The Kyoto Protocol: an economic appraisal

Michael Grubb
Professor of Climate Change and Energy Policy,
Imperial College, London

Associate Fellow,
Royal Institute of International Affairs

Introduction

The Kyoto Protocol addresses probably the most profound and difficult global environmental problem that we face. The exact implications of climate change remain impossible to quantify, but we know enough to recognise that any rational response, including an element of precaution and risk aversion in the face of planetary uncertainties, must include significant efforts to limit emissions.

This paper summarises wide-ranging research on both institutional structure and the quantitative economic aspects of the Kyoto Protocol, and is divided into three main parts.

The first part considers the structural elements of the Protocol in relation to economic ideals and institutional practicalities, and the prospects for taking these forward in the post-Kyoto process.

Part II then analyses quantitative aspects of the Protocol's commitments, drawing upon a range of modeling results and other analyses, including recent data.

The final part of the paper then explores the longer term implications of the Protocol, including issues surrounding the involvement of and implications for developing countries and global emission trajectories.

Part I: Flexibility in the Kyoto Protocol commitments

In terms of optimal resource allocation within the general equilibrium framework, efficiency can be directly equated with flexibility in the implementation of commitments.

Four dimensions of flexibility are identified within the economics literature surrounding climate change, that are assumed to minimise the costs of any given degree of control:

- *What* flexibility – constraints should apply to the overall 'global warming potential' of aggregate emissions, rather than to only a subset of relevant gases or to different gases in isolation);

- *How* flexibility – countries should be free to judge the most efficient tools to apply within their national context, to achieve a specified level of emissions, rather than for example defining action in terms of technology standards and other specific policies (except where a direct economic case can be identified for harmonising measures);

- *Where* flexibility – since CO2 is a globally and uniformly mixed gas, the location of emissions is irrelevant and countries should be free to meet their emission obligations at home or abroad;

- *When* flexibility – there should be flexibility as to the timing of emission constraints consistent with the long-term policy objective.

The Kyoto Protocol matches surprisingly well against these four objectives:

What flexibility. The Protocol commitments are defined in terms of a basket of the six major greenhouse gases from industrial and agricultural sources, with adjustments for land-use change and forestry (LUCF), which are largely identified with 'sinks'.[1]

How flexibility. The Protocol specifies its main quantified obligations in terms of aggregate emissions during the commitment period. It suggests a range of specific policies and measures for consideration with obliging these, and states that *if* the Parties 'decide that it would be beneficial to ooordinate any of the policies and measures', they should then 'consider ways and means to elaborate the coordination of such policies and measures..' (Art. 2.4). Some economists have suggested that a harmonised carbon tax would be more efficient (Cooper, 1998). However this is both economically highly debatable,[2] and politically wholly unrealistic.[3]

Where flexibility. The Protocol contains four instruments of international flexibility:

- 'bubbling' (allowing redistribution of emission commitments at the time of ratification, principally for the EU: Article 4);
- 'joint implementation' (trans-border project investments among the industrialised countries that credit savings to the investing Parties: Article 6);

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[1] The LUCF provisions are particularly subject to limits of monitorability, anthropogenicity, and other considerations; detailed rules for sinks are still to be negotiated subsequent to a Special Report by the IPCC on the technical issues. In addition to the six major gases, some other human emissions have an indirect effect on radiative forcing, but this has proved extremely difficult to quantify, and furthermore most such emissions have effects that are not directly comparable: for example, sulphur emissions that affect aeorsol formation act locally and regionally over periods of a few weeks (and of course are also implicated in acid rain deposition). For details on the issues debated and outcome concerning multiple gases and LUCF see Grubb et al., (1999, chapters 3 and 4).

[2] Economically, the rationale advanced for preferring taxes over quantity constraints derives from the judgement that the marginal cost schedule of abatement may be steeper than the marginal benefit schedule (Newell and Pizer 1998) in which case, gi ven uncertainties about absolute rates and assuming a perfect market, price instruments would be preferrred for reasons elaborated by Weizmann (1974). All this of course is itself a highly uncertain judgement and global energy markets are not noted for being perfect. Price structures vary widely, and serve to meet multiple objectives; and removal of subsidies, liberalisation, voluntary agreements, emission permits, technology programmes, etc, all have a role to play. All these can have a role to play in a target-based system, unlike one specified upon a coordinated international tax.

[3] In practice, the US led widespread rejection of attempts to specific specify policies and measures in the Protocol both on the grounds that this would constrain 'how' flexibility (in contrast to emission targets) and that it would be an unwarranted interference in national sovereignty. Trying to place onus on a coordinated international tax was the original EU position in the early 1990s. In practice of course effective and efficient carbon taxation has proved not negotiable even within the EU or most nation-states, and hence it is clearly impossible in an international agreement for the foreseeable future.

- the 'clean development mechanism', that allows international project investments in developing countries that also contribute to their sustainable development, to generate emission credits that may be used by the investing countries (Article 12);
- emissions trading (Article 17), with all the rules, modalities, guidelines, etc still to be negotiated.

Although these four are institutionally very different, these mechanisms introduce in principle a very large degree of global flexibility in the implementation of commitments.

When flexibility. The Protocol defines a structure of successive five-year commitment periods, with specific numerical targets for the first period, 2008-2012, and over-compliance in the first period may be 'banked' for use in subsequent periods. The first period was set relatively broad (5-year breadth) and, from an institutional perspective, rather distant (centred on 2010). The US in particular argued that such time would be needed to allow adjustment for capital stock and to allow for interannual fluctuations.

Therefore, the Protocol has major elements of all four dimensions of flexibility. The first two are absolutely intrinsic. The third, 'where' flexibility, is embodied in four different instruments for which many institutional aspects remain to be resolved, and on which some Parties propose constraints, as discussed below.

The fourth, *when* flexibility, is probably the area where economists have most attacked the Protocol. Specifically they argue that the Protocol should allow 'borrowing' of emissions from subsequent commitment periods; and, more generally, that the Protocol is flawed in focussing on limiting emission *levels* rather than specifying aims in terms of long-term concentration targets (Toman, Anderson and Morgenstern, 1999).

The fact that borrowing is not included in the Protocol is the only area in which the US-led drive for flexibility did not succeed, although the timing and duration of the commitment period was indeed strongly influenced by the US stance (the EU pushed for a shorter period, closer than several electoral cycles away). US proposals on borrowing were rejected by every other country except Australia for one simple reason: unconstrained borrowing would make the whole agreement meaningless under international law, because there would be no point in time at which non-compliance could be established.[4]

Concerning proposals for concentration targets, no-one has come up with any politically or legally credible way of defining a concentration target-based agreement, because future generations cannot hold current generations accountable for inadequate action which would leave them in an impossible position. The only proxy is intermediate emission targets, which is exactly what the Protocol contains. Long-term concentration targets would also violate a basic economic principle of adapting the strength of action in response to evolving knowledge.

Furthermore, it is wrong to classify climate change purely as a stock problem. There is ample evidence that the rate of climate change matters, perhaps more so even than the ultimate degree; thus the climate change has dimensions of both stock and flow.

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[4] A country could simply avoid any non-compliance assessment by claiming it was borrowing from some subsequent period, rending any such agreement legally meaningless. Faced with this observation, the US retreated to recast the proposal in terms of deducting emission allowances from subsequent periods as one of a number of non-compliance penalties, but by this time there was deep suspicion that the net effect – and perhaps clandestine purpose – of 'borrowing' proposals was to undermine the basic integrity and clarity of the commitments and compliance procedures.

In short, the most striking feature of the Kyoto Protocol is the degree of flexibility afforded, which appears to be as wide-ranging as feasible in the real world. In consequence, at least in terms of economic equilibrium precepts, the Protocol commitments for industrialised countries are also as structurally efficient as could reasonably be expected.

The degree of flexibility is particularly striking in comparison to previous agreements. Though the Montreal Protocol has some international production-rationalisation clauses, and the Oslo Sulphur Protocol allows for some 'joint implementation' in an unstructured way, the Kyoto Protocol is wholly unprecedented in the range of its flexibilities, which include global reach through the clean development mechanism.

The difficulties and economic criticisms of the Protocol relate centrally to three other aspects.
First, whether the Protocol's institutions can be made to work. The evidence on this is encouraging. The first major political milestone after Kyoto was the next annual Conference of Parties to the Climate Change Convention, COP-4, held at Buenos Aires in November 1998. In many respects COP-4 was an epilogue to the Kyoto agreement itself, confirming the basic agreement and defining the follow-up process. It was widely referred to as 'dealing with Kyoto's unfinished business.' Despite extensive prior opposition, it became clear that all negotiators accepted the Protocol, including the mechanisms (together with other issues under the Convention) as the basis upon which they would work henceforth, and that the key agenda of COP-4 would be to set out a credible work programme. The specific result of the Conference was the Buenos Aires 'Plan of Action', which consisted of decisions in six specific areas:[5]

- Financial mechanism
- Development and transfer of technologies
- Addressing the specific needs and concerns of developing countries, including minimisation of adverse impacts (Articles 4.8 and 4.9).
- Activities implemented jointly under the pilot phase
- The mechanisms of the Kyoto Protocol
- Preparations for the first session of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol (including compliance)

The Buenos Aires decisions thus set a programme and timetable of negotiations on how to implement the Kyoto Protocol. Most central to this paper, the decision on the mechanisms established a work programme, undertaken 'with priority given to the CDM, to take a final decision on the mechanisms (JI, the CDM, and emissions trading) at COP-6' (the sixth Conference of Parties, around the end of 2000).

The second main area of concern expressed particularly by economists surrounds the lack of quantified commitments for developing countries. With the Clean Development Mechanism offering global distribution of the effort expended by the Annex I Parties, this is strictly speaking more of a political and ethical issue than one of economic efficiency, if the CDM works effectively. Furthermore, the Protocol does move forward the involvement of developing countries in other ways, and under the Buenos Aires plan establishes a new set of negotiations to aid technology diffusion to developing countries.

[5] Specifically: Decisions 2/CP.4 and 3/CP.4 on the financial mechanism, with others numbered sequentially in the order given here.

Global efforts on climate change have since their inception been based on the principle, enshrined in the original UN Framework Convention on Climate Change, that industrialised countries should take the lead. They are, after all, responsible for most of the accumulated greenhouse gas emissions (and hence concentrsation increase) to date, and still have per-capita emissions some 5-10 times those typical in the poorer developing countries, as well as far greater wealth and technological expertise.

In previous environmental regimes, developing countries have become progressively more involved over time as industrialised country action leads the way. The rolling 5-year structure of the Kyoto commitments regime provides a natural structure for drawing more countries into binding constraints over time, as appropriate to their level of development.

