

FOIA MARKER

**This is not a textual record. This is used as an
administrative marker by the William J. Clinton
Presidential Library Staff.**

Collection/Record Group: Clinton Presidential Records
Subgroup/Office of Origin: Council of Economic Advisers
Series/Staff Member: Judson Jaffe
Subseries:

OA/ID Number: 20748
FolderID:

Folder Title:
Climate Change Modeling [2]

Stack:	Row:	Section:	Shelf:	Position:
S	20	6	4	1

Briefing on EIA's

Kyoto Study

August 19, 1998

Kyoto Study Objective:

To determine the impact on the U.S. energy system and the economy of possible alternative target emission reduction levels that may result from the Kyoto Protocol.

Assumptions - 24

ref = 33% above 1990

- AEO Reference Case Assumptions (including technology)
No foresight *L endogenously*
- Begin in 2005
- “Kyoto Forever”
- Nuclear Life Extension, if Economic
- No New Nuclear Construction

Major Sensitivities for Kyoto Study

- Low and high economic growth
- Low and high technology - ?
- Nuclear plant construction

Scenarios for Kyoto Study

- 34 percent above 1990 levels (AEO Base Case)
- 24 percent above 1990 levels (Substantial International Permit Trading) *122 mmt*
- 14 percent above 1990 levels (Stabilization at 1998 Levels)
- 9 percent above 1990 levels (State Department Offsets and Sinks plus Estimate of Permits Available from FSU)
- Stabilization at 1990 Emissions Levels
- 3 percent below 1990 levels (State Department Offsets and Sinks)
- 7 percent below 1990 levels (Kyoto Protocol Target)

Benefits of Using NEMS

- All Energy Markets Represented
- Transitional Effects Captured/Annual Model
- Vintaged Capital Stock and Turnover Modeled
- Detailed Technology Menus
- Representation of Technological Learning
- Competitive Electricity Markets Included
- Direct Macroeconomic and World Oil Market Feedback

Independent Expert Reviewers

John Weyant	Energy Modeling Forum
Mike Toman	Resources for the Future
Dallas Burtraw	Resources for the Future
Billy Pizer	Resources for the Future
Richard Newell	Resources for the Future
Ray Kopp	Resources for the Future
Bill Nordhaus	Yale
Joe Boyer	Yale
Lorna Greening	Hagler Bailly
Bill Hogan	Harvard University

Examples of Other Consultations

Industrial Technology

Arthur D. Little

Buildings Technology

Arthur D. Little

Mr. James Rannels, Energy Efficiencies and Renewable Energy, Office of Photovoltaics and Wind Technologies

Mr. Lew Pratsch, Energy Efficiencies and Renewable Energy, Office of Geothermal Technologies

Transportation Technology

Phil Patterson, Energy Efficiency and Renewable Energy/
Transportation Technologies

Mr. Suski, American Trucking Association

Biomass Consultations

Energy Efficiency and Renewable
Energy/Office of Energy Outreach

Lynne Gillette

Ray Costello

Tien Nygyen

Oak Ridge National Laboratory

Marie Walsh

Bob Perlack

Robin Graham

Lynn Wright

Antares Group, Inc.

