of fossil fuels

So far, we have argued that the social costs of carbon dioxide emissions were, at most, approximately one percent of GDP. Adding other greenhouse gases, most notably methane and nitrous oxide, would add some tenths of a percent at most. Our next step is to compare these global effects to the local effects. For a first approximation, we concentrate on the fuel of the industrial revolution – coal. Roger Fouquet (2011) has made a comprehensive estimate of the total external costs of coal production and consumption for United Kingdom. Firstly, he estimated the premature deaths associated with coal production and local air pollution in the United Kingdom between 1700 and 2000. The reasons for premature death included local air pollution caused by coal burning, deaths from accidents in coal mines and deaths of coal miners from respiratory disease (pneumoconiosis). Having estimated the number of deaths, his next step was to place a value on them. In other words, he identified the number of years prematurely lost and multiplied this number by the value of a life year lost. His results for the period 1750 to 2000 are reported in Figure 6 below. The costs peaked in 1891, when air pollution from coal was estimated to have caused close to £(2000) 17.5 billion in damage, as close to 73,000 people were estimated to have died as a result of coal production and consumption.

[5] http://www.epa.gov/nitrousoxide/scientific.html

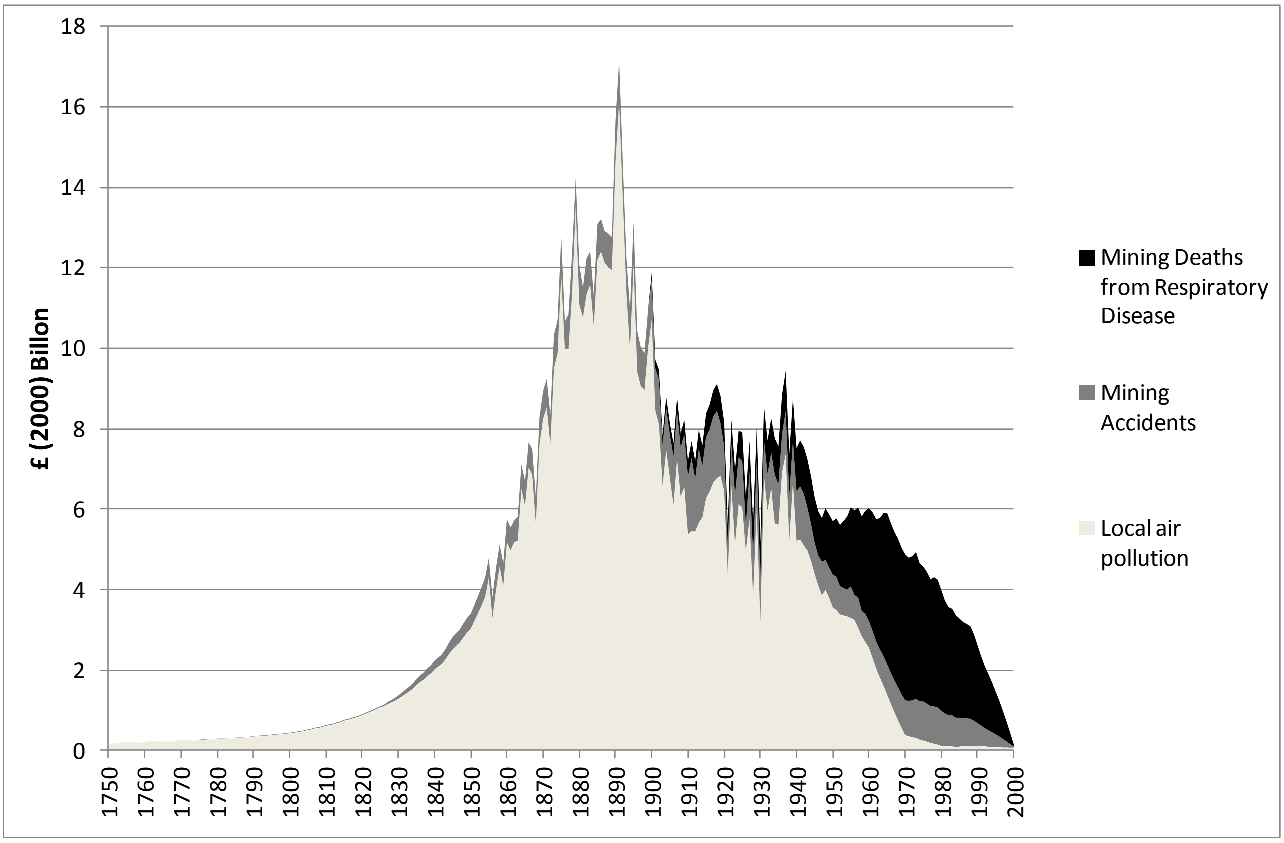

Figure 6. The costs of premature deaths caused by coal production and consumption in UK, 1750—2000

