Ancillary Benefits of Climate Policy

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Summary

The benefits of climate policy normally consist exclusively of the reduced impacts of climate change, i.e., the policy's primary aim. Our analysis of benefits of climate policy suggests, however, that researchers and policymakers should also take account of ancillary benefits, e.g., in the shape of improved air quality induced by climate protection measures. A consideration of both, primary and ancillary benefits, has a positive influence on global climate protection efforts, e.g., because the regional impact of ancillary effects attenuates easy-riding motives of countries with respect to their provision of climate protection. In this article, we analyze the nature of ancillary benefits, present an overview of European assessment studies and explain possible methods to estimate ancillary benefits. Main differences between primary and ancillary benefits are pointed out. Furthermore, we stress the major influences of ancillary benefits on climate policy. Finally, we present one of the first models integrating primary and ancillary benefits. By this model quantitative results are calculated with respect to ancillary benefits in the UK considering different green-house gas (GHG) control levels. It is observed that the ancillary benefits could cover about 4 percent of the full GHG reduction cost.

Keywords: Climate Policy, Ancillary Benefits, Pollution Control

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1 Ancillary Benefits

Climate policies initiate the reduction of atmospheric and biospheric GHG concentrations, and hence, the slowing of global warming, which provides primary benefits. But what has been widely omitted so far in the economic literature on climate change is that climate policies also induce ancillary benefits, i.e., benefits which result from climate policies but not from the slowing of climate change.[1] Since primary benefits are intensely discussed in the scientific literature, we mainly focus on the discussion of ancillary benefits. These ancillary benefits are not only considerable in size, they also exhibit characteristics which are different to those of primary benefits. Hence, the consideration of ancillary benefits has not only quantitative impacts with respect to the results of cost-benefit analyses, it additionally induces qualitative effects. Different climate policies have different impacts and may initiate different concrete actions reducing GHG concentrations. Consequently, they imply different ancillary benefits. This is illustrated by considering the control of the most important greenhouse gas CO_2 by way of example. Climate policies which intend to reduce CO_2 concentrations mainly initiate the reduction of CO_2 emissions (sequestration of carbon would be another option):

Implications of the Reductions of Carbon Dioxide Emissions:
Fuel combustion reductions - e.g. caused by the implementation of more efficient technologies or the reduction of road traffic - and the *substitution of carbon-intensive fuels* reduce CO_2 emissions. Ancillary benefits induced by activities reducing CO_2 emissions accrue from the abatement of non-CO_2 emissions, for example. In fuel combustion processes CO_2 emissions are accompanied by emissions of e.g. CO, NO_X, SO_2, N_2O, CH_4 and particulate matter (PM). Therefore, measures reducing CO_2 not only cause a decrease in CO_2 emissions but also an emission reduction of other pollutants. In general, positive health effects of air pollution reduction that accompany GHG control are considered to represent the most important category of ancillary benefits (see e.g. Ayres and Walter (1991: 258) as well as Heintz and Tol (1996: 7)). According to Olsthoorn et al. (1999: 345) mortality is the crucial effect in the economic valuation of health effects. Other negative impacts of air pollution like accelerated surface corrosion, weathering of materials and impaired visibility are also mitigated by fuel combustion reductions. Improved air quality also causes

[1]The term ancillary benefits is one of a number used to convey this idea. The others are secondary benefits, or co-benefits or spillover benefits (see IPCC 2001). The main difference is the relative emphasis given to the climate change mitigation benefits versus the other benefits. For some policies these 'other benefits' may be as important as the GHG reduction benefits, in which case the term 'co-benefits' is more appropriate. Indeed, the 3rd Assessment Report of IPCC prefers the term co-benefits on the grounds that it makes 'the case for an integrated approach, linking climate change mitigation to the achievement of sustainable development and other policy objectives' (IPCC 2001: 461). In this paper we stay with the term ancillary benefits simply on the grounds that it is more commonly used and understood. The types of impacts being covered, however, are the same as those discussed under each of their labels.

a reduction of the vegetation harming acidic deposition of photochemical oxidants. Furthermore, road traffic reduction as a means to reduce fuel combustion generates not only ancillary benefits by reducing the emission of air pollutants: less road traffic is also accompanied by lower noise levels and frequency of accidents, less traffic congestion and road surface damage. Only a minority of studies considers these non-pollution-specific ancillary benefits in the transport sector (as can be easily observed from the overview of European studies on ancillary benefits in Table 1). But though these benefits are regularly assessed to be small in comparison to the ancillary benefits arising from less air pollution, they are not negligible as e.g. Barker, Johnstone and O'Shea (1993) illustrate.