Ed Gray

Dan Packey

Kevin Comer

USDA-Economic Research Service

Roger Conway

Hosein Shapouri

Richard Haynes

University of Maryland

Erik Lichtenberg

Colorado School of Mines

Mike Graboski

Environmental Protection Agency

Jim Turnure

Bob Shackleton

National Renewable Energy Laboratory

Shaine Tyson

Electric Power Research Institute

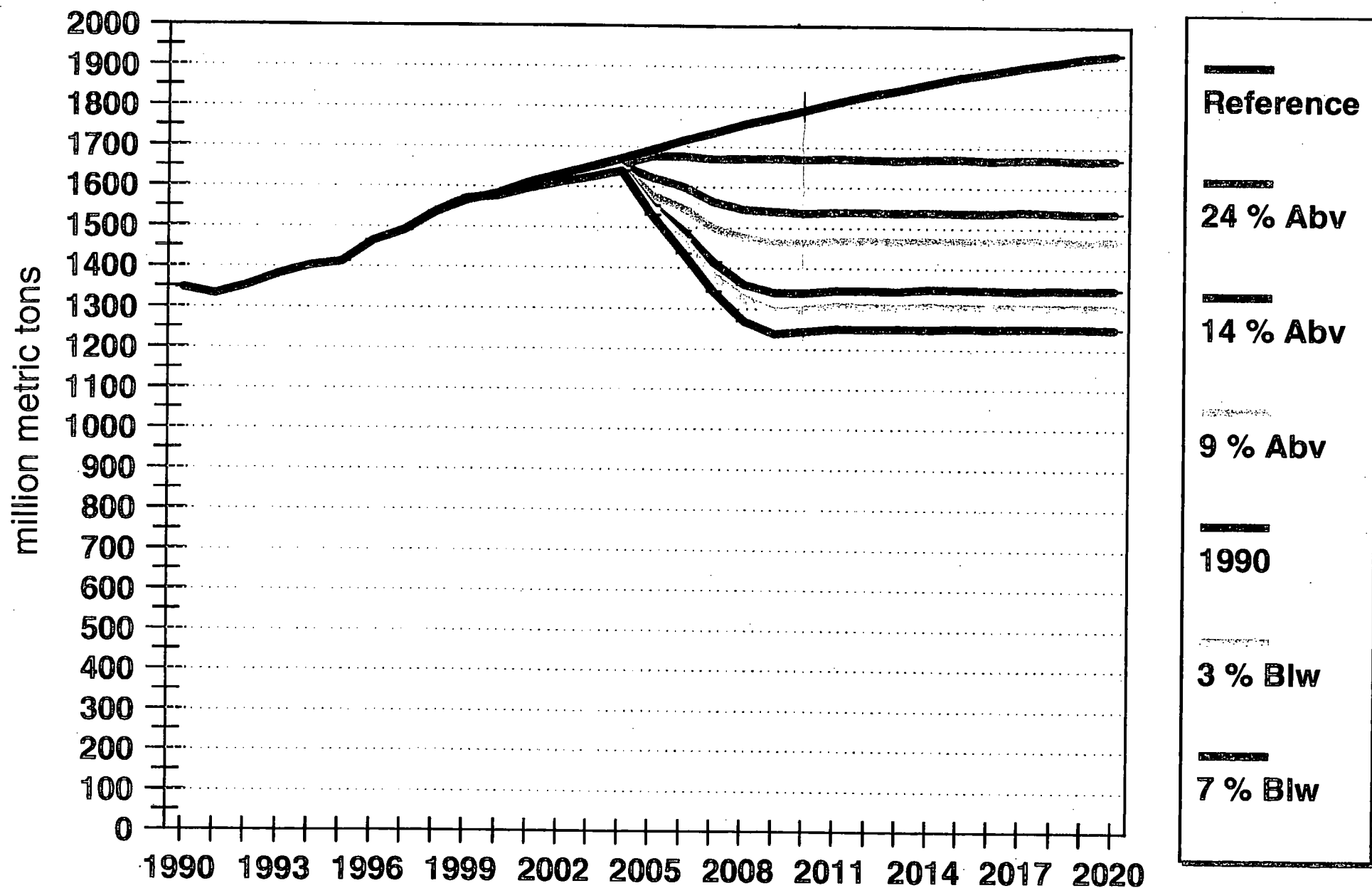
Keith White

Jim Burk

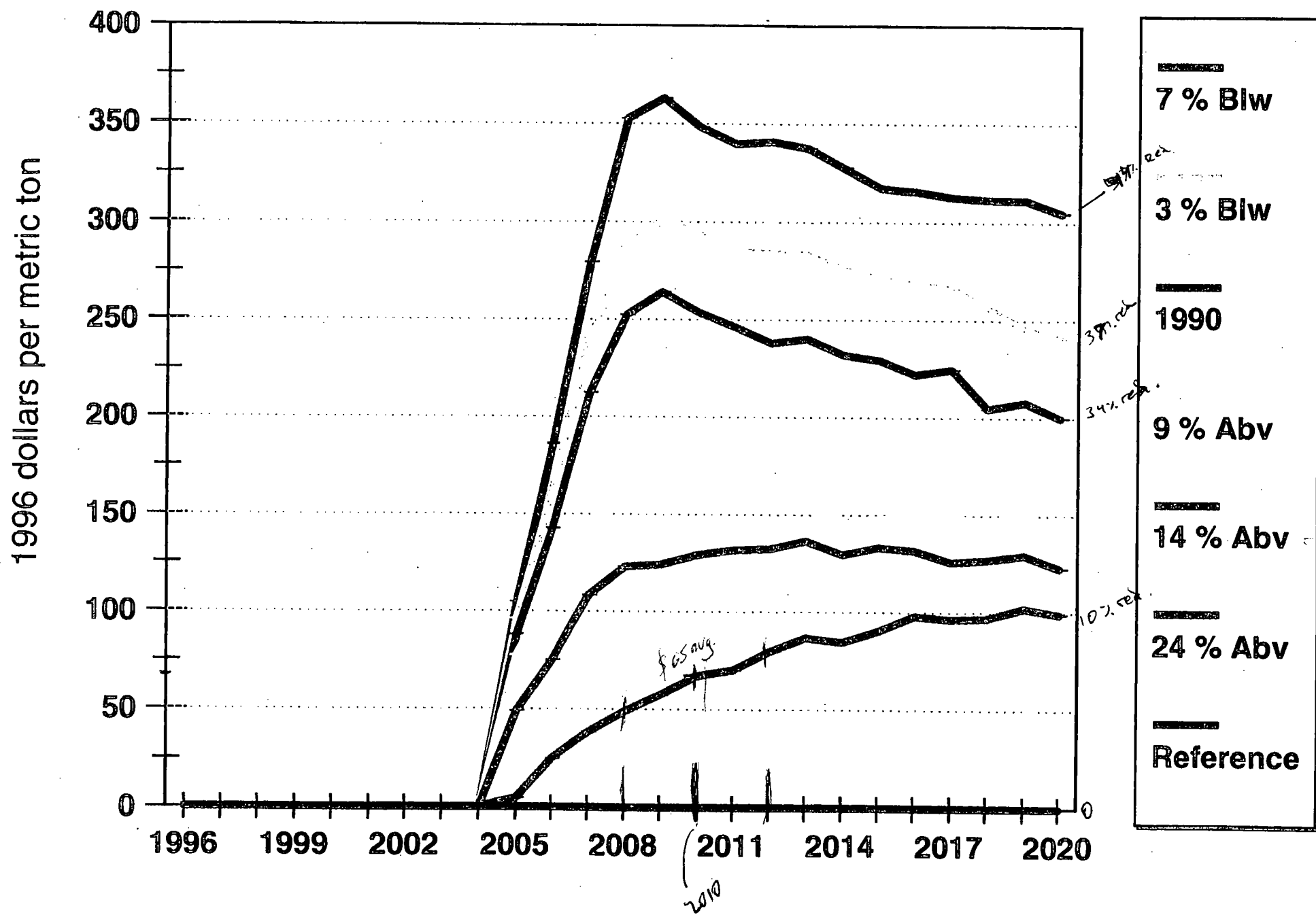
Issues

- Majority of Emissions Reduction from Electric Generation Sector
 - Feasibility of Plant Construction
 - Feasibility of Gas Deliverability
 - Feasibility of Renewable Supply
- Technology
 - Completeness of the NEMS Technology Menu
 - Technological Optimism/Manufacturing Incentives to Improve the Current Technology Slate
 - Consumer Behavior

