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An Integrated Approach to the Modelling of the Economic Costs of a Climate Change Policy

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ABSTRACT

Climate change is a long-term issue because of the long lifespan of greenhouse gases and the delayed response of the climate system. To reach a particular target in the future in terms of climate change, there can be several different emission paths. To determine if one path is more cost effective than another, we need to use an integrated-assessment (IA) approach. In this paper we combine the multi-sector multi-gas and multi-regional global economic model GTAPEL with the reduced form climate change model ICM to use in an integrated assessment approach to the estimation of the economic costs of climate change policies. We set, as an illustrative example, the target of reaching a radiative forcing level of around 6 w/m^2 in the year 2100 and then consider alternative emission paths which can reach this same target. In using the IA approach, we develop an alternative way to assign the 'Global Warming Potential' (GWP) weights to various greenhouse gases which can reflect dynamic and specific nature of these potentials depending on a particular climate change and economic scenario being considered. This is then compared with a conventional approach which simply uses the fixed GWP weights as recommended by the IPCC (Intergovernmental Panel on Climate Change). We found the results to be significantly different, and this has implications for the existing methods of measuring the economic costs of climate change policies.

Key words: Integrated Assessment of Climate Change, Multi Gas Investigation

JEL classification: D 58, C 68, Q40

1 Introduction

Climate change is a long-term issue because of the long lifespan of greenhouse gases and the delayed response of the climate system. To reach a particular target in the future in terms of climate change, there can be several different emission paths. To determine if one path is more cost effective than another, we need to use an integrated-assessment (IA) approach. In this paper we combine the multi-sector multi-gas and multi-regional global economic model GTAPEL (Burniaux, 2002; Burniaux and Truong, 2000) with the reduced form climate change model ICM (Bruckner *et al.*, 2003) to use in an integrated assessment approach to the estimation of the economic costs of climate change policy. We set, as an illustrative example, a particular climate change target of reaching a radiative forcing level of around 6 w/m^2 in the year 2100. We then consider alternative emission paths to achieve this particular target. In using the IA approach, we develop an alternative way to assign the 'Global Warming Potential' (GWP) weights to various greenhouse gases which can reflect dynamic and specific nature of these potentials depending on a particular climate change and economic scenario being considered. This is then compared with a conventional approach which simply use the fixed GWP weights as recommended by the IPCC (Intergovernmental Panel on Climate Change). We found the results to be significantly different, and this has implications for the existing methods of measuring the economic costs of climate change policies.

The plan of this paper is as follows: Section 2 develops a theoretical framework for assessing the economic costs of climate change policy which takes into account the dynamic intertemporal nature, not only of climate change, but also of economic costs. This provides a foundation for the calculation of relative global warming potential for various green house gases (relative to CO2) as used in the experiments in reported in Section 3. Section 3 also describes in details the integrated assessment (IA) approach used and the experiments carried out in this study. Section 4 reports on the important results and Section 5 concludes the paper.

2 Economic costs of climate change policy

Let x_t = $\{x_{1t},\ldots,x_{nt}\}$ be the (vector of)[1] levels of radiative forcing contributed by various green house gases (GHGs) i's to the total level of radiative forcing in year t[2], and let e_t = $\{e_{1t},\ldots,e_{nt}\}$ be the levels of emissions from these GHGs in year t. Let $\dot{x}_t$ be the temporal rate of change of x_t from year t-1 to year t, and $\dot{e}_t$ be the temporal rate of change of e_t. We assume that an economic cost function for GHG emissions and climate change can be written as follows:

$$C_t \; ? \; C(x_t, e_t) \qquad (1)$$

where $(?C/?x_{it})>0$ represents the marginal damage cost (MDC_{it}) of climate change as caused by a change in the radiative forcing level contributed by green house gas i in year t[3], and $(-?C/?e_{it}) >0$[4] represents the marginal abatement cost (MAC_{it}) of green house gas i in year t. The objective of any climate change policy is to minimise the intertemporal economic costs of climate change:

$$J \; ? \int_{t?0}^{t?T} e^{??t} C(x_t, e_t)dt \qquad (2)$$

subject to a vector of constraints:

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[1] Wherever there are more than one green house gases involved in the model, the word 'vector of' will be implied, unless the gas subscript "i" also appears explicitly.

[2] Although the chemistry of climate change is complex, we assume here for simplicity that the total radiative forcing level can be considered as a linear additive function of the various components attributable to various GHGs.

[3] In this study we look at climate change over 100 years from 2000 to 2100 over 21 five-yearly time periods, so the word 'year' is used here in a generic sense because, depending on the construction of the model, t can represent a longer time period.

[4] Economic cost level C is increasing with a reduced level of emissions because this involves losses in economic activities associated with a reduced emission level as well as increase in actual production costs associated with abatement activities. In an intertemporal framework, we compare the actual level of emission e_t in year t with a 'reference' or 'business-as-usual (BaU) emission level e_{tBaU}. Often, the objective of any climate policy is to reduce e_t below the e_{tBaU}.level, hence, even if e_t is seen to be increasing over time, this still represent a reduction in emission levels as compared to the BaU situation. In this case, we define ratio $\{[(C(e_{it}) - C(e_{itBaU})]/[e_{itBaU} - e_{it}]\}>0$ as the marginal abatement cost of green house gas i in year t.

$$\dot{x}_{it} \; ? \; f^{i}(x_t, e_t), \quad i \; ? \; 1,...,n. \tag{3}$$

where ? is the discount rate and T is the target year or the end period of a particular climate change policy[5]. Forming the present-value Hamiltonian for this optimisation problem as:

$$H \; ? \; e^{??t} C(x_t, e_t) \; ? \; \underset{i}{?} \; ?_i \dot{x}_{it} \tag{4}$$

where ? = {?$_1$,…,?$_n$ } is the (vector of) co-state variables[6], we can then state the first-order conditions for optimisation as:

$$\frac{?H}{?x_{it}} \; ? \; \frac{d}{dt} ? \frac{?H}{?\dot{x}_{it}} ? \; ? \; 0 \tag{5a}$$

$$\frac{?H}{?e_{it}} \; ? \; \frac{d}{dt} ? \frac{?H}{?\dot{e}_{it}} ? \; ? \; 0 \tag{5b}$$

Equations (5a) and (5b) hold for each of the green house gas[7] i in year t. From (5a)-(5b), we derive:

$$e^{??t} \frac{?C}{?x_{it}} \; ? \; ?_i \frac{?f^{i}(x_t, e_t)}{?x_{it}} \; ? \; \frac{d?_i}{dt} \tag{6a}$$

$$e^{??t} \frac{?C}{?e_{it}} \; ? \; ?_i \frac{?f^{i}(x_t, e_t)}{?e_{it}} \; ? \; 0 \tag{6a}$$

For the simple case where the change in radiative forcing level is a function of the emission levels only, i.e. $\dot{x}_t \; ? \; f(e_t)$, we have:

$$e^{??t} MDC_{it} \; ? \; \dot{?}_i \tag{6a}$$

[5] In equation (3), we assume that the rate of change of radiative forcing level in year t is a function of the level of radiative forcing prevailing in that year as well as the level of emissions occurring in that year. Often, we can simplify this further as $\dot{x}_t \; ? \; f(e_t)$. However, for the moment, we keep the general relationship as in (3).

