Mitigating Factors:
Assessing the Costs of Reducing GHG Emissions

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Summmary

The debate over the costs of GHG emission reduction has become more complex recently as disagreements over the existence of economic and environmental double dividents have been added to discussions over the existence of a negative cost potential. We argue that basic assumptions about economic efficiency, the (sub-)optimality of the baseline and the rate of technical change are more important than model structure, and we underline the importance of the timing of decisions for determining the costs. Moreover the use of a single baseline ‘no policy’ scenario and several policy intervention scenarios may be fundamentally misleading in the longer term simply because the very idea of a business as usual scenario is deeply problematic. Ultimately the debate turns on political judgments about the desirability of alternative development paths.

Keywords

Introduction

Until recently, most analysis of the economics of climate change has focused on the costs of reducing GHG emissions below what they could be expected to be in the absence of climate policies. Given the difficulties involved in estimating the benefits of mitigation (i.e. the costs of the expected impacts of climate change), there were few attempts to provide an explicit cost-benefit comparison (Nordhaus, 1991; Cline, 1992), until the recent wave of integrated assessment models. Instead, the tendency has been to estimate the mitigation costs of reaching particular emission targets. This amounted to asking the question: do the costs of climate mitigation policies exceed a reasonable willingness to pay to prevent possibly important but uncertain damages? Even this narrower question, however, gives rise to a set of issues and a range of answers which make it difficult to draw unambiguous lessons for policy making. On the one hand, policy makers ask for clear-cut answers to such questions as the economic impacts of a particular carbon tax, preferably in a simple form, such as the aggregated loss of GDP. To this request, analysts typically reply with a range of heavily qualified and sometimes contradictory answers. On the other hand, when apparently clear-cut results do exist, but they are contrary to what is expected or politically palatable, policymakers often point out the many valid reasons for doubting the capacity of economic models to provide reliable predictions. Analysts respond by complaining about the ‘political (mis)use’ of their results. Both sides remain sceptical of each other.[1]

In this context, it is instructive to examine the summary for policy makers of Working Group III (WGIII) of the IPCC, which states that, for OECD countries:

“Although it is difficult to generalize, top-down analyses suggest that the costs of substantial reductions below 1990 levels could be as high as several percent of GDP. In the specific case of stabilizing emissions at 1990 levels, most studies estimate that annual costs in the range of -0.5 percent of GDP (equivalent to a gain of about $60 billion in total for OECD countries at today’s GDP lev-

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[1] For discussion of the sometimes vexed relationship between energy modellers and energy policy makers, see Robinson (1992).

els) to 2 percent of GDP (equivalent to a loss of about $240 billion) could be reached over the next several decades. However, studies also show that appropriate timing of abatement measures and the availability of low-cost alternatives may substantially reduce the size of the overall bill.

Such a statement may seem cautious and vague and may therefore reinforce doubts about the capacity of economic modelling to contribute usefully to policy debates. It is important to remember however that the rules of the IPCC require that the text of the summary for policy makers (unlike the text of the underlying report) has to be approved line by line by the general assembly in consultation with the relevant writing teams. In other words, the text of the policy makers' summary represents a combined product of both the research and policy communities. And this process of creating a combined text was in turn based upon an underlying process whereby a large team of analysts coming from many different countries, and representing a wide spectrum of viewpoints, was required to exchange views and attempt to reach consensus. Perhaps the most interesting result is that instead of claiming to provide the "right" answer in separate contexts (reviews, workshops, reports for national and international organizations, etc), these analysts recognized as a group that various views were scientifically legitimate and that the range of disagreement can be explained and is meaningful for policy making.

In the spirit of IPCC, and of avoiding either uncritical acceptance or total distrust of current analyses of emission reduction costs, we will argue in this article that the diversity of results in costing studies can itself help us to understand better the policy parameters apt to affect the magnitude of costs for meeting a given abatement target. In this context we will discuss the reasons for the variance in published costing estimates. We will then discuss the limitations of existing costing studies with respect to their ability to address underlying issues about alternative social and technological development paths. Finally we will discuss the implications of the view expressed in the IPCC WGIII report that the timing of actions is in fact the most critical policy parameter and reach some general conclusions about the value of costing analyses, their lessons for climate policy, and the possible directions of future research. In so doing, we will argue that addressing these issues will require not only technical advances but also a change in the questions posed to economic modelling and in the framing of decision-making.

I. The basis for differences in cost estimates

The wide range in published estimates of GHG mitigation costs over the past decade or so, masks the emergence of some important policy-relevant conclusions that cut across the different results reported in the literature. In an attempt to cut through some of the underbrush, we begin by outlining a simple taxonomy of costs.

I.1. A taxonomy of costing concepts

There are a number of different cost categories used in the GHG mitigation literature, which are sometimes confused with each other. They can be grouped into four broad categories:

The two first cost concepts are used to analyze the technical 'margins of freedom' of particular policy options. The direct engineering and financial costs of specific technical measures represent the life-cycle cost of the technology or project in question (i.e. the initial cost of the measures considered plus annual energy and operating costs, all reduced to a net present value or levelized cost). In turn, these costs can be used, at a somewhat more general level, as input data in sectoral models that compare the relative sectoral costs of different emission scenarios in ‘a partial equilibrium’ analysis**.** Such analysis is broader than an analysis only of direct costs but does not capture the feedbacks between the behaviour of a sector and that of the overall economy.