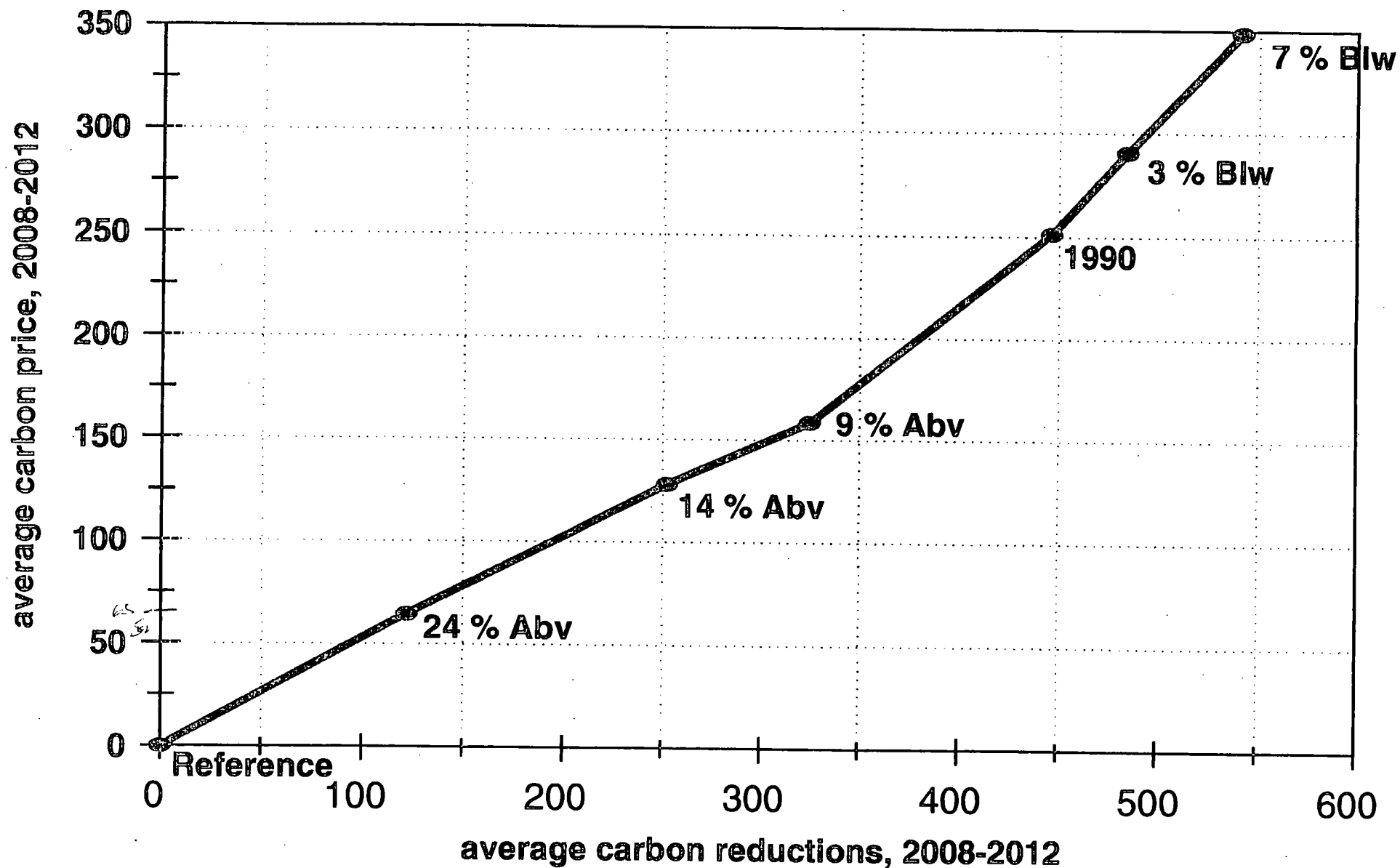
Carbon emissions in the reference and six target cases, 1990-2020



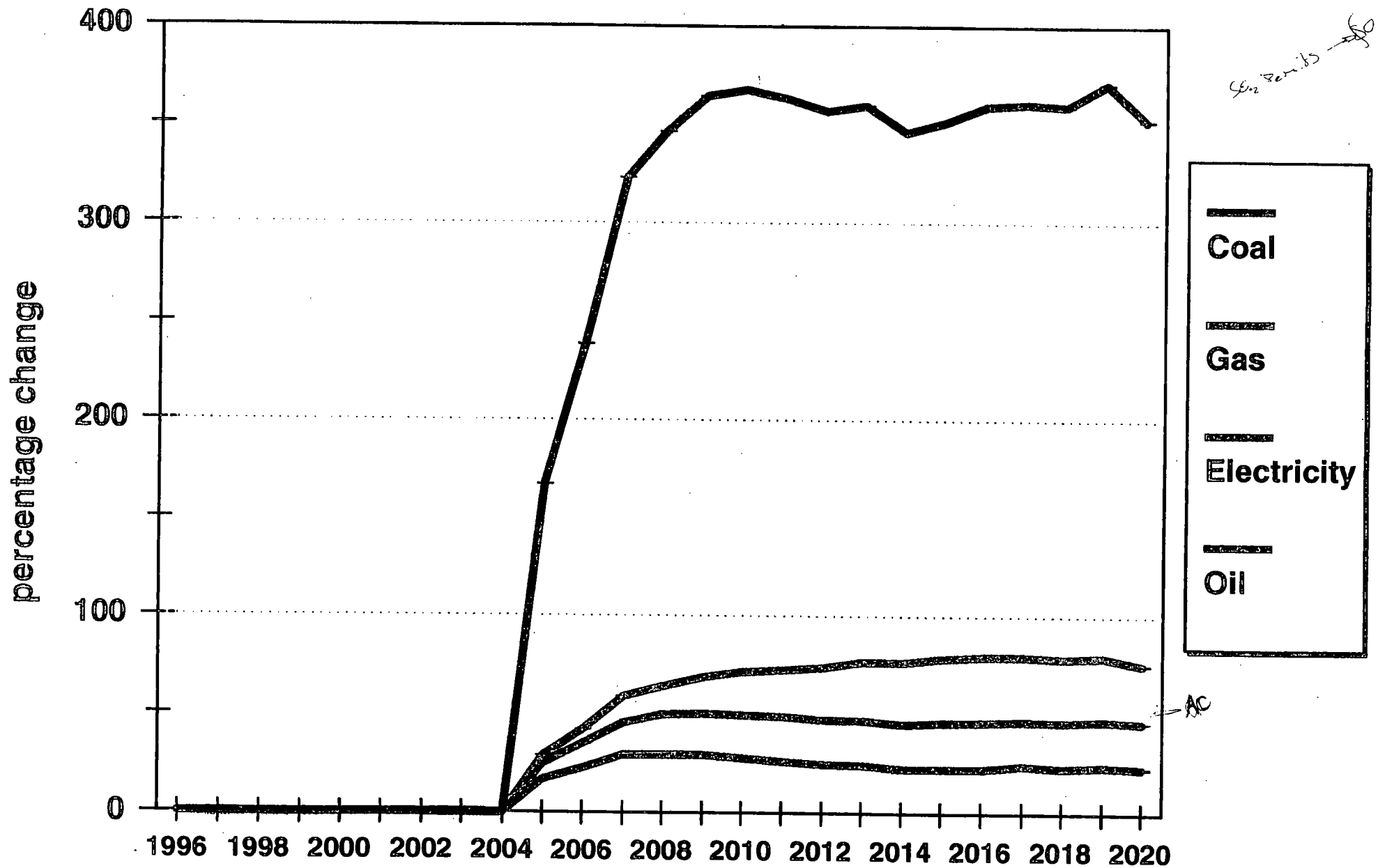
Carbon prices in the six target cases, 1996-2020