There is no doubt that the structural division between industrialised and developing countries forces an extremely crude division that has many undesirable features. Grubb et al (1999, p.113) note this as the biggest structural problem of the Protocol, but conclude that 'in this respect, the Kyoto Protocol is a victim of the UN system itself. Its structural failures are no greater than those of the UN system; and the task of moving forward no less awesome in its complexity.' I return to the economic implications in the final part of this paper.

Finally, although scientists and environmentalists have attacked the commitments for being far too weak, many economists by contrast claim that they are far stronger than is justified or politically feasible. The next part of the paper explores these claims.

Part II: Strength, cost, optimality and feasibility of commitments

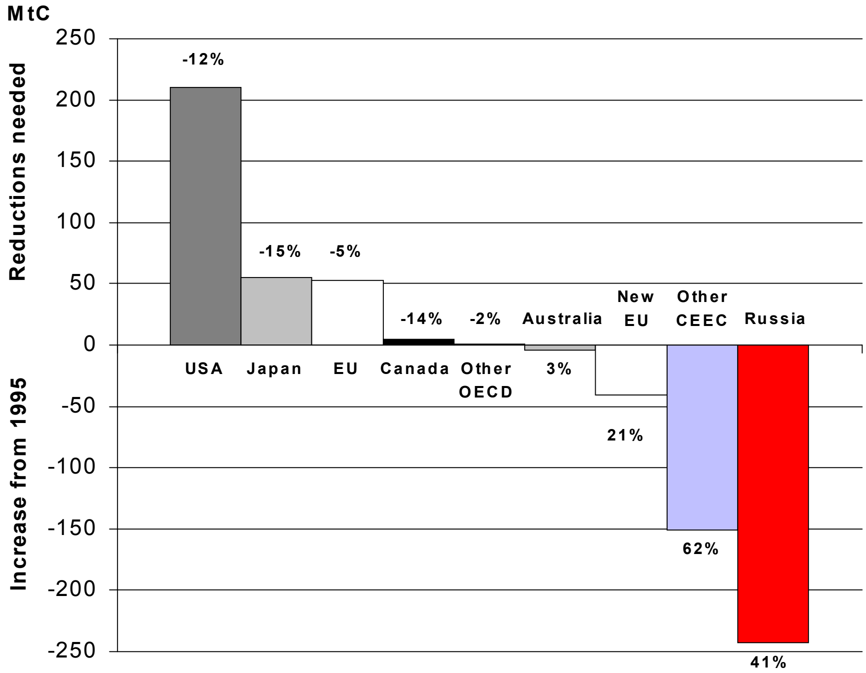
2.1 Current situation

A first indication of the task facing industrialized countries in implementing the Kyoto commitments may be observed simply by considering the reductions required from the levels already attained during the 1990s. Due to the transition in the Economies in Transition, emissions from the industrialised countries *in aggregate* by 1995-6 had decloined by about 6% from 1990 level, so that the *aggregate* Kyoto commitment is to hold Annex I emissions roughly at the levels of the mid-1990s fifteen years hence.

In terms of *distribution* the story is of course radically different. In the EU, emissions had declined – albeit not primarily due to climate change policies - and the most recent projections suggest that member states will – just – achieve the Convention's aim of holding emissions of CO_2 and other greenhouse gases below 1990 levels in the year 2000. In fact, it is likely that the modest abatement policies adopted in some European countries during the 1990s have tipped the balance in this respect. The rest of the OECD is commited to bigger reductions from the higher levels they had reached in the mid-1990s, while the EITs have scope for a big increase.

Figure 1illustrates the specific changes from emission levels in the mid 1990s (mostly 1996 data) for different groups within Annex I. This confirms that the Kyoto commitments represent a big reduction from 1996 levels for all the OECD countries except Australia, and a big increase for all the central and east European countries, especially the ones less advanced in their economic transition that are not currently on track for EU membership.

Figure 1 Gap from 1996 emission levels to Kyoto commitments in principal Annex I groups



Notes. The bars show the difference between reported emissions in 1995 and the Kyoto commitments in absolute (height of bars) and percentage (data) terms. Negative data indicate scope for increase from 1995 levels (positive % allowable emissions growth as indicated). LUCF emissions are not included: they would increase the allowed scope for emissions growth in Australia especially.

Source: M. Grubb, C.Vrolijk, D.Brack, *The Kyoto Protocol: a Guide and Assessment*, London: RIIA/Earthscan; Washington: Brookings, 1999 (Figure 5.3).

Table 1 shows results from a wide range of economic modelling studies presented to an OECD workshop (the models are 'top down' in nature; they contain various engineering detail, but most assume the reference trajectory to be optimal). These show wide divergences in results of achieving the Kyoto commitments domestically in the different regions. The marginal cost of hitting the target tends in most of the models to be highest in Japan and Europe and somewhat lower in the US, and across the full range of models span a factor of ten *within* each region. Neglecting the two outlier models (GTEM and WORLDSCAN), costs *without* international flexibility are mostly grouped in the range \$80-\$200/tC. These reflect modelling estimates of meeting the commitments without any international flexibility and mostly model CO2 taxes alone, without allowance for possible 'no net cost' reductions from other approaches (see text). The biggest national economic study of the cost of the Kyoto commitments, by the US administration, assumed full flexibility and estimated that the actual marginal costs to the US would lie in the range \$14/tC to \$23/tC (Yellen, 1998). The study estimated that this was about a quarter of the costs in the absence of international flexibility.

Table 1 Estimated costs of achieving Kyoto commitments from various economic models

Model	Marginal cost of target achieved domestically, $/tC			% GDP loss with domestic implementation [a]	% GDP loss with full trading
	US	Europe	Japan		
SGM	163			0.4%	
MERGE	274			1%	0.25%
G-Cubed	63	167	252	0.3-1.4% [b]	'Decline significiantly'
POLES	82	130-140	240	0.2-0.3%	
GTEM	375	773	751	0.7-2.0%	0.3%
Worldscan	38	78	87	-	
GREEN	149	196	77	0.4-0.9%	0.1-0.5%
AIM	166	214	253	Less than 0.5%	

a) Note that the exact welfare measure varies between the models and these estimates may not be directly comparable

b) GNP: In G-Gubed the US GDP increases slightly due to competitiveness gains: GDP stated as a gain of 0.1% for the US, 1.6% loss in Japan and 1.5% loss in other OECD.

Source: Derived from OECD (1998) Tables 1 and 2., as summarised in Grubb et al. (1999), Table 5.1.

The total costs, expressed in terms of estimated GDP losses by the year 2010, also span a large range across the OECD studies. If no allowance is made for the international flexibility mechanisms in the Protocol – the commitments are implemented entirely domestically – the estimated GDP losses range from 0.2 to 2% of GDP, or 0.3-1.4% neglecting the outlying models. International flexibility (modeled as trading within Annex I) greatly reduces these costs in all the modeling studies, to under 0.5% of GDP across Annex I. Also it is intriguing that the only fully macro-economic model (in the traditional sense of the word) of those in Table 1 predicts a net gain to the US economy from implementing Kyoto, due to competitiveness and exchange rate effects.

Furthermore, and quite apart from technical debates about modelling approaches, these figures probably substantially over-estimate the actual costs of implementing the Kyoto Protocol because most of them do not include the non-CO2 gases, sinks, or the CDM, but assume rather that the commitments apply to CO2 alone.

There are of course various ways of presenting such numbers. Something under a 0.5% loss in Annex I GDP by 2010 is equivalent to foregoing a few months of GDP growth and is hardly discernible compared to the projected overall growth and uncertainties therein. In absolute terms of course it is more impressive: projected Annex I GDP by 2010 is around $17,000bn, 0.5% of which is $85bn. To put this in perspective, however, even this maximum estimate is less than the value wiped off shares on the London stock exchange on the day of the Brazilian currency crash in January 1999. Most models depicted far lower costs – and more detailed and updated analysis seems likely to throw further doubt upon the claims that Kyoto will be unmanagebly costly, for reasons I now consider.

2.2 Economic determinants and uncertainties

Four main economic issues can be identified that are likely to alter cost estimates as analysis proceeds beyond the first efforts summarised above.

(a) Full range of flexibilities

The Protocol contains many more dimensions of flexibility than have generally been modeled. It allows countries to choose different base year data for some purposes – 1995 emission levels of the industrial trace gases, different base years for some of the EITs, and to include land use emissions if these constituted a net source in 1990. Then, of course, the Protocol includes multiple gases. These 'other greenhouse gases' are estimated to have comprised about 20% of total 1990 greenhouse gas emissions in the EU and Canada, about 15% in the United States, and a little over 5% in Japan. For certain other countries – notably Australia, New Zealand, the Scandinavian countries and most of the former Soviet countries – the other greenhouse gases are even more important. Most of these gases appear cheaper to control than CO2; The Energy Journal Special Issue (hereafter EJSI: p.xli) notes that 'preliminary estimates show that the the inclusion of sinks and other gase have the potenial to reduce the total cost of meeting the obligations specified.' Emissions trading and joint implementation in effect give the big OECD emitters access to these emission reduction opportunities in other countries, including the EITs.

Then of course, the Protocol also include sinks, with rules still being negotiated, and the CDM. In principle, the CDM may also allow them to offset their commitments against emission savings in the developing world, where some of the 'other gases' are also more important.

Note that even a moderate increase in flexibility, for example through sinks or the CDM, may substantially reduce marginal costs since these are commonly considered to rise non-linearly.

None of the modeling studies cited actually include all these dimensions of flexibility. That should be a first task of improved modeling. Although a few model runs have erred on the optimistic side (the MERGE analysis in EJSI makes some allowance for sinks assumed at no cost) , in general doing so will incline to lower costs. Bringing in more options without more obligations will *always* lower marginal costs.

(b) Macroeconomic realities and institutional change

A second important area concerns the macroeconomic and institutional context. The optimising models generally assume rational policies that minimise costs, and several assume a high degree of capital malleability. In these respects they may underestimate adjustment costs. On the other hand, most of the models applied above assume that economies start from an optimum state, so that CO2 constraints inevitably imply costs. Reality is more complex. Many economies still contain large subsidies, explicit or hidden, in the energy sector. In the UK, where economists in the late 1980s were still proclaiming coal power to be the cheapest source and projecting emission increases of 30% by 2005, the liberalisation of the electricity sector has led to large reductions in emissions that have in fact been associated with economic gains.

This is but one example of the complexity of institutional realities underlying claims of 'no-regret' options. Many engineers continue to maintain that the scope for cost-effective improvements in energy efficiency especially mean that the Kyoto targets could be achieved with net economic benefits. This appears implausible to most economists, but fundamental economic debates continue concerning ways of defining and estimating abatement costs, and accounting for options that appear already cost effective (but are not taken up due to a variety of institutional barriers), technological progress, and secondary benefits of emissions control.