[6] In the language of optimal control, x_t is also referred to as the state variables, and e_t is the control variables. ?.is also referred to as the Lagrange multipliers.

[7] In this study, we consider only three GHGs: CO2, CH4, and N2O.

$$e^{??t} MAC_{it} \; ? \; ??_i \dot{MRA}_{it} \qquad (6a)$$

where $\dot{MRA}_{it}$ stands for rate of change over year t (i.e. d/dt) of the 'marginal contribution to radiative forcing level by green house gas i over time period t', and the latter is defined as $MRA_{it} \; ? \; ?x_{it} / ?e_{it}$. If we also assume for simplicity that MDC_{it} = MDC_t for all i's[8], then $?_i$ = $?$, i.e. the same for all gases. This allows us to simplify equation (6a) further to:

$$MAC_{it} / MAC_{jt} \; ? \; \dot{MRA}_{it} / \dot{MRA}_{jt} \quad \text{for } ? \; i, j. \qquad (7)$$

Equation (7) provides us with an optimal formula for assigning 'global warming potential' (GWP) weights to different gases. If MRA_{it} can be estimated from a climate change sub-module and MAC_{it} from an economic module, then combing the two modules in an integrated assessment approach implies that we assign the GWP weights to each gas in such a way that the ratio of the marginal abatement costs coming out of an economic module should also reflect the ratio of the marginal contributions to climate change (radiative forcing levels in this case), the later is calculated from a climate model. In the next section we illustrate how this formula can be applied.

3 An Integrated Assessment Approach

The integrated-assessment (IA) model that we use to measure the economic costs of achieving a particular climate change objective consists of two sub-modules, an economic sub-model and a climate sub-model.

The Economic sub-model: This is based on the GTAP-EL model developed by Burniaux (2002)[9]. The model consists of 5 regions and 11 sectors. The regional definitions are given in Table 1 below, and the sectoral aggregations are given in Table 2.

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[8] This assumption is without loss of any generality since in practice, one is concerned only with damage caused by a change in the *total* radiative forcing level coming from all the gases combined rather than that coming from any particular gas.

[9] See also Burniaux and Truong (2002) and Truong (2000) for a description of the GTAP-E model on which GTAP-EL is based.

	Regions
USA	United States of America
EU	European Union 15
RoA1	Rest of Annex 1 regions
CHIND	China and India
ROW	Other Countries

Table 1: Definitions of Countries and Regions in GTAP-EL

	Sectors
USA	United States of America
1 Rice	Paddy rice
2 Crops	Primary Agriculture and Fishing
3 Livestock	Livestock products
4 Forestry	Forestry
5 Coal	Coal Mining
6 Oil	Crude Oil
7 Gas	Natural Gas and Gas distribution
8 Oil_Pcts	Oil and Coal products
9 Electricity	Electricity
10 CRP	Chemical Rubber and Plastics
11 Oth_ind_ser	Other industries and services

Table 2: Definitions of Sectors in GTAP-EL

We expand the production structure in the GTAP-EL model to allow it to take on a more general case where *both* CH4 and N2O emissions can occur in any given industry[10]. To do this, we use a nested CES (constant elasticity of substitution) production structure (see Figure 1). This applies to industry sectors which do not have N2O emissions associated with the use of an input (such as fertilizers, or 'chemical', in the production of 'crops'). For this latter category of industry sector, a different production structure is assumed to capture the nature of

[10] Currently, the production structure of the GTAP-EL model developed in Burniaux (2002) allows only for the case where CH4 and N2O emissions occur in *non-overlapping* industries. This means it does not account for *all* CH4 and N2O emissions in all industries. Thus, for example, if N2O emission is assumed to occur in the 'CROPS' sector due to the use of 'CHEMICAL' (fertiliser) as an input, then this sector cannot have CH4 emissions associated with its output. Conversely, other non-crops industry sectors which are assumed to have CH4 emissions associated with its output will not have N2O emissions associated with the same output.

N2O emissions as arising from the use of an input (see Figure 2). We also extend the model to allow it to incorporate 'dynamic' global warming potential weights to the three GHGs considered (namely CO2, CH4, and N2O) (see Section 4 below).

Figure 1: Production structure in a modified GTAP–EL model to allow for both CH4 and N2O emissions at the output level

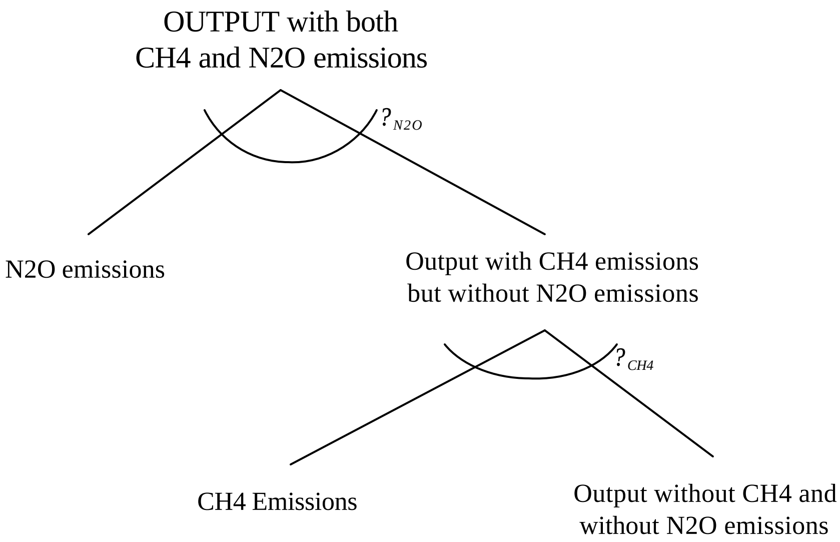

Figure 2: Production structure to allow for N2O emissions associated with the use of a production input