Average annual carbon reductions and carbon prices, 2008-2012

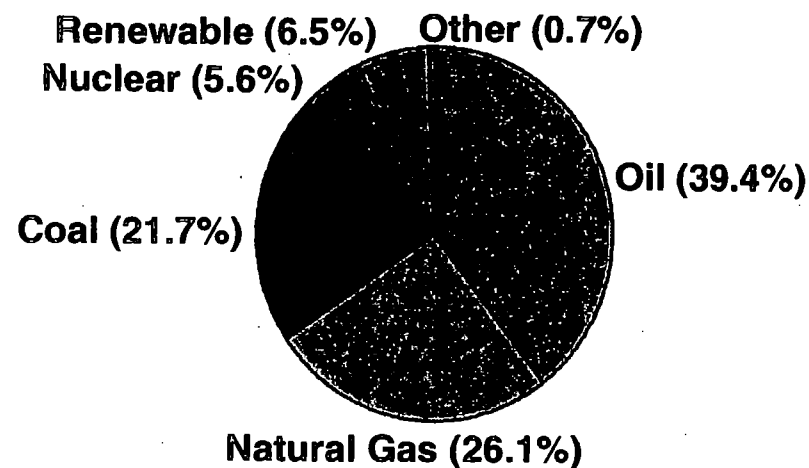


Change in delivered energy prices from reference case to 9%-above-1990 case, 1996-2020

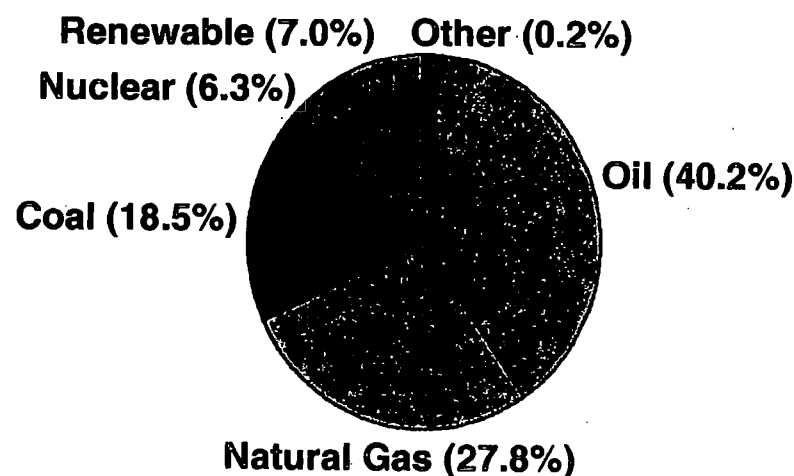


Fuel mix in the reference, 24%-above-1990, 9%-above-1990, and 3%-below-1990 cases, 2010

