UNCERTAINTIES IN RESPONDING TO CLIMATE CHANGE:

on the economic value of technology policies for reducing costs and creating options.

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Abstract

The paper presents a simplified model of the form often used to project long-term emissions of carbon dioxide from energy production and use. It then considers three uncertainties in the structure and parameters of the model concerning (a) the rate of improvement in energy efficiency and its influence on energy demands, (b) the costs of environmental damage, and (c) the rate of technical progress in the development and use of technologies for abating CO_2 *emissions. The uncertainties are subject to Monte Carlo analysis to explore the expected and probable ranges of costs and benefits under different policy assumptions. It is shown that one class of policies in particular—the development of technological options—is robust under uncertainty.*

1. Introduction

The estimated costs of climate change vary over an extra-ordinary range. The survey by Tol (1999) and his own Monte Carlo simulations show estimates of the marginal damage costs to vary from a few to several hundred dollars per ton of carbon emitted. In addition, there are appreciable uncertainties about the costs of responding to climate change—the costs of developing and introducing new, non-carbon technologies, for example. Which technologies will be used, and what will their costs be? Nuclear energy? The costs and risks of this are well known. Renewable energy? This is now a widely researched and promising possibility, but it still only occupies a small share (<1%) of world energy supplies, excluding hydro electricity, and there are still a number of technical problems to be resolved, for example to reduce the costs of energy storage devices such that the 'intermittency' of the more promising forms

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renewable energy is no longer an issue. The decarbonisation of fossil fuels with the carbon being sequestered (in the form of CO_2) in deep saline aquifers or used for enhanced oil recovery or for the production of coal bed methane? Actually these are well-known and proven processes, but can they 'deliver' energy without CO_2 emissions on the scale required, and at what costs?

What we can say is that, while promising options are emerging, there is much uncertainty about the extent that we should invest in them arising from uncertainties both about climate change, and about the costs and potential of technologies themselves. Scenarios of CO_2 emissions for the next century range from some that at first rise from today's levels of roughly 6 gigatons of carbon per year, peak at around 10 gigatons, and then decline to zero by 2100, to others that continue to rise exponentially to 40 gigatons or more. The principal reasons for such huge differences lie in the assumptions of the various authors as to the rates of development of non-carbon substitutes for fossil fuels and the 'strength' of climate change policies; however, as the recent studies for the Special Report on Emissions Scenarios (SRES) for the IPCC have shown, (Nakicenovic, et al. (1998)), it is possible to defend scenarios of both high and low carbon emissions in the long-term by varying assumptions about rates of progress in non-carbon technologies.[1] The estimated costs of responding to climate change vary enormously with the buoyancy or otherwise of assumptions about progress in the development and use of non-net-carbon emitting technologies.

It is thus hard to disagree with the recent simulation study of Nordhaus and Popp (1999) on the value of scientific knowledge that the returns to reducing uncertainties about the costs of climate change, and the costs of mitigating it, are appreciable. In the case of mitigation they estimate an expected value of information that would reduce uncertainties about mitigation costs to be $26 billion with a standard error of $7 billion, this for knowing now what we would otherwise not know, without investment, for another 50 years. However, it is possible that they have understated the case for the following reason. Resolving uncertainties requires investment in research and in the development and manufacture of technological options. Without investment to explore options we will be forever locked into irresolvable 'paper arguments' over the merits and costs of this or that technology versus others, or whether or not costs will come down with scale economies and innovations in manufacturing. A merit of current energy policies in OECD countries is that such investments are in fact taking place, though on a scale which a recent report of the U.S. President's Committee of Advisers on Science and Technology (1999)argued is still too low in relation to the problem in hand. But once we start out on this path—in fact many countries already have started out on it—engineers and scientists become engaged in a dynamic process of discovery and innovation in which new possibilities are continually being opened up and costs are reduced, for example through developments in materials sciences and in new design concepts, that were previously unanticipated. We have seen this over the past 20 years in a number of technologies, for example in a range of renewable energy technologies and fuel cells. While some of these developments may lead to dead ends and failure, the possibility of an engineering-economic surprise cannot be ruled out, such that the effort to find technologies to address the climate change problem may prove to be economically beneficial even ignoring the external benefits of mitigating climate change. Alternatively we may end up with an intermediate situation, in which the non-carbon

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[1] The terms of reference of the team involved in the SRES study were to develop scenarios ignoring the

options are available but at some cost in excess of the costs of using fossil fuels. We do not know—though we do know that a diverse range of technological possibilities lies ahead if we are prepared to invest in their development.

In this paper we assess the implications of uncertainties in the costs-of-response through a simulation model of the energy sector. The costs of technological alternatives to fossil fuels are represented by an elementary learning-by-doing cost function in which the rate-of-learning parameter is uncertain. The category of technologies we focus on is renewable energy, though there are good reasons why the analysis should in future studies be extended to include other options, such as the decarbonisation of fossil fuels and carbon sequestration (Socolow (1997)). The costs of climate change are represented by a probability distribution function that reflects both the range and the distribution of possibilities found in the economic literature. We then estimate the probability distributions of the energy and external costs of three scenarios, each of which are now regularly found in the academic and official literature, and in some industry studies (see Inter-government Panel On Climate Change (1995), Nakicenovic, et al. (1998) and Kassler (1994)): (a) a fossil fuel scenario, in which future energy demands are met by fossil fuels; (b) a technology response scenario in which the non-net-carbon-emitting options, primarily renewable energy and hydrogen, are gradually substituted for fossil fuels such that they meet half of the world's energy demands by 2075; (c) as in (b) but with half the world's energy demands being met by non-net-carbon-emitting options by 2050. Comparisons of (b) and (c) with (a) give us the traditional 'with and without' cost-benefit analysis, and of (b) with (c) the option value of bringing (b) forward by 25 years. Besides comparing estimates of the mean, we also look at the effects of policies on the probability

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possibility of climate change policies beyond those in place at the time (1998-2000).

distribution of energy costs and external costs since this gives us some insight into the role of technology policies for reducing risks, or even for springing an economic surprise.

The results are necessarily exploratory given the approximations of the model. But they suggest that policies to develop technological alternatives are especially likely to be robust in the presence of uncertainties. In fact, the greater the uncertainties, the more attractive technology policies appear likely to be. They create options that would not otherwise exist, or at least bring options forward in time; reduce the costs of responding to climate change; reduce both the variance and the extreme values of the costs of climate change; require relatively modest expenditures and are thus not economically disruptive; contain the *possibility* of an economic surprise; reduce, it will be suggested in the conclusion, the size of the optimal carbon tax (or the imputed price of its regulatory alternatives) required to achieve substitution in the long-term; and for all these reasons are likely to increase the chance international agreements being reached on future policies. Even on the basis of elementary simulations it thus seems likely that the ideal policy would be one which combined technology policy to create options and reduce costs in the immediate term, accompanied or followed by a carbon tax that is less than the one that would normally follow from standard theory.

Section 2 outlines the model, Section 2 the results. Section 4 presents the conclusions and a comment on the limitations of the analysis.

2. Model Description

The distinguishing feature of the model is a learning-by-doing cost function in which the costs of the non-carbon options decline endogenously with investment; this is similar to the approach taken by Anderson and Bird (1992) and more recently by Chakravorty, et al. (1997), except that the learning curve parameter is treated as being uncertain. Otherwise, the model has a simple form. Its structure is outlined in Figure 1.[2] Consider each component in turn:

Energy Demand. We have used the form:

$$D_t / D_0 = e^{-gt} (y_t / y_0)^{a} (P_t / P_0)^{b} (N_t / N_0) \qquad (1)$$

Where D_t is the energy demand in time t, g the rate of technical progress in energy efficiency, y per capita income, P the price of energy, N population, a per capita income elasticity, and b energy price elasticity between energy price and energy demand.[3] The initial level of demand for year 2000 is 8.5 gigatons of oil equivalent energy (or 370 Exa-Joules). (In 1998 it was 8.4 gigatons, according to the *BP Amoco Statistical Review of World Energy,* 1999.)

One parameter that is the source of much uncertainty in the literature concerns the rate of growth of energy efficiency, for which estimates vary widely. So far as we know, no econometric estimates of γ have been made, though quoted values based on engineering studies of technical developments in energy efficiency to range from <0.5%/year to >1.5%/year (Grubb, et al. (1993))[4]. In the present study, we have

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[2] A more detailed description of the model is to be found in the dissertation by Papathanasiou (1998).

[3] Energy Demand forecasts for this model range from around 30 Gtoe to 75 Gtoe by year 2100. In comparison, Working Group III of the Inter-Governmental Panel on Climate Change estimates a range of 40-68 Gtoe in the energy intensive - high growth scenario and 17-36 Gtoe in the low energy - low growth scenario (IPCC, 1998). Similar trends of values and ranges are available from other sources (EIA, 1998; WEC, 1998; Nakicenovic, et al. (1998)).

[4] An important line of analysis that promises to address the problem is the recent paper presented to the 1999 meeting of the British Institute of Energy Economists by Hunt, Judge and Nimomiya, “Modelling Technical Progress: An Application to the Stochastic Trend Model to UK Energy Demand.” BIEE

treated it as an uncertain parameter with a uniform probability distribution over the interval {0.005, 0.02}.