Source: Fouquet, R. (2011) "Long Run Trends in Energy-Related External Costs" Ecological Economics 70(12) 2380-9.

Again, it might be more instructive to show the costs of coal consumption compared to the GDP and this is presented as Figure 7, below. For comparison, we have added the costs of carbon dioxide emissions using our price tag choice, that of Tol (2012), with a 1.99 percent annual deduction. The local costs due to premature deaths, caused by the production and consumption of coal alone, peaks in 1879 at around 18 percent of GDP, while the global cost of carbon dioxide emission's peaks at 0.3 percent in 1971.[6] By choosing a higher carbon price estimate, we could have increased that to around 1.5 percent, which is still only one-tenth of the local costs. Furthermore, the local costs were realized in the year examined, while the global costs are discounted values of future costs. Thus, it is no surprise that the former problem is more or less solved, while global warming is still proceeding.

[6] Note that peak percent is slightly lower than the 20 % in the Ecological Economics article by Roger Fouquet, as he has kindly provided us with an updated dataset, and our GDP used differs slightly from his.

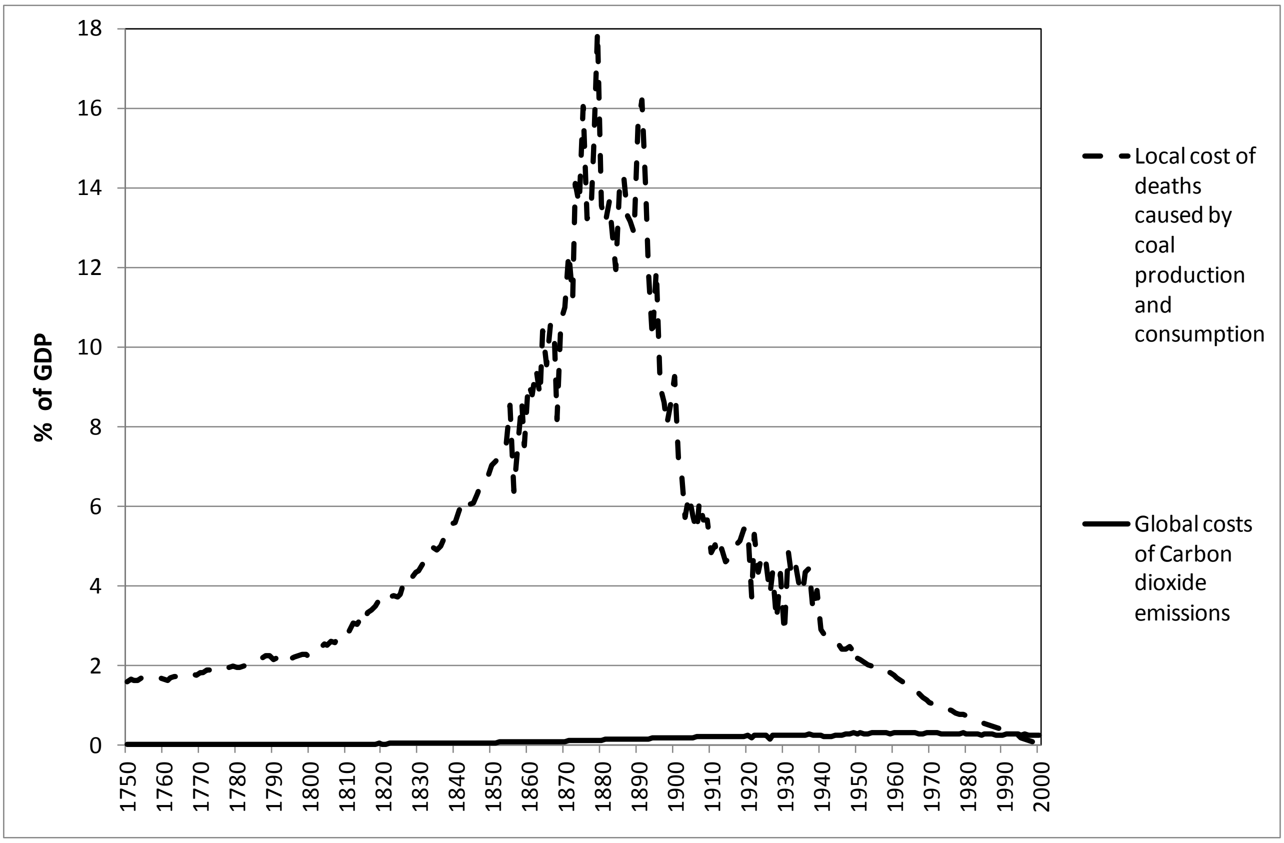

Figure 7. The costs of premature deaths caused by coal production and consumption in UK versus the global costs of UK carbon dioxide emissions, 1750—2000

So could we, and should we include the costs of premature deaths calculated by Roger Fouquet into the national accounts of the UK – we believe not as it would cause serious double counting. The premature deaths are to some degree included in normal national accounts through the missing work contribution, which reduces GDP. Considering the Genuine Savings measure, it could be argued that these deaths cause a loss in the value of human capital, if one uses a discounted lifetime earnings approach to value human capital. The World Bank Manual for Calculating Adjusted Net Savings suggests taking human capital into account through public expenditure on schooling (Bolt, Matete and Clemens, 2002). Such information is provided by Vincent Carpentier (2001, 2003 & 2008). According to his estimates, the public expenditure on education amounted to only 0.01% of GDP in 1833, and not until late 1890s would it reach 1 percent. During the same period, the local costs of premature deaths due to coal production and consumption varied between 5 and 18 percent. Thus, its deduction would cause negative human capital growth for the whole 19th century.

We suggest a different approach to account for the negative effects of local pollution. In general, human capital can be calculated via two different approaches: 1) Retrospective (or resource-cost) methods based upon expenditures on education, 2) Prospective methods through the discounted sum of the wages the population would receive over the remaining expected number of working years.[7] We suggest using the latter method, as air and water pollution and other environmental problems enter human capital to the extent that it impacts on people's capacity to work as part of the work force. For example, people that have lost their health and working capacity or have met a premature death due to environmental pollution are permanently out of the work force.