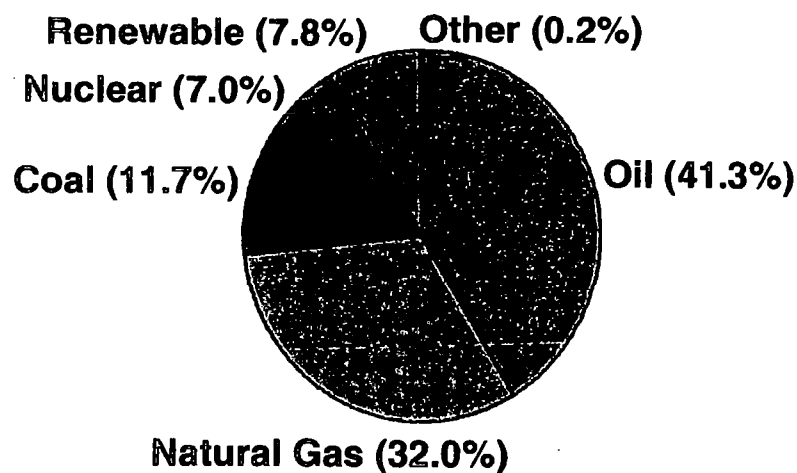
Reference



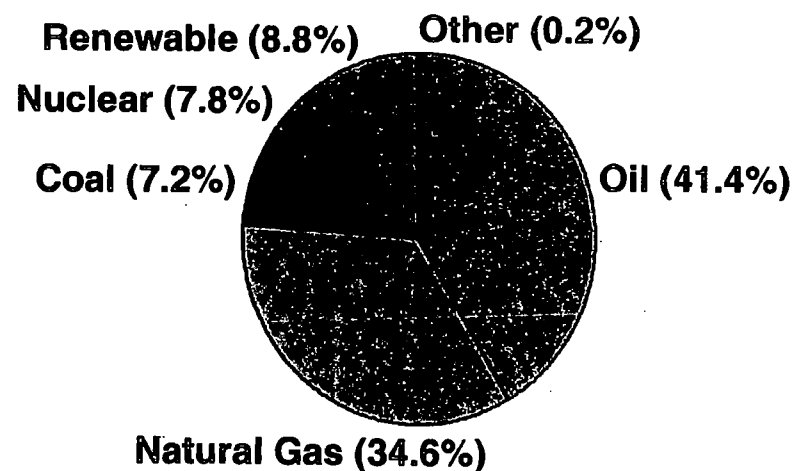
24%-Above-1990



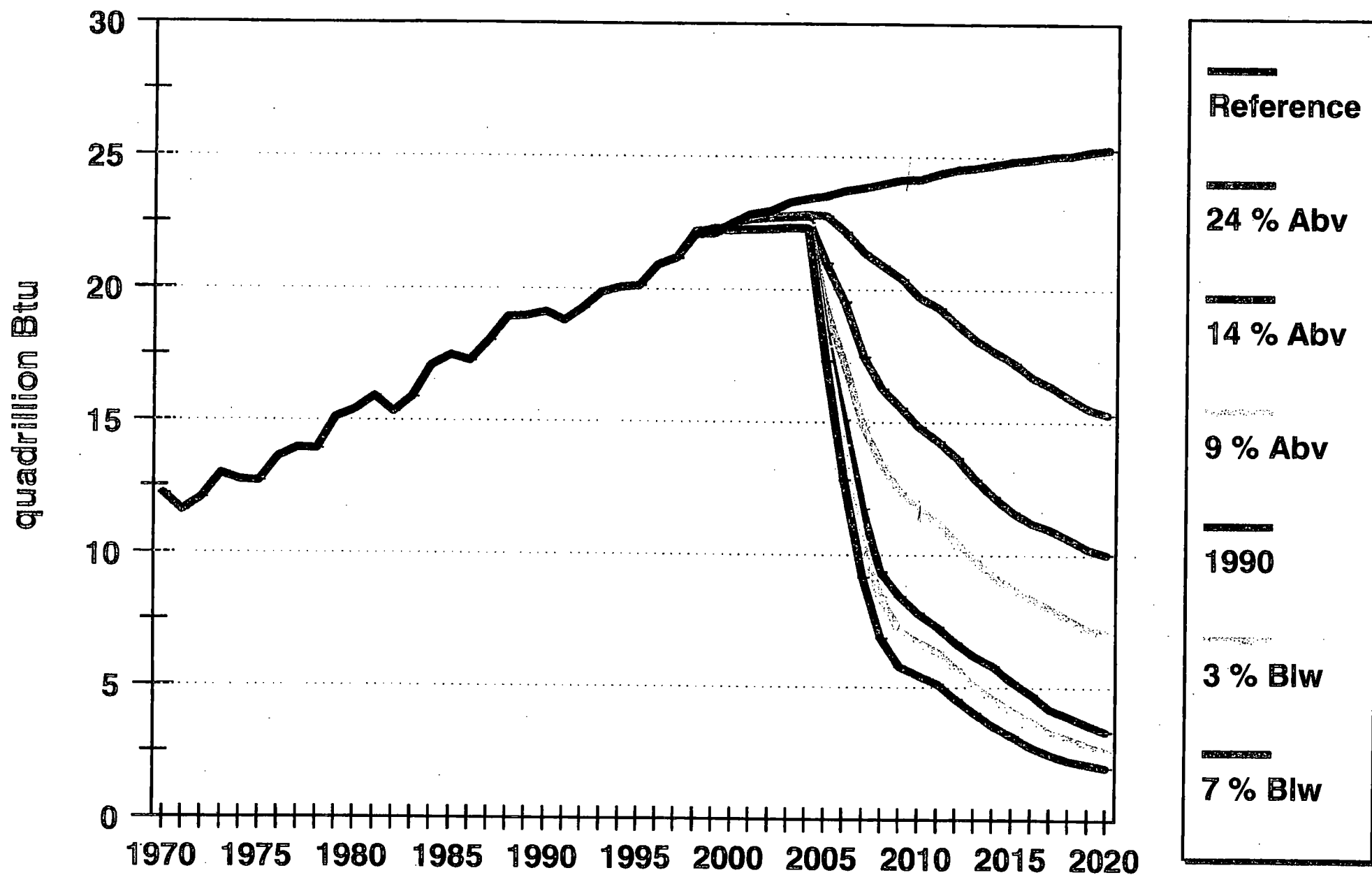
9%-Above-1990