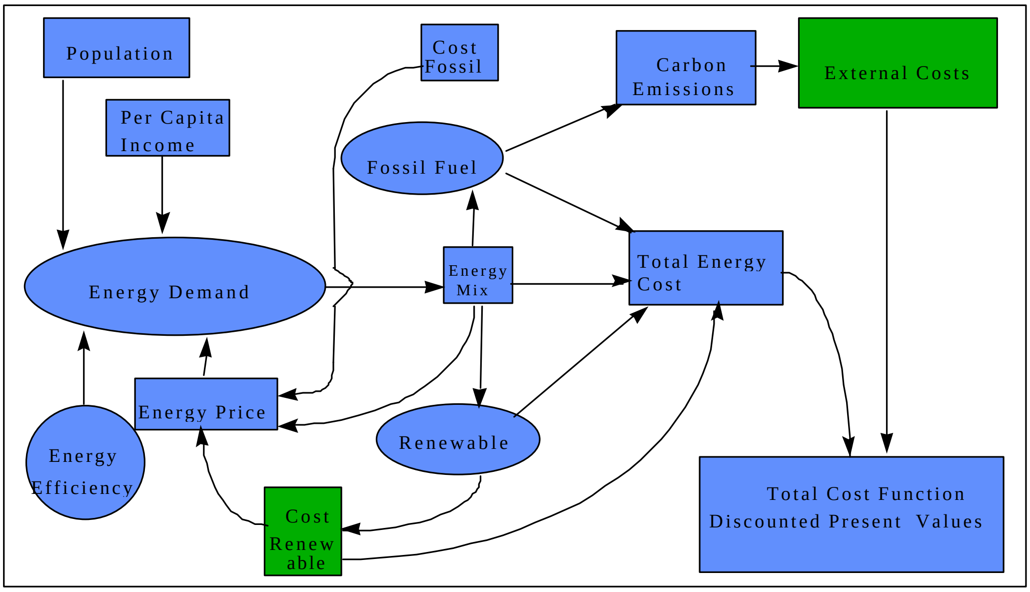

Figure 1: Flow diagram of the simulation model.

The *energy price* P_t is an endogenous variable in the model, and is a function of the costs of renewable energy (determined by a 'learning-by-doing' function, discussed below) and the costs of fossil fuels. The *price elasticity* was taken to be -0.5 based on the reviews of Bates and Moore (1992) and Dargay and Gately (1995). Per capita incomes and populations are exogenous variables. *Per capita income* (an average global value is used) is assumed to grow at an average rate of 2% (based on World Bank 1991, OECD 1997). The initial average global value for per capita income in is approximately $5100 (based on OECD, 1997; World Bank 1997) and includes the developing countries, where greater growth in energy demand is expected; the

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1999 Conference Paper. They find that for the UK for all energy sectors a specification that includes some form of technical progress term is preferred to one where it is omitted, that a non-linear specification is also preferred, and argue that estimates of both price and income elasticities are likely to be biased if the term is omitted. In theory we actually need separate equations to explain technical progress in terms of product and energy prices, investment and other factors.

average per capita income elasticity is taken to be unity.[5] The *population projections* are based on WHO, 1998. From a starting value of about 5.8 billion in 1998 the world population reaches 13.7 billion by year 2100.

Energy Supply Mix. We have chosen to explore a range of "what if?" scenarios to estimate the (probability distribution of) the costs and benefits of alternative rates of adoption of renewable energy technologies. The energy supply mix is derived from:

$$S_t = D_t = R_t + F_t \quad \text{and} \quad R_t = \lambda_t D_t ; \; F_t = (1 - \lambda_t) D_t \qquad (2)$$

Where S_t is the total supply of energy (assumed to be equal to energy demand D_t); R_t is the amount supplied by renewable energy in period t; F_t the amount supplied by fossil fuels; and λ_t is the share of renewable energy in supply. By varying λ_t, which follows a logistic form to represent market diffusion (see Knapp (1999)), we can estimate the (probability distributions of) the costs and benefits of accelerating or decelerating the rates of introduction of renewable energy technologies.[6]

Energy Supply Costs and Prices. The costs of renewable energy are derived from 'learning-by-doing' function in which costs decline with the cumulative volume of

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[5] For developing countries the value is around 1.5, while for the industrial countries it is 0.5 or less and declining. A regional model would allow for these differences, and also for the point that income elasticities are declining functions of per capita income in the higher income ranges. Judson, et al. (1999). Reviews of income elasticity data are also to be found in Bates and Moore (1992) and Dargay and Gately (1995).

[6] An alternative would be to estimate λ as a function of the relative prices of fossil fuels and renewable energy, with the prices of the former being inclusive of a postulated carbon tax and of the latter exclusive of any investment incentives provided for their development and use. A difficulty here is the shortage of information on substitution elasticities for the new technologies. An alternative approach might be to use mathematical programming approach to estimate the optimum mix of the two energy sources under alternative assumptions about prices, taxes and investment incentives. The advantage of the 'what if' approach in the present exercise is that it enables us to estimate the imputed costs of alternative rates of substitution and thus what sorts of tax and investment incentives would be consistent with any particular scenario.

investments in renewable energy technologies. A commonly used function is the following:

$$c_{rt} = \mathrm{K}\{R_t\}^{-b} \qquad (3)$$

where c_{rt} is the unit cost of renewable energy (price) at time period t; K is a constant coefficient used to calibrate the initial cost value; b is a parameter (the greater b, the more rapid the rate of decline of costs). Note that although $\boldsymbol{R_t}$ is current output the specification of the cost function in this way reflects, to a reasonable approximation, *cumulative* experience with the technology, in the way intended in learning-by-doing cost functions, since $\boldsymbol{R_t}$ is the output from the sum of all previous investments in the technology still in operation in period t.[7]

In the following, we explored the consequences of uncertainties in the parameter b, since this varies widely among new technologies, from around 0.15 to over 0.4 (Kemp (1997)). This is an appreciable variation, since the cumulative volume of would have to rise 100-fold for costs to halve in the former case, but only 5-fold in the latter case; in the former, we could be waiting half a century or longer for costs to begin to approach those of fossil fuels, in the latter we could even be approaching a situation where they are lower, an economic surprise, in the early decades of the century. For photovoltaic technologies, it has averaged around 0.3 over the past 25 years, such that a 10 fold-increase of cumulative production would be necessary for costs to halve, assuming the relationship continues to hold (Cody and Tiedje (1992), Tsuchiya (1992), and Rannels (1998)). As with the energy efficiency parameter, we do not

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[7] A good review of Learning Curves in the literature is available from Christiansson (1995)

have information on the distribution of b, and only a rough indication of its range. For the following runs, we assumed a uniform distribution over the range: {0.15, 0.4}

Prices are based on the use-weighted average of the marginal costs of fossil fuels and the marginal costs of renewable energy. (The weights follow directly from the λs.) The initial cost of fossil fuels is taken to be a weighted average of the pre-tax c.i.f. price of gas, the pre-tax costs of gasoline and the average of bulk and retail supply costs of electricity; this is approximately \$7 per Giga-Joule (≈\$300 per toe.). For renewable energy the initial weighted average cost varies with assumptions about the mix of applications, location (e.g. wind regimes, incident solar energy, availability of geothermal energy, and so forth) and the RD&D (research, development and demonstration) strategies of public and industry programmes; for the following runs, the initial weighted average costs is taken to be 100% higher than that for fossil fuels, or \$14 per GJ.[8] We will discuss the sensitivity of the results to uncertainties in these estimates later.

***Marginal External Costs*.** The present value of the external costs of a ton of carbon dioxide emitted into the atmosphere is represented by a probability density function

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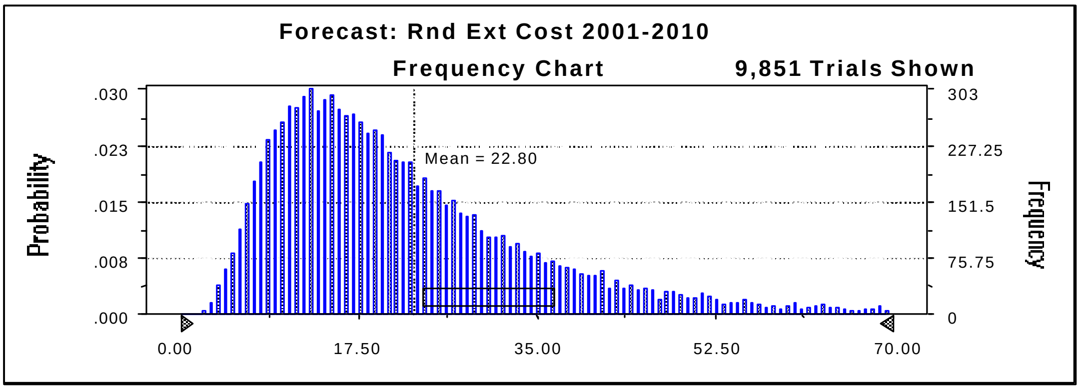
[8] The weights are 20% of *final* energy supply from electricity, including the inputs of coal, nuclear, gas and hydro for electricity generation, 50% from oil and 30% from natural gas. For electricity, many of the more promising options, such as photovoltaics and fuel cells based on renewable sources of energy are likely to compete at the retail end, so distribution costs are important in the comparison; other sources, such as geothermal, biomass (including waste incineration) and wind, are able to compete for grid-based generation directly; hence we took an average of retail and bulk supply costs, of US\$0.06 per kWh or \$17/GJ (c.f. the costs of wind energy, which are about \$10/GJ, geothermal, which in many locations is <\$10/GJ, and photovoltaics, which range from being competitive with grid supplies in remote areas or where there is good co-incidence between demand peaks and solar peaks, to \$50/GJ). For oil, we are assuming that vehicle fuels derived from renewable energy would have to compete with ex-refinery costs of fuels, of around \$0.8 per gallon, or \$250 per toe (≈ \$6/GJ). For gas, the c.i.f. price of which was approximately \$100 per toe (≈ \$2.5/GJ) in 1998, renewable energy would probably substitute at the ‘injection’ point into the main transmission systems; this is for example a commonly discussed possibility for the use of hydrogen derived from renewable energy sources, the so-called ‘hythane’ option. Ogden (1999) estimates the delivered costs to range from \$11 to \$25 per GJ, the lower estimate relating to hydrogen from natural gas, the latter to electrolytic hydrogen. There is thus some discretion over the technology mix that is initially favoured by public policies, and thus over the incremental costs of the technology programme. Taking the costs renewable energy to be 100% higher