At a more general level still, estimates of macroeconomic costs try to account for the interrelationships between a specific sector and the overall economy in terms of variation of the level of the gross domestic product (GDP). Such analyses capture the general equilibrium effects of climate policies, though often at the expense of the kind of detail represented in engineering cost studies. Most macroeconomic analysis, however, does not encompass the full welfare costs of mitigation policies, since welfare is not equivalent to GDP, for a number of well-known reasons.[2] Some studies calculate welfare costs as the

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[2] First, changes in the relative share of investment and consumption can change welfare without changing GDP levels. Second, differences in patterns of income distribution can clearly affect welfare, though they may not change GDP. Third, human welfare does not increase linearly with

variation in welfare at the margin of a given equilibrium but they do not capture variations in welfare caused by large modifications in development patterns and they tend to assume the separability of the utility of environmental quality from that of other goods and services, an assumption which does not hold for the relationship between climate and economic growth over the long-term. We return to this issue in the last section of this paper.

Though rather simple, this taxonomy helps to explain why the debate over the costs of GHG mitigation has become more complex over the past several years. In the early 1990s, as pointed out by Edmonds and Grubb , the debate was dominated by the opposition between what they called the engineers' optimism and economists' pessimism, over the magnitude of the potential for 'no-regrets' policies, that is GHG mitigation measures (mainly concerned with energy efficiency improvements) which are economic whether or not climate change occurs (ie they are 'worth doing anyway' (Robinson *et al.* 1993)). This first generation of studies focused on 'no regrets' measures based on the existence of a negative cost potential (emission reductions caused by technologies whose costs are lower than the technologies currently in use). More recently, increasing attention has been paid to 'no regrets' measures that reflect an environmental double dividend (the additional benefit of GHG emission reduction strategies which mitigate other environmental problems such as SO_2 emissions, urban congestion or land degradation), or an economic double dividend (positive effects on growth or employment of the recycling of carbon tax revenues or of the technological externalities of R&D programs).

The wider set of issues associated with these two latter sources of 'no regrets' potential has broadened the debate, and controversy about the existence and magnitude of these positive side-effects has blurred the original division line between different types of costing studies. The original difference between studies that were optimistic or pessimistic regarding the technological potential for emissions reduction has therefore been complicated by a separate difference between studies that are optimistic or pessimistic on the existence of positive side effects. Since these two sorts of optimism/pessimism are in principle independent, the resultant situation can be represented as in Table 1. Some studies which are rather conservative as regards to technical flexibilities

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consumption. Fourth, spending money on disaster relief or environmental rehabilitation enhances economic growth without increasing welfare.

but are optimistic about the double dividend of, say, recycling the revenues of a carbon tax, may produce cost figures lower than a technologically optimistic study which neglects this latter side effect. To put it in another way, part of the current debate is about the magnitude of gross costs of climate policies (ie the sum of the costs of implementing carbon saving technologies, including any negative cost potential) but another part is about the gap between these gross costs and the net costs (i.e. gross costs plus side effects in the form of double dividends).

		Technical Costs	
		optimists	pessimists
Double Dividends	optimists	O/O	O/P
	pessimists	P/O	P/P

Table I. ***Division Lines in Assessing Costs of Climate Policies***

We turn now to the arguments behind each of these alternative views and their policy implications.

I.2. Technology dynamics, consumption behaviour and economic incentives

I.2.1. The efficiency gap

Historically, debates about energy efficiency have been framed by the distinction between top-down and bottom-up analysis. The terms top-down and bottom-up suggest a distinction between aggregate and disaggregated models. They are probably somewhat misleading in that the differences between these approaches lie less in the level of disaggregation *per se* than in the type of disaggregation: many top-down models, for example, account for economic activities at a two digit SIC level and can break down consumer demand into many household types, which allows for testing the income distribution effects of policies. The actual gap between both approaches comes from the way technology and consumer demand are represented. In top-down models, individual household or industrial demand functions allocate demand among a very limited number of commodity groups. Energy is then grouped into no more than two or three commodities. Bottom-up models, on the other hand, rely on detailed analysis of end-use energy services, focus on the integration of technology costs and performance data and try to ascertain the magnitude of the 'efficiency gap' between the best available technologies and the equipment actually in use.

The most fundamental controversy underlying this debate between modeling approaches is about the size and meaning of this efficiency gap. Bottom-up studies tend to find that a substantial efficiency gap exists and therefore that there exists a potential for achieving substantial emission reductions with a negative cost. In other words, they suggest that market forces do not operate perfectly. The policy implication is that a 'no regrets' climate strategy could be pursued by removing the barriers to adoption of the most efficient end-use equipment: imperfect information, financing systems that impose investment criteria that differ from the social time preference of consumers and the opportunity costs of capital, imperfections in the energy market such as the well-known tenant-landlord relationship, etc.

In response, the professional reflex of many economists has been to suggest that this apparent 'efficiency gap' may not be real. The argument is that bottom-up analysis may be too focussed on energy issues and that many reasons other than energy market failures explain why consumers may not adopt technologies which could in principle minimize the costs of providing a given amount of energy service. The apparent market failures described by bottom-up modellers could be explained in terms of two other factors: (1) the complexity and heterogeneity of consumer preferences (e.g. the extra satisfaction that a consumer derives from using her private car even when the cost per km is higher than in using public transport), and (2) hidden costs such as the costs of better information about technology options or the perceived risks associated with the capital costs of a technology. When these factors are taken into account, the actual efficiency gap may be much smaller than estimated by bottom-up analysis, or even non-existent. Moreover, it may or may not be economically efficient to close any remaining efficiency gap, depending upon the transaction costs of removing market imperfections. The net result of all these considerations is to offset the apparent negative cost potential revealed in bottom-up analyses (Jaffe and Stavins 1994).[3]

- This view is supported by many top-down modellers who suggest that this complex set of behavioural factors is captured in price and income elasticities emerging from econometric regressions of historical data sets. These data record actual behaviour and incorporate *de facto* all tangible and intangible costs including differences in consumer surplus. It is argued that such data provide support to the intuition that intangible costs may explain why actual flexibility in production and consumption systems are lower than those postulated in bottom-up analysis.