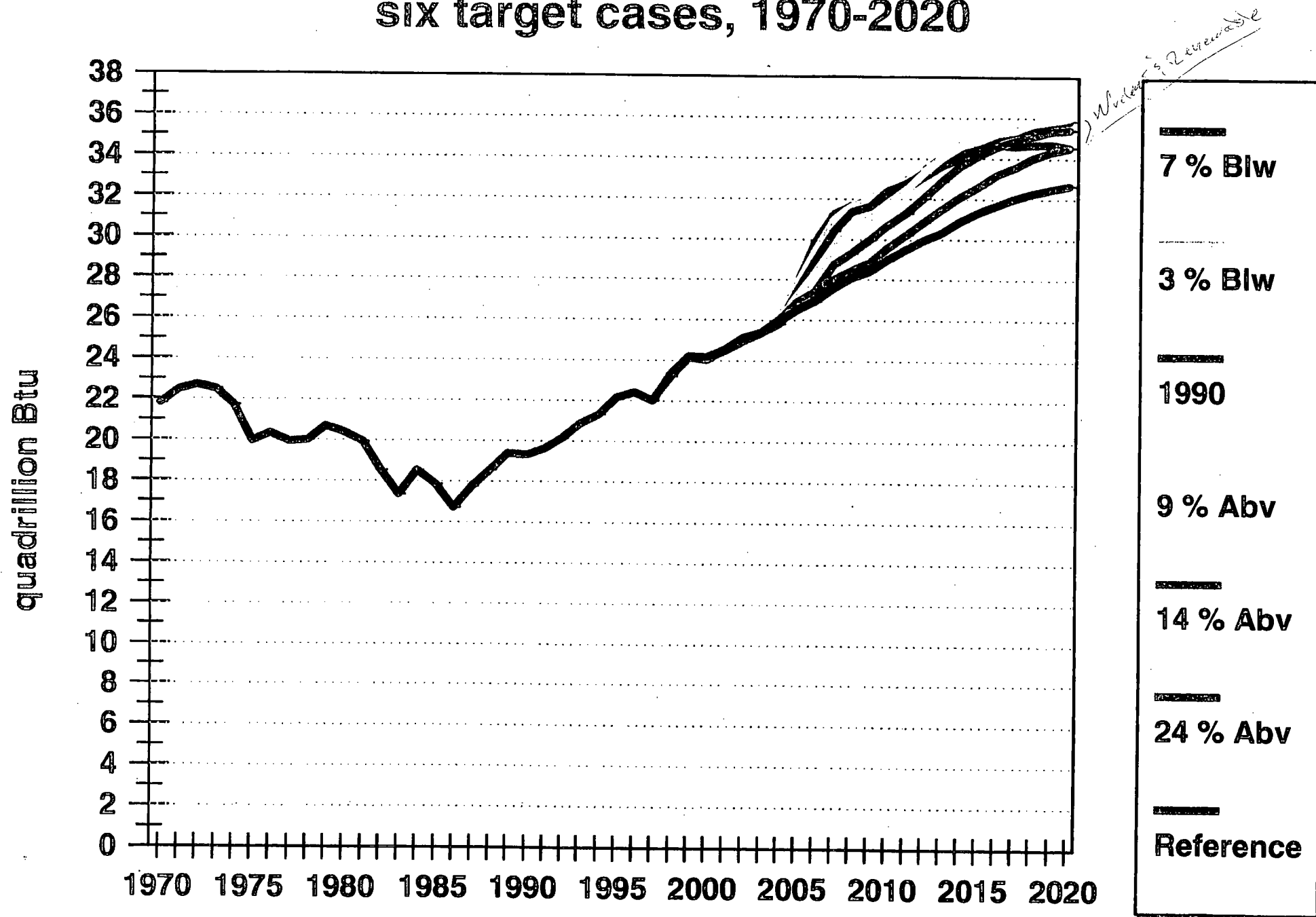
3%-Below-1990



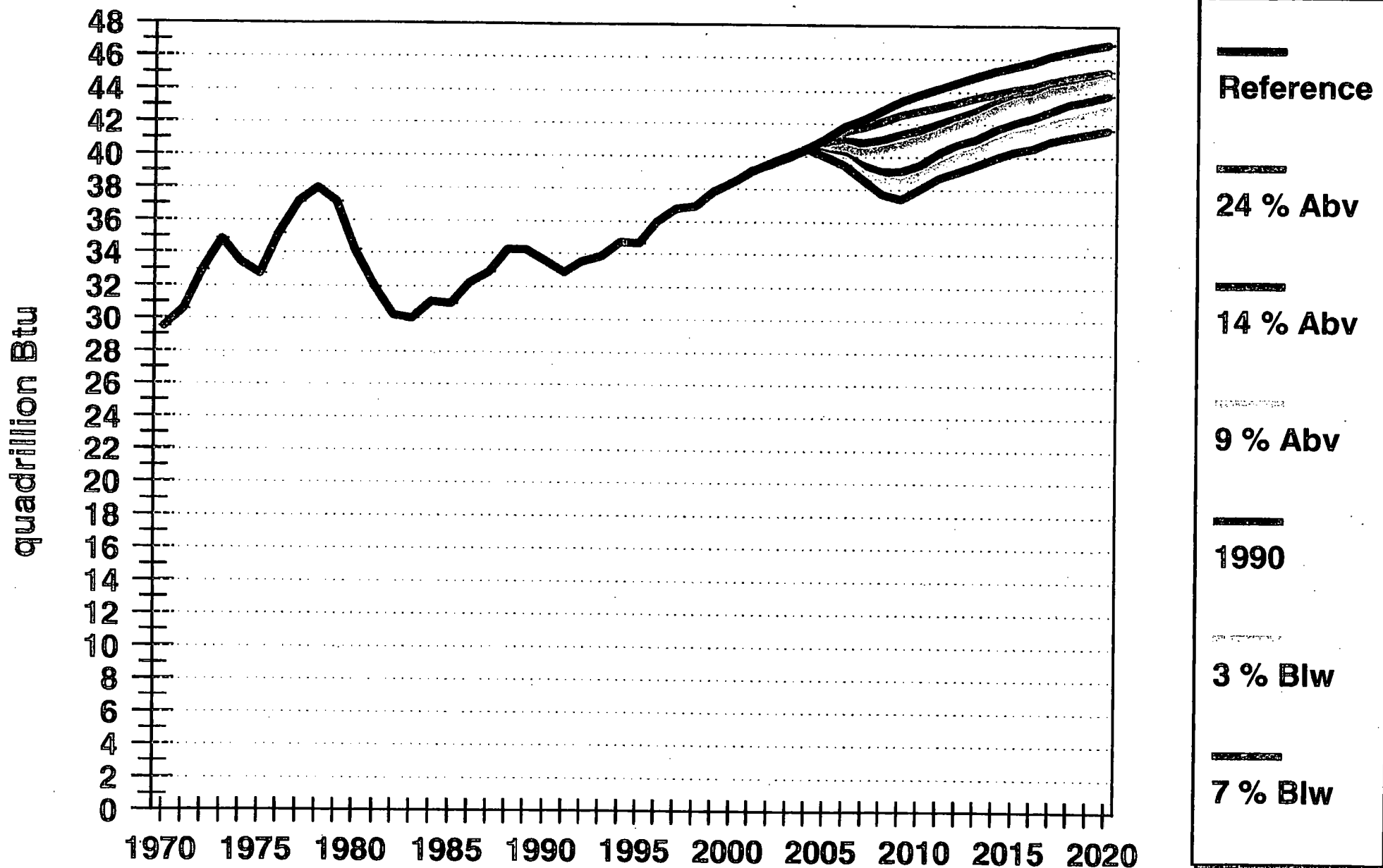
Coal Consumption in the reference and six target cases, 1970-2020