Indeed there is a vast technical literature on how greenhouse gas emissions can be reduced with net economic benefit. To European and Japanese visitors, the opportunities seem particularly large in North America, where the continued lack of some basic housekeeping measures of energy efficiency help (but only in part) to explain CO_2 emissions almost twice as high per person, and significantly higher also per unit of GDP, than in Europe or Japan. American negotiators in turn tend to be more conscious of the waste in east European societies and in developing countries.

Of course, technical opportunities do not readily translate into rapidly achievable emission reductions, for a whole host of reasons beyond the scope of this book. But it is not at all unreasonable to suppose that certain kinds of policy reforms can lower emissions without significant macroeconomic costs, and this is generally excluded in the economic models applied to assessing Kyoto.

(c) Emissions projection uncertainties

A related but more specific indication of the scale of the uncertainties may be gleaned from the uncertainties in projection 'business-as-usual' emissions in the absence of CO2 control. Energy forecasting, according to an old adage, was invented to make economic forecasting look good. Projections have repeatedly been proven wrong by reality. With relatively rare exceptions (notably, trends in some regions in the early 1990s, probably due to reactions to the oil price collapse) projections have usually been too high.

Table 2 shows estimates of BAU projections of CO2 emissions by 2010 from a range of sources. The first column summarises results from a comparison of 10 models by the Energy Modeling Forum. Despite being run under comparable assumptions, and with many sharing some common fundamental aspects of general equilirbrium frameworks, they generate a wide range of BAU forecasts. The US Energy Information Administration has also recently produced revised forecasts with different scenarios, with the high and low variants displayed. Finally, these are compared with official national emission projections submitted by governments to the UNFCCC (where available) or estimates derived from such national data and projections as the author could derive.

Table 2 'Business as usual' CO2 forecasts from various sources: % change from 1990 levels

Region	Range of forecasts from EMF-16 models	Energy Information Administration forecasts		Official national communications to UNFCCC / ITEA estimates	
		Low scenario	High scenario	Base	High
European Union	11 - 38% (outliers 56, 75%)	2.5%	15.8%	2.3	
United States	21 - 36%	27.6%	38.0%	23.2	
Japan	19 – 34 % (outliers 11, 75%)	5.8%	30.3%	14.9	20.0
Australia	28 – 41 % (outliers 75, 102 %)	17.7%	34.4%	42.1	
Canada	48%	19.8%	38.1%	18.7	
Other OECD		18.3%	32.9%	26.5	
Russia	- 14%	-39.2%	-18.4%	- 17.8	- 4.7
New EU	48%	-18.0%	5.9%	- 18.4	9.0
Other CEEC	-14%	-31.9%	-10.0%	- 23.6	- 12.6
(of which Ukraine)				- 17.7	- 9.2
Total Annex I		2.5%	18.2%	2 %	7 %

Source: Energy Journal Special Issue, 1999; Energy Information Administration, 1999; National Communications/ITEA (Grubb et al, 1999)

Considerable caution needs to be exercised in using such projections. There is the semantic but important question of what is meant by 'business-as-usual' projections, since one of the few things known for certain about the future is that it will not be 'as usual'. Furthermore, projections are inevitably influenced by perceptions, hopes and political objectives.[6] The low EU governmental projections undoubtedly reflect both hope and intent to constrain greenhouse gas emissions in their 'reference' scenario. EIA projections have historically tended to be very high.

The enormous range of estimates is striking. Even more notable is that for Europe and Japan particularly, but also for the US to a lesser extent, the projections of the global models tend to be on the high side – or well above – the detailed national projections submitted by governments to the UNFCCC. This may reflect optimism on the part of government ministries making these submissions. It may also reflect that they are making far more detailed assessments of their national prospects, taking into account structural changes and other factors that are beyond the scope of the global models. For some countries, interestingly – notably, Australia and the EITs - the reverse is true.

Modeling projections themselves have started to come down recently, and may do so further in the light of recent data indicating that US emissions, after the jump in 1996, climbed less than 2% over the two subsequent years despite above 8% economic growth. Most striking of all are the recent revisions of projections for the EITs by the US Energy Information Administration: within the space of one year, their reference projections for carbon emissions from the Former Soviet Union were reduced by more than 30%, from 967 MtC (1998 Outlook) to 666 (1999 Outlook). The situation in EITs and the implications of this are discussed further.

[6] T. Baumgartner and A. Midttun, *The Politics of Energy Forecasting*, Oxford: Clarendon Press, 1987.

Not for the first time, it seems, energy and emissions projections of only a couple of years back show evidence of being too high. The projections towards the low end of the spectrum now suggest that aggregate Annex I emissions in 2010 may only be a little above 1990 levels *even in the absence of policies directed at implementing Kyoto*. Given all the additional flexibilities, and scope of policy reforms, this is not a big gap.

(d) Economies in Transition

Uncertainties in projections are particularly dramatic concerning the situation in central and eastern Europe. According to official projections, the desperately sought economic growth will inevitably result in emissions rising back towards their levels before the transition from communism, albeit to widely varying degrees. In reality this seems debatable. Most of these countries are still much less efficient in their use of energy than the EU or Japan, and Russia at least remains more energy intensive than the United States.[7] Since 1992, despite economic growth in several EIT countries including the Czech Republic, Hungary, Poland and Slovakia, emissions continued to decrease before roughly stabilizing in the mid-1990s. It is arguable that CO_2 emissions need not grow, and could even decline, on account of the efficiency improvements associated with renewed economic growth. The uncertainties are particularly large – and important – in Russia and Ukraine, given their size and chaotic economic situation (see Box), and as noted the EIA has in the space of one year radically revised its forecasts for this region.

Box: Which way for Russian and Ukrainian net greenhouse gas emissions?

Russia and Ukraine between them account for over 22% of the total 'assigned amount' of emissions under the Kyoto Protocol.. Their likely emissions are thus particularly important within the context of EIT uncertainties. Ukrainian emissions are estimated to have declined by more than 40% since 1990 and as yet they show no sign of upturn. In Russia, emissions since 1993 appear to have been fairly static at about 30% below 1990 levels. However, Russian industrial production has declined by almost 60%.

One reason why Russian emissions have declined less than elsewhere in the former USSR appears to be that it has not been politically possible to reform the energy sector. Vast amounts of energy are still delivered to customers who do not pay: in October 1998, following the financial crisis, the giant gas supplier Gazprom stated that only 6% of customers had paid bills in September, and surveys suggest that less than half of industrial customers *could* pay; the rest would simply go out of business if payment were enforced. The possibility needs to be recognised that Russian emissions could go down, not up, if and as economic reforms succeed. In addition, Russia and Ukraine are countries with huge land areas, including some potentially very productive soils; Ukraine used to be the 'breadbasket of Europe'. The potential for sinks must be enormous, though no data were found for Ukraine. The Russian 2nd National Communication estimates total net sinks from forests in 1994 at about a third of its CO_2 emissions. In short, there is a distinct possibility that Russia and Ukraine will have far more surplus assigned amounts under the Protocol than any quantified analysis has so far considered possible.

[7] Economic structures dependent upon energy-intensive industries, often with old technologies, have resulted in high-energy consumption per unit of GDP and high carbon intensity. This in turn has led to high per capita and absolute emissions of CO_2, generally between those of the EU and the United States. National carbon intensities (CO_2 emissions per unit of GDP) are declining, but most remain well above the levels in the EU. More relevant indicators based on purchasing power parity estimates suggest that by 1993 carbon intensities in Hungary, for example, were comparable to those in the UK and Germany, while Polish carbon intensity was below that of the United States. By 1993, most central European countries were less carbon intensive than the United States but more so than the EU, while Russia (and probably other FSU) remained well above US levels. See K. Simeonova and F. Missfeldt, *Emission Trends in Economies in Transition,* EEP Climate Change Briefing, No. 8, November 1997.

The situation of the EITs – which between them comprise well over a quarter of the allowed emissions under Kyoto - is crucial in interpreting the relationship between model results and likely real outcomes. The fact is that these countries pose almost intractable problems for modeling: economic models assume by their very nature that economies are functioning, in the sense that people pay the prices modeled. Aggregate economic models can tell us very little indeed about the real prospects for a country where the precondition of successful economic growth will be to establish the institutional conditions (such as payment enforcement) that models take for granted. And the effect of payment enforcement is likely to be to lead to further reductions in emissions, and bring the energy intensities in these countries at least somewhat closer to western levels.

The Energy Journal Special Issue does not contain overview data on the reference projections of the EITs. Where such data are given in the individual papers, however, most of these projections are for considerable growth from current levels, in stark contrast to more detailed and recent analyses. This is not surprising. Most of these models assume by construction that the EITs are functioning market economies. The largest ones – Russia and Ukraine – are demonstrably not. They are still in the throes of economic transition that may well see further emission reductions. This has huge implications for the Kyoto regime, to which we now turn.

2.3 The cost of Kyoto: a sensitivity study

Emissions trading and joint implementation in effect give the big OECD emitters access to emission allowances and reduction opportunities in other countries, including the EITs. Overall this makes the Kyoto Protocol a complex agreement: there are so many dimensions of flexibility that its real quantitative implications are unclear. This combines with the underlying uncertainties in baseline assumptions indicated above. This section looks in generic terms at how basic assumptions may affect the estimates costs. The following section then explores the impact of the flexibilities in more detail. The analyses use a simple analytic framework intended to capture the main points and uncertainties discussed above.

Analytic framework

The analysis uses a simple computer-based model of emissions from each industrialized country during the commitment period. Given data on likely emissions in the absence of abatement and on the costs of control, the model presents behaviour that minimizes total abatement costs during the commitment period among the Annex I countries. In principle, the result could be obtained by using any mix of the Annex I mechanisms for international adjustments and flexibility (bubbling, emissions trading and JI), in combination with optimal choices by each country about the mix of different gases and sources to be limited. Thus, for example, it means that Japan can contribute to meeting its formal commitment by trading 'assigned amounts' or by investing in Russian methane reductions, if that is cheaper than limiting its domestic CO_2 emissions. In terms of a purely static economic analysis, bubbling and the two Annex I transfer mechanisms are almost identical, and this chapter seeks simply to explore the possible overall implications of such mechanisms for the level and distribution of emissions and costs.

In common with the economic studies cited in the previous section, the model assumes competitive, least-cost behaviour during the commitment period; Russia, for example, 'sells' its methane reductions to the highest bidder (which also defines the average price of emission quotas). Given the commitments, each Party trades on any difference in abatement costs, to mutual benefit. In effect the model assumes a competitive market for emission quotas, completely transparent for participants and without costs for the trading itself. Obviously this is a crude representation of reality for such a nascent system, but the results are instructive for understanding the potential implications of what has been created.