Measures reducing CO_2 emissions could also cause ancillary costs (Burtraw and Toman 2000a: 3). A switch from fossil fuels like oil, gas or coal in the generation of electricity to the application of nuclear technologies reduces CO_2 emissions but also causes negative externalities. External costs from nuclear electricity generation accrue e.g. from the higher risk of catastrophic accidents in power plants (Ewers and Rennings 1996: 418-419).

Ancillary benefits might also stem from the act of protecting the global climate itself (Rübbelke 2002: 13-14). Industrialized countries may enjoy a kind of 'warm glow' from supporting developing countries by mitigating global warming: *"A strong argument for trying seriously to slow climate change is that the developing countries are vulnerable and we care"* (Schelling 1992: 7). Climate protection can, therefore, be considered like a charitable giving to developing countries.[2] Some industrialized countries may also 'feel' guilty since the industrialized world represents the group of main GHG emitter countries, and is, thus, mainly responsible for the anthropogenic greenhouse effect.[3] Consequently, a contribution to the mitigation of the greenhouse effect may relieve their conscience. This 'relief' may also be considered as a secondary effect of GHG control from which industrialized countries enjoy ancillary benefits.

Some authors consider ancillary benefits of climate policies that are associated with employment effects or technological change: By levying carbon taxes, funds are collected which could be used to remove distortionary labor taxes, i.e. taxes which raise labor cost and induce a sub-optimal low employment of labor force. With it, the price of the factor labor declines and employment is raised. In recent years a large strand of literature discussed double dividends of environmental tax schemes which recycle revenues by reducing labor cost.[4] Not all contributions supported the

[2] *"Any action combating global warming will be, intended or not, a foreign aid program"* (Schelling 1997: 8).

[3] *"The OECD is often held responsible for the larger part of the enhancement of the greenhouse effect while non-OECD countries appear to be the main victims of climate change"* (Tol et al. 1995: 59).

[4] The dividends of such revenue recycling are on the one hand the carbon-tax induced improvement of environmental quality and on the other hand the increase of employment by reducing labor costs. For the double dividend debate see e.g. Bovenberg and de Mooij (1994); Goulder (1995);

double dividend hypothesis. With respect to technological change, Pearce (2000: 11) stresses that technological improvements induced by climate policies might diffuse outside of the sectors targeted for GHG control. Benefits associated with these spillover effects may also be regarded as ancillary benefits of climate policy.

2 European Studies

European studies of ancillary benefits show that secondary benefits are substantial. One of the earliest attempts to integrate secondary benefits into a cost-benefit analysis of GHG control was undertaken by Ayres and Walter (1991). They criticized the influential studies of Nordhaus, since these did not consider secondary benefits and thus, provided too low estimates of GHG control benefits. This view has been supported by Pearce (1992: 7), who points out that Nordhaus (1991a,b) has omitted a major category of benefits by neglecting the secondary benefit category.[5]

European models assessing ancillary benefits are heterogeneous from a methodological as well as from a geographical point of view. A couple of studies deal with Scandinavian countries. Glomsrød, Vennemo and Johnsen (1992) estimate secondary benefits in a computable general equilibrium model for Norway. They investigate a carbon-tax-induced CO_2 stabilization and consider the secondary benefits associated with an air pollution decrease as well as a transport activity reduction. Alfsen, Brendemoen and Glomsrød (1992) employ a macroeconomic model to assess ancillary benefits related to changes in air pollution and road traffic in Norway. Håkonsen and Mathiesen (1997) refer to the externality cost estimates provided by Alfsen, Brendemoen and Glomsrød (1992) in their general equilibrium analysis of ancillary benefits of CO_2 stabilization in Norway. A different approach is chosen by Alfsen, Birkelund and Aaserud (1995), who assess the reductions in the abatement costs required to meet the Sofia Protocol and the Helsinki Protocol brought about by an EC Carbon/Energy Tax for nine western European countries. Yet, they neglect traffic related benefits of CO_2 control. In contrast, Barker, Johnstone and O'Shea (1993) focus on measuring the importance of traffic related benefits of a carbon/energy tax in the UK and omit the benefits of reduced air pollution.