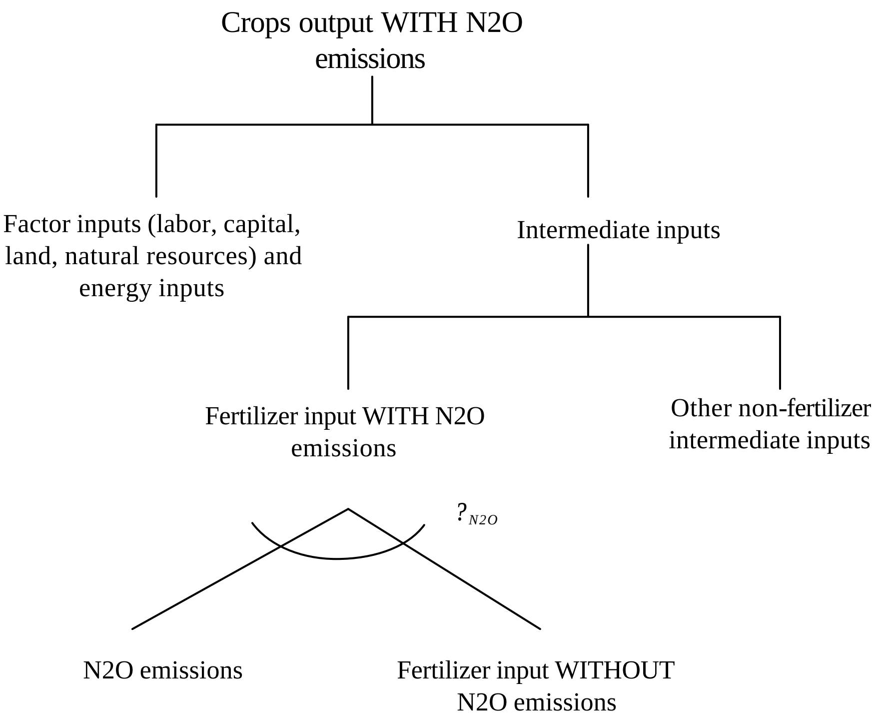

Table 3: CH4 Abatement elasticities

? $_{CH4}$	USA	EU	RoA1	CHIND	RoW
1 Rice	0.05	0.08	0.04	0.05	0.03
2 Crops	0	0	0	0	0
3 Livestock	0.05	0.08	0.04	0.05	0.03
4 Forestry	0	0	0	0	0
5 Coal	0.03	0.03	0.03	0.03	0.03
6 Oil	0	0	0	0	0
7 Gas	0.12	0.12	0.12	0.12	0.12
8 Oil_Pcts	0	0	0	0	0
9 Electricity	0	0	0	0	0
10 CRP	0	0	0	0	0
11 Oth_ind_ser	0.11	0.11	0.11	0.11	0.11

Table 4: N2O Abatement elasticities

? $_{N2O}$	USA	EU	RoA1	CHIND	RoW
1 Rice	0	0	0	0	0
2 Crops(*)	.04	.04	.04	.02	.02
3 Livestock	0	0	0	0	0
4 Forestry	0	0	0	0	0
5 Coal	0	0	0	0	0
6 Oil	0	0	0	0	0
7 Gas	0	0	0	0	0
8 Oil_Pcts	0	0	0	0	0
9 Electricity	0	0	0	0	0
10 CRP	0	0	0	0	0
11 Oth_ind_ser	0	0	0	0	0

(*) This applies to 'CRP' (Chemical Rubber and Plastic, as a proxy for 'fertilizer') input into 'Crops' only (see Figure 2).

The Climate sub-model: This is based on a reduced form version of the Non-linear Impulse-response representation of the coupled Carbon cycle-Climate System, or NICCS model (see Bruckner *et al.* (2003), Hooss *et al.* (2001), Hooss (2001), Joos *et al.* (2001), Meyer *et al.* (1999)). In this reduced form version of the NICCS model, called ICM (or ICLIPS[11] Climate Model), the original NICCS model is rewritten and supplemented with modules describing the atmospheric chemistry and radiative forcing contributions of non-CO2 greenhouse gases (Bruckner *et al.*, (2003)). ICM is driven by time-dependent paths of the anthropogenic emissions of CO2, CH4, N2O, halocarbons, SF6 and SO2. In this paper, we will be concerned only with CO_2, CH_4, and N_2O, as these are the gases covered in the GTAP-EL economic model.

***The Experiments*:** Since the main aim of the paper is to consider the usefulness of an integrated approach to climate change policy study, we choose some experiments which highlight the important features of this approach. First, we note that climate change is often measured in terms of a change in a variable such as the radiative forcing level in a particular target year. This change is influenced by environmental factors such as the emission levels (and hence concentration) of various GHGs. The economic costs of constraining these emission levels are calculated in an economic model. Thus when an economic models is linked to a climate model, this allows us to link the 'benefit'[12] of achieving a certain climate change target with its economic costs. To highlight the benefit of this link, in this paper we choose a set of three experiments. First, we conduct a 'Business-as-Usual' experiment to record the levels of emissions and the radiative forcing level that will be reached in the absence of any climate control policy. Next, we assume a climate control policy which is to reach a target radiative forcing level of, say 6 w/m^2, by the year 2100. In reaching this target, there can be several different paths. One most efficient path is to assume the world as a whole will combine and trade in their emissions of all (CO_2, CH_4, N_2O) greenhouse gases to allow the overall radiative forcing target level to be reached. This is considered in Experiments A. In combining

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[11] After the name of a project called ICLIPS (**I**ntegrated Assessment of **Cli**mate **P**rotection **S**trategies), see Toth *et al*., (2003).