The International Trading of Emissions Allowances (ITEA) model is designed to be simple, transparent and readily adaptable to explore the implications of different assumptions about emission trends and abatement costs. It aims to be comprehensive in its coverage of gases and regions, and to relate to official projections and real-world phenomena, giving some aggregate scope for 'no net cost' potentials, rather than pursuing economic detail. The model does not contain any explicit representation of sinks and the CDM, because of the huge uncertainties involved and (even more) inadequate data; but these can be considered as contributing to a 'no net cost' portion of the abatement curve.

ITEA is based upon a simple function defining the cost of abatement relative to 'reference' projections, as summarised Box 2. Given its commitments, each Party trades on any differential in abatement costs. Although the model separates fossil fuel CO_2 emissions from other gases, all trade takes place in the full basket of greenhouse gases.[8] The model is published and explained further in Vrolijk & Grubb (1999), which also explores many aspects of the model sensitivities and behaviour under both Kyoto and other assumptions.

Box 2: Abatement cost modelling in ITEA

The basis of ITEA is a straightforward marginal abatement cost function for each of the involved Parties. This cost curve is defined in reductions relative to the BAU emissions in 2010 and is broken down into a two-piece linear approximation to marginal abatement costs.

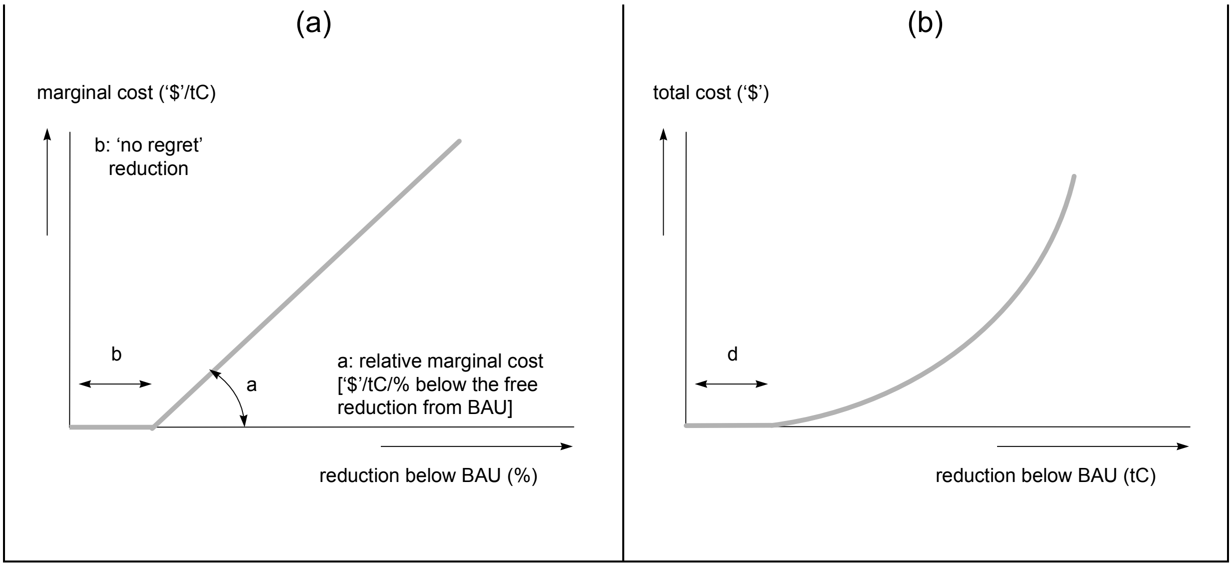
- The first component comprises reductions which incur negligible economic costs (see text)
- The second part represents linearly rising marginal costs after this 'zero cost' portion is exhausted (Figure 2a). The linearly rising segment results in quadratically increasing total costs for reductions (Figure 2b).

ITEA includes the non-CO_2 greenhouse gases, which have very different abatement costs and 'zero cost' portions. Therefore we have created a second marginal cost curve for each country representing the other GHGs, grouped together according to their global warming potential (GWP). In a scenario with multiple gases, as is the case with the Kyoto Protocol, we have summed the two marginal cost curves of each country.

The model is explained and explored more fully in Vrolijk and Grubb (1999).

[8] Since it is commitments that would be exchanged, not physical emissions, it would be meaningless to talk of trading CO_2 when the commitments themselves are defined in terms of a CO_2-equivalent basket of gases. See Chapter 6.

Figure 2 Standard marginal (a) and total abatement (b) cost curves for the ITEA model



In the model *assigned amounts* for all Parties are calculated exactly in accordance with the provisions of the Kyoto Protocol, namely base year emissions exactly as defined in the Protocol adjusted by the prescribed percentage commitment.[9] The base year emissions data for all Parties are acquired from the National Communications (the Second National Communications, where available), except for Ukraine (no Communication: 1990 base year assumed with data taken from International Energy Agency).

Our analysis is almost unique among optimising models in incorporating a modest quantity of 'no net cost' reductions relative to the reference case. This may be identified either as the linearisation of low-cost options – including sinks, multiple gases and the CDM - or as fully 'no regret' options, according to ones preferences and prejudices.[10] The scope of this and the relative marginal costs for the different countries in Annex I define the abatement cost curve (see Box).

The marginal cost slopes have been defined relative to costs in the United States. The marginal cost data for the US presented in the *Energy Journal Special Issue* appear to cover a wide range

[9] Base year emissions are thus defined as:

- reported 1990 emissions of the basket of the six greenhouse gases, except for:
- the Economies in Transition that have chosen to use a different historical base year as agreed at COP-2 (see Table 4.1);
- the three industrial trace gases for which 'any Party included in Annex I may use 1995 as its base year'; in ITEA the choice of each country is automatically the year with the highest emissions, and therefore easier compliance;
- the 'Australia clause' that includes 1990 land-use emissions where these are positive (Australia and marginally for the UK and Estonia).

[10] Most economic models are optimizing models in which such possibilities are excluded by construction, or, more formally, are assumed either to be incorporated automatically in the reference case (if genuinely no cost) or not really 'no regret' due to various hidden costs. In our view this is inadequate and some climate change policies would bring additional real benefits that would not be realized in the absence of pressures to limit greenhouse gas emissions. However, the 'zero net cost' portion of the curve can equally be interpreted as representing an extended tail of low cost options such as sinks and efficiency improvements in less efficient economies through the CDM.

from about 2 to 10 $/tC/% reduction,[11] and we take this as the basis for translating the relative cost calculations in ITEA into absolute quantities.

Sensitivity analysis

In response to queries about the difference between our published results and those of many full economic models, here we conduct a simple sensitivity exploration.

For all analyses, we assume that the slope of the marginal cost curve is similar for the large coal-based New World countries (US, Canada and Australia), 20% higher for the EU, 40% higher for Japan, and 50% higher for the other OECD countries (notably New Zealand, Norway, Switzerland) that have largely hydro-dominated systems and hence a lack of low-cost options in the electricity sector. We assume the marginal cost slope of the EITs is 75% of that in the US, given their much lower efficiency. These reflect widely shared analysis of cost variations between countries, and details of inter-regional differences do not affect the main points of this section.

To explore the sensitivity of cost estimates to the scope of analysis, assuming unconstrained trading, we construct eight cases (Table 3) to explore sensitivity to three basic factors:

- *Choice of baseline emission projection.* We start with the projections for OECD countries representing the mid point of the EMF modeling projections presented in the *Energy Journal Special Issue*, and (given the absence of this data for the EITs) the MIT model, one of the central models of the EMF studies, for the EITs. We then consider the impact of using the official emission projections set out in national communications ('ITEA High Cost', Table 4), and a variant including lower emissions for the countries of the former Soviet Union (Russia and Ukraine (Russian and Ukrainian data for ITEA 'low cost' case, Table 4).[12]

- *Inclusion of zero net cost portion of the cost curve.* The standard case (assuming no net zero cost portion) is compared against a case assuming some linearised approximation to the impact of easy sinks / CDM / no-regret measures, as set out in Table 4.

- *Inclusion of non-CO2 greenhouse gases*. We include analysis of other gases, based upon national inventories and assuming (in all except the last case these other gases have a 10% 'no net cost' portion and marginal cost slope at 0.75 of that for CO2 (ITEA 'High cost'). Where not available in the National Communications emission projections for 2010, the non-CO_2 GHGs are assumed to be equal to the most recent data available or the latest year in the projections.

[11] Energy Journal Special Issue: Figure 10(a), p.xxxvii.

[12] For the EITs that have presented a credible range of scenarios for 2010 (mostly the New EU) we take as reference their 'low' projections as our 'base' case, and their 'high' projections for our 'high' case; for other EITs we assume annual growth from the most recent year for which data are available (including projections up to 2000) at rates of 1% (base case) or 2% (high case).

Table 3 Cases for study of Kyoto cost sensitivities to scope of analysis

Case	BAU projection	CO2 'no cost' portion to represent no-regret / sinks / CDM	Other greenhouse gases
I	EMF-16 mid / MIT	N	N
II	EMF-16 mid / MIT	N	Y
III	EMF-16 mid / MIT	Y: ITEA lower case	Y
IV	National Communications	N	Y
V	Nat. Comms with adjusted FSU	N	Y
VI	National Communications	Y: ITEA lower case	Y
VII	Nat. Comms with adjusted FSU	Y: ITEA lower case	Y
VIII	Nat. Comms with adjusted FSU	Y: ITEA higher case	Y

Table 4 Base economic assumptions for the ITEA cases

Region	No net cost portion (% from BAU)		Relative marginal cost slope ('$'/tC/% : US = 1)	
	Upper case	Lower case	Upper	Lower
European Union	6	3	1.20	
United States	10	6	1.00	
Japan	5	3	1.40	
Australia	12	8	1.00	
Canada	10	8	1.00	
Other OECD	4	0	1.50	
Russia	14	10	0.75	
New EU	10	8	0.75	
Other CEEC (excl. Ukraine)	12	8	0.75	
Ukraine	14	10	0.75	
Other GHGs (all regions)	20	10	0.50	0.75

Source: See Grubb and Vrolijk (1999), Appendix 3.

Results

Table 5 shows the resulting marginal and average costs. As explained the ITEA model produces relative costs and, based on the EMF analysis, we convert these to absolute costs using a cost curve for US CO2 abatement over the wide range 2-10 $/tC/% .

Table 5a Costs of Kyoto under different sensitivity cases

	Average Annex I cost $ per person per year	Marginal Annex I cost $ / tonne C
I	22 - 110	42 – 210
II	7 – 35	24 – 120
III	3.4 – 17	16 – 80
IV	3.4 – 17	16.6 – 83
V	1.4 – 7	11 – 55
VI	1 – 5	9 – 45
VII	0.4 – 2	4 – 20
VIII	-	-

The results are striking. In the first case – the closest approximation to the major EMF studies – the marginal cost is in the range 42 to 210 $ per tonne abated, with an average annual cost of 22 to 110 $ per person in the industrialised world. Including the other gases alone, on these assumptions, roughly halves the marginal cost, and more than halves the average costs. Either of the next two steps – moving towards official national baseline projections, or including some portion of 'no cost' measures, halves the average costs and reduces the marginal costs by about 30%. Combining these choices of course reduces costs further still.