Meyer et al. (1998; 1999) and Lutz (1998) simulate the effects of CO_2 tax and permit schemes on emissions of non-CO_2 pollutants and CO_2 for Germany, but do not translate the secondary effects into monetary values. Their simulations, based on an econometric model, suggest that there are important air quality improvements associated with CO_2 control policies in Germany. Complainville and Martins (1994) consider emissions of CO_2, SO_X and NO_X in a dynamic general equilibrium model (OECD GREEN). Their results suggest that air quality improvements may be as significant in developing countries as they are in industrialized countries. Morgen-

Kirchgässner (1996) as well as de Mooij (1999).

[5] Nordhaus (1991b: 928) himself has pointed to the problem that his *"calculations omit other potential market failures, such as ozone depletion or air pollution"*.

Source	Region	Consideration of Ancillary Effects Associated with	Comments
Ayres and Walter (1991)	Western Germany, USA	air pollution	
Alfsen, Brendemoen and Glomsrød (1992)	Norway	air pollution and road traffic	
Glomsrød, Vennemo and Johnsen (1992)	Norway	air pollution and road traffic	
Pearce (1992)	UK, Norway	air pollution	
Barker (1993)	UK, USA, Norway	air pollution	two different methods of valuing benefits of emission reduction are considered
Barker, Johnstone and O'Shea (1993)	UK	road traffic, but no air pollution	
Brendemoen and Vennemo (1994)	Norway	air pollution and road traffic	
Complainville and Martins (1994)	world-wide	air pollution	oxides of nitrogen, oxides of sulphur, and carbon dioxide are considered; not translated into monetary benefits
Alfsen, Birkelund and Aaserud (1995)	nine western European countries	air pollution	reduced technological abatement cost of reaching environmental targets are considered
Ekins (1996a)	UK, Germany	air pollution	the analysis finds that the secondary benefits from abating sulphur dioxide alone beyond the limits of the Second Sulphur Protocol provide a substantial offset to the costs of a carbon tax
Aaheim, Aunan and Seip (1997)	Hungary	air pollution	
Håkonsen and Mathiesen (1997)	Norway	air pollution and road traffic	
Lutz (1998)	Western Germany	air pollution	not translated into monetary benefits
Meyer et al. (1998)	Western Germany	air pollution	not translated into monetary benefits
Capros et al. (1999)	European Union	air pollution	
Meyer et al. (1999)	Germany	air pollution	not translated into monetary benefits
Aunan, Aaheim and Seip (2000)	Hungary	air pollution	
Barker and Rosendahl (2000)	19 regions of Western Europe	air pollution	oxides of nitrogen, sulphur dioxide, some fine air-borne particles, and carbon dioxide are considered
RIVM et al. (2000)	European Union	air pollution	data which consider ancillary effects from road traffic are also employed (see the first method, page 63)
Sommer et al. (2000)	Austria, France and Switzerland	air pollution	

Table 1: European Studies on Ancillary Benefits (Rübbelke 2002: 19).

stern (2000: 7) stresses that the limited literature on ancillary benefits in developing countries suggests that the ancillary benefits there are even higher than in the US. Studies investigating regions outside industrialized countries are provided e.g. by Wang and Smith (1999a,b); Aunan et al. (2000) as well as Garbaccio, Ho and Jorgenson (2000) who analyze ancillary benefits in China, and Dessus and O'Connor (1999) as well as Cifuentes et al. (2000) who regard co-benefits of GHG control in Chile. Aaheim, Aunan and Seip (1997) as well as Aunan, Aaheim and Seip (2000) investigate ancillary benefits of energy saving in Hungary.