of the form shown in Figure 2. It is based on the Monte Carlo studies of damage functions reported by Tol (1999), whose estimates reflect the wide range of possibilities analysed in the economic literature (see Table 1). The asymmetry in the distribution is also in agreement with the analyses of other studies, and arises (among other reasons) from non-linearities and lags in the damage function.

Figure 2. *Probability Distribution Function of the Marginal External Costs of Carbon Dioxide Emissions for the Period 2001-2010 (in 4/tC), for a 5% discount rate.*



The figure shows the distribution up to 3 standard deviations about the mean; the full range of estimates is $2 to $225/ ton C.

Table 1. *Existing estimates of the marginal costs of CO2 emissions ($/tC).*

Study	Type	1991-2000	2001-10	2011-20	2021-30
Nordhaus (1991)	MC		7.3 (0.3-65.9)		
Ayres and Walter (1991)	MC		30-35		
Nordhaus(1993)	CBA	5.3	6.8	8.6	10.0
Cline (1992, 1993)	CBA	5.8-124	7.6-154	9.8-186	11.8-221
Peck and Teisberg (1992)	CBA	10-12	12-14	14-18	18-22
Maddison (1993)	CBA	5.9-6.1	8.1-8.4	11.1-11.5	14.7-15.2
Fankhauser (1994)		20.3	22.8	25.3	27.8
Hope and Maul (1996)			2-7		
Plambeck and Hope (1996)			10-48		
Tol (1999)	MC		9-23		

Note: MC= actual marginal costs,
CBA= shadow value of a cost-benefit study

Source: Fankhauser, 1995; Pearce et al in Arrow et al, 1996; and Tol (1999).

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initially reflects the policies of OECD countries in which a mix of technologies are supported, some of which have costs close to those of fossil fuels, others which are still relatively expensive.

The century long-period is broken down into ten decade-long periods, with each simulation representing the mid-point of each decade. The marginal expected damage costs, discounted to the mid point of each period, are taken to rise gradually over time (see Table 2), also as much of the literature suggests (see Table 1). The reasons given in the literature for this assumption differ, but include the effects of rising incomes on assessments of costs, the rise in populations exposed to the effects of climate change, and a rising social concern over the possibility of the most impoverished income being most effected, which has led several studies to use a social weighting function in their analysis, and some to use lower discount rates.

Table 2: *Summary of Statistics of the Probability Density Functions representing the Marginal Impact of an Extra Tonne of Carbon Emitted into the Atmosphere*

Period (Years)	**Mean Value ($/tC)**	**Range ($/tC)**	**90% Percentile**
2001-2010	22.80	1.68-225.01	41.09
2011-2020	25.28	1.78-156.93	45.02
2021-2030	27.82	2.26-231.47	48.82
2031-2040	30.13	2.52-276.29	52.50
2041-2050	32.04	3.22-181.99	55.63
2051-2060	33.70	4.41-181.87	58.71
2061-2070	35.00	3.28-244.60	61.13
2071-2080	36.48	3.59-242.99	63.85
2081-2090	39.03	4.71-319.84	67.65
2091-2100	41.99	5.02-264.83	72.03

Although the above distributions cover a wide range, they are unlikely to reflect the full range—or even, perhaps, the distribution—of possibilities ahead. Not only do estimates of the means vary appreciably, but so do estimates of all other moments (where they are estimated at all) of the distribution. For his estimates of the probability distribution functions Tol used the following distributions as a basis for his Monte Carlo studies of external costs: gamma distributions for climate sensitivity (^{o}C/doubling CO_2), sea level sensitivity (m/^{o}C), and the value of a statistical life when evaluating health impacts; normal distributions for hurricane sensitivity, flood sensitivity, impacts on agriculture, coasts, health and other; triangular distributions for other parameters. In an candid assessment he remarks that the “quantification of uncertainties about the parameters [he uses] is largely based on [his] qualitative interpretation of a informal selection of the literature and informal talks with topical experts….The modal values equal best guesses. Distribution and spread are ... informally based on the literature. Parameters are assumed to be independent, across both regions and sectors. In some cases, it is hard to think of correlations… In other cases, the sign of the correlation is unclear… In any case, estimating correlations between unknown parameters is a daunting task.” Furthermore, the stochastic processes linking the impacts of climate change over time and region are at present unknown, have been modelled in only the most rudimentary form in the economic literature, and are unlikely to be stationary. Thus the probability distributions of environmental damage could very well assume more complex forms than the one shown in Figure 2.

In light of these uncertainties, and bearing in mind the purposes of the present paper, we decided to use the above distributions as a basis for analysis, and then to explore the sensitivity of the results with respect to changes in the variance of the distributions. This enables us to consider how an increase in uncertainty affects the results.

Emissions. Emissions are related to energy consumption using the identity:

Emission of pollutants = [energy consumption] x [emissions per unit of energy consumption]

The term *emission of pollutants* here refers to carbon emissions. An average value of *0.8* ton C emitted per ton of oil equivalent energy is used for fossil fuels.

Total Costs. These are the sum of energy supply plus external costs:

$$C_{Tot} = (c_{ft} F_t + c_{rt} R_t) + Cext \tag{4}$$

where C_{Tot} denotes total costs at time period t; c_{ft} the unit cost of fossil fuel energy; c_{rt} the unit cost of renewable energy; and $Cext$ the external costs induced by greenhouse gas emissions. The present value of total costs is given by:

$$PVC_{Tot} = \sum_{0}^{t} \frac{(c_{ft} F_t + c_{rt} R_t)}{(1+r)^t} + \sum_{0}^{t} \frac{Cext_t}{(1+r)^t} \tag{5}$$

where r is the discount rate. The first term in the above equation is the PV of the total energy cost and the second the PV of the total external cost.

The 'Without' Case and Other Options. Another calculation of interest is the change in the probability distribution of total energy costs compared to the case where there is no or negligible investment in renewable energy. Using the superscripts r and 0 to denote the annual costs of meeting the same demand with and without renewable energy, the change in annual costs is given by:

$$\boldsymbol{C^{r}_{Tot} - C^{0}_{Tot} = (c_{rt} - c_{ft}) R_t} \tag{6}$$

The probability distribution of the present value of this term has been estimated for the first 20 years and then for the whole 100 year period. The reason is that it is in the first 20 years or so when the costs of the renewable energy option relative to fossil fuels will be at their highest, and the added costs in this period can be considered an investment to develop and demonstrate the renewable energy option.[9]

3. The Scenarios and the Results[•]

Three scenarios and the differences between them are explored in order to estimate the costs and benefits of investing in the development of renewable energy. The first two form the basis of a traditional 'with and without' calculation in which the costs and benefits of a fossil fuel scenario are compared with those in which renewable energy (and related technologies such as fuel cells and hydrogen) is gradually substituted for fossil fuels. The third considers the option of delaying the introduction of renewable energy on a significant scale by 25 years. The probability density functions of the present values of following quantities are calculated using Monte Carlo methods:[10]

1. The external costs (***Cxf***) and the costs of energy (***Cf***) if only fossil fuels are used—a fossil fuel scenario, denoted by ***FF***.
2. The costs and benefits of investing in renewable energy and related technologies such that 50% of world energy demands are met by 2050. This is termed a renewable energy scenario, denoted by ***RE'50***:[11]

    (a) The external costs: ***Cx50.***

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[9] The calculation is approximate since energy demands are different in the with and without cases. The effect is second order in the first period however, owing to the small weight of renewable energy in overall supplies.

[•] More details of the model and further results are available at the ICCEPT's web site at http://www.iccept.ic.ac.uk/a5-1.html#work

[10] The model was set as an Excel 5.0 worksheet and for the Monte Carlo Analysis the add-in 'Crystal Ball 4.0' was used, with the number of trials set at 20,000.

[11] This corresponds to scenarios developed by industry, the World Bank and several reviewed by the IPCC, See Nakicenovic, et al. (1998), Kassler (1994), and World Bank (1992).

(b) The energy costs relative to those of the fossil fuel scenario: ***Cr50 – Cf***, where ***Cr50*** denotes the total energy cost of the scenario.