Finally, in the last case – which combines official national projections and the low FSU projections with the more optimistic assumptions about the 'no cost' portion of the cost curve, the costs disappear entirely. This shows in a startling way the potential impact of Kyoto's various flexibilities under some circumstances. We proceed to a more detailed analysis of these flexibilitiies, to understand what is going on.

2.4 Analysis of Kyoto flexibilities

This section analyses numerically how the specific emission commitments could combine with the flexibility mechanisms within Annex I, focusing upon the possible implications for plausible emissions of CO_2 and other greenhouse gases during the commitment period that would be consistent with the Protocol. The specific data are as indicated above for the ITEA cases, and spelled and explained in more detail in Grubb et al. (1999), Appendix 3. The economic assumptions are made on the basis of a comparison of important energy indicators between the regions, though inevitably based partly upon judgment.

Table 4 above gives the assumptions for ITEA, for the base and 'high' cases. The 'high' assumptions test the sensitivity of results to more pessimistic assumptions that involve less scope for 'no net cost' reductions, reflecting a more conservative view of the ability to limit emissions at low cost, and the higher emission projections from national studies in Table 1.

In general there are no restrictions on trading in the analysis. We do, however, also analyse one important variant, concerning the issue of 'hot air' for EITs. To the extent that these countries' 'business-as-usual' emissions are still below their assigned amounts, this gap represents a surplus allocation. If sold to another Party, this could then increase total emissions. Various proposals have been put forward for eliminating such 'hot air' trading, many quite unsatisfactory. In our numerical analysis here, rather than place any caps upon trading in general, we explore the implications of allowing countries only to trade emission reductions below their projected reference emissions levels. The countries are thus not constrained; nor are they allowed, however, to make windfall profits in the event of their allocations turning out to be genuinely surplus to "business as usual" requirements.

Aggregate results

Some aggregated results are displayed in Table 5, comparing results obtained from national projections against those from using the projections from the Energy Information Administration. With unrestricted trading, total Annex I emissions in the commitment period equal the sum of the quantified commitments at 94.7% of 1990 levels. This is almost exactly the level attained by the mid-1990s, due to the collapse of the EIT emissions. As noted, therefore, the Kyoto Protocol as it stands is an agreement to stabilize aggregate industrialized-country emissions at the level of the mid-1990s over the subsequent 15 years.

Table 5b: Aggregate implications of Kyoto emission commitments under different scenarios

Reference Scenario	'No net cost' assumption[a]	No trade: Annex I net emissions[c] (Rel. 1990) All GHGs	No trade: CO2 only	No trade: Relative cost indicator ('$'/cap)	No restrictions: Average costs /cap/yr Relative indicator	No restrictions: Equivalent cost [b] at 2-10$/tC/% for US	EIT surplus excluded ('no hot air'): Average costs /cap/yr Relative indicator	EIT surplus excluded ('no hot air'): Equivalent cost [b]
National	Upper	-10.0%		1.37	0	-	0.05	0.1-0.5
National	Lower	-7.8%		3.12	0.49	1-5	0.9	1.8-9
EIA high	Lower	-8.8%	-3.1%	7.54	2.13	4.2-21	3.77	7.6-38
EIA reference	Lower	-11.8%	-7.6%	5.12	0.32	0.6-3.2	2.17	4.4-22
EIA low	Lower		-12.0%	3.4	-	-	-	-
EIA reference	Zero	-11.8%	-8.0%	8.99	2.3	4.6-23	5.86	11.8-59

Notes:
(a) Assumed degree of reduction-equivalent available at no net cost (low-cost or no regret reductions, offsetting ancillary benefits, low-cost sinks or CDM, etc (including first part of marginal cost linearisation). For key see Table 4.
(b) Equivalent cost for marginal cost slope range after the 'no net cost' portion of 2-10$/tC/% for US
(c) Note that Aggregate Annex I GHG Emissions with 'no restrictions' would equal the Kyoto target of –5.2% below 1990 levels; with surplus allowances excluded from trading ('no hot air') aggregate emissions would equal the case of no trading indicated in this column, but with very different distribution

The most startling result is that with the national / base case assumptions, unrestricted trading enables the commitments of the Kyoto Protocol to be met without aggregate resource cost. This is also the case using the EIA low projections even with our low case of ‘zero net cost’ assumptions. This does not imply that nothing is done. Countries are exploiting most of the ‘zero cost’ potential, which, for some, would itself imply radical changes in energy policy. In addition, there is a large volume of East–West emissions trade. Since the model assumes emissions trading to be competitive and no country has to take ‘positive cost’ measures, the model assumes that such trading is free. In practice, of course, the sellers would extract some price, reflecting for example the value of enabling some importing governments to avoid difficult political steps required to realize ‘no net cost’ measures, so there would probably be some transfer payments.

Nevertheless, given the observations earlier in this chapter that the headline commitments for the major OECD countries would mean extremely onerous reductions if the targets had to be implemented domestically, this seems a remarkable finding. In fact, it is not so surprising. It was observed that national projections, upon which this ITEA analysis is based, tend to be below the projections of many global modeling studies. The low case of the US Energy Information Administration projections result in aggregate CO2 emissions rising only to just above 1990 levels, as do the aggregate national emissions in our base case. Since we assume that the collective ‘no net cost’ opportunities amount to more than 6% below BAU projections, the aggregate Kyoto commitment falls within this span.

Under the national / base case assumptions, if hot air is excluded then countries have to move just beyond ‘no net cost’ measures. The costs are still small, with large savings arising from emissions trading. Under the ‘high’ assumptions, costs are greater, but are again greatly reduced by trading, and the vast majority of these savings are still realized even when ‘hot air’ is excluded. Imperfect trading, and the difficulty of distinguishing implementation difficulties from actual economic costs in the real world, mean that the results concerning costs should be considered only as a crude guide. Aggregate costs with unrestricted trading fall in the range 0 to 20 $ per person per year.

In the base case, the surplus allowances amount to several percentage points of the total allowed Annex I emissions. Excluding this surplus increases costs, but not as much as might be expected. Even with such ‘hot air’ excluded, the maximum costs across these studies are in the range 1 to 40 $ per person per year.

Implications for trading and emissions in different regions

The various Annex I Parties will be affected by the Kyoto Protocol in very different ways. As noted before, the abatement costs, commitments and expected emissions growth vary widely across Annex I: the extraordinary divergence in emission commitments relative to levels of the mid 1990s levels was illustrated above. This regional variation explains why international flexibility has such a large impact. Large volumes are traded; and this has striking implications for emissions in different regions. Tables 6 and 7 summarise results for our analysis based upon national emission projections.

Table 6 shows the absolute volumes of trade and the implications for emissions under the ‘high’ case, with no restrictions; this probably corresponds most closely to official projections, including those for eastern Europe. In this case, aggregate trading between the regions amounts to about 300 million tonnes per year of carbon-equivalent, the great majority of which is acquired by the United States. This country adds about 16% to its basic commitment (QELRC) by imports, and its aggregate net emissions end up at 8% above 1990 levels (CO2 could be higher than this). Japan’s position is similar relative to its commitment and 1990 levels. In this scenario the EU and Australia join the EITs in exporting assigned amounts.

Table 6: Traded volumes under the national / high case (no constraints)

	QELRC	Volume bought/sold		Resulting domestic emissions	
	MtC	MtC	% QELRC	% QELRC	% 1990 emissions
EU	1035	- 34	- 3	97	89
US	1485	241	16	116	108
Japan	291	46	16	116	109
Australia	148	- 14	- 10	90	98
Canada	146	12	8	108	102
Other OECD	49	3	7	107	105
Russia	768	- 166	- 22	78	78
New EU	231	- 12	- 5	95	89
Other CEEC	333	- 76	- 23	77	75

Source: Grubb et al (1999), Chapter 5.

Table 7 shows domestic emissions relative to the base year under the different scenarios. Trading is greatest in the base case with no restrictions, with over 500 million tonnes traded, more than 10% of the total 4,500 MtC Annex I assigned amount. For reasons already discussed, we consider this scenario more plausible, and quite possibly still too high in terms of EIT trends, suggesting that trading could be even greater.

The most striking and consistent result to emerge from these analyses is the large gap between domestic emissions (particularly CO_2) and the overall 'Kyoto commitment' in some OECD countries. Most of the political debate about emission targets concentrates on domestic CO_2 emissions, and assumes that these will be more or less the same as the Kyoto commitment. Our results show wide differences. Emissions in the EU do end up close to the Kyoto commitment in aggregate (or a little lower if 'hot air' is excluded). This reflects the low BAU projection. Aggregate CO_2 emissions would be higher, quite close to 1990 levels if 'hot air' trading is included. Within the EU, emission levels could be widely distributed, with emissions in Germany, the UK and others in the range of 10–20% below 1990 levels in order to accommodate growth in some of the less developed member states. Countries faced by high costs to limit domestic CO_2 emissions will take the cheaper options of action on other gases and emissions trading, leaving domestic CO_2 emissions at higher levels.

Table 7: Emission distribution in Annex I after trade (% relative to base year)

Region	**Commitment**	**National / base case**		**National / high case**		**CO_2 gap**
		No restrictions	**No hot air**	**No restrictions**	**No hot air**	**(%)**
Annex I	- 5.23	- 5.23	- 10.00	- 5.23	- 7.08	+ 4–5
EU	- 8.0	- 8.6	- 12.7	- 11.0	- 12.5	+ 7–8
US	- 7.0	+ 11.4	+ 6.0	+ 8.1	+ 6.1	+ 3–5
Japan	- 6.0	+ 7.5	+ 4.1	+ 8.7	+ 7.3	+ 4–5
Australia	+ 8.0	- 0.1	- 6.8	- 2.4	- 4.5	+ 30–31
Canada	- 6.0	+ 6.6	+ 1.2	+ 1.6	- 0.4	+ 4–6
Other OECD	- 1.8	+ 6.4	+ 0.8	+ 4.9	+ 3.1	+ 20–25
Russia	0.0	- 26.5	- 31.3	- 21.6	- 23.6	- 2–1
New EU	- 6.5	- 26.5	- 30.9	- 11.4	- 13.6	+ 1–3
Other CEEC	- 3.5	- 29.1	- 33.3	- 25.5	- 27.4	+ 0–1

Source: ITEA.

Note: The CO_2 gap is given in percentage points relative to overall GHG emission levels; that is, the GHG emissions in Annex I without restrictions will be about 5% below base year, CO_2 emissions could end up 4–5% higher, at 0–1% below base year.