Ayres and Walter (1991) were among the first researchers who compared European ancillary benefit estimates with estimates for the US. They found out that ancillary benefits in Germany are likely to exceed those in the US, which might be due to the fact that the population density in Germany is higher than in the US.[6] That population density matters for the importance of ancillary benefits is supported by Burtraw and Toman (1997: 22; 2000a: 10, 15; 2000b: 23) as well as Burtraw et al. (1999: 15). They compare European and US estimates of ancillary benefits, too. With respect to the European assessments their main focus is on a survey of studies provided by Ekins (1996a). Burtraw and Toman (1997: 21-22; 2000a: 15; 2000b: 23) as well as Burtraw et al. (1999: 15) point out that the discrepancies between the high European assessments and the US data may also be due to geographic differences. A greater proportion of sulfur emissions in the Eastern US is deposited off-shore rather than on-shore as in Europe. Apart from the demographic and geographic arguments, the discrepancies between the US and European studies considered by Burtraw and Toman (1997; 2000a,b) as well as Burtraw et al. (1999) are attributable to several other factors, e.g. the more aggregate level of modelling in the European studies (Burtraw et al. 1999: 15; Burtraw and Toman 2000b: 23), high economic valuations of environmental impacts employed by the European researchers (Morgenstern 2000: 7-8), and the application of a fixed coefficient procedure in the considered European studies (which does not allow for the possibilities of substitution in production, and therefore results in higher damage costs) (e.g. Pearce 1992 and Barker 1993).

3 Primary vs Ancillary Benefits

Primary and ancillary benefits can in general be distinguished with respect to the degree of publicness, the delay of occurrence and the scientific knowledge required for the assessment:

- *Publicness:* Primary benefits are global, while ancillary benefits are local or regional (IPCC 1996: 217; Pearce 1992: 5). Therefore, ancillary effects of climate policies have mainly the character of a private good to the policy

[6] More recent estimates of ancillary benefits for western European regions provided by Barker and Rosendahl (2000) also exceed the estimates found in studies for the US, although the Barker/Rosendahl results are below the results found in earlier European studies.

providing region or country. This contrasts sharply with the primary effect because the mitigation of global warming is a global public good, i.e., everyone can enjoy this good without affecting other agents' consumption of it and nobody can be excluded from the consumption. Thus, a country's provision of climate policy can be considered as an impure public good since it contains pure public as well as private characteristics.[7]

- *Delay:* The intervals between the implementation of a GHG abatement policy and the occurrence of benefits differ among primary and secondary benefits. Secondary benefits can be enjoyed widely in the present, since the avoided damages, e.g. from air pollution or noise, would have otherwise occurred immediately or shortly after the GHG emitting activity.[8] Primary benefits of GHG abatement on the other hand arise with a delay of about a half century. If economists discount benefits with a positive rate,[9] today's ancillary benefits get a higher weight compared to the primary benefits in distant future. The time lag between GHG abatement measures and the occurrence of primary benefits raises questions on the 'correct' discount rate and, consequently ambiguity with respect to the assessment of these future benefits.

- *Required Scientific Knowledge:* A prerequisite to assess primary benefits is an immense knowledge of processes in local spheres *and* the whole global system. Because knowledge especially of processes in a global context is incomplete, uncertainties accompany the assessment of primary benefits which exceed the ones associated with the assessment of ancillary benefits.[10]

The claim that ancillary benefits arise only from avoided damages affecting the emitting region may hold as long as CO_2 control is regarded. It would not hold anymore if abatement of greenhouse gases such as CFCs is considered (Rübbelke 2002: 23). The abatement of CFCs generates an important positive ancillary effect by protecting the ozone layer. The benefits enjoyed from this effect obviously represent *global* ancillary benefits.

4 Ancillary Benefit Modelling

Much of the discussion on ancillary benefits has focused on what would be gained from the associated reductions of other pollutants when greenhouse gas reductions

[7]For a discussion of climate policy as an impure public good, see Rübbelke (2003).