(c) The environmental benefits or external costs avoided relative to the fossil fuel scenario, less the increase in energy costs: ***(Cxf – Cx50) – (Cr50 – Cf)***.

3. The option of delaying the renewable energy scenario by 25 years, such that 50% of world energy demands are met by 2075. This option is termed ***RE'75***:

(a) The external costs: ***Cx75.***

(b) The increase in energy costs relative to the 'without' case: ***Cr75 – Cf.***

(c) The environmental benefits or external costs avoided relative to the 'without' case, less the increase in energy costs: ***(Cxf – Cx75) – (Cr75 – Cf)***.

4. Finally, the option value (or cost) of advancing or delaying the policy is estimated by computing the differences in the probability distribution functions between the quantities in 2 and 3:

(a) The extra energy costs of bringing the renewable energy option in (3) forward: ***Cr50 – Cr75***.

(b) The environmental benefits of the earlier policy: ***Cx75 – Cx50***.

(c) The net benefits of the earlier policy: **(*Cx75 – Cx50*) – (*Cr50 – Cr75*)**.

Table 3 summarises the results of the Monte Carlo simulations. It shows the means, variances and the 2.5 and 97.5 percentiles of each quantity estimated. To calculate the probability distributions of the differences between the various cost and benefit terms, for example ***Cxf – Cx75*** in row 5 and ***Cr50 – Cr75*** in row 15, it was necessary to run the simulations for three scenarios simultaneously. This is partly because it is the only practical way of calculating the differences in the probability distributions given the analytic interconnections between the variables in the above model. Second, within the assumptions of the analysis, the external cost of any *particular level* of emissions postulated in the Monte Carlo simulation in any given year is the same in all three scenarios[12] —though the *probability* of the level postulated may differ between the scenarios on account of the effects of prices and substitution on the probability distribution of emissions. Similarly, to estimate the probability distributions of the differences in costs and benefits between scenarios, we need to the compare energy and external costs for each particular (Monte Carlo "trial") value of the technical progress parameters $\boldsymbol{b}$ and $\boldsymbol{l}$.

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[12] If the marginal costs were expressed as a function of accumulations, there would be differences in the marginal costs of emissions depending on the differences in accumulations.

Table 3: Summary statistics for the simulations. Figures are present values in $trillions over the century (except for row 13) at 5% discount rate.

		Strd.	**Percentiles**		
	Mean	**Dvtn.**	**2.50%**	**97.50%**	**Range** [a/]
Fossil Fuel Scenario:					
1. External Cost, Cxf	5.9	3.7	1.6	15.6	0.8 to 33.0
2. Energy Cost, Cf	80.6	9.5	66.6	97.8	66.0 to 98.8
Renewable Energy Scenario 2075:					
3. External Cost, Cx75	5.2	3.3	1.4	13.7	0.7 to 29.8
4. Energy Cost, Cr75	80.1	9.0	66.7	96.9	65.1 to 101.4
5. Benefits: Cxf-Cx75	0.7	0.5	0.2	1.9	<0.1 to 4.4
6. Costs: Cr75-Cf	-0.5	1.7	-4.0	2.4	-5.4 to 2.9
7. Benefits-Costs: [(Cxf-Cr75)-(Cr75-Cf)	1.2	1.9	-1.8	5.1	-2.5 to 8.6
Renewable Energy Scenario 2050:					
8. External Cost, Cx50	4.4	2.8	1.2	11.8	0.6 to 26.6
9. Energy Cost, Cr50	77.6	8.6	64.5	95.6	62.4 to 102.1
10. Benefits: Cxf-Cx50	1.4	1.0	0.4	3.9	0.2 to 8.9
11. Costs: Cr50-Cf	-2.9	3.8	-10.7	3.3	-13.4 to 4.1
12. Benefits-Costs: [(Cxf-Cr50)-(Cr50-Cf)	4.4	4.0	-2.3	12.9	-3.5 to 19.9
13. Extra Energy Cost in first 25 years [(Cr50(25)-Cf(25)]	0.6	0.1	0.4	0.9	0.4 to 1.0
Option of Bringing the Renewable Energy Scenario Forward:					
14. Change in External Costs [Cxr75-Cxr50]	0.7	0.5	0.2	2.0	<0.1 to 4.5
15. Change in Energy Costs [Cr50-Cr75]	-2.5	2.1	-6.6	1.0	-8.0 to 1.3
16. Benefits- Costs: [(Cxr75-Cxr50)-(Cr50-Cr75)]	3.2	2.2	-0.5	7.8	-1.0 to 11.3

a/ The range refers to the lower and upper ends of the distribution.
The use of the first decimal place is not intended to convey a (false) sense of accuracy, put to avoid rounding errors; we are often dealing with small differences between large numbers—even when comparing energy costs between scenarios—a point which we believe strengthens the conclusions.

The probability distributions of selected variables in the above table are shown in Figures 3 to 6. They will be commented on shortly. Let us first consider the main features of the results and then their the sensitivity to uncertainties and variables omitted from the analysis:

External costs. It is an indication of the magnitude of the problem of addressing global warming that, even with the fundamental long-term changes in the energy supply mix implied by either of the two renewable energy scenarios explored above, the estimated effects on external costs are relatively small. This can be seen when we compare the probability distributions of external costs for the three scenarios, shown in Figures 3a, b, and c. The mean value of external costs declined by only one-quarter between the fossil fuel and the earlier of the two renewable energy scenarios. For ease of comparison, the relevant estimates in Table 3a are regrouped below:

Table 3a: Comparisons of External Costs. Present values in $trillion. $\boldsymbol{r}$ = 5%.

			Percentiles		
Scenario	Mean	s.d.	2.5%	97.5%	Range
FF	5.9	3.7	1.6	15.6	0.8 to 33.3
RE ’75	5.2	3.3	1.4	13.7	0.7 to 29.8
RE ’50	4.4	2.8	1.2	11.8	0.6 to 26.6
RE ’75 → RE’50	0.7	0.5	0.2	2.0	0.5 to 4.5

See table 3 for details. FF denotes the fossil fuel scenario, RE the renewable energy scenario and RE ’75 → RE’50 bringing the RE scenario ’75 forward 25 years.

Nevertheless there is a downward shift in three quantities: in the expected value of external costs; in the variance external costs, and thus of risks; and in the upper extreme of external costs, and thus in the costs of extreme events. The option of moving RE ’75 forward by 25 years also reveals the probability of a small but unambiguous reduction in external costs.

Energy costs.[13] These rise slightly, but perhaps surprisingly the effects are small and insignificant, and there is also a non-negligible possibility of the costs of the transition from the fossil fuel scenario to RE ’75 or RE ’50 being negative. Again to facilitate comparisons, the following are the relevant estimates taken from Table 3b:

Table 3b: Comparisons of Energy Costs. Present Values in $trillion. ***r*** = 5%.

Scenario	Mean	s.d.	Percentiles: 2.5%	97.5%	Range
Fossil fuel	80.6	9.5	66.6	97.8	66.0 to 98.8
RE ’75	80.1	9.0	66.7	96.9	65.1 to 101.4
RE ’50	77.6	8.6	64.5	95.6	62.4 to 102.1
RE ’75 → RE’50	-2.5	2.1	- 6.6	1.0	-8.0 to 1.3

The reason for the small effect on costs lies in the technical progress function, or more specifically in the learning curve parameter ***b***, which we took to vary from 0.1 to 0.4. Currently renewable energy (other than hydro) meets only 0.5 to < 1.0 percent of the world energy demands; costs vary appreciably between technologies, applications and regions, but above we have taken them to average about twice those of using fossil fuels. On this assumption, a twenty-fold expansion to a point where they met, say, 10 percent of world energy demands, would reduce costs by 25% to 70% depending on the starting point (where we are on the learning curves) and the value of the parameter, i.e. to a point when they would still remain appreciably more costly than fossil fuels if the lower values of the parameter were to be the case, but less costly for higher values of the parameter. The effects are smaller in later periods, assuming the learning curve parameter remains unchanged: a further tenfold fold increase such that

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[13] In the present exercise, we have not modelled several other uncertainties with respect to energy demands, for example the effects of the growth of incomes and populations on demands, of future energy taxes, and of uncertainties in price and income elasticity parameters. Allowing for such

(after allowing for demand growth) they accounted for half of total supply, would see costs reduced, relative to the starting point, by 40% to 85%. In other words: the costs of renewable energy are high relative to fossil fuels in the initial period when its share in energy supplies is small; reductions in costs are also the greatest in this period such that, when its share becomes large, the costs are much reduced.

The range of possibilities is summed up in Figures 4a and 4b, which show the probability distributions of the differences in energy costs between the fossil fuel and the two renewable energy scenarios. That such a wide range exists can also be defended by reference to ongoing engineering research—in photo-conversion, for example, in solar-thermal, biomass, wind and ocean energy sources, and in hydrogen and fuel cells for transport and decentralised forms of combined heat and power.[14]

Net Benefits. Figures 5a and b show the distributions of net benefits for two ‘with and without’ calculations, in which the total energy and external costs of the fossil fuel scenario are compared with those of the two renewable energy scenarios. Figure 6a shows the net benefits of the option of bringing RE ’75 forward 25 years, and Figures 6b and 6c the components of the net benefits of this option. The estimates of net benefits are compared in Table 3c:

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uncertainties would of course widen the range of energy cost estimates. A comment on the possible effects on the results reported below is provided in the conclusions.