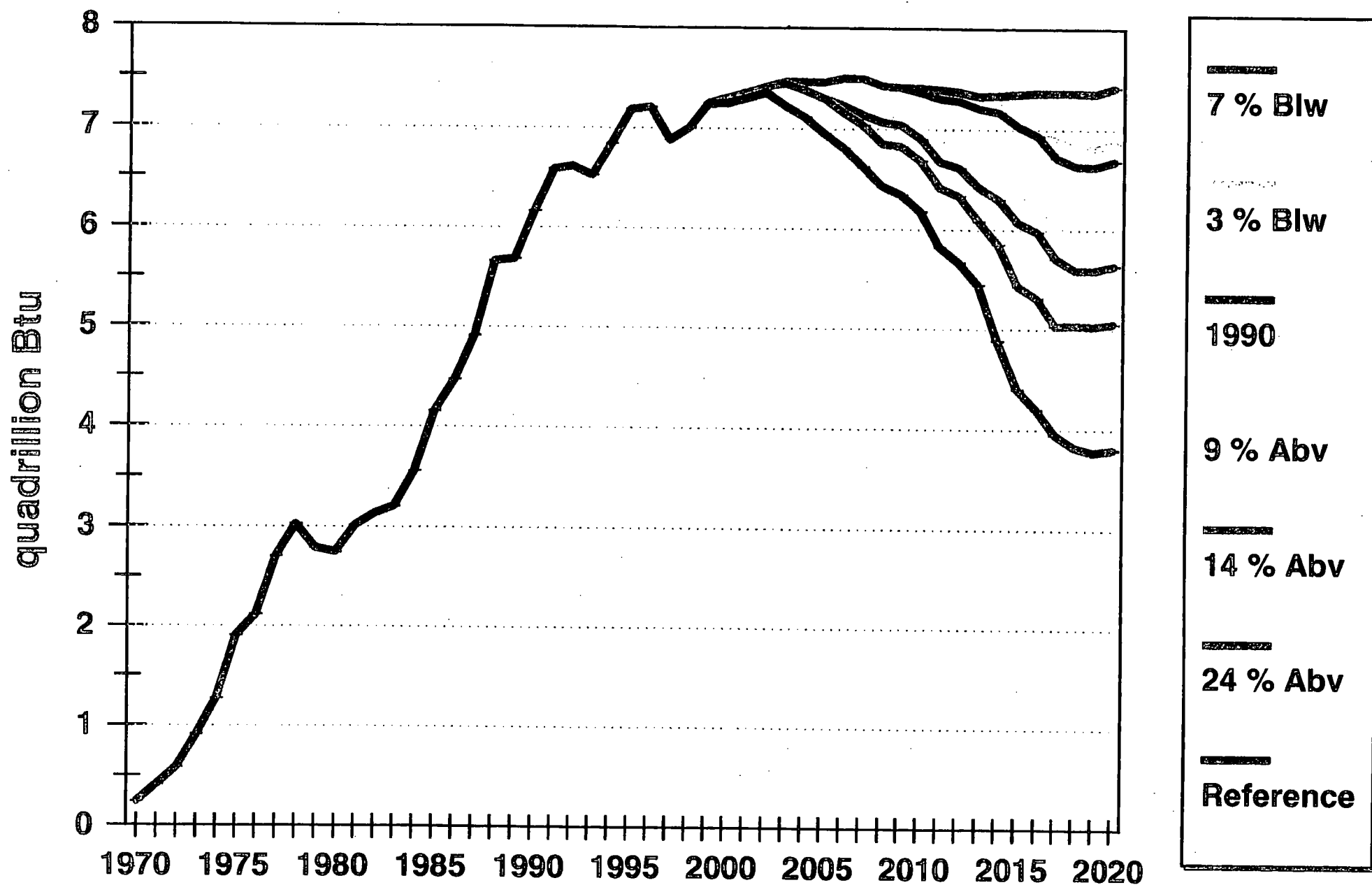
Natural gas consumption in the reference and six target cases, 1970-2020