But this interpretation of the historical record is not the only one possible. If it is instead correct that markets do not behave perfectly, as bottom-up analysts argue, then econometric relationships simply register the consequences of these imperfections and provide no information about the share of the efficiency gap that could be tapped through removing market barriers. Moreover, the other factors introduced by top-down analysts to explain why any apparent efficiency gap is not achieved may themselves be subject to change through innovation (e.g. new products that meet consumer preferences in new ways) or changes in consumer behaviour (e.g. driven by increased environmental concern).

The new generation of bottom-up analyses, based on the now extensive literature on energy efficiency programs and the behavioural dimensions of energy use, explicitly incorporates decision making behaviour and tries to incorporate the results of market research about consumer preferences and about the administrative costs of public policy. The result has been to increase the estimated cost of mitigation measures but such studies still show considerable potential for cost-effective energy efficiency improvements, given appropriate incentive policies and market reforms.

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[3] In response, a bottom-up analyst might suggest that postulating such hidden costs and transaction costs amounts to an attempt to reconcile observed market failures with theories of rational choice, rather than a demonstration that those market failures are socially efficient.

The effect of recent analysis has thus been to expose more clearly the basis of the differences between top-down and bottom-up approaches. The main point is that differences in results are driven less by differences in model structure than by differences in input assumptions about the way the economy functions, the relative efficiency of energy markets, and the costs of improving the efficiency of these markets.

I.2.2. The representation of technological change

In the longer term, we need to consider not only the adoption of existing technologies but the role of innovation and technological change. In this connection, a critical factor affecting the costs of GHG mitigation is the linkage between economic incentives and technological change in a given institutional context. The level and type of incentives needed to achieve a given level of mitigation will determine not only the nature of the policy response but also the sign and magnitude of the feedbacks to the overall economy. For example, if one assumes very efficient policy signals, then the side effects of climate policies will be modest.

From the top-down perspective, it is difficult to establish explicit links between production functions in economic models and trends in technology on the other. Since it focuses on financial flows across the whole economy, macro economic analysis cannot easily address the specific determinants of technological change. Instead, it captures technology at an aggregate level, in the form of cost functions (which allocate the sales revenue among the cost of intermediary inputs, wages and returns to capital) and expenditure functions (indirect consumer utility functions). Moreover, econometrically-driven models consider only price effects and do not explicitly capture non-price signals and potential reforms in energy markets. Finally, econometric relationships are calibrated on historical experience, where energy price changes were in the form of price shocks. This experience may not be very useful for explaining the effects of less abrupt and discontinuous policy measures intended to induce energy saving technological change.

On the other side, bottom-up approaches, which describe technology directly, can easily incorporate technological innovation. However, bottom-up analyses do not capture the macroeconomic feedbacks and linkages described in top-down analysis since they focus at a different level of analysis altogether. The new generation of bottom-up analysis described above does begin to link behavioural and technical analysis but still at a fairly micro level.

There is as yet little experience in combining these two approaches in fully interactive modelling analyses. Hybrid models which couple bottom-up and top-down modules typically make use of exogenous and *ad hoc* input assumptions upstream from the macroeconomic module; but these models can then confront unsolved internal consistency problems when large departures from business as usual trends are to be considered.

Put another way, both bottom-up and top-down descriptions of technology and the causes of technological change make sense but each captures a different aspect of that change. If these translation difficulties are clearly understood, it becomes clear that there is no *a priori* reason that the two modelling approaches will give different results. Whether they do or not depends largely on their respective input assumptions.

The potential for similar results can be exemplified by considering top-down models which account for technological changes via two parameters: (1) the autonomous energy efficiency index (AEEI), and (2) the elasticity of substitution between the aggregate inputs to household and firms. AEEI is a function of time (a proxy for all the reasons why some energy efficiency improvements will be embedded in technological trends) and suggests the rate at which the penetration of new technologies may change the energy intensity of the economy. The elasticity of substitution is a function of the relative prices of inputs, and allows measurement of the degree to which capital or labour can be substituted for energy as energy prices rise relative to these other inputs. The values of AEEI and elasticity of substitution can be adjusted to provide results that match those frequently suggested by bottom-up modellers. Thus a relatively high value for AEEI, say a 2% decline per year, and a relatively high value for the elasticity of substitution between fossil fuels and other factors of production (labour, capital), could lead top-down simulation results in which the cost of carbon emission stabilization, and even a 15-30% reduction, were below or close to zero.

On the supply-side, top-down modellers can resort to optimistic views about the future costs of carbon-free ‘backstop’ technologies, which would have the effect of producing low or negligible costs in the very long-run, as in the integrated top-down low emission supply system (LESS) analysis carried out for Working Group II of IPCC (Edmonds *et al*, 1994).