[12] Despite the use of this word, the main concern in this paper is only with cost-effectiveness of a climate change policy, i.e. the 'benefit' of climate change is measured or proxied here by the change in radiative forcing level only. Measuring the economic and environmental benefits (or costs) of this change in radiative forcing level is beyond the scope of this paper.

different GHGs, it is important to assign weights which reflect their relative 'global warming potential (GWP). In Experiment A, we use the fixed GWP weights recommended by the IPCC[13]. As analysed in section 2, there is an alternative and more accurate way of assigning these weights: in Experiment B, we assume that the optimal weights can be derived by linking the ratio of marginal abatement costs (MAC_{it}) to the ratio of the rate of change of the marginal contribution to radiative forcing level ($M\dot{R}A_{it}$) as described in equation (7). We then compare the results of Experiment A and Experiment B.

4 Results

Figures 3 and 4 show the emission paths and the radiative forcing levels contributed from the three GHGs (CO2, CH4, and N2O) for the Reference case. Figures 5 and 6 show similar pictures for the case of Experiment A. It is seen from these Figures that to reduce the radiative forcing level in the year 2100 from a reference level of 7.25 w/m^2 to a target level of 6 w/m^2, this requires substantial reductions in emissions of the three GHGs. If we use the fixed GWP weights for CH4 and N2O (of 21 and 310 respectively), then there are some peculiarities in the levels of these emissions as seen from Figures 5 and 6: while the levels of CO2 and CH4 emissions are reduced quite substantially from the Reference scenario (-56% and –51% respectively for CO2 and CH4[14]), the figure for N2O actually shows an increase of 20%. To understand this peculiarity, we can refer back to equation (7). According to this equation, the cost of achieving a particular climate change target is minimised if the ratio of the

[13] These weights are: 1 for CO2, 21 for CH4, and 310 for N2O. This means one ton of CO2, CH4, and N2O can be converted into (12/44), 21*(12/44), and 310*(12/44) tons respectively, of carbon equivalent (Ceq)

marginal abatement costs for any two gases in any period (MAC_{it}/MAC_{jt}) must be equal to the rate of change of the ratio of their marginal contribution to the radiative forcing level in that period (MRA_{it} / MRA_{jt}). If we plot these ratios as calculated from the GTAP-EL economic model and the ICM climate models, then it is clear (from Figures 7 and 8) that when fixed GWP weights are used for CH4 and N2O, there is no guarantee that the two ratios will be close, even on average. First, we note that the ratios of the *MAC*'s are held constant (at 21 and 310 respectively for CH4 and N2O) by virtue of their fixed GWP weights, but the corresponding ratios of the MRA's can vary substantially over the periods of time being considered.. Initially, the ratio of the MRA's for N2O (versus CO2)[15] is close to 310 (the IPCC weight for N2O). But over time, this ratio increases steadily to a high level of 522 before declining back to around 450 by the end year 2100. The picture is different for CH4. Initially, the ratio of (MRA_{it} / MRA_{jt}) for CH4 versus CO2 is negative[16]. This then increases slowly to reach a level of around 17 by the end year 2100. All along, the ratio remains below the IPCC figure of 21 for CH4 as its GWP. In short, if we use the IPCC fixed weights as indicators of the GWP for CH4 and N2O, then in our particular experiment, this grossly overestimates the potential contribution to global warming by CH4, while grossly underestimating the potential of N2O. This also implies that the tax imposed on CH4 emissions is too heavy, while that on N2O is too light, and this explains why while CO2 and CH4

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units, if we are using these relative GWP weights.

[14] These figures are total or cumulative reductions, i.e. over the whole period from 1995 to 2100

[15] This is always implied.

[16] This can be explained by the fact that CH4 has a shorter lifespan than other gases, and therefore, with low emission levels from CH4, its concentration level may actually decline and therefore, the potential contribution to radiative forcing from these low emission levels will become negative.

emissions are being reduced (in Experiment A, to reach a target level for radiative forcing level), the emissions from N2O actually increased (relative to the Reference or Business-as-Usual Scenario). From this, it also implies that the resulting level of emission reductions from CH4 is greater than the optimal, while that from N2O emissions is less than the optimal. By 'optimality', we mean the *economic* costs of reducing N2O emissions should reflect (i.e. be linked to) the *environmental* cost of increased radiative forcing level from N2O emissions, and this can be achieved only via an integrated approach to climate change policy assessment.

To return the emissions reductions to the optimal levels, in Experiment B, we allow the GWP indices to vary across the time periods, reflecting closely the ratios of the MRA_{it}'s as calculated from the ICM climate model. The results are reported in Figures 9 and 10. As can be seen from these Figures, the economic ratios of the *MAC*'s are now closer[17] to the climate change ratios of the *MAC*'s. To show that the results in Experiment B (integrated assessment approach) is superior to the results of Experiment A (non-integrated approach), we show the total costs of emission reductions associated with these two experiments in Table 5. It is quite clear that using an integrated assessment approach will result in a lower emission reduction costs (to achieve the same climate change objective) as is compared with a non-integrated assessment approach. Tables 6 and 7 also report on the levels of emission reductions (from the Reference Case) for Experiments A and B and the contributions this makes to the radiative forcing levels in Experiments A and B.

[17] Due to the fact that the GTAP-EL economic model is recursive dynamic while the ICM climate model is fully intertemporal, we can only integrate the two models via an iterative process. This explains why the two curves representing the MAC and MRS ratios in Figures 9 and 10 are close but not identical. With further iterations, they can be made closer.

5 Conclusion

In this paper, we have shown how an integrated approach to the assessment of climate change policy can be carried out using a combination of a multi-sectoral multi-regional and multi-gas economic model with a reduced from climate change model. The approach is based on some firm theoretical foundation which was explained in the paper. The experimental results confirm the theoretical findings and also indicate that the use of an integrated approach towards the assessment of climate change policy can yield substantially better results than are those coming out of a non-integrated approach.