We find that by 2010, under either set of assumptions, comprehensive gas coverage and emissions trading leaves domestic CO_2 emissions in Japan and the United States at 15 to 20 percentage points higher than their Kyoto commitment. For some of the smaller OECD countries like Norway and New Zealand, domestic CO_2 emissions may exceed the Kyoto commitment by up to 30%. This is a huge gap, and it illustrates most starkly both the dangers and the opportunities offered by emissions trading. Taken at face value, the Kyoto agreement could still leave greenhouse gas emissions in the United States and Japan around 10% above 1990 levels (and even much more for some other countries) without breaching the letter of the formal agreement – and that is before considering additional flexibility from sinks and CDM investments outside Annex I. This is not the intended outcome of the Kyoto agreement. Particularly if some of this international exchange represents 'hot air' trading, such an outcome would risk bringing mechanisms for 'flexibility and efficiency' into serious disrepute, and delay still further the time when developing countries accept that they too need to act.

These results – in contrast to the absolute costs associated with any given commitment – are not very sensitive to differing assumptions within plausible ranges, given the official BAU projections as a basis. This can be seen by comparing the two cases. This is because certain fundamental characteristics are almost universally accepted: across Annex I it is cheaper to achieve a given reduction relative to 1990 levels in EITs than in the major OECD countries, and it is easier to do so on multiple gases than on CO_2 emissions alone. Inevitably, therefore, flexibility means that OECD CO_2 emissions will be above the level of the Kyoto commitment. More pessimistic assumptions about the costs of limiting CO_2 emissions only widen the gap between domestic CO_2 and the Kyoto commitment further.

Cost distribution and related implications

Table 8 illustrates the approximate cost implications of the commitments and the impact of emissions trading on different regions. In this analysis, the United States incurs higher costs than Japan or the EU, which is contrary to the results of the economic models discussed earlier (Table 1). This highlights the fundamentally different basis of the analysis, in working from official reference emission projections submitted to the Climate Change Secretariat Most global economic models project emissions growth in the EU, sometimes to a degree comparable to that in the United States, but the official EU projection is for approximate emissions stabilization, contrasting sharply with the projected US growth of 26% (23% for CO_2) above 1990 levels. This swamps the higher 'no net cost' potential and slightly lower marginal cost slope assumed for the United States. We note also that the cost curves summarised in the *Energy Journal* special issue suggest emission reductions in the US to be relatively cheaper (a greater divergence between US and EU marginal cost curves) than we have assumed.

Under the base assumptions, commitments in the EU and Australia (as well as most of the EITs) can be met through 'zero cost' measures only, given the large scope for such reductions, particularly for non-CO_2 gases, combined with the modest baseline projections for the EU and the very large contribution of non-fossil fuel sources in Australia. Most other OECD countries incur costs, which emissions trading (excluding 'hot air') reduces by a factor of up to 10, because of the access it gives to the large pools of low-cost reductions in EITs and the smaller OECD countries; Australia joins the EITs in benefiting significantly from exporting assigned amounts ('quotas' in the following economic discussion).[13]

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[13] It is sometimes stated that the EITs could form a cartel and extract a high price for access to their 'hot air'. I find the idea of an EIT cartel even less credible than most cartels - especially since the rules on sinks,

Table 8: Impact of trading on the cost distribution for the Kyoto targets (relative costs, '$'/cap)

Region	National / base case			National / high case		
	No trade	**No restrictions**	**No hot air**	**No trade**	**No restrictions**	**No hot air**
Annex I	+ 1.37	–	+ 0.05	+ 3.12	+ 0.49	+ 0.90
EU	–	–	- 0.07	+ 0.02	+ 0.02	+ 0.02
USA	+ 5.00	–	+ 0.62	+ 10.80	+ 3.14	+ 4.21
Japan	+ 1.78	–	+ 0.18	+ 4.96	+ 1.11	+ 1.49
Australia	–	–	- 0.66	-	- 0.86	- 1.16
Canada	+ 1.64	–	+ 0.33	+ 3.85	+ 1.70	+ 2.28
Other OECD	+ 0.24	–	+ 0.10	+ 2.10	+ 0.93	+ 1.25
Russia	–	–	- 0.43	–	- 2.01	- 1.57
New EU	–	–	- 0.23	+ 0.02	+ 0.06	+ 0.22
Other CEEC	–	–	- 0.25	–	- 1.40	- 0.89

Source: ITEA, with EU in a bubble, Kyoto commitments, all GHGs.

For our 'national/high' assumptions (which include less scope for cheap reductions in all greenhouse gases & sinks), abatement costs for North America and Japan are again substantially reduced by trading; their average annual abatement costs probably lie in the region of $1 to 10 per capita.[14] The EU and Australia are again marginal exporters of quotas. The model assumptions are set so that revenues equal additional costs (i.e. the model assumes that political and practical constraints act to prevent OECD countries from excess profits from quota sales), hence the EU does not benefit significantly and Australia benefits only from modest sales of 'no net cost' quotas. The major benefits accrue to the EITs.

Excluding surplus allowances ('hot air' , mainly from Russia and Ukraine) raises the price of quotas: the costs to Japan and North America increase by around 30% (this is still far lower than the costs without trading), revenues to the non-FSU EITs increase, and the benefits accrue much more evenly across the transition countries overall.

According to our model, emissions trading could reduce costs by 70% compared to domestic action in a restricted scenario (high growth, no 'hot air' trading) or by much more still with no restrictions. It is important to note that big cost reductions from trading are not contingent upon 'hot air' trading. On top of this, the CDM and sinks, offer scope for additional cost reductions.

During the negotiations in and before Kyoto much effort was put into differentiating the commitments to spread costs more evenly among Annex I Parties. The differentiation formulas proposed by various Parties did not survive the negotiations, and our results suggest that the

CDM etc are still ongoing and the US has a simple get-out of threatening non-ratification whilst rules to ensure competitive access are being negotiated. The EITs do not have any real power in this.

14 The numbers in the table are relative: multiplication by a factor in the range 1 to 10 would yield estimates in $US corresponding to relative optimism or pessimism in the underlying aggregate assumptions: see text. US$10 per capita corresponds to about US$10 billion across Annex I, which is somewhat under 0.1% of projected annual GDP in the industrialised countries for the commitment period. These costs are substantially lower than most of the results reported in Section 2 principally because the ITEA model includes a the full range of gases and commitments exactly as signed in the Protocol, works from officially-submitted reference projections, and includes some allowance for 'no net cost' possibilities (see discussion).

commitments are largely independent of abatement costs or effort needed, but reflect political will. The ITEA model indicates that the mechanisms for international transfer, such as the emissions trading modelled here, will not only reduce but also spread the costs of the Kyoto Protocol more evenly between the Annex I countries.

In this context it is important to recall that the Kyoto commitments were adopted in tandem with the mechanisms for international transfer, which were absolutely central to agreement particularly by the United States and other JUSSCANNZ countries. The authors recall a finding they made before the negotiations in Kyoto:[15] 'For a given cost to the major OECD countries, the two forms of flexibility [multiple gases and emissions trading] could enable an increase of up to 5 percentage points each in the strength of the target, and the effects are more than additive; thus, full flexibility should enable a commitment about 10 percentage points greater than could be expected from a flat-rate CO_2-only commitment without trading.' The evidence is clear that the mechanisms for international transfer did lead to much stronger commitments than would have been agreed without them. It is less clear that negotiators realized the extraordinary scale of flexibility that is potentially available in the Kyoto agreement as signed.

This fact, and the growing recognition of the possible extent of 'hot air' in the system, has reinforced proposals from some Parties for constraints on the use of emissions trading in particular. The protocol itself states that the use of emissions trading should be 'supplemental' to domestic actions, and there is much debate about what this exactly should mean. It reflects a fear that emissions trading will be used, particularly by the US, to purchase surplus emission allowances from abroad and thereby avoid significant domestic action. The political concern is that this will abrogate the basic principle of leadership by the industrialised world, and particularly by the biggest emitter. The economic concern is that by avoiding domestic action on CO2 emissions, for example through tree-planting internationally, the big economies will never change course in terms of their basic infrastructure and technologies, and will not face sufficient pressure to innovate and generate technologies that could help to provide global solutions.

This fear – which derives from an economic view of dynamic efficiency and induced innovation that is quite distinct from traditional equilibrium concepts – is exacerbated by the situation in the Economies in Transition. When combined with the other flexibilities, the excess in these countries could lead to the price falling to very low levels indeed. For this reason, the EU has proposed limits on how much a country can sell. It is a measure of the complexity of the agreement, and the economics thereof, that whilst many in the US remain concerned that the costs will be too high, the EU's concern is now more focused upon the possibility that the price will collapse to a degree that will undermine the basic purpose of the Protocol – and, along with it, the perceived legitimacy of international economic instruments. If further analysis should support the common US view that prices may be quite high, of course, then the US, Japan, and others certainly would not support the EU's proposals. If the EU view of the economics turns out to be more accurate, its proposals will have more chance of being adopted. Access to the 'EIT surplus' may turn out to be the control valve on the costs of Kyoto.

Cost-benefit perspectives

US economists such as Nordhaus have for many years been sceptical about the economic value of significant emission constraints. Nordhaus (1999) claims that the costs of Kyoto would exceed the benefits by a factor of 7. In reality, the balance cannot yet be plausibly established and there are many reasons for doubting such estimates. In addition to all the cost uncertainties noted, the

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[15] Michael Grubb and Christiaan Vrolijk, *'Defining and Trading Emission Commitments: the Implications of Flexibility'*, EEP Climate Change Briefing, No. 10, December 1997.

environmental benefits are even more difficult to quantify and Nordhaus's estimates lie towards one extreme of a wide range. Quite apart from the direct problems of physical estimation, typical problems are that such estimates neglect or underrepresent:[16]

- risk aversion given large uncertainties;
- the dynamic impacts of continually changing climate;
- the very low-probability very high-cost possibilities (for example associated with ocean current collapse);
- the real welfare impact on most developing countries (due to inappropriate applications of 'willingness to pay' criteria;
- the real welfare loss to future generations (due to inappropriate application of discounting).