[14] On which for example see Johansson, et al. (1993), Ogden (1999) and Srinivasan, et al. (1999).

Table 3c: Comparisons of net benefits. Present values in $trillion. ***r*** = 5%.

Scenario	Mean	s.d.	Percentiles: 2.5	97.5	Range
RE ’75 – FF	1.2	1.9	-1.8	5.1	-2.5 to 8.6
RE ’50 – FF	4.4	4.0	-2.3	12.9	-3.5 to 19.9
RE ’75 → RE’50	3.2	2.2	-0.5	7.8	-1.0 to 11.3
Components of RE ’75 → RE’50:					
-- External benefits: ***Cr50 – Cr75***	0.7	0.5	0.2	2.0	0.1 to 4.5
-- Energy costs: ***Cx75 – Cx50***	- 2.5	2.1	-6.6	1.0	-8.0 to 1.3

The net benefits of pursuing either of the two renewable energy scenarios are more likely to be positive than negative under the assumptions of the analysis. RE ’50 is better than RE ’75 since bringing the investments forward reduces external costs unequivocally (penultimate row of the above summary and row 14 of Table 3) while holding the possibility of an *earlier* economic surprise (last row of the above summary and row 15 of Table 3). In other words it would make options available in the first quarter of this century that might not otherwise be available until it is half over. Even if the costs do turn out to be higher than fossil fuels, the reductions in costs that would be achieved would lower marginal costs of mitigation, and thus the carbon tax (or the imputed tax of the regulatory alternative) required to encourage substitution toward non-carbon technologies.

Furthermore, the increase in energy costs in the first 20 years are small in relation to both the overall costs of energy supplies, and the scale of the problem in hand. The estimate in row 13 of Table 3 is higher than would be expected in practice. *First*, the learning curve equation (3) and the single parameter attached to it averages over a diverse range of technologies and conceals the opportunity for reducing costs through optimisation. *Second*, in many areas there are ‘niche’ markets where the investments are already economically justified, such as geothermal projects in many countries, and photovoltaics for off-grid and for distributed generation where there is a good co-incidence between the solar peaks and the demand peaks. *Third*, costs differ appreciably between regions, especially (but not only) for the solar technologies; thus tradable permit and instruments such as the Clean Development Mechanism, if introduced, would provide considerable opportunities for concentrating applications in regions where costs are lower. *Fourth*, it is possible to opt out of particular technologies *if* the cost do not decline as expected, and refocusing on the more promising ones.

Changes to the discount rate (***r***) . The results of the simulation when a 5% discount rate is used instead of the 8% rate assumed above are presented in the Annex. Table 4 compares statistics for the fossil fuel and the renewable energy scenarios (FFS and RE’50) and for moving RE’75 forward to RE’50.

Table 4: Effects of changes in discount rate on costs and benefits

Quantity estimated	***r*** **%**	**Mean**	**s.d.**	**Range**
Effects on FFS and RE’50:				
External Costs: ***Cxf***	8	2.9	1.4	0.5 to 12.2
	5	5.9	3.7	0.8 to 33.0
External Costs: ***Cx50***	8	2.6	1.3	0.4 to 11.5
	5	4.4	2.8	0.6 to 26.6
Energy Costs: ***Cf***	8	43.2	3.0	38.4 to 50.0
	5	80.6	9.5	66.0 to 98.8
Energy Costs: ***Cr50***	8	43.2	2.9	38.0 to 50.1
	5	77.6	8.6	62.4 to 102.1
Benefits – Costs: ***RE’50 – FF***	8	0.3	0.7	-1.3 to 3.0
	5	4.4	4.0	-3.5 to 19.9
Bringing RE’75 forward 25 years:				
Change in energy costs: ***Cr50 – Cr75***	8	-0.4	0.4	-1.4 to 0.4
	5	-2.5	2.1	-8.0 to 1.3
Benefits – Costs : ***RE’75 ® RE’50***	8	0.5	0.4	-0.4 to 2.1
	5	3.2	2.2	-1.0 to 11.3

See Table 3 and Annex Table 1 for further details.

Raising the discount rate reduces the present value of both the external and direct costs of energy uses for obvious reasons in both scenarios. All statistics are affected in the same direction: the means, the standard deviations, and the extremities of the distributions. However, the preceding results remain intact, and virtually unaffected: the possibility of an economic surprise remains; the distribution of external costs is narrowed when we move from the fossil fuel scenario to RE'50, and the upper extreme of the external costs is reduced. RE'50 also remains the better option than that of delaying it by 25 years, as can be seen by comparing the statistics in the last two rows.

Overall therefore, the case for the early RE policy is not crucially dependent on the discount rate. There are two reasons for this. *First*, all measures of the probability distributions of the external and the direct costs of energy use are affected in roughly the same proportions when the discount rate is changed, such that the *relative* effects, though not secondary, are not first order. *Second*, and far more significant in our judgement, is the contribution of technical progress to reducing the costs of the non-carbon technologies: the means, standard deviations and the ranges of the costs are of the fossil fuel and renewable energy scenarios are comparable (see ***Cf*** and ***Cr50*** in Table 4) at both low and high discount rates. In other words, the importance of technical progress for creating new options for—and in reducing the costs of—responding to global warming remains central at high or low discount rates.

An increase of uncertainties in the damage function. Simulations were also undertaken to ascertain what the effects would be if the damage function was more uncertain than assumed in the preceding analysis. An elementary way of doing this is to increase the standard deviation of the distributions shown in Table 2. Table 5 summarises the results when the standard deviation is doubled relative to the base case results reported in Table 3 above.

Table 5. Effects of Doubling the Variance of the Damage Function (D.F.) Figures are present values in $trillion using a 5% discount rate.

Quantity	**Var. of D.F.**	**Mean**	**s.d.**	**Percentiles:**		**Range**
				2.5	**97.5**	
External costs:						
Cxf	Base	5.9	3.7	1.6	15.6	3.8 to 33.0
Cxf	Base x 2	5.8	6.9	0.6	24.9	0.2 to 88.5
Cx50	Base	4.4	2.8	1.2	11.8	0.6 to 26.6
Cx50	Base x 2	4.4	5.4	0.4	19.2	0.2 to 71.5
Benefits – Costs:						
RE'50 – FF	Base	4.4	4.0	-2.3	12.9	-3.5 to 19.9
RE'50 – FF	Base x 2	4.3	4.3	-2.5	13.5	-3.9 to 31.8
RE'50 – RE'75	Base	3.2	2.2	-0.5	7.8	-1.0 to 11.3
RE'50 – RE'75	Base x 2	3.2	2.3	-0.6	8.1	-1.2 to 17.5

See Table 3 and Annex Table 2 for further details.

The main effect is to increase the importance of the RE option for reducing the upper extremities of the distribution of the possible costs of climate change. The lower percentiles are virtually unaffected, on account of the asymmetries in the probability distribution; but higher percentiles and the upper end of the ranges of external costs are reduced, as can be seen if we compare the external costs of the fossil fuel and renewable energy scenarios (***Cxf*** and ***Cx50***) in the two cases. The effect is especially apparent when we compare the range of the benefits for RE '50 with those of the option of delaying it 25 years (see the last column and the last two rows of Table 5), which shows that the *range* of benefits is likely to be greater on account of the benefits of reducing the extreme values of external costs. In sum, the more uncertain we are about the costs of climate change—and about the costs of extreme events in particular—the stronger the case for developing non-carbon technologies such as renewable energy sooner rather than later.

4. Conclusions

The preceding analysis sought to show how uncertainties with respect to the rate of development of non-carbon technologies affect estimates of the future costs of mitigating climate change. Using an elementary learning-by-doing cost function, and by considering a range of values for the learning curve parameter we suggested that there is a wide range of possibilities ahead than is commonly recognised in the economic literature. These are that (a) mitigation policies may raise energy costs, (b) have little effect on energy costs, or (c) eventually reduce energy costs relative to those of using fossil fuels such that, with hindsight, addressing climate change may prove to be economically beneficial even ignoring the external benefits of mitigation.

Furthermore, the analysis understated the range of possibilities. The costs we considered were rough averages related to those of renewable energy technologies, hydrogen and fuel cells; there are other possibilities, including hydrogen from natural gas and coal bed methane, which can be extracted on closed cycles without CO_2 emissions to the atmosphere.[15] The cost function for the alternatives to fossil fuels was rudiamentary, and the uncertainties of only a single parameter, representing the non-linear effects of learning on costs, were explored; we are in need of empirical research on the cost functions and the stochastic, non-linear (and probably non-stationary) processes that underlay the relationships between technical progress and costs. Uncertainties in the long-term costs of fossil fuels and energy conversion technologies also deserve analysis. Not lastly, we made no allowance for the

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[15] Socolow, op. cit. (1997). We also made a crude allowance for the effects uncertainties about the rate of improvement of energy efficiency on future energy demands. Recall equation (1) and the subsequent discussion.

possibilities for reducing the costs of exploring non-carbon options through optimisation and the use of such instruments as tradable permits, trade and the Clean Development Mechanism (if the latter is ratified).