Figure 3: Emission path for the Reference Case

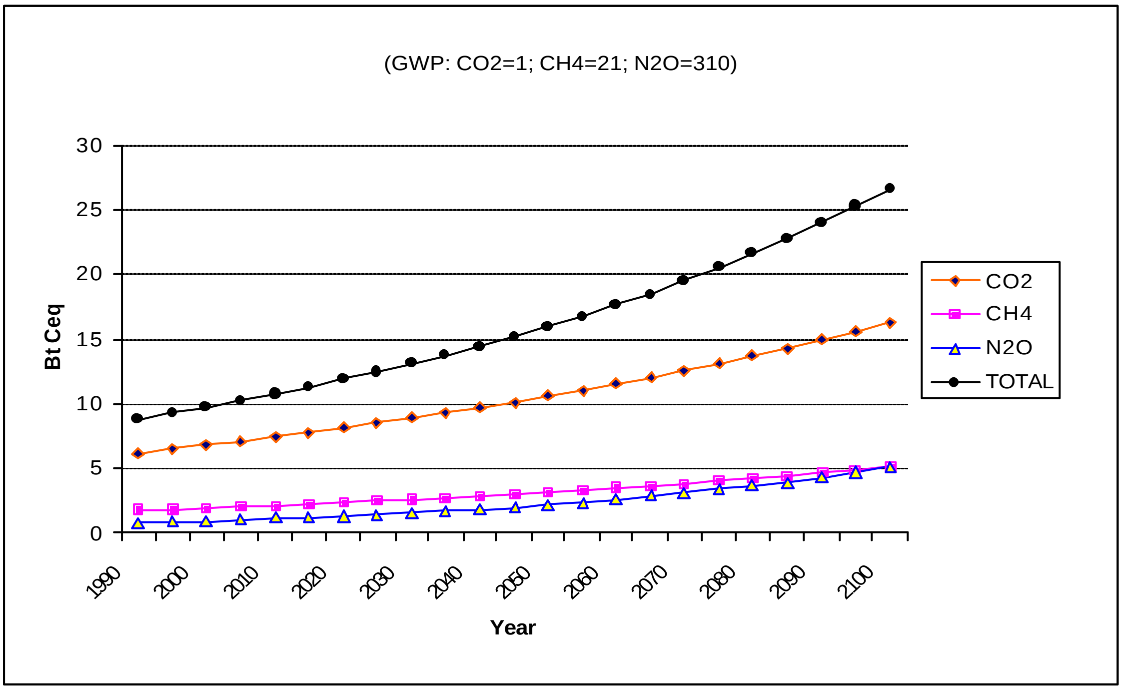

Figure 4: Radiative Forcing Levels for the Reference Case

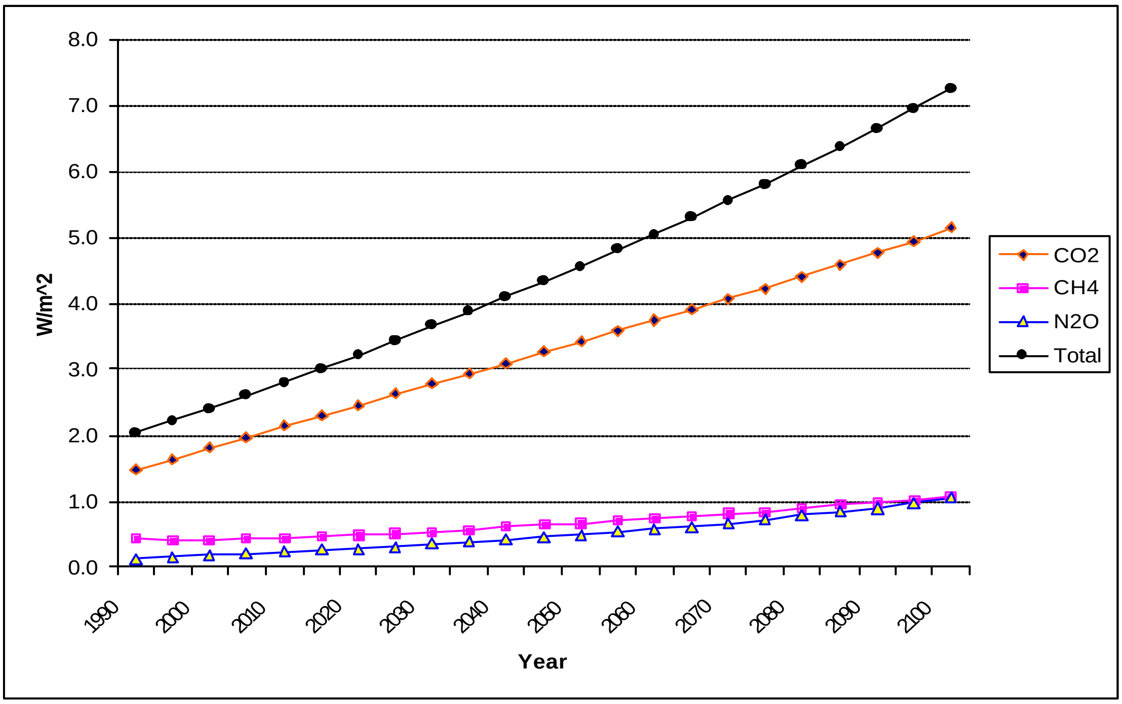

Figure 5: Emission path for Experiment A

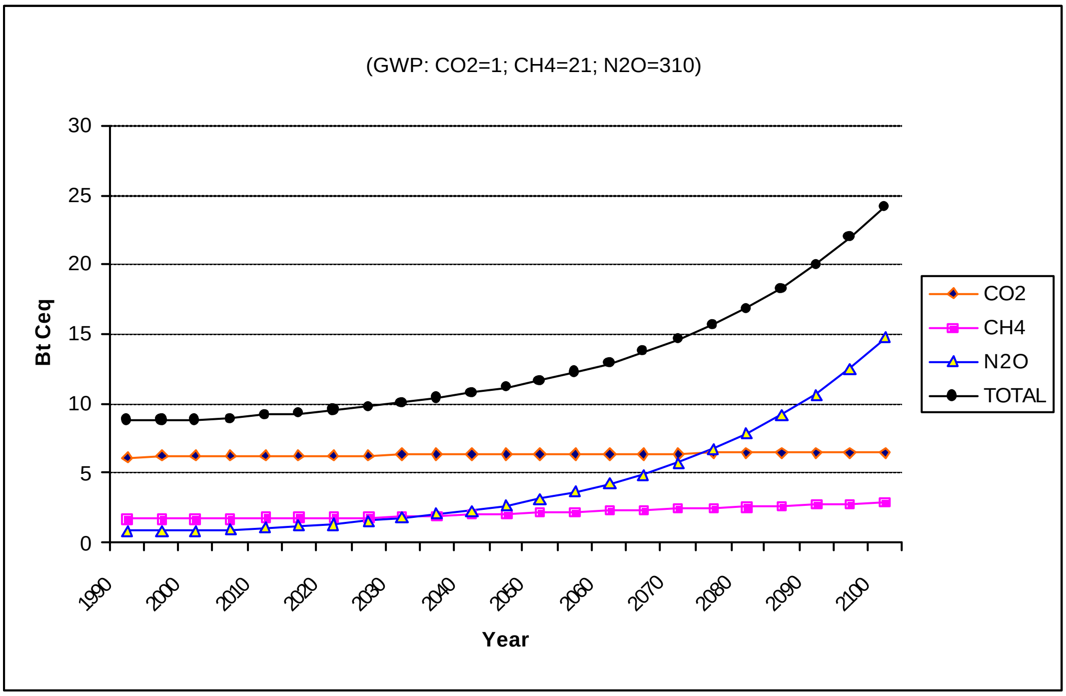

Figure 6: Radiative Forcing Levels for Experiment A