[8] *"Unlike the benefits of reducing CO_2 emissions now in order to reduce damage from global warming in the future, reducing other emissions, which are causing damage now, yields benefits immediately"* (Ekins 1996b: 15).

[9]Economists regularly discount future costs and benefits, e.g., because it is assumed that the present welfare level of people is more important from a politician's point of view than the welfare level of people living in future.

[10] For the uncertainties surrounding the estimates of ancillary benefits and costs see Krupnick, Burtraw and Markandya (1999: 33-34).

are targeted. What is missing, however, is an analysis of the overall scope for such reductions, taking account of the fact that government has already undertaken measures to reduce non GHG emissions, and taking account of the fact that an optimal policy needs to balance the losses of output against the combined benefits of GHG and non GHG reductions in emissions.

In the appendix we present a simple but effective model to look at the scope for, and the amount of, ancillary benefits in this context. The model assumes that before climate change became an issue, governments concerned themselves only with the control of the 'ancillary' pollutants. They set their policies so as to limit emissions of these pollutants to the point where the marginal costs of reductions in the pollutants were equal to the benefits in the form of reductions in emissions. Once climate change became an issue, however, they had a new problem to solve - that of achieving a reduction in the emissions of greenhouse gases as well as paying attention to the ancillary pollutants. The model formalizes these choices and the solutions and compares them numerically. Data are taken from the UK to demonstrate the methodology and to show the impacts of reductions in GHG emissions in the range of 5-30 percent from the status quo.[11]

A key issue in ancillary benefit modelling is to determine the level of ancillary benefits in the absence of GHG impacts. We have to assume that the level of ancillary related activities are determined in something approaching an optimal way and then see how they change when GHG considerations are brought in. In the model presented we work with ancillary benefits arising from fossil fuel emissions only.

The main results of our model is that we can report the implied estimates of ancillary benefits for

(a) ancillary emissions that are 33 to 50 percent below maximum emissions in the absence of any climate change policy (i.e. for domestic pollution control reasons),

(b) 'optimal' reductions in GHG emissions that range from 5 percent to 30 percent below 1999 levels.

The results are presented in Table 2, which shows:

a. Additional ancillary emissions reductions resulting from introducing a GHG policy with a CO_2 price of $10/MT are in the range of 3 to 6 percent, which is not so wide, given that the optimal reductions they cover range from 5 percent to 30 percent of baseline GHG emissions and the assumed optimal reductions in non GHG range for 33 to 50 percent of the maximum non GHG emissions.

b. The ancillary benefits range from $0.7 to 1.7 billion, which are about 4 percent of the full costs of the GHG reduction.

[11] It should be noted that the actual values are only indicative; a full deployment of this model would need a more careful and detailed analysis of the data.

Optimal Reduction in Non GHG Emissions = 33%	**Optimal Reduction in GHG Emissions (%)**					
	5	10	15	20	25	30
Estimate of Ancillary Benefit						
% Reduction in Emissions.	*2.6*	*4*	*5.00*	*5.7*	*6.17*	*6.45*
Benefits in $BN.	*0.71*	*1.1*	*1.36*	*1.54*	*1.66*	*1.74*
Cost of GHG Policy without AB						
In $BN.	*16.98*	*26.18*	*32.43*	*36.74*	*39.60*	*41.30*
As % of No Control GDP.	*1.16*	*1.78*	*2.20*	*2.48*	*2.67*	*2.78*
Cost of GHG Policy with AB						
In $BN.	*16.26*	*25.2*	*31.07*	*35.20*	*37.94*	*39.56*
As % of No Control GDP.	*1.11*	*1.72*	*2.11*	*2.38*	*2.56*	*2.66*
AB as percentage of total costs	*4.18%*	*4.20%*	*4.19%*	*4.19%*	*4.19%*	*4.21%*
Optimal Reduction in Non GHG Emissions = 50%	**Optimal Reduction in GHG Emissions (%)**					
	5	10	15	20	25	30
Estimate of Ancillary Benefit						
% Reduction in Emissions.	*2.6*	*4*	*3.63*	*4.13*	*4.46*	*4.66*
Benefits in $BN.	*0.71*	*1.1*	*1.21*	*1.38*	*1.48*	*1.55*
Cost of GHG Policy without AB						
In $BN.	*16.98*	*26.18*	*32.43*	*36.74*	*39.60*	*41.30*
As % of No Control GDP.	*1.12*	*1.78*	*2.2*	*2.48*	*2.67*	*2.78*
Cost of GHG Policy with AB						
In $BN.	*16.45*	*25.37*	*31.42*	*35.60*	*38.37*	*40*
As % of No Control GDP.	*1.13*	*1.73*	*2.13*	*2.41*	*2.59*	*2.69*
AB as percentage of total costs	*4.18%*	*4.20%*	*3.73%*	*3.76%*	*3.74%*	*3.75%*