Even with such limitations in the analysis, it nevertheless shows why there is a good case for pursuing policies that would promote the development of technologies in response to the climate change problem. By comparing the probability distributions of external costs, energy costs and the totals of external and energy costs, it was concluded that the benefits of introducing such a policy today were significantly greater than those of a ‘wait and see’ option of delaying it for a quarter of a century.

Such a policy would lead to a reduction of the expected value of the external costs of using energy use, and to equally (if not more) important reductions in the variance of external costs and in the likelihood and the magnitude of the costs of extreme events. This at least is on the basis of probability distributions of the external costs of CO_2 emissions and accumulations in the current literature. The stochastic and non-linear process that determine external costs are considerably more complex that economic models have so far assumed, and it is possible that further research will show that the distributions of external costs are a good deal wider and take on more complex forms than the ones used above and in the economic literature. Yet when we experimented by increasing the standard deviation of the probability distribution of the external cost function, the effect (not surprisingly) was simply to increase the importance of policies that would reduce the likelihood and costs of extreme events. In this respect, policies to develop technological alternatives become more attractive the more uncertain we are about the costs of climate change.

Although (with exceptions) many of the more promising technologies such as solar energy, hydrogen and fuel cells are still expensive relative to using fossil fuels, the overall effects on energy costs of ambitious policies to develop them are comparatively small. The reason is that their share in total investment is small when their costs are high and large once their costs are reduced to levels more comparable to those of fossil fuels. The result is broadly consistent with earlier studies that concluded that the overall affects on economic growth of addressing climate change are likely to be small Weyant (1993); however, our analysis suggests that the possibilities for a beneficial effect on growth (even ignoring external benefits) have been underestimated in previous studies.

Perhaps surprisingly, the conclusions of the analysis not much affected by the choice of discount rate. Raising the discount rate reduces the present value of external costs and energy costs in roughly the same proportions. The relative contributions of technology developments to reducing the costs of (a) mitigating climate change, and (b) the expected value, dispersion and upper extremes of the probability distribution of the costs of climate change, are not significantly affected under the assumptions of the analysis.

The results also call into question whether economists are right to focus on a single policy instrument for addressing climate change, such as a carbon tax or a tradable permit. Policies to support the positive externalities of innovation seem especially relevant for industries and technologies intended to address an environmental problem (Baumol (1995)). When learning curves are steep, the positive externalities can amount to as much as 40-50% of costs, depending on the prospective use of the technology (Anderson and Williams (1993)). A tax incentive on capital costs, aside from being desirable for internalising positive externalities, has the added merit of bringing developments forward in time and reducing external costs sooner than would be the case for an environmental tax alone. The size of the optimum pollution tax, or the imputed value of its regulatory alternative, would also be reduced. This in turn would facilitate future decision making on policies toward climate change.

As to future research, the limitations of the present analysis are themselves sufficient to point to the importance of an effort to improve our understanding of cost functions, and of the dynamics of the development of technological options for mitigating climate change. The implications of uncertainties in a wider range of variables than were considered above also merit analysis—uncertainties about energy prices, for example, and the economic and demographic variables in the demand functions—as do the implications of regional variations in costs. Experiments with tradable permits have found that the costs of mitigation vary appreciably even between economically comparable countries, as Bohm (1999) reported for the Nordic region. The disparities in the costs of response will likely vary even more widely between other regions and countries, particularly between developing and industrial countries, such that tradable permits, trade and foreign direct investment would open up major opportunities for reducing the costs of developing and using non-carbon technologies.

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Annex Table 1. As for Table 1 in text, but with an 8% discount rate:

RESULTS TABLE: -- Discount Rate at 8%					
	Mean	**Strd Dvtn**	**2.50%**	**97.50%**	**Range**
Fossil Fuel Scenario					
*External Cost, **Cxf***	2.861	1.379	1.057	6.331	0.5 to 12.2
*Energy Cost, **Cf***	43.213	3.031	38.598	48.613	38.0 to 49.0
Renewable Energy Scenario 2075					
*External Cost, **Cx75***	2.716	1.317	0.996	6.051	0.4 to 11.9
*Energy Cost, **Cr75***	43.557	2.981	39.003	48.878	38.5 to 49.8
*Benefits: **Cxf-Cx75***	0.145	0.069	0.054	0.317	0.0 to 0.6
*Costs: **Cr75-Cf***	0.3	0.3	-0.2	0.9	(-0.4) to 1.1
Benefits-Costs: ***(Cxf-Cr75)-(Cr75-Cf)***	-0.2	0.3	-0.7	0.4	(-0.9) to 0.9
Renewable Energy Scenario 2050					
*External Cost, **Cx50***	2.6	1.3	0.9	5.8	0.4 to 11.5
*Energy Cost, **Cr50***	43.2	2.9	38.7	48.7	38.0 to 50.1
*Benefits: **Cxf-Cx50***	0.3	0.1	0.7	3.9	0.1 to 1.2
*Costs: **Cr50-Cf***	0.0	0.7	-1.4	1.2	(-1.9) to 1.5
Benefits-Costs: ***(Cxf-Cr50)-(Cr50-Cf)***	0.3	0.8	-1.0	1.8	(-1.3) to 3.0
Extra Energy Cost in first 25 years ***[(Cr50(25)-Cf(25)]***	0.4	0.1	0.3	0.6	0.3 to 0.7
Option of Bringing the Renewable Energy Scenario Forward					
Change in External Costs (Benefits) ***[Cxr75-Cxr50]***	0.2	0.1	0.1	0.3	0.3 to 0.7
Change in Energy Costs (Costs) ***[Cr50-Cr75]***	-0.4	0.4	-1.2	0.4	(-1.4) to 0.5
Benefits- Costs ***[(Cxr75-Cxr50)-(Cr50-Cr75)]***	0.5	0.4	-0.2	1.4	(-0.4) to 2.0

a/ The range refers to the lower and upper ends of the distribution.

Annex Table 2. As for Table 1 in text, but with an a doubling of the standard deviation.

RESULTS TABLE: Discount Rate at 5% -- 2 x Standard Deviation --					
	Mean	**Strd Dvtn**	**2.50%**	**97.50%**	**Range**[a/]
Fossil Fuel Scenario					
External Cost, ***Cxf***	5.8	6.9	0.6	24.9	0.2 to 88.5
Energy Cost, ***Cf***	80.5	9.4	66.6	97.7	66.0 to 98.9
Renewable Energy Scenario 2075					
External Cost, ***Cx75***	5.1	6.1	0.5	22.0	0.2 to 80.7
Energy Cost, ***Cr75***	80.0	8.9	66.7	96.8	65.1 to 101.3
Benefits: ***Cxf-Cx75***	0.7	0.8	0.1	3.0	0.0 to 10.9
Costs: ***Cr75-Cf***	-0.5	1.7	-4.1	2.4	(-5.4) to 3.0
Benefits-Costs: ***(Cxf-Cr75)-(Cr75-Cf)***	1.2	2.0	-1.9	5.4	(-2.9) to 14.3
Renewable Energy Scenario 2050					
External Cost, ***Cx50***	4.4	5.2	0.4	19.2	0.2 to 71.5
Energy Cost, ***Cr50***	77.5	8.5	64.3	95.5	62.4 to 102.1
Benefits: ***Cxf-Cx50***	1.4	1.7	0.1	6.2	0.1 to 22.0
Costs: ***Cr50-Cf***	-2.9	3.8	-10.8	3.3	(-13.4) to 4.1
Benefits-Costs: ***(Cxf-Cr50)-(Cr50-Cf)***	4.3	4.3	-2.5	13.5	(-3.9) to 31.8
Extra Energy Cost in first 25 years ***(Cr50(25)-Cf(25)]***	0.6	0.1	0.4	0.9	0.4 to 1.0
Option of Bringing the Renewable Energy Scenario Forward					
Change in External Costs (Benefits) ***[Cxr75-Cxr50]***	0.7	0.9	0.1	3.1	0.0 to 11.1
Change in Energy Costs (Costs) ***[Cr50-Cr75]***	-2.5	2.1	-6.7	1.0	(-8.1) to 1.2
Benefits- Costs ***[(Cxr75-Cxr50)-(Cr50-Cr75)]***	3.2	2.3	-0.6	8.1	(-1.2) to 17.5

a/ The range refers to the lower and upper ends of the distribution.