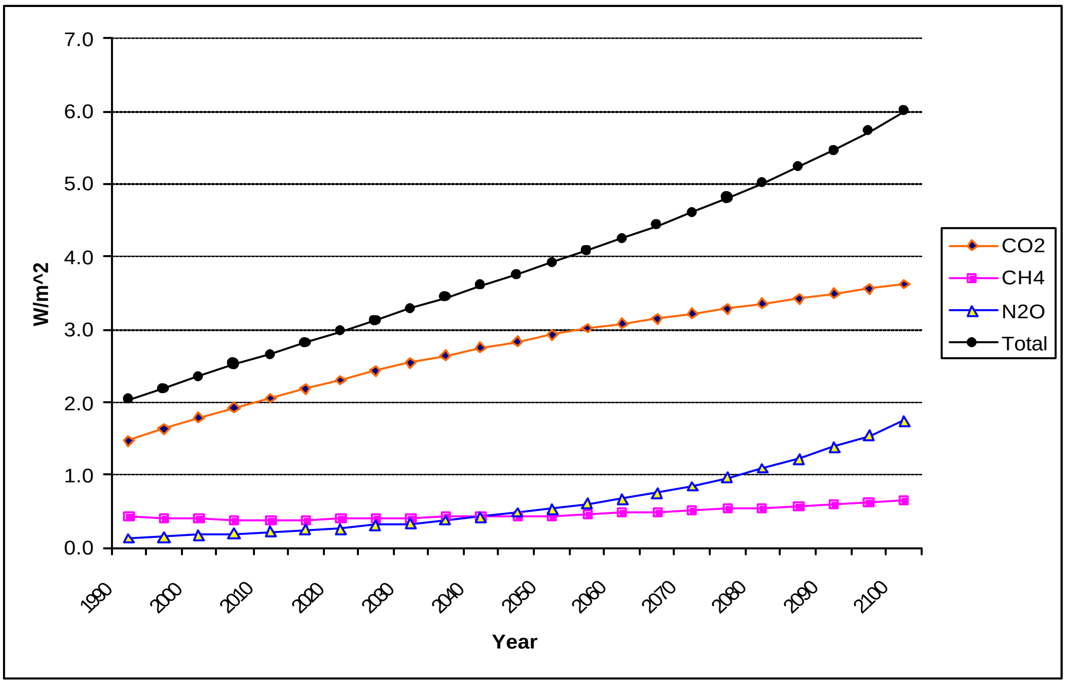

Figure 7: Marginal Abatement Costs (MAC) versus Marginal Contribution to Radiative Forcing (MRA): CH4 relative to CO2
Experiment A

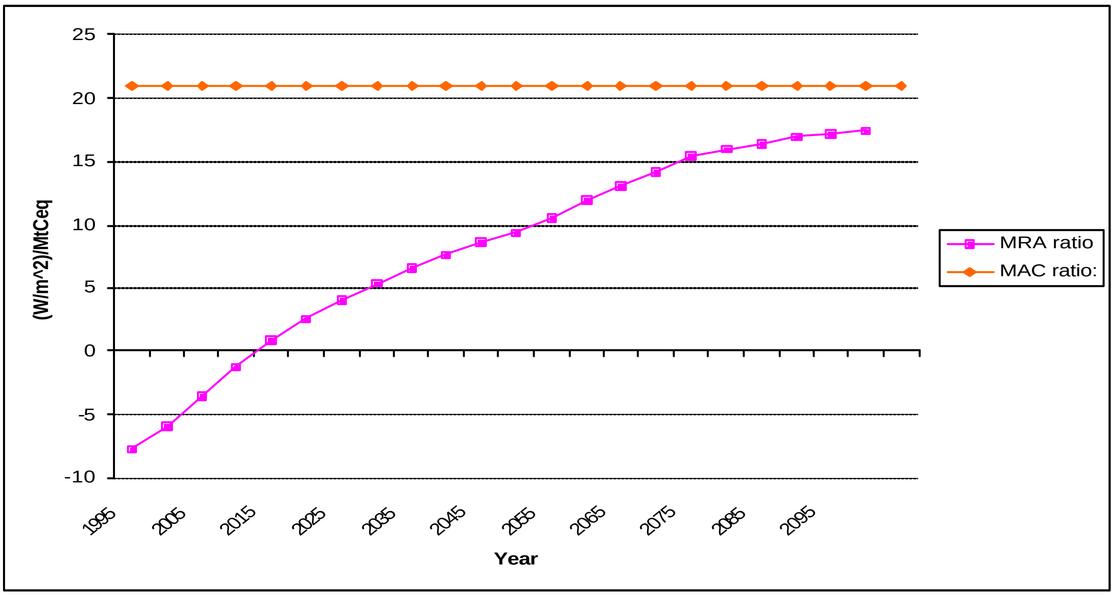

Figure 8: Marginal Abatement Costs (MAC) versus Marginal Contribution to Radiative Forcing (MRA): N2O relative to CO2
Experiment A