The IPCC Second Assessment Report concluded that a doubling of pre-industrial CO2 concentrations would probably involve welfare losses amounting a 'a few per cent' of global GDP (IPCC, 1996). The economically optimal marginal cost in the face of this, of course, also depends critically upon the discount rate, which raises another set of fundamental uncertainties. So too does the ethical issue of how to evaluate human impacts caused by emissions from one country upon another, where widely divergent 'equity weights' and other criteria can and have been proposed.[17]

Balancing costs against benefits involves additional considerations. Amongst these is the extent to which emission commitments induce technical changes that lower subsequent costs, and lead to global diffusion of lower carbon technologies. Drawing upon basic concepts of learning-by-doing (Arrow, 1962), and experience curves in energy systems (Grubler et al., 1994), Grubb et. al. (1995) explored optimising trajectories including ones in which 'initial abatement stimulates technology and infrastructure development, and behavioral changes, which lower the cost of further abatement.' Ironically, given Nordhaus's recent estimates of the cost-benefit ratio cited above, they estimated the marginal benefits of control in their 'adaptive / high inertia' case to be about seven times that derived from a classical economic perspective, due to these dynamic learning effects. A range of subsequent studies have produce divergent claims about the importance of induced technical change, that take us beyond the scope of this paper.[18]

An alternative perspective takes a more science and environmental approach focused upon trajectories towards stabilisation of atmospheric concentrations. Again, there are a range of viewpoints. Obviously, stringent concentration targets – for example below 450ppm – demand strong action. For much higher concentrations, Wigley et. al (1996) are widely cited as given rationales why it may be optimal to take little action at present. Responses in turn show that prudent policy preparing for possible stabilisation anywhere in a wide range above 450ppm should adopt a precautionary trajectory with significant near-term abatement (HaDuong et. al., 1997). Grubb et al (1999) conclude that the Kyoto Protocol is consistent with being the first step in an optimal trajectory towards stabilisation somewhere in the range 450-550ppmCO2 – or 500–650ppmCO2-equivalent in terms of the full basket of gases. Depending in part upon how stringently some of the provisions are implemented, Kyoto is probably on an optimal trajectory

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[16] The IPCC Second Assessment Report (IPCC, 1996) gives an extensive discussion of cost-benefit studies and the limitations thereof. A summary of some of the economic debates behind this are given in Grubb et al. (1999), Appendix II. The authors own views of Nordhaus' estimates in relation to Kyoto are summarised in a debate with Prof Nordhaus (Volkswagen Stiftung, March 1999; publication forthcoming 2000).

[17] Ibid. See also Fankhauser et al., 1997.

[18] See proceedings from a Conference on Induced Technical Change, IIASA, Laxenburg, June 1999; forthcoming 1999.

towards the upper part of this range but with a considerable degree of uncertainty. This is explored more fully below, but the 'bottom line' is simple: the optimal level of control is hugely uncertain and the Kyoto Protocol falls well within the range of uncertainty in the literature.

Despite this, a popular view amongst sceptics is that irrespective of this, the Kyoto Protocol will not be effective because it does not contain enforcement mechanisms and because governments will not take actions to meet their commitments. The former objection really reveals political naivete and a lack of understanding of the processes of international law: the Kyoto Protocol itself establishes a negotiating process to develop compliance procedures and that is as much as any international treaty generally does at the time that initial commitments are established – indeed the Kyoto Protocol probably signals a stronger compliance regime than most treaties (Grubb et al, 1999, Chapter 4). The core question is indeed whether governments are willing to honour the non-binding promise implicit in signing, and turn it into a legal commitment by ratifying the Treaty. This is a political judgement that economists are not well placed to make. In fact most governments in Europe at least are now embarking upon significant implementation measures. The UK is introducing a range of measures including a 'climate levy', several Scandinavian countries are well on the way to introducing emission trading schemes, Germany and the Netherlands already have a raft of measures ranging from strong energy efficiency and renewable energy programmes to voluntary agreements in the industrial sector, and programmes aimed at methane capture and reductions in other gases. A recent appraisal from the Energy Directorate of the European Commission (EC DGXVII: forthcoming 1999), taking account of recent trends, multiple sources, and policies in train, concludes that the EU as a whole is likely to get to within about four percent of its Kyoto target, with the remainder available either from stronger domestic actions or through Kyoto's international transfer mechanisms.

In practice, one major contribution in most of the OECD is likely to come from progressive liberalisation of the electricity sector, which already accounts for the UK's substantial decline in greenhouse gas emissions. Substantial reductions, for basically the same reasons, are quite possible within both Germany and the US, despite some claims to the contrary. The idea that the Kyoto commitments are politically unattainable reflects a lack of understanding of the extent of changes that are possible, and indeed ongoing, in the OECD's energy systems; as well as a lack of appreciation of the many degrees of flexibility in the agreement as signed. There remains however one core economic objection to Kyoto, which brings us to the final part of this paper.

Part III. Developing countries and the longer term prospects

Developing countries are an intrinsic part of the Protocol and broader negotiations on climate change, but are excluded from quantified commitments for several reasons. Their historical contribution to the problem is minimal; their emissions per person are still a small fraction of those from industrialised countries; their institutional and technological capabilities are still far from those of the industrialised countries and their priority has to be basic development and poverty alleviation. The original Rio Convention agreed that industrialised countries must establish leadership in emissions control and show that they could return emissions to former levels. That has not yet been achieved.

Nevertheless, the claim remains that excluding developing countries from quantified commitments in the Protocol renders it ineffective. Developing countries accounted for about 4/5 of the world's population and about 30% of global CO_2 emissions in 1990. Rapid growth of these emissions means that global emissions could grow substantially even if industrialised countries meet their commitments, which in turn are puny compared with the deep emission cuts that would be required to stabilise the atmosphere.

On these grounds, the Kyoto Protocol has been widely declared as inadequate. The then chairman of the IPCC, Bolin (1998), criticised the relative weakness of the agreement overall. Wigley (1998) quickly published a quantitative analysis showing that the Kyoto commitments on their own would have limited impact on global trajectories of concentration, temperature or sea-level rise even with various scenarios of follow-up in industrialised countries. Economists' concerns about the commitments are buttressed by the claim that the lack of quantified commitments for developing countries makes the Protocol ineffective, and that action by the industrialised countries would be offset by 'leakage' of emission as industries migrate from industrialised countries to developing countries to escape emission controls.

In this concluding section I argue that these perspectives are wrong for three fundamental reasons. First, they underestimate the extent to which lower-emission technologies can be implemented and improved and the lasting effects this will have over the longer term. Detailed analysis of technological trends and innovation responses conducted over many years at IIASA and elsewhere highlights the extent to which energy technologies have developed and are continuing to do so, with the potential to lead to steady ongoing declines in carbon emission intensities (Grubler et al., 1999). Second, they ignore the institutional dynamics of regime development: all global environmental regimes (and many other global regimes) start with commitments from the leading countries - the richest and bigger polluters - that expand and strengthen over time. The Protocol's core structure of rolling five-year commit periods provides a natural base for such evolution. Third, conventional analyses ignore the fact that both technology and institutional structures (including policy reforms) diffuse internationally. Modern economies are linked by vast and continually expanding flows of trade, investment, people and ideas. The technologies and choices of one region will inevitably be affected by developments in other regions.

The final part of this paper focuses particularly upon the last of these issues, but they are all interrelated. First, we present results of an analysis that explores the possible longer term and global implications of the Kyoto targets (which we accept as the middle ground between the poles of scientific and economic criticism) under various assumptions about subsequent developments and their international diffusion.

The core rationale for this analysis is the inescapable fact that economies worldwide are interrelated by flows of trade, investment, technology and ideas; and furthermore, that they are becoming steadily more integrated through globalisation as we enter the 21st century. In some sectors this is already an intrinsic feature of industrial structure. The great majority of motor vehicles are dominated by designs and innovations of only about half a dozen multinational corporations. Technologies for bulk power generation are similarly dominated by a few major global engineering companies. Increasingly, these companies seek to design and market new products for use worldwide. Demands for improved efficiency or low carbon technologies in the industrialised world - which still account for the great majority of such companies' sales - will have a similar impact on their global product lines.

There will also be demand-side pressures from the developing countries too: developing countries increasingly strive to ensure that they harness the better, cleaner, more efficient technologies developed in the industrialised countries, as they grapple with their own resource and pollution problems. India, for example, is now the second largest market in the world for renewable energy after the European Union.

In addition, institutional developments diffuse (Ruttan (1995))emphasises the importance also of the diffusion of institutional changes). The idea that large subsidies for fossil fuel production are economically undesirable has now gained widespread recognition: reductions of such subsidies in China may help to account for the continued slowdown in the growth of Chinese CO2 emissions. The experiments of electricity liberalisation in Latin America and the UK, generally leading to considerable improvements in efficiency and greater use of natural gas and cogeneration, is spreading globally. Some developing countries have already started to discuss their possible involvement in CO2 emissions trading systems that are beginning to emerge in some OECD countries under the Kyoto Protocol.

The modeling assumption in studies such as those by Wigley, that the industrialised countries could steadily reduce emissions whilst those in developing countries remain wholly unaffected, is thus not tenable. However, no global models yet exist that could credibly quantify directly the process of global diffusion of technologies, policies and institutions.

Hence in this paper we use *emissions intensity,* defined as the ratio of CO2 emissions to economic output, as a proxy indicator of technology choice and its international diffusion. In the context of CO2 abatement, we therefore represent such diffusion (or 'spillover') in terms of the impact that accelerating the trend of decarbonisation in the industrialised world is likely to have on the rest of the world. This reflects the tendency of action in the industrialised world to drive technological developments that help to decarbonise their economies, and for these improvements to diffuse globally. It could also be considered as reflecting the tendency of certain kinds of institutional change - from the spread of electricity liberalisation policies to the adoption of policies directly to limit emissions - to spread. Such institutional diffusion may occur through a mixture of example (recognition that certain policies are shown to bring varied benefits), carrots (direct inducements) and sticks (eg. the threat that industrialised countries will not continue to reduce emissions unless the developing countries take stronger action themselves). At present it is not possible to disentangle the different factors and the diffusion of lower carbon intensities is taken as a proxy for these various processes.

Specifically, our analysis links carbon intensities as follows. For simplicity we define aggregate intensity tends for two main regions. We identify region 1 with the Annex I countries under the Kyoto Protocol, and region 2 with the rest of the world. As well as reflecting the current political divisions, this also reflects the dominant direction of international technological flows (with advanced technologies and institutions mostly generated in the OECD and diffusing globally). Also, with the industrialised countries forming such a large share of the global technological economy, it is clear that that action taken in the industrialised world will exert huge influence on technology development and choice. We denote:

$e_r(t)$ is the emissions intensity at time in regions r = 1,2 respectively (ie. the ratio of emissions to GDP at time t)

$e^*_r(t)$ represents the trajectories in the absence of any abatement in *either* region.

A simple equation links emission intensities in region 2 to those in region 1, with the degree of international diffusion represented by a spillover variable σ that may be varied between 0 and 1:

$\sigma = 0$ represents a classical case in which there is no international diffusion of technology or institutions; intensities in one region are completely independent of those in another

$\sigma = 1$ represents a case of perfect spillover, given sufficient time, in which all energy systems ultimately convergence to the same carbon intensity.