In a similar way, the new generation of bottom-up models that incorporate explicit treatment of behavioural and implementation factors could adjust these factors so as to significantly increase the overall cost of mitigation measures, bringing them closer to typical top-down results. Or the cost of new energy supply technologies in the long-term could be increased. The point is that the results are driven less by the differences in models structure than by the differences in input assumptions about the way the economy functions.

In fact, the difference between top-down and bottom-up baseline results has narrowed considerably over the past 15 years, as illustrated, for example in the difference between the reviews of Caputo (1984) and Grubb *et al.* (1993). In general, top-down forecasts of future energy demand have dropped considerably, while bottom-up projections have increased somewhat less. But important differences remain and it seems clear that the future research agenda will need to address the gap between these two complementary approaches to describing technological change. In this connection, it is likely that an important issue will be the role of expectations and incentives in inducing technological innovation, and how this can best be represented in a modelling framework.

So far, both top-down and bottom-up models describe technical progress by means of purely exogenous assumptions. This means that, in the models, the cost of technological change is independent of the level of abatement and of prices. This of course is misleading. On the one hand, it is unlikely that learning by doing and the increasing returns to innovation pointed out in the literature on technological change would have no impact on the costs of carbon-saving technology. On the other hand, it is also inappropriate to interpret the results of the more optimistic scenarios as suggesting that R&D programs will induce a costless and effortless trickle-down of carbon- saving technology.

I.3. Analyzing side-effects: the economic double dividend

Much of the concern over the macroeconomic implications of climate policies has been driven by the observation that the level of carbon tax needed to reduce CO_2 emissions significantly is such that they would induce important price distortions and changes in investment structure. Because it is inconsistent to treat such a carbon tax without internal recycling of the tax revenues, different studies made different assumptions about how the tax revenue would be recycled. Many empirical models explored the hypothesis of a lump-sum recycling while others, mostly in Europe, assumed targeted recycling policies aiming at decreasing payroll taxes, income taxes or corporate taxes (the choice usually depending on the internal context and the overall fiscal policy of the country in question). This was the case for example for the QUEST simulations by the European Commission or for national studies in most of the European countries such as Germany, France, and the K.

On the theoretical side, analysis by Bovenberg and Van der Mooij (1994) and Goulder (1994) explored more systematically the conditions under which a double dividend was likely to occur. Without entering into the details of this discussion, we can say that a double dividend occurs when the marginal distortionary effect of a carbon tax is lower than the distortionary effect of the taxes for which it is substituted and when the amount of overall fiscal burden remains constant.[4] An important point is that the existence of these conditions depends on parameters far beyond the energy field:

- *preexisting energy tax levels* The difficulty here is that the distortionary effect of these taxes cannot be directly derived from their observed level. If energy taxes are seen primarily as a way to increase government revenues, then the marginal cost of a carbon tax will be high (increasing as the square of the tax); and if conversely energy taxes are viewed as a way to internalize environmental costs and congestion costs or to fund the maintenance of transport infrastructure, the welfare costs of pre-existing taxes will be considered low (or even negative if total external costs are higher than tax revenues).
- *the organization, content and funding of the welfare system* Many European countries finance not only their public administration system but also their health system, social security and teaching system by raising funds from taxes levied directly or indirectly on wages: the resulting difference between the labour cost and the net wage for the employee may be a cause of structural unemployment. The fiscal system is very

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[4] Without this constancy hypothesis, the double-dividend may turn into an incremental burden if the average efficiency of public investments is lower than the efficiency of private investments.

different in the USA and in Japan as a practical translation of different views of social organization.[5] This can significantly alter the potential for a double dividend from a carbon tax.

- *the pre-existing level of unemployment and the functioning of the labour market* Although most Keynesian models are 'pessimistic' with regard to responses to changes in prices and technology, they often suggest a short- and medium-term positive effect on employment and growth from recycling a carbon tax through lowering payroll taxes (high enough to more than offset the cost of mitigation). As unemployment decreases this effect disappears and the double dividend vanishes. This also explains why GCE models which assume perfect functioning of the labour market tend to suggest that there are positive net costs of a carbon tax (even if this net cost is generally low in these models because they assume generally higher technological flexibility).[6]

Another determinant of the double dividend over the long run is the labour, capital and material intensity of technical change and the impact of energy saving technological innovation on overall productivity *(productivité globale des facteurs)*. One interpretation is that of Jorgenson (1984) and Hogen and Jorgenson (1990) who find a negative correlation between energy prices in the US economy and technological change (in terms of global productivity). However, this result seems inconsistent both with the parallel observation that, historically, higher prices also lead to accelerated technological innovation which embodies increased energy efficiency, and with the results of cross-sectional analysis which suggest that high levels of industrial competitiveness are correlated, at least in part, with energy efficiency since energy efficient processes tend to be underpinned by better control systems and a more efficient use of material flows. The reason for this apparent inconsistency is that global productivity is correlated with many other factors than the characteristics of technology. Reductions in overall demand or growing uncertainties, due for exam-

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[5] For a provocative analysis, see Krugman (1994).

[6] In other words, Keynesian models correspond to the O/P quadrant of Table 1, while GCE models correspond to quadrant P/O. In this case the double dividend optimism of the Keynesian models more than offsets their technical costs pessimism, while the double dividend pessimism of the CGEs more than offsets their (relative) technical costs optimism. However, a greater gap exists between those analyses that are pessimistic, and those that are optimistic, on both fronts.

ple to oil shocks, can result in a lower level of productivity even if the technical efficiency of energy-using equipment is increasing.