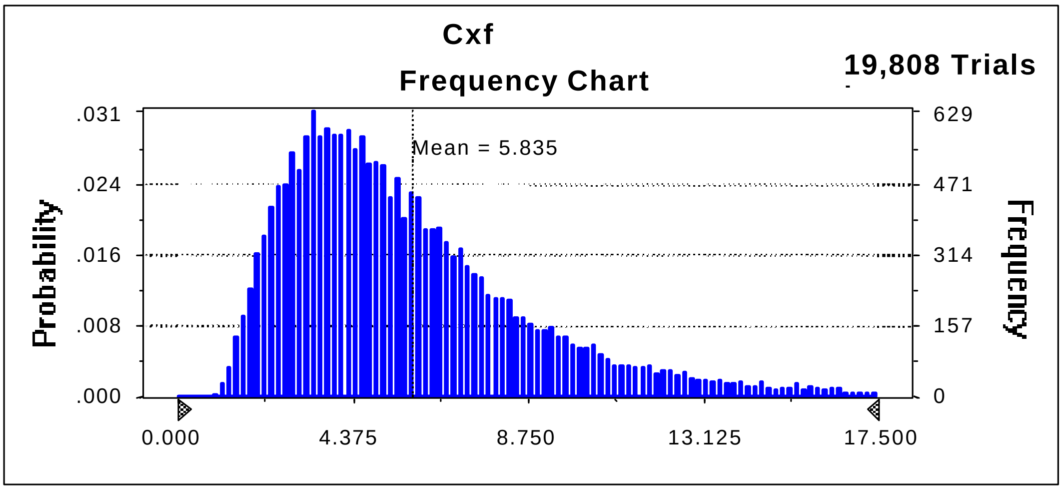

Figure 3a: External Cost Distribution for FF scenario

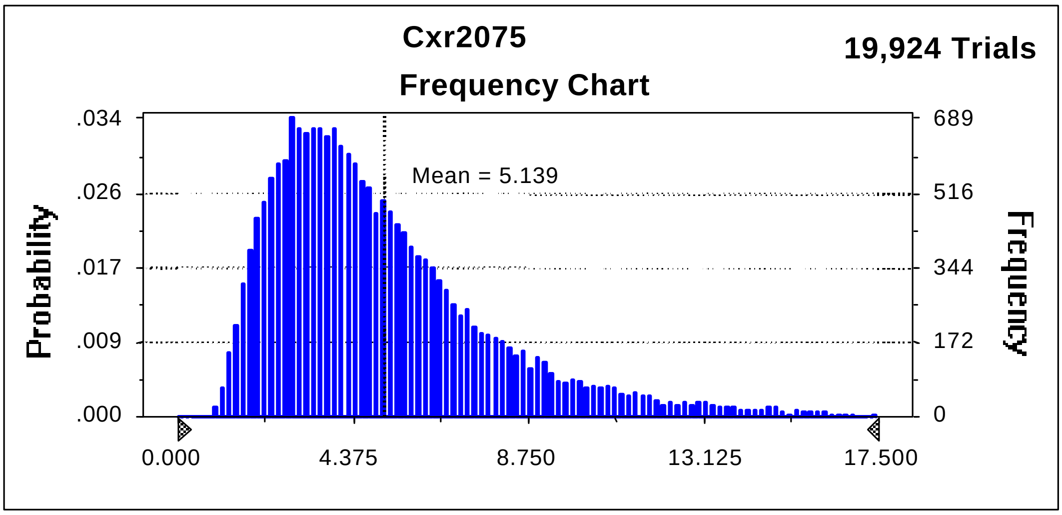

Figure 3b: External Cost Distribution for RE'75 scenario

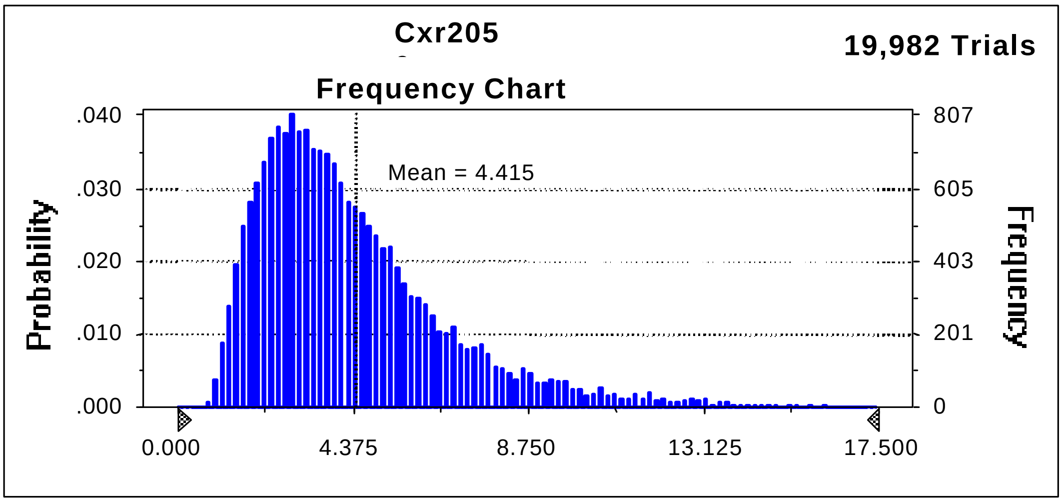

Figure 3c: External Cost Distribution for RE'50 scenario

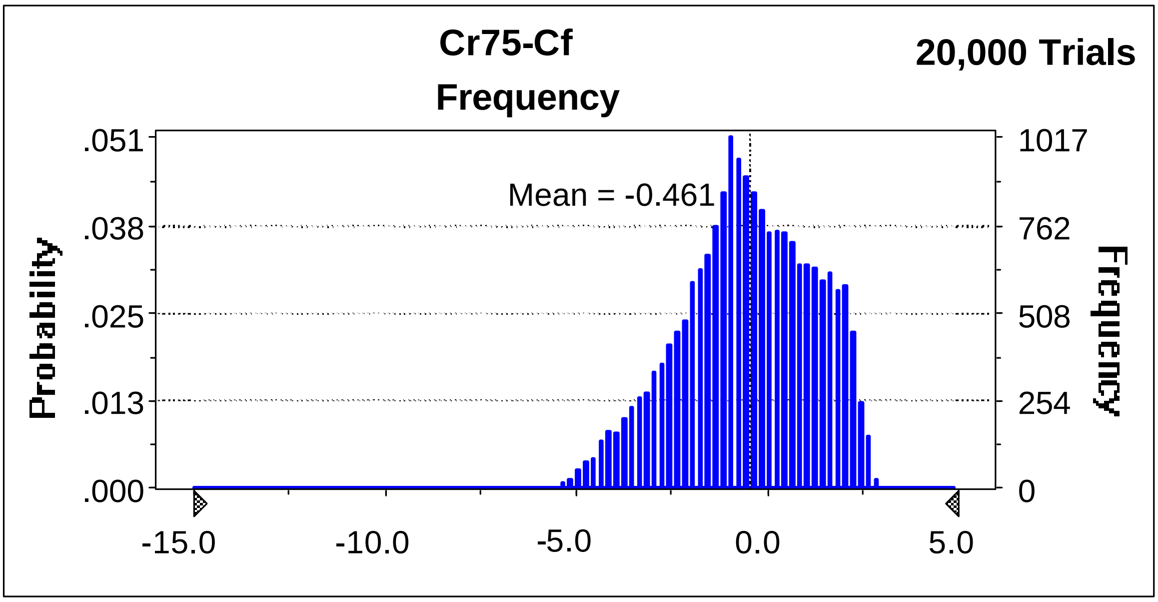

Figure 4a: Distribution of Energy Costs of the RE’75 scenario

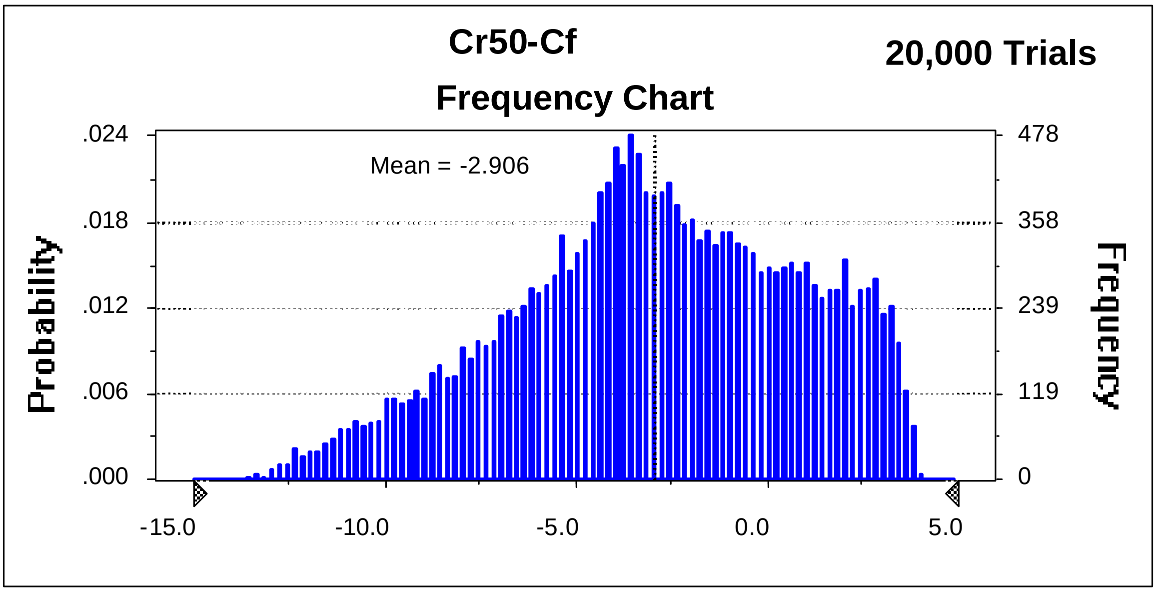

Figure 4b: Distribution of Energy Costs for the RE’50 scenario

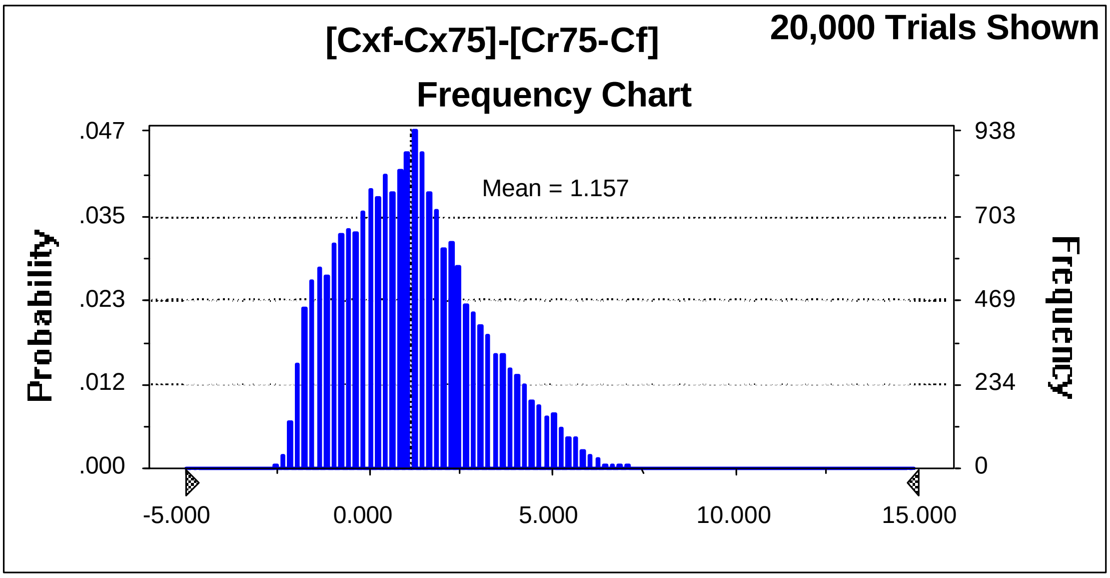