Table 2: Ancillary Benefits and Cost of GHG Policy

c. GHG reduction costs are in the range of 1.1 to 2.8 percent of GDP, depending on what is considered the optimal level of reduction.

5 Ancillary Benefits and Climate Policy

There are several differences between primary and ancillary benefits of climate policy, which have qualitative as well as quantitative impacts. The immediate occurrence of ancillary benefits makes discounting unnecessary and gives these benefits a higher weight compared to primary benefits which are expected in distant future. The requirement of scientific knowledge to assess primary benefits exceeds the one of the estimate of ancillary benefits. Therefore, less ambiguity is associated with the assessment of ancillary benefits. Furthermore, ancillary benefits could have a considerable impact on the GHG abatement levels as well as a privatizing impact on the 'global public good' nature of climate policy. The privatizing effect is induced by the private character of ancillary benefits: ancillary benefits are national/regional, while primary benefits are global. Consequently, climate policy should be treated as an impure public good from an individual country's point of view. The privatizing impact of ancillary benefits helps to narrow the gap between an individual country's optimal and the Pareto-efficient abatement level. Furthermore, as a result of the privatizing effect, easy-riding motives are attenuated (Cornes and Sandler 1994). The impure publicness is also of importance when international transfers as a means to increase the level of GHG abatement are considered. The neutrality of transfers does not hold if the public goods involved are of an 'impure' variety (see, e.g., Andreoni (1986; 1989; 1990)).

According to quantitative aspects, our simple model shows that additional ancillary emissions reductions resulting from introducing a GHG policy with a CO_2 price of \$10/MT are in the range of 3 to 6 percent. Furthermore, ancillary benefits would cover about 4 percent of the full GHG reduction cost.
The simple model developed here can be extended in the following directions:

a. The fossil fuels can be separated so that each is treated individually.

b. More sophisticated production functions can be used (e.g., CES).

c. A range of values for the price of GHG emissions can be tried.

In spite of its great simplicity, however, the present version offers some real insights into the magnitude and relative importance of ancillary benefits at a macro level. Furthermore, the model itself tends to estimate low ancillary benefits as a percentage of the GHG reduction costs because it derives itself from a model of costs that is 'macro' or 'top down' based. It is well known that such costs are generally higher than those from a more 'bottom up' or mixed basis.

Therefore and in order to prevent the impression that ancillary benefits are negligible, we finally point out that the European ancillary benefit literature widely estimates higher ancillary benefits as a percentage/multiple of primary benefits than our paper does. As Pearce (2000) illustrates, European ancillary benefit studies estimate ancillary benefits as a multiple of primary benefits of between 0.98 and 6.93. However, newer estimates tend to be lower than the ones in the early 1990ies. And yet, there are US studies on ancillary benefits which are very close to our results. Estimates (as a multiple of primary benefits) are between 0.07 and 6.67 in Pearce's overview. Considering such comparisons of studies is of course a questionable issue since almost all studies reveal to different kinds of ancillary benefits, different geographical regions and use different models of costs. We think it should be to the reader which modelling he believes to be adequate. And we share the view that ancillary benefits are an important category of benefits but it is likely to be much more important to developing and transformation countries than for the UK.