Generally modelling exercises capture price induced technical change as the movement of a combination of factors along the frontier of a given production function; they do not capture the changes in the coefficient of this function at given point in time induced by long-term price signals. However, it is unlikely that significant price signals will bias technical progress in the energy field without any impact on the shape of the production functions. Two questions are critical at this level: what will be the capital intensity of such a change, and to what extent a shift towards more labor-intensive technology is required by more energy saving technology?

The result of these factors is that analysis of the potential for an economic double dividend turns in part on what is the appropriate description of micro-economic behaviour. In order to address the economic double dividend issue, we need to understand better the interplay between parameters such as changes in the use of equipment, changes in the structure of final demand in the direction of less energy-intensive goods, variation of the level of risk taken by an entrepreneur when employing a worker due to changes in labour market regulations etc. All such factors will affect the substitution between energy and labor, even without any change in the characteristics of the production technique itself. Further progress in knowledge can be achieved only through a more detailed description of labor markets (does a decrease of payroll taxes lower the labor cost or is it transformed into an increase in net wages? What is the role of informal and "black" economies?) and of the employment decisions of entrepreneurs in an uncertain market (do variations in final demand increase the risks of an employment decision when the wedge between labor costs and net wages is high?). An important issue is whether climate policies are apt to reduce the level of uncertainty an entrepreneur has to cope with or, on the contrary, will these policies induce such uncertainty that the overall effect may be a decrease in productivity.

I.4. 4. The Suboptimality of the Baseline

The methodological and technical differences discussed above reflect different views about the efficiency of energy markets (size of short-term 'no-regrets' potentials, induced technical change), the degree of distortions due to preexisting fiscal systems, and the existence and meaning of distortions in labour markets. These differences result, at least in part, from policy and value judgments about each of these parameters. A useful way to summarize these differences is in terms of how they are conveyed in the definition of the baseline scenario constructed for costing analyses. The interpretation of the baseline scenario directly influences the way the 'no regrets' issue, which is of direct relevance for short-term policy decisions, is conceived.

The linkages between the discussion of ‘no regret strategies’ and the choice of’the baseline can be summarized in very simple graphical form. (see Figure 1). Let curve *F(Q,E)* representing the theoretical production frontier which represents the trade off between economic activity *(Q)* and emission reduction *(E)*. For a given economy at a given time, each point on this curve shows the maximum size of the economy for each level of emission reduction; put another way, it shows the maximum emission reduction for each level of economic activity. From the point of view of cost analysis, a key consideration is what is assumed about the location of the reference or baseline scenario with respects to this curve.

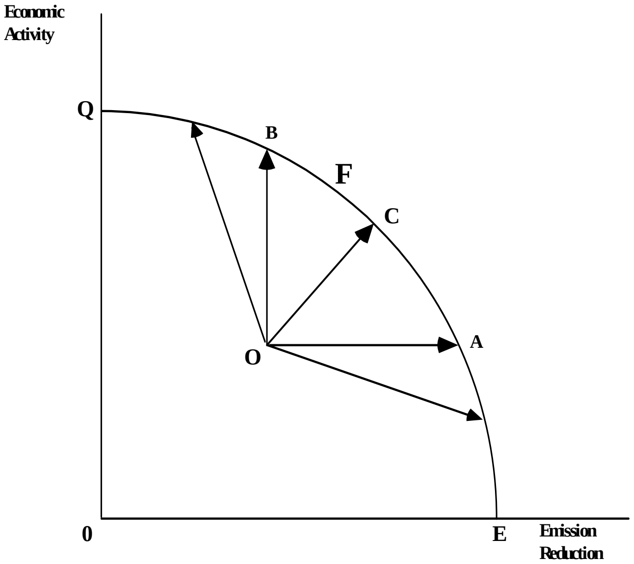

Figure I. ***Relationship between economic activity and emission reductions***

If the baseline scenario assumes the economy to be located somewhere on the production frontier (*curve F*), it is clear that there is a direct trade off between economic activity and the level of emissions. In effect, all increases in emission reduction (moving down the surface of the curve to the right) will decrease economic activity (ie increase costs). That is, there is no potential for 'no regrets'. Moving up to the left on the curve will increase economic activity but also increase emissions. In such a context, an appropriate policy mix can minimize the net cost of lower emissions but can never offset it totally (Goulder, 1994).[7] Conversely, in a baseline scenario which describes an economy below the production frontier represented by curve *F*, 'no regrets' strategies are possible. Under these conditions, emissions can be reduced without reducing the size of the economy (ie without increasing overall costs) and, possibly can enhance economic activity.[8]

The critical question is then whether the reference or baseline scenario to which emission reduction scenarios are compared is on this frontier or not. Assuming that some 'no regrets' potential exists implicitly suggests that any baseline scenario is below the frontier and that appropriate policies would move the economy up towards that frontier. In this sense the economic debate is as much about the location and characteristics of the baseline scenarios as it is about the nature and costs of specific emission reduction measures. If the economy is not on the production frontier, then it should be possible to move from *O* to a point *C* between *A* and *B* by using the surplus derived from removing market imperfections to increase both economic product and emissions reductions.

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[7] Goulder, L.H. (1994) "Environmental Taxation and the Double Dividend: A Reader's Guide". 50th congress of the International Institute of Public Finance, Session I "Green Taxes and the Rest of the Tax System", Harvard University, 22-25 August 1994, 35 p.