Estimates of the cost of environmental pollution or degradation proposed by, for example, Roger Fouguet (2011), could be used in such an approach to explain changes in human capital. Using a counterfactual approach, we could then explore how much larger the human capital would have been if this pollution had not had taken place. Through the contribution of human capital on economic growth, we can also estimate the effect of pollution on economic growth. Similarly, the environmental effects of pollution, for example, acid rain on, buildings and forests also enter through depreciation of the capital stock in buildings and forests.

Summary and conclusions

In this paper, we have examined means by which we might incorporate the environmental effects of fossil fuel use into national accounts and Genuine Savings estimates, particularly if we consider retrospective and prospective estimates. We started by making a distinction between local, regional and global emissions and between stock and flow emissions as each require different approaches. Regional emissions that are exported outside the country under scrutiny can be ignored from the national accounts as long as the recipient country does not have an effective way of imposing a payment from the emitter.

The effect of global emissions such as carbon dioxide, involves a combination of the effects of domestic and regional emissions. In the short run, it seems that a single country can isolate itself from the detrimental effects of global warming, but in the long all countries are unable to free ride. Thus, we support the use of a single global price tag for carbon dioxide emissions worldwide. We argue that the price tag should decrease as we move back in time to take into account the fact that carbon dioxide is a stock pollutant and the estimates of its future cost are increasing while the

[7] For a nice overview of different approaches to calculate human capital see chapter three in Kokkinen (2012).

possibility that human induced climate change might initially have a positive effect cannot be excluded.

A comparison of the local effects in UK, of the production and consumption of coal alone versus the effects of carbon dioxide, showed that the former exceeds the latter by at least tenfold in terms of its importance relative to GDP. Thus, there is no surprise that the former problem is more or less solved, while global warming is still proceeding. We hope that the latter does not become as serious as the local effects of coal use, which peaked at approximately twenty percent of GDP, before genuine action to solve it is taken.

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