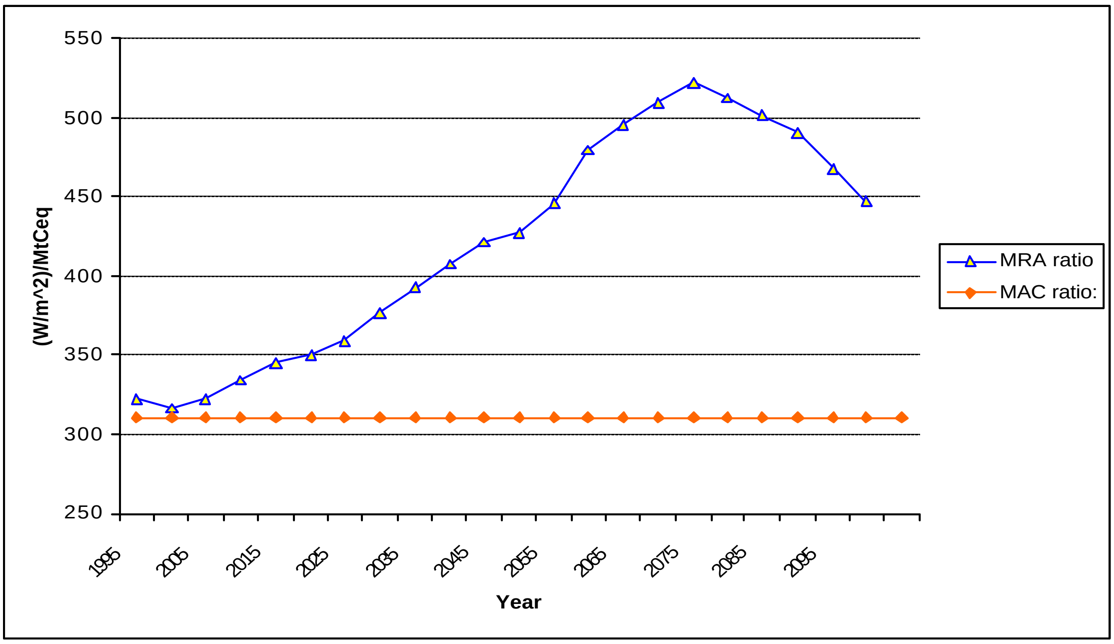

Figure 9: Marginal Abatement Costs (MAC) versus Marginal Contribution to Radiative Forcing (MRA): CH4 relative to CO2
Experiment B

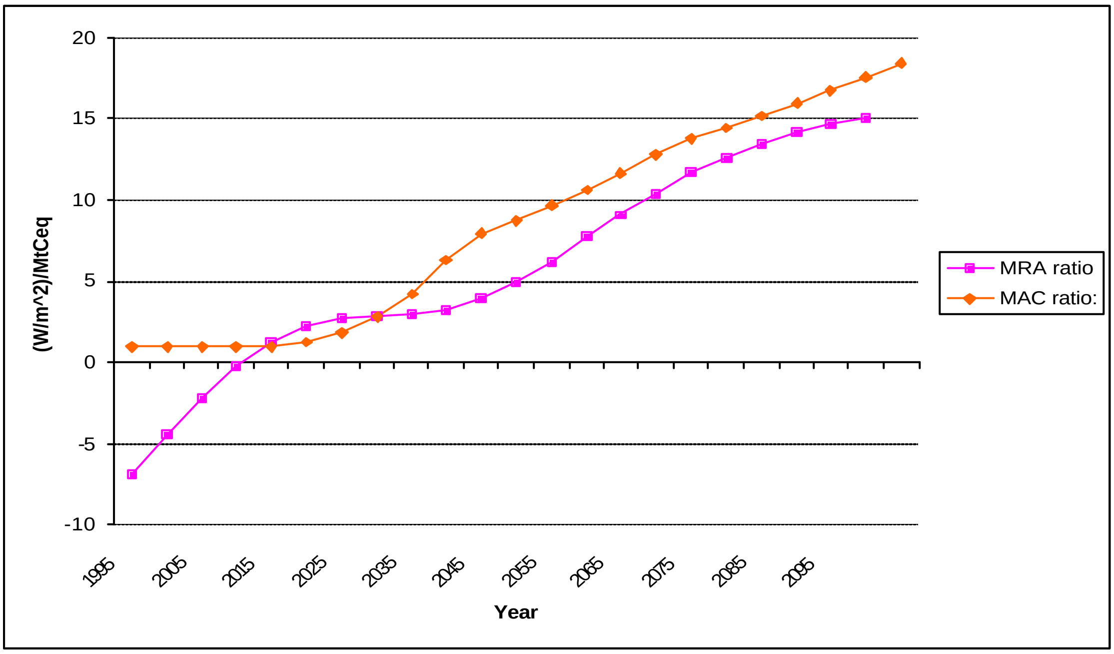

Figure 10: Marginal Abatement Costs (MAC) versus Marginal Contribution to Radiative Forcing (MRA): N2O relative to CO2
Experiment B

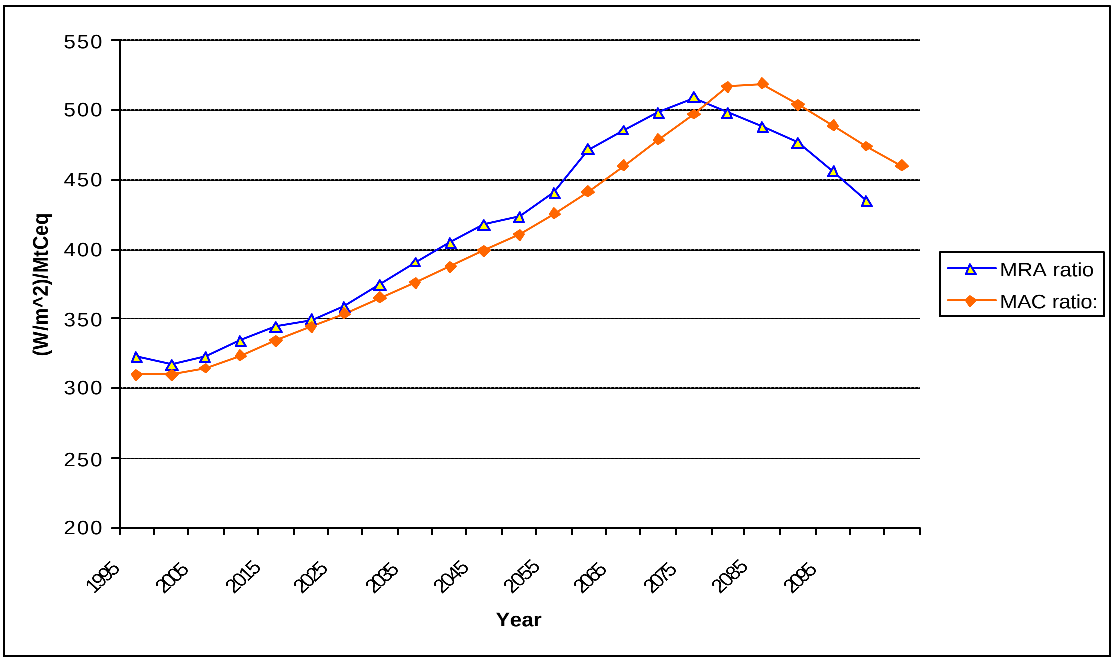

Table 5: Economic costs (in Million 95$US) of emission reductions associated with a climate control policy to reduce radiative forcing level to 6 W/m^2 by 2100.