[8] Of course it would also be possible to move from O to a point above and to the left of point B, thus increasing economic growth and also increasing emissions; this means that the economic surplus gained thanks to the removal of inefficiencies (*i.e.* moving from O to curve F) will be devoted to improving environmental quality only if there is a collective preference and political will to do so. It could also be possible to move to a point below and to the right of A (reducing both emissions and economic activity) if the surplus is devoted to very high investments with a low return and a very low efficiency in terms of environmental quality improvement. This could occur in the case of misallocation of efforts for a given level of concern for environmental quality.

The situation is of course complicated by the facts that, on the one hand, the production frontier is itself not static but changes over time,[9] and, on the other, that the existence of market and institutional failures that give rise to a ‘no regrets’ potential is a necessary but not sufficient condition of the development of strategies to realize that potential. Achieving the potential also depends on the existence of significant political desire to reduce emissions, and the availability of strategies that cost less to implement than the savings they create by eliminating market and institutional failures. Moreover, in many fields of public policy making, countries will consider climate policies in a multi-objective decision-making framework, whereby GHG emission reduction policies are likely to be a by-product or joint product of policies developed primarily for other reasons. The result is that, in practice, the methodological and technical debate over the existence of 'no regrets' potential is overshadowed by other factors of perhaps more immediate relevance to decision making. However, this does not prevent that debate from being used strategically by various interest groups or stakeholders to advance their views.[10]

II. Beyond the efficiency gap: the multiplicity of baselines

We have focused so far on the relationship between the costing of climate policies and the various types of suboptimality that may be embedded in the baseline scenarios. This is the critical issue in assessing GHG mitigation costs over the short and medium term. Over the long term, however, the focus changes and more emphasis needs to be placed on the question of the structural content of the long term baseline scenario and its predictability. The nature of that baseline may be much more important in determining GHG emissions than any energy policy measures, and different assumptions about the baseline will alter mitigation costs in a fundamental way.

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[9] In fact, much of the debate over this issue arises because more optimistic assessments of emission reduction potential implicitly compare the present state of the economy to some possible future production frontier, assuming technological change that moves the frontier outward over time.

[10] For an extensive discussion of the ‘strategic’ use in the policy arena of energy demand forecasts in several industrialized countries, see Baumgartner and Midttun (1987).

Let us begin with a rather trite observation: GHG emissions over the long run depend not only on the rate of economic growth measured in dollars, yen, pounds, deutschmarks or francs but also on the material content of the consumption or production activities behind this economic growth. Experience to date shows to what extent that countries with rather similar income levels may have very different levels of energy consumption per capita or transportation requirements. While part of these differences is due to factors such as climate and geography, comparative studies (Martin 1992, Darmstadter *et al.* 1977) also suggest the importance of underlying development patterns. Five main determinants seem to be at work at this level:

technological patterns (overall consistency of technological systems in energy, transport, construction, agriculture);

consumption styles (housing patterns, leisure, durability and rate of obsolescence of goods, distribution of income);

- the geographical distribution of activities within a given area (human settlements, nature of urban forms);
- structural change in industry (shares of high and low energy-intensive industries and services, value added for a given material content); and

trade patterns and international specialization.

These factors are in some way captured by changes in model parameters such as the structure of household expenses, the distribution of the value added or import-export elasticities. This type of treatment however, which is convenient for analyzing economic or fiscal policies over the short term, or for developing medium-term scenarios framing sectoral planning and policies, is much less relevant for time horizons where it is less acceptable to assume continuation of the speed and direction of historical trends in the main determinants of development patterns. Three examples will illustrate the difficulties of predicting such future developments:

- A given amount of value added produced by the chemical or steel industries may correspond to very different levels of material inputs and outputs depending upon the level of sophistication of the final product. In fact, the energy intensity of many industrial processes has dropped rapidly (a process sometimes called dematerialization) over the two past decades as the information intensity of the economy has increased.

There is no way to predict today whether this trend will reach an asymptote and level off, or not.

- Trends in the share of household budgets devoted to transport express changes in mobility and transportation patterns which depend on the evolution of the density of towns; on the distance between working places, leisure areas and commercial areas; and on the supply of transportation infrastructure at the disposal of consumers. These important feedbacks within the complex relationship among policy, consumption and technology in this sector are difficult to predict.
- Developing countries could, in principle, follow a development path which 'leap-frogs' the most energy-intensive (and environmentally damaging) stages of industrialization historically passed through by western countries. The potential for such a path depends in part upon the removal of a set of constraints (indebtedness which prevents investing in capital-intensive transport infrastructures; tariff and non-tariff trade barriers; etc) and this will be a critical factor in determining global GHG emission rates after the beginning of next century.

The difficulty in predicting the evolution of development patterns over the long run stems in part from a lack of knowledge about the dynamic linkages between technical choices and consumption patterns and about their interactions with economic policies and economic signals over the long run. It also derives from more general uncertainties about political, social, religious and other factors, which in turn are linked to fundamental questions about intentionality, meaning, power, trust, credibility, social organization, etc. While many of the social sciences and humanities address these latter issues such information is not typically available in a form easy to process in a numerical model. The result is that modellers are reduced to generating alternative scenarios that express some subjective (or more formalized) judgment about how such qualitative factors might influence those variables that can be expressed in terms of the model.