A Appendix

Define the following variables

Y_0 = Level of economic activity (e.g. as measured by GDP in \$BN.),

Y_1 = Reduction of level of ancillary emissions from a no control level (000 MT),

Y_2 = Reduction of level of GHG emissions from a no control level (000 MT),

P_0 = Price of output (=1 since only relative prices are of interest here, in \$BN.),

P_1 = "Price" of ancillary emissions, based on marginal damages (\$BN/000 MT),

P_2 = Price of GHG emissions (\$BN/000 MT, based on targets set by international agreements).

From the producer's perspective what matters is the reduction in emissions he is required to make, always measured of course from the maximum desired emissions. From a consumer's perspective, however, what matters is the difference between maximum emissions and the reductions. The present formulation allows both these perspectives to be represented.

In a world before climate change was an issue $P_2 = 0$ and the country obtained the solution values

$$Y_{0*}, Y_{1*}, Y_{2*}$$

as determined by

$$\max \quad Y_0 + P_1 Y_1 \tag{1}$$

$$\text{s.t.} \quad Y_0 = F(Y_1, Y_2). \tag{2}$$

In other words, emissions allow production and the lower the level of emissions the lower will be production. Of course other inputs are also needed but we can hold these constant for the time being. We can assume this production function has the usual properties of concavity.

In the post climate change world the country seeks to solve the following problem:

$$\max \quad Y_0 + P_1 Y_1 + P_2 Y_2 \tag{3}$$

$$\text{s.t.} \quad Y_0 = F(Y_1, Y_2). \tag{4}$$

The new solution is given by

$$Y_{0+}, Y_{1+}, Y_{2+}.$$

The following points may be observed:

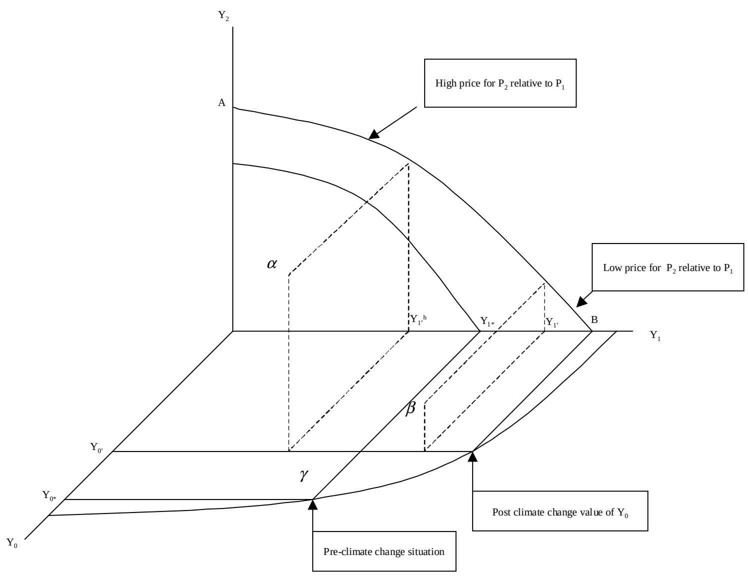

Figure 1: Emissions and Output

- We would expect $Y_{2+} > Y_{2*}$. Emissions of GHG should decline as the price rises. But we cannot guarantee that $Y_{1+} > Y_{1*}$. This will depend on how strongly complementary ancillary and GHG emissions are.

- Assuming $Y_{1+} > Y_{1*}$ we can formally define ancillary benefits as:

$$\bar{P}(Y_{1+} - Y_{1*}) \tag{5}$$

  Note, $\bar{P}_1$ may be different from P_1. As we go from one solution to another marginal damages from ancillary emissions may change.

- The true cost of the GHG mitigation policy is:

$$Y_{0*} - Y_{0+} - P_1.(Y_{1+} - Y_{1*}). \tag{6}$$

Figure 1 shows the solutions diagrammatically. The pre-climate change equilibrium is at γ, with $Y_{2*} = 0$. In the post-climate change situation P_2 becomes positive. Suppose further that Y_{0+} is as shown. Then the trade off between Y_1 and Y_2 is given by AB. If the price of Y_2 is relatively high the new equilibrium will be at α, with less reduction of Y_1. If the price is relatively low the new equilibrium will be at β, with a greater reduction in Y_1. It depends on how much Y_1 and Y_2 are substitutes or complements.