	Experiment A Using Fixed GWP weights				Experiment B Using Flexible GWP weights from an Integrated Assessment Approach			
	Costs of reducing emissions from Reference Case				Costs of reducing emissions from Reference Case			
YEAR	CO2	CH4	N2O	Total	CO2	CH4	N2O	Total
1990	723	125	15	863	863	2	17	882
1995	1179	61	3	1244	1089	2	3	1094
2000	1427	55	3	1485	1283	2	2	1287
2005	1676	56	2	1735	1487	2	2	1492
2010	1943	60	3	2005	1709	3	3	1714
2015	2231	66	3	2300	1939	4	3	1946
2020	2546	72	3	2621	2179	6	3	2189
2025	2888	79	4	2971	2440	11	4	2455
2030	3262	88	4	3354	2726	19	4	2749
2035	3669	97	5	3771	3036	32	5	3073
2040	4112	107	5	4224	3398	43	6	3446
2045	4594	118	6	4718	3803	49	7	3859
2050	5117	130	6	5254	4236	58	8	4301
2055	5684	144	7	5835	4699	68	9	4776
2060	6299	158	8	6465	5197	81	10	5288
2065	6966	174	9	7148	5731	97	12	5840
2070	7689	190	10	7889	6310	112	14	6436
2075	8472	209	11	8692	6937	127	16	7080
2080	9322	228	13	9563	7611	145	18	7774
2085	10241	250	14	10505	8336	165	19	8520
2090	11231	273	16	11520	9116	187	21	9324
2095	12289	298	18	12605	9955	213	22	10191
2100	13389	324	20	13733	10856	243	24	11123
		NPV at (0%)		130498		NPV at (0%)		106841
		NPV at (5%)		61224		NPV at (5%)		50409

Table 6: Radiative Forcing Levels from GHG Emissions

	Experiment A Using Fixed GWP weights				Experiment B Using Flexible GWP weights from an Integrated Assessment Approach			
	Radiative Forcing Level contributed by				Radiative Forcing Level contributed by			
YEAR	CO2	CH4	N2O	Total	CO2	CH4	N2O	Total
1990	1.49	0.42	0.13	2.04	1.49	0.42	0.13	2.04
1995	1.64	0.41	0.16	2.20	1.64	0.41	0.16	2.20
2000	1.79	0.40	0.18	2.36	1.79	0.40	0.18	2.36
2005	1.93	0.39	0.20	2.52	1.93	0.40	0.20	2.53
2010	2.06	0.39	0.22	2.67	2.07	0.39	0.22	2.68
2015	2.19	0.39	0.25	2.83	2.19	0.40	0.25	2.84
2020	2.31	0.39	0.28	2.98	2.32	0.40	0.28	3.00
2025	2.43	0.40	0.31	3.14	2.44	0.41	0.31	3.15
2030	2.54	0.41	0.35	3.29	2.55	0.41	0.35	3.31
2035	2.64	0.42	0.39	3.45	2.65	0.41	0.39	3.46
2040	2.74	0.43	0.43	3.60	2.76	0.42	0.44	3.61
2045	2.83	0.44	0.48	3.76	2.85	0.42	0.49	3.77
2050	2.93	0.46	0.54	3.92	2.95	0.43	0.55	3.93
2055	3.01	0.47	0.61	4.09	3.04	0.44	0.61	4.09
2060	3.09	0.49	0.68	4.25	3.12	0.45	0.69	4.25
2065	3.16	0.50	0.76	4.43	3.19	0.46	0.77	4.43
2070	3.23	0.52	0.86	4.61	3.27	0.47	0.87	4.61
2075	3.30	0.54	0.97	4.80	3.34	0.48	0.98	4.80
2080	3.36	0.56	1.09	5.01	3.41	0.50	1.10	5.00
2085	3.43	0.58	1.22	5.23	3.47	0.51	1.24	5.22
2090	3.49	0.60	1.38	5.46	3.54	0.53	1.39	5.46
2095	3.55	0.62	1.55	5.72	3.61	0.55	1.56	5.72
2100	3.62	0.65	1.74	6.00	3.68	0.57	1.76	6.00

Table 7: Emission Reductions from the Reference Case

	Experiment A Using Fixed GWP weights			Experiment B Using Flexible GWP weights from an Integrated Assessment Approach		
YEAR	CO2 (Mt C)	CH4 (Tg CH4)	N2O (Tg N2O)	CO2 (Mt C)	CH4 (Tg CH4)	N2O (Tg N2O)
1995	282.2	14.6	0.815	272.3	11.6	0.742
2000	296.1	11.4	0.536	284.2	10.3	0.519
2005	308.7	10.4	0.460	296.2	9.8	0.456
2010	321.6	10.0	0.435	308.8	9.5	0.435
2015	335.1	9.8	0.430	321.6	10.0	0.432
2020	349.4	9.9	0.436	334.9	11.0	0.438
2025	364.5	10.0	0.449	349.1	11.9	0.451
2030	380.4	10.2	0.466	364.4	12.6	0.468
2035	397.2	10.5	0.488	380.8	13.3	0.490
2040	414.9	10.8	0.512	398.7	13.2	0.514
2045	433.4	11.2	0.539	417.8	12.9	0.542
2050	452.9	11.6	0.569	437.5	13.0	0.572
2055	473.3	12.0	0.601	458.0	13.2	0.605
2060	494.6	12.4	0.636	479.4	13.4	0.640
2065	516.9	12.9	0.674	501.7	13.8	0.678
2070	540.1	13.4	0.715	524.9	14.2	0.719
2075	564.4	13.9	0.758	549.2	14.6	0.763
2080	589.6	14.5	0.805	574.4	15.1	0.809
2085	615.8	15.0	0.855	600.5	15.6	0.858
2090	643.0	15.6	0.909	627.7	16.2	0.911
2095	671.3	16.3	0.966	655.9	16.8	0.968
2100	700.5	16.9	1.028	685.0	17.4	1.029

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