Perhaps equally challenging is the difficulty posed by self-reinforcing loops among technical choices, consumer demand and the geographical distribution of activities and human settlements. Such loops give rise to a time dependence of development patterns rather similar to the one which emerges from literature on technical innovation (learning curves, economies of scale, increasing informational returns, positive network externalities) and which may result in "lock-in" effects and a resultant foreclosure of options (Arthur 1988). Resorting to Bayesian approaches to cope with the resultant uncertainty could be misleading for decision making because this is a case of 'endogenous uncertainty' where the probability of certain states of the world to occur in $t + n$ is determined by decisions in t. The point is that alternative baseline scenarios represent quite different and internally consistent patterns of development due to the long-term consequences of current decisions and current behaviours and to the collective expectation regarding time $t + n$ prevailing at time t.

In turn, these decisions, behaviours and expectations are part of a particular sequence of events, and cannot simply be combined with the components of other such sequences to produce an average or most likely sequence. Given the high research and development costs involved in a new automobile engine, it is unlikely for example that, in a no-climate-policy scenario, R&D and D risks will be incurred simultaneously on electric cars, 2l per 100km gasoline engines and biofuels engines. As in the past example of the dominance of the four-stroke example over the two-stroke engine and the promising rotary motor, the first innovation which succeeds in attracting significant R&D can preclude the development of other alternatives, however attractive they may be in principle.

These considerations strongly suggest the need to work on the basis of several baseline scenarios. These would not be simply scenarios with high, medium or low versions due to various assumptions regarding exogenous parameters such as GDP growth or oil prices, but instead would represent alternative baselines, each characterized by different assumptions about development patterns and innovation. The point is not to predict what long-term outcomes are most likely (an exercise at which few have been successful (Ascher 1978, 1990)) but to explore the economic and technological feasibility and costs associated with quite different development paths.

While there exists a history of attempts to explore unconventional energy paths, sparked in the 1970s by the arguments of Amory Lovins (1977) about 'soft energy paths', most of the GHG mitigation costing literature, of both the top-down and the bottom-up kind, has focused upon developing single baseline 'no climate policy' scenarios and several policy or intervention cases. In fact, neither approach has been effectively used to explore the issues of underlying development paths, technological change, irreversibility and bifurcations through the analysis of multiple baseline scenarios.

A strong theoretical background can be found for the study of several baseline scenarios in the works of advanced economic theory about the existence of multiple economic equilibria generated by different sets of expectations and sequences of choices. This issue has been raised by works on technological change but can also profit from insights from many other fields of economic theory and decision theory: ‘sunspot theory’ (Azariadis and Guesnerie 1986), self-fulfilling prophecies (Henshell), ‘common knowledge’ and ‘conventions’ (Lewis 1969, Dupuy, 1989), coordination games (Schelling 1960) and repeated games (Fudenberg and Tirole 1991).

The implication for the assessment of the costs of GHG mitigation is that any results are meaningful only at the margin of a given baseline scenario and that there are as many cost assessments as there are potential baselines. This would be true even if all these baselines are assumed to be on, or below, the production frontier over the long run (ie this finding is independent of relative merits of the top-down and bottom-up arguments about the efficiency of the baseline). As a result, comparing a single baseline ‘no climate policy’ scenario with several policy or intervention cases can provide only a very partial view of the matter. Bifurcations in development patterns and technological change could well generate alternative scenarios whose emission levels may differ more than the difference between a baseline scenario and its associated policy case.

It might be argued that a generalized cost-benefit analysis could in principle provide a ranking of alternative baseline scenarios. However, even if we leave aside the question of the potential qualitative incommensurability of different baselines, this would require some reliable information on several (and mutually exclusive) baskets of goods, services and techniques. More fundamentally it would require the assumption that consumers and policy-makers have a complete set of preferences with partial ordering and transitivity. This transitivity condition is likely not to be respected here because the consumer preference is not about each good in a given context (the utility attached to driving a car to go to work) but on each good for alternative states of the world (the utility attached to driving a car in many types of urban areas with various endowments of public transport).

The upshot is that bifurcations toward alternative scenarios are not at random; they are generated, generally in passing, by policy decisions and behaviours which have little or nothing to do with energy and environmental policies (urban planning, effect of advertising on consumption, etc.). This has two implications for the use of existing cost assessments in negotiations about the implementation of the Berlin mandate: (1) a baseline scenario that gives rise to lower estimates of emission reduction costs cannot be interpreted as being economically superior to other baselines (since achieving this baseline depends on policy decisions, and associated costs and benefits, that have little to do with energy or environmental policy); and (2) given the 'multi-purpose' nature of alternative baselines, it is very difficult to allocate costs so as to determine the incremental cost of reducing GHG emissions.

A simple historical example helps to illustrate that these problems are far from being simple intellectual fancies. If the climate debate had emerged in 1973, just before the decision to launch the nuclear program in France, two possible baseline scenarios could have been considered:

- the first without the nuclear program, and consequently a higher CO2 emission level; in this case the projected cost of the nuclear program could have been included in the estimated emission reduction costs; and
- the second including a nuclear program; the emission reduction requirements would have been lower, but paradoxically the costs of an incremental emission reduction of, say, 20% would be far higher.

Beyond the fact that assessing the relative costs of two totally different energy systems is technically difficult (for example in the non-nuclear case France would not have developed electrical heating to the degree it did), the critical point is that although the nuclear choice would not have been made, in practice, purely for climate-related reasons: in any negotiation, the French administration would have tended to argue the contrary so that this program would have been considered as a specific contribution to a collective climate policy.