In general we would expect Y_1 and Y_2 to be complements, in which case the new solution has a greater reduction in Y_1. This will be the case, for example, when Y_1 consists of fossil fuel emissions. But it may not be the case when Y_1 represents land use. Reductions in GHG gases may require an increase in the use of land making these two factors substitutes.

In order to obtain some numerical values, let us consider a simple macro level model, which assumes that the 'production function' in equation (1) is of the is of the Cobb-Douglas form

$$Y_0 = A.(\bar{Y}_1 - Y_1)^{\alpha}(\bar{Y}_2 - Y_2)^{\beta} \tag{7}$$

$A > 0$, $\alpha > 0$, $\beta > 0$, and $\bar{Y}_1$, $\bar{Y}_2$ are the maximum (no control) values of ancillary emissions and GHG emissions. Note that $\bar{Y}_i \geq Y_i$, $i = 1, 2$. This means that corner solutions must be investigated.

The optimal level of output for the problem defined by (3) and (4) is given by

$$Y_{0+} = K.P_1^{(-\alpha/(1-\alpha-\beta))}P_2^{(-\beta/(1-\alpha-\beta))}, \tag{8}$$

where K is

$$K \equiv (A\alpha^{\alpha}\beta^{\beta})^{(1/(1-\alpha-\beta))}, \tag{9}$$

and the corresponding values of Y_{1+} and Y_{2+} are given by

$$Y_{1+} = \bar{Y}_1 - \alpha Y_{0+}/P_1, \tag{10}$$

$$Y_{2+} = \bar{Y}_2 - \alpha Y_{0+}/P_2. \tag{11}$$

The model can be calibrated using the following data for the UK.[12]

Y_{0+} = Output of economic activity with climate change policy ($1442 BN in 1999).[13]

$\bar{Y}_1$ = Maximum ancillary emissions, taken as the sum of SO_2, NO_X, and $VOCs$ in 1990. It is assumed that these are fifty percent higher than current emissions, which are 6092 thousand metric tons. In other words pre GHG policy had reduced emissions by 50 percent, making the 1990 emissions level equal to 9200 thousand metric tons.

P_1 = Price of ancillary emissions. Estimates of damages are in the neighborhood of 4 percent of GDP, which would amount to $9500/MT, or $BN 0.0095 per thousand tons.

P_2 = Price of CO_2 emissions. As a rough guide these are taken as $10/MT, based on IPCC 2001 studies of mitigation costs to meet plausible targets.

[12] Data on emissions are taken from WRI (2000).

[13] The model is calibrated with the 1999 level as optimal GDP. Of course in reality this is not the optimal level, but it does not matter much, as it is the variations in GDP we are interested in and choosing this value for calibration makes only a minor difference to the results.

Y_{1+} = Optimal reduction of level of ancillary emissions from a no control level. This reduction is not known and has to be determined from the model or different values tried.

$\bar{Y}_2$ = GHG emissions without controls, taken as 1990 level of 563,281 thousand tons of CO_2.

Y_{2+} = Reduction of level of GHG emissions from a no-control level of GHGs (000 MT). This is to be determined within the model or different values tried.

In the model, if we knew the values of α and β from independent sources, we could use them to determine the optimal reduction in GHG emissions. It would be with a price of \$10/MT of CO_2 and the optimal reduction in ancillary emissions with a price of \$9500/MT. At present we do not know these parameters. Hence we can look at the implications of different levels of reductions in GHG gases and ancillary emissions being the optimal ones. If we assume we know Y_{1+} and Y_{2+} we can calculate the value of α from (10) and that of β from (11).

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(liii) This paper was circulated at the International Conference on “Climate Policy – Do We Need a New Approach?”, jointly organised by Fondazione Eni Enrico Mattei, Stanford University and Venice International University, Isola di San Servolo, Venice, September 6-8, 2001

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