Figure 5a: Distribution of Net Benefits for RE’75 vs. FF

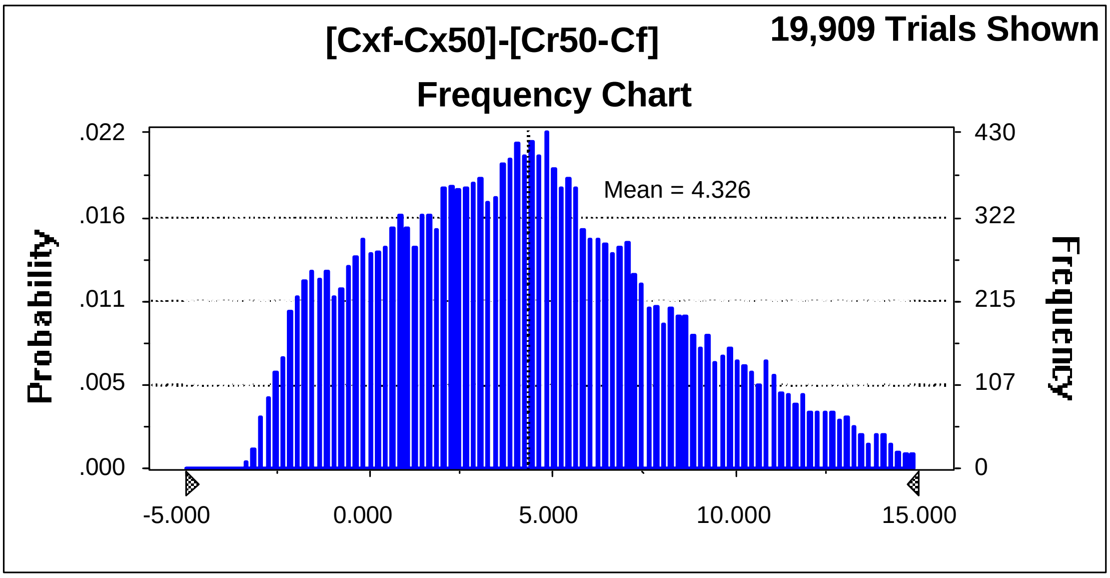

Figure 5b: Distribution of Net Benefits for RE’50 vs. FF

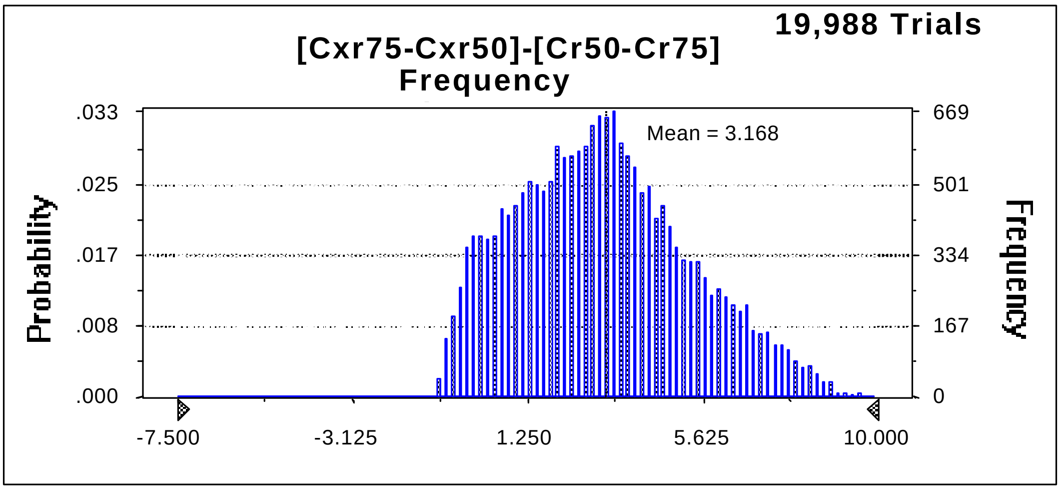

Figure 6a: Distribution of Net Benefits of RE’50 vs. RE’75

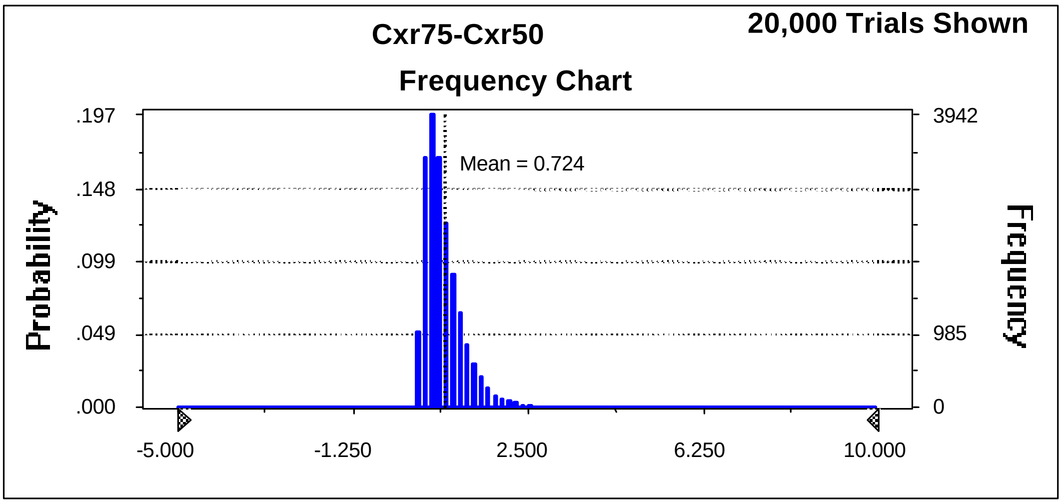

Figure 6b: Distribution of Benefits of RE’50 vs. RE’75

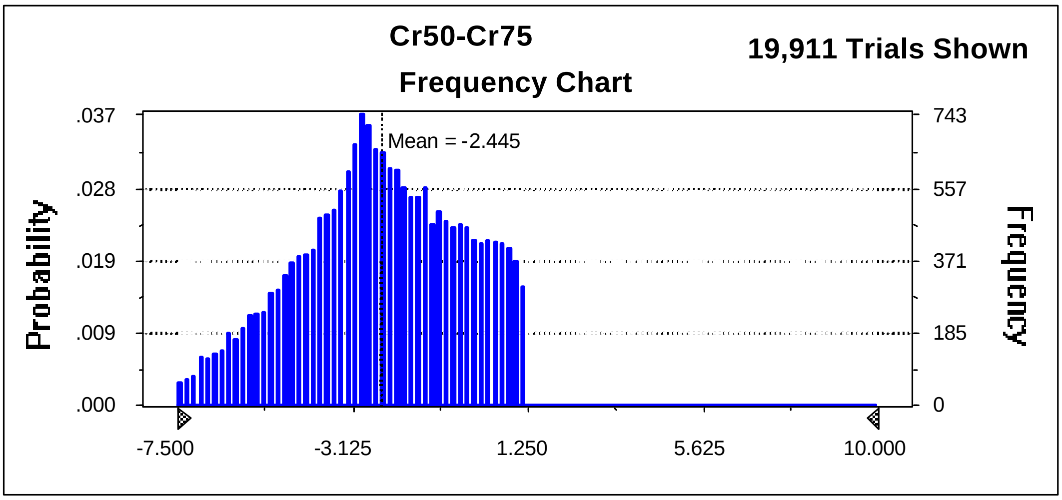

Figure 6c: Distribution of Energy Costs for RE’50 vs. RE’75

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