III. Costs, timing and targets: towards a new decision making framework?

The preceding discussion may induce the feeling that, given the uncertainties about baseline scenarios and cost assessments, no guidance for policy-making can be derived from existing mitigation costing studies. We would argue, on the contrary, that a recognition of the limitations of both bottom-up and top-down approaches to estimating the long-term costs of GHG mitigation helps to frame better the decision-making problem raised by climate change. We turn now to the question of the timing of the policy response to climate change, and the implications of the arguments presented in this paper for research and policy.

Despite the differences in specific results, most cost studies suggest that the key short-term factor is the potential for ‘no regrets’ savings through increased energy efficiency. While debate continues as to the size and achievability of that potential, it is clear that improving energy efficiency is likely to be the most cost-effective strategy in the short-term.

In the longer term, the emphasis shifts to a focus on low carbon energy sources, and the structure of technological change and alternative development paths. A key issue here is the need to consider the long-term implications of ongoing decisions about infrastructure and long-lived capital stock that will affect GHG emissions for many decades. Since replacing capital stock before the end of its economic lifetime will significantly increase mitigation costs, this suggests the need to consider investment patterns carefully as that stock is turned over.

Another critical influence on mitigation costs is the expected growth in the underlying consumption activities that give rise to GHG emissions. When targets are set for levels of emissions calculated from a given benchmark year, growth in baseline emissions over time increases the gap between baseline and target emissions. The higher the rate of growth, the bigger the emission reductions that are required to meet the target. This tendency is counterbalanced if the baseline scenario embeds optimistic assumptions about the availability of new energy technologies in the long run, by incorporating some decoupling between economic growth and emissions, by assuming a high responsiveness of consumption to price and non-price signals, by including induced technical change which is biased towards low carbon-intensive techniques, or by assuming a great deal of flexibility in the system. These counter tendencies may even be high enough that costs over the long run may be lower than over the short term.

All this indicates the importance of the timing of mitigation measures. In discussing timing issues, two different insights need to be considered simultaneously:

- First, in considering the evolution of low carbon futures, there is a distinction between the transition period (the period of transition away from a carbon-intensive energy system) and the backstop period (the period after that transition is achieved). The transition period is characterized by a pre-existing capital stock and limited technological options for replacing existing technologies with carbon-free technologies. The backstop period is entered after sufficient time elapses to allow the entire capital stock to be replaced by available carbon free backstop technologies at the end of the economic life of existing equipment. Over this backstop period the cost of carbon-free technologies places an upper limit on how great the costs of reducing carbon emissions can be. Successful R&D that accelerates the availability of carbon-free technologies can reduce costs in the backstop period. Over the transition period costs are directly function of the pace of the abatement. If technological progress will significantly reduce the costs of emission reduction, then delaying such reduction until that technology is available, and capital stock is at the end of its economic lifetime, may reduce costs (Wigley *et al*, 1996).

- Second, and in the opposite direction, the inertia due to existing equipment and more fundamentally to the interplay between preference curves and infrastructure endowments would also play the role of an important cost multiplier if after a long ‘wait and see’ period, it becomes necessary to accelerate abatement (Hourcade and Chapuis 1995). Both the technical cost and welfare costs will be higher for the case of an excessively delayed action if energy-intensive investments in long-lived capital stock have been made in the meantime. For example, shifting towards a low energy-intensive transportation systems (railways and bicycles) will be far easier in a medium sized and dense town than in huge conurbations designed around the automobile.

As a result, the choice of abatement paths involves balancing the economic risks of rapid abatement now (that premature capital stock retirement will later be proved unnecessary) against the corresponding risk of delay (that more rapid reduction will then be required, necessitating premature retirement of future capital stock). Whatever position is taken on this issue, considerable effort should be expended on generating the right signals today to direct future technological innovation, on lowering transaction costs which create a barrier for no regrets measures, on implementing mitigation measures that are economic at the point of turnover of capital stock, and on the implementation of new infrastructure, especially in developing countries and economies in transition.

Perhaps the most general conclusion that can be reached by examining the methodological issues underlying GHG mitigation cost studies is that estimates of the costs of mitigation of GHGs depend critically on policy decisions, and assumptions, expectations and conjectures about social and technological developments, that have little to do with climate policy. We have tried to illustrate the nature of some of these dependencies in this paper. In this sense, the GHG mitigation issue is tied up in a set of more general issues that will heavily influence not only the costs but the very availability of mitigation measures.

This has both methodological and political implications. On the methodological side, there is a need to move to more general analyses of alternative development paths which represent alternative baseline configurations of social behaviour and technological change. Given the difficulty in predicting the future over the very long run there is a need for tools transparent enough to sustain ‘backcasting’ exercises (Robinson 1988, 1992) that explore various views in a consistent way. On the political side, it is useful to remember that a model is no more (and no less) than a communication and negotiation tool for information about possible future conditions coming from various fields of knowledge. As a result, there is a need to recognize that ultimately a political judgment will need to be made on the desirability of alternative development paths. This is a judgment that cannot be made by costing experts.

Of course mitigation costs, no matter how broadly conceived, are only one part of the picture. It is also important to consider the benefits of mitigation, that is, the costs or damages associated with climate change impacts. A truly integrated assessment of climate policy would include both the costs and benefits of mitigation in the analysis. Given the importance of the underlying methodological and substantive assumptions discussed in this paper, given the extreme instability of very long-run predictions, and considering need for a sequential decision-making framework, the purpose of such an integrated assessment should not be to determine the real cost-benefit ratio or net benefits of climate policies over the long run. Instead it should be to make explicit the competing world-views underlying the analyses and to help point out what uncertainties and what controversies really matter for climate policy decisions.

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