In this application it is assumed that relative convergence, to the degree specified, occurs over the 21st century. Thus, emissions intensity in region 2 at time t depends upon those in region 1 as:

$$e_2(t) = (1 - \sigma \tfrac{t}{T}) e_2^*(t) + \sigma \tfrac{t}{T} e_1(t)$$

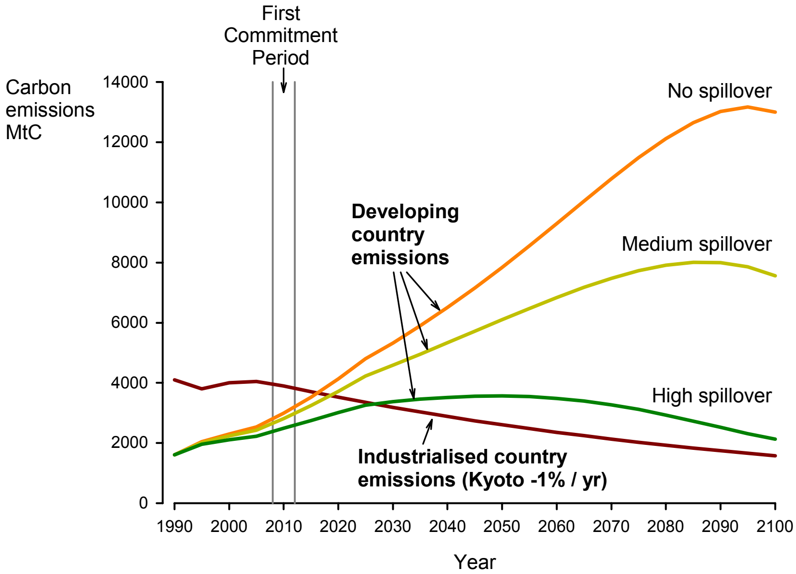
Where the control parameter $0 < \sigma < 1$, and t=0, .. T=110 years goes from 1990 to 2100.

Note that although $\sigma = 1$ is here considered as a case of perfect spillover on a century timescale, some strands of the general literature argue the case for 'super-spillover' in which developing countries might 'leapfrog' industrialised countries and become *more* carbon efficient (less carbon intensive) than established industrialised countries. This is argued on the grounds that they would not be held back by existing infrastructure and vested interests, and could move more promptly to adopt more efficient and low-carbon technologies. This case of 'super spillover / leapfrogging' is not considered here.

Numerical application

We apply the model to the IPCC IS92a emissions scenario, using the background GDP data for that scenario and variants of Wigley (1998) for industrialised country trajectories subsequent to Kyoto. We identify region 1 with the Annex I countries under the Kyoto Protocol, and region 2 with the rest of the world. As well as reflecting the current political divisions, this also reflects the dominant direction of international technological flows (with advanced technologies and institutions mostly generated in the OECD and diffusing globally). Also, with the industrialised countries forming such a large share of the global technological economy, it is clear that that action taken in the industrialised world will have a global influence on technology development and choice. Wigley's analysis only explored the case in which actions taken by the industrialised countries have no influence upon emission trends in the rest of the world, which over the next century thereby swamp any restraint in Annex I. The analysis here explores the possible implications of relaxing that (highly implausible) assumption.

For illustrative purposes, we take a scenario in which industrialised country emissions reach the collective Kyoto target of -5.2% by 2010, and then continue declining at 1%/yr thereafter, the stronger case considered by Wigley. In this case the 'business as usual' fossil-fuel CO2 emissions from the developing countries rise above industrialised country emissions in about 2020.



Grubb (2000) explores the carbon intensity trends for industrialised countries under this case (together with historic trends since 1970), and for the developing countries under the three different spillover assumptions. Industrialised country emission *intensities* (per unit GDP) have to decline by roughly a factor of four over the sixty-year period 1990-2050 (part of which would be met by catch-up of the Economies in Transition), and more than halve again to the end of the next century. This compares with an approximate halving of carbon intensities observed in the 30 years 1970-2000 (the data are complicated by the EIT transition but this does not appear unrepresentative: UK carbon intensities declined by almost 60% in the 35 years 1960-1995 and projected to continue declining sharply, though this is probably an unusually strong case (Eyre 1998, Figure 2 and discussion).

In the absence of international spillover, emission intensities in the developing countries are projected roughly to halve in the 'business-as-usual' case by 2050 - by which time they would have reached roughly the levels of the industrialised world in 1990. By 2100, in this case, emission intensities in the developing world are about five times those in the industrialised countries. In the case of full international spillover ($\sigma = 1$), however, intensities decline roughly twice as fast to 2050, and as specified they converge to the levels of the industrialised countries by 2100, as the technologies and practices induced in the industrialised countries diffuse through the developing world.

Figure 3 illustrate the impact on total developing country emissions - which can be startling. Since the 'full spillover / intensity convergence' case leads to intensities in the middle of the next century at about half the 'business as usual' case, emissions are halved. In the developing country BAU/no spillover case, their emissions carry on rising steadily, as the gap between emission intensities in the industrialised countries and the developing countries becomes ever wider. In the 'full spillover / intensity convergence' case, however, developing country emissions are stabilised around mid century and start to decline slowly; total global emissions return to 1990 level by about 2060 and are about 30% below that by the end of the century.

Table 9 summarises global implications, including those derived from an application of these scenarios in the PAGE integrated assessment model (Hope and Maul, 1996) using reference assumptions under uncertainty as set out in that paper. Cumulative emissions by 2100 are radically different in the different cases: 1178GtC without any spillover, but half that with full spillover/intensity convergence, with the intermediate case lying between these extremes. The corresponding global mean temperature rises are 3.55 and 2.11. The mean present value of climate damages, discounted at 5% using the Nordhaus-based assumptions, are 24.7 trillion dollars without international spillover compared with 14 trillion dollars with full spillover/intensity convergence, and 20 trillion dollars in the intermediate case.

Table 9. Global cumulative emissions 1990-2100 & impacts (from PAGE)

	Cumulative emissions 1990-2100 GtC	Global temp rise Deg. C	Mean NPV PAGE/Nordhaus assns. $Trillion
No spillover (σ=0)	1178	3.55	24.7
50% spillover (σ=0.5)	944	3	20.2
Complete spillover (σ=1.0)	656	2.11	14

Another interesting feature is the broader perspective this brings to the debate on 'emissions leakage'. This is generally considered to reflect the idea that if industrialised countries limit their emissions, emissions elsewhere may increase as a result, due to the migration of some industries into non-controlled regions, and the response to potentially lower global energy prices. Such leakage is generally quantified as the ratio of the increase in developing country emissions to the decrease in industrialised country emissions, relative to reference projections in both cases. Estimates of such leakage in the classical economic modeling literature - arising particularly from the migration of heavy industry to areas outside the emissions control zone - are mostly in the range 3-30%, with the OECD's GREEN model estimates at the low end.

However, these models do not take account of the implications of induced technical change and its international diffusion, which is a positive factor tending to offset the negative aspects leakage. Although far more work needs to be done on this issue, the results of the above analysis suggest that these positive aspects of leakage could swamp the classical, negative components. Indeed, by the end of the Century, emission reductions in the industralised countries are roughly matched by equivalent induced emission reductions in developing countries in the central (0.5) case, and are double that in the full spillover / intensity convergence case.

This is not so surprising. The international migration of heavy industry to escape emission controls is intrinsically limited. The international diffusion of induced technologies, practices and institutions can take purchase throughout a steadily-expanding global market in which the developing economies are eventually larger than the industrialised world, giving a large multiplier effect. There are other components of international leakage and other interactions that should be explored, of course, but the finding is not really so remarkable.

The conclusion is simple, but bold. The view that the Kyoto Protocol is rendered ineffective by the absence of quantified commitments for developing countries is not only politically naïve but economically misleading. It is based upon a static analysis that bears little relationship to the real economics by which technologies and policies can be expected to evolve and diffuse internationally. Far more work needs to be done on this issue, but it is entirely possible that implementing the Kyoto Protocol will indeed lay the basis for effective global responses to the problem of climate change.

Conclusions

The Kyoto Protocol, together with the Convention upon which it rests and the Buenos Aires implementation plan, is a complex and far-reaching agreement that seeks to define the basic structural elements upon which global efforts to tackle climate change should rest in the next century. The agreement has been widely attacked by analysts. Scientists have criticised it for being too weak. Many economists, particularly in the US, have attacked the Protocol for what is perceived as excessively strong commitments, and the failure to include quantified commitments for developing countries.

This paper has argued that these criticisms are erroneous and misguided: and that economists, above all, should welcome the Kyoto Protocol. The structure of commitments contains more flexibility, in more dimensions, than any previous international environmental agreement: indeed, flexibility based upon economic considerations is the hallmark of the Protocol and this represents a huge step forward in terms of the inclusion of effiicency considerations in an international agreement. The Protocol has moved the debate on international economic instruments from whether to use them, to how to implement them. Economists should not underestimate the scale of that achievement, in terms of international relations.

The US accepted relatively strong commitments as part of the bargain for this leap forward in international affairs. In fact, it is already apparent that the commitments are not as strong as they appear. This paper has demonstrated that it is possible that the Protocol may raise the opposite dilemma: recent trends and analysis show that the flexibilities, combined with large surplus allowances in Russia and Ukraine, may reduce the need for action to considerably less than is economically desirable. If this should turn out to be correct, however, the ongoing negotiations on implementing the mechanisms could be developed to address this.

The final area of objection explored in this paper concerns the lack of quantified commitments for developing countries. There are powerful political and ethical reasons why this is the case, though economically it is clearly not optimal. The Clean Development Mechanism may go a long way towards offsetting the economic drawbacks of this. More fundamentally, however, industrialised country action is likely to have impacts on both technology and upon the willingness of developing countries to adopt commitments, which over time foster global solutions to climate change. Provisions on technology transfer and other processes under the Convention and the Protocol could contribute to such expansion, yielding multiplicative returns upon industrialised country actions. These dimensions have yet to be explored adequately, but preliminary analysis suggests that, indeed, the action of industrialised countries under the Kyoto Protocol could well lay an effective basis for global solutions to the world's most daunting environmental problem.

The Kyoto Protocol is a pinnacle of both economic and environmental globalisation. Economically, the agreement– the culmination of many years of intensive negotiation, with several more now set out on how to implement the mechanisms - represents a huge advance.

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For the other modelling studies referred to in Part 2, the reader is referred to *The Energy Journal, Special Issue on the Costs of the Kyoto Protocol: a multi-model evaluation*, 1999, particularly the overview paper by John Weyant and Jennifer Hill.

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Michael Grubb is Professor of Climate Change and Energy Policy, T.H.Huxley School, Imperial College of Science, Technology and Medicine, London; Associate Fellow and former Head of the Energy and Environmental Programme at the Royal Institute of International Affairs, London; and Associate Research Fellow at the Department of Applied Economics in Cambridge University.