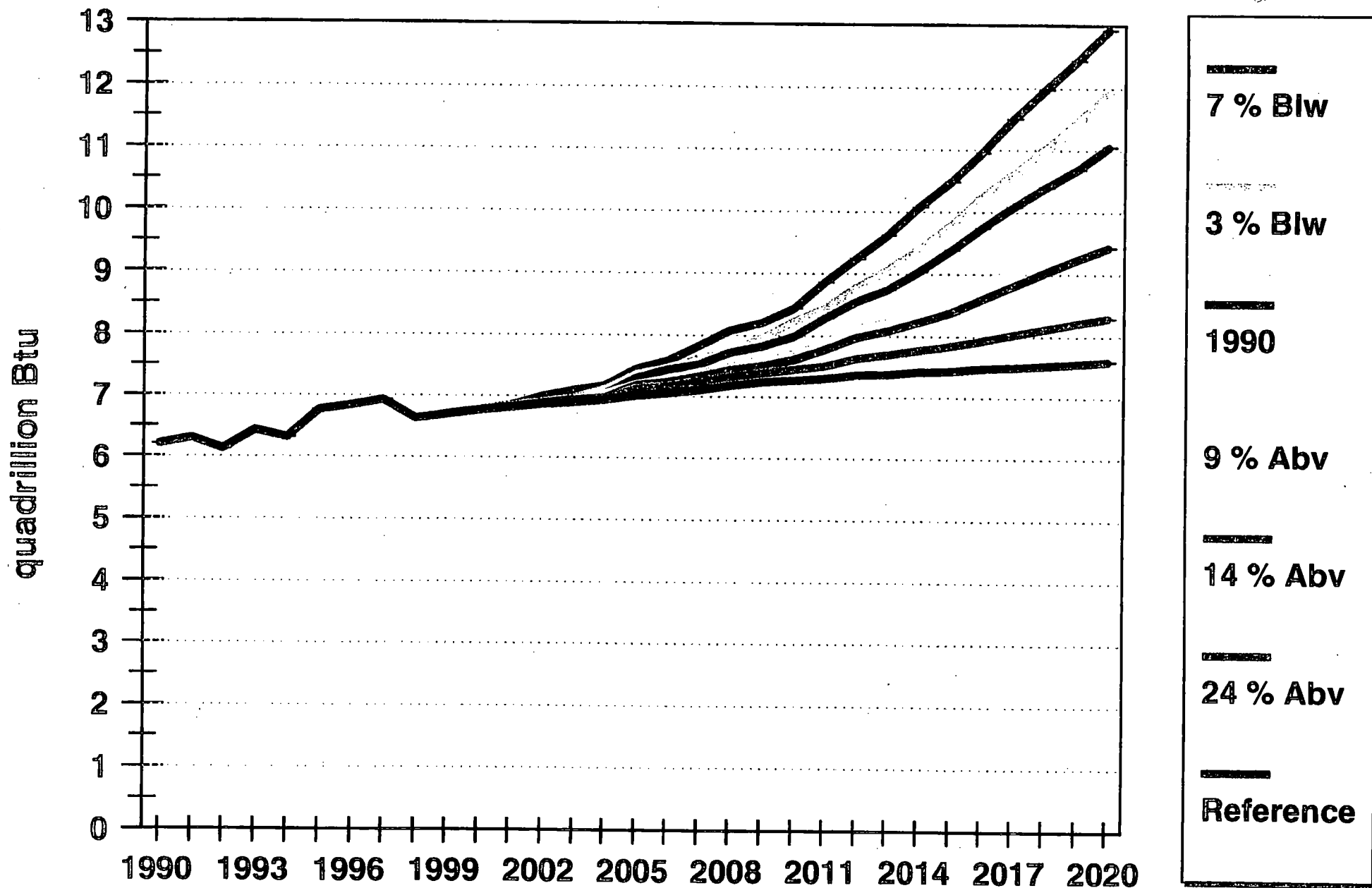
Petroleum consumption in the reference and six target cases, 1970-2020



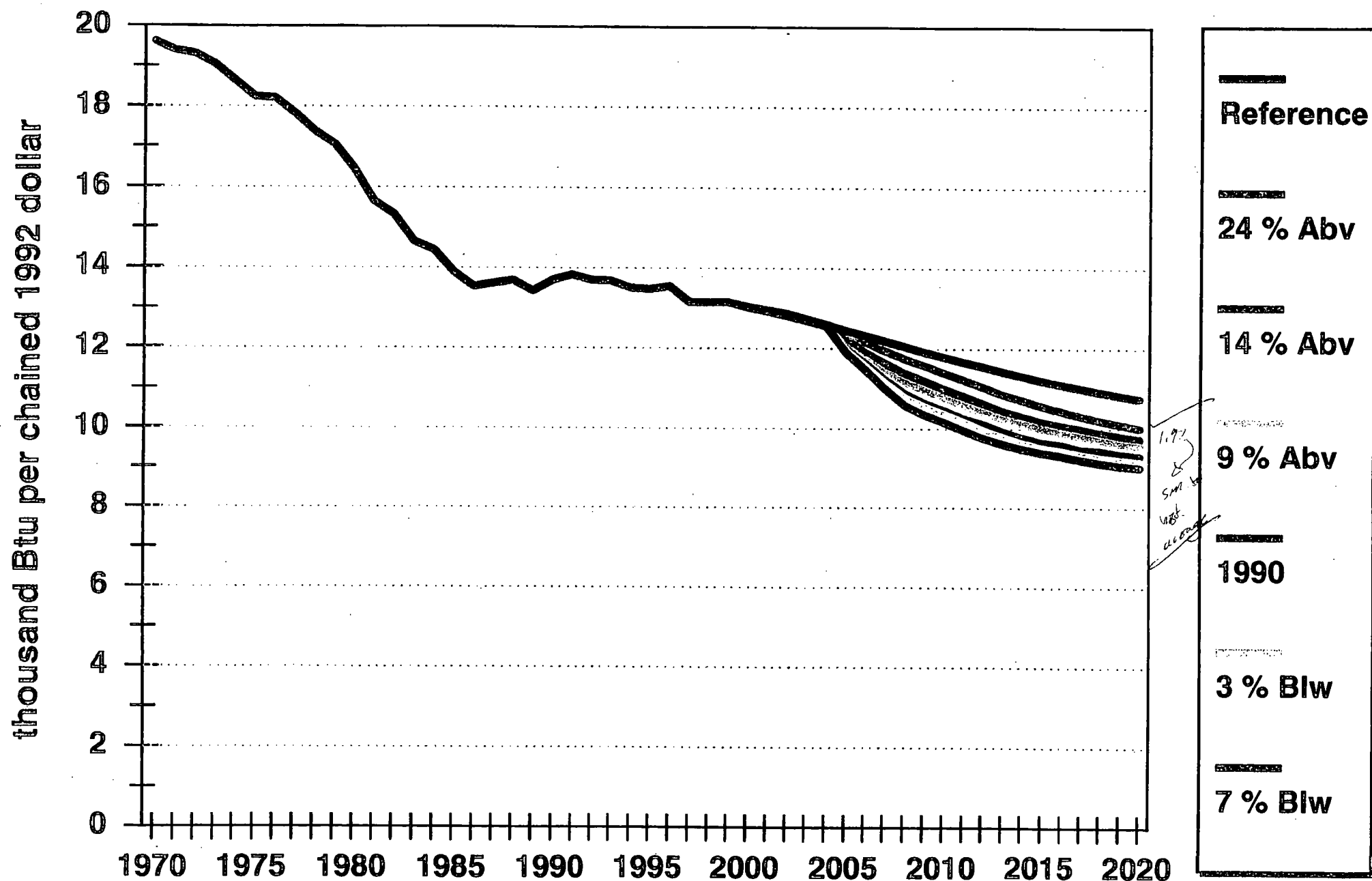
Nuclear energy consumption in the reference and six target cases, 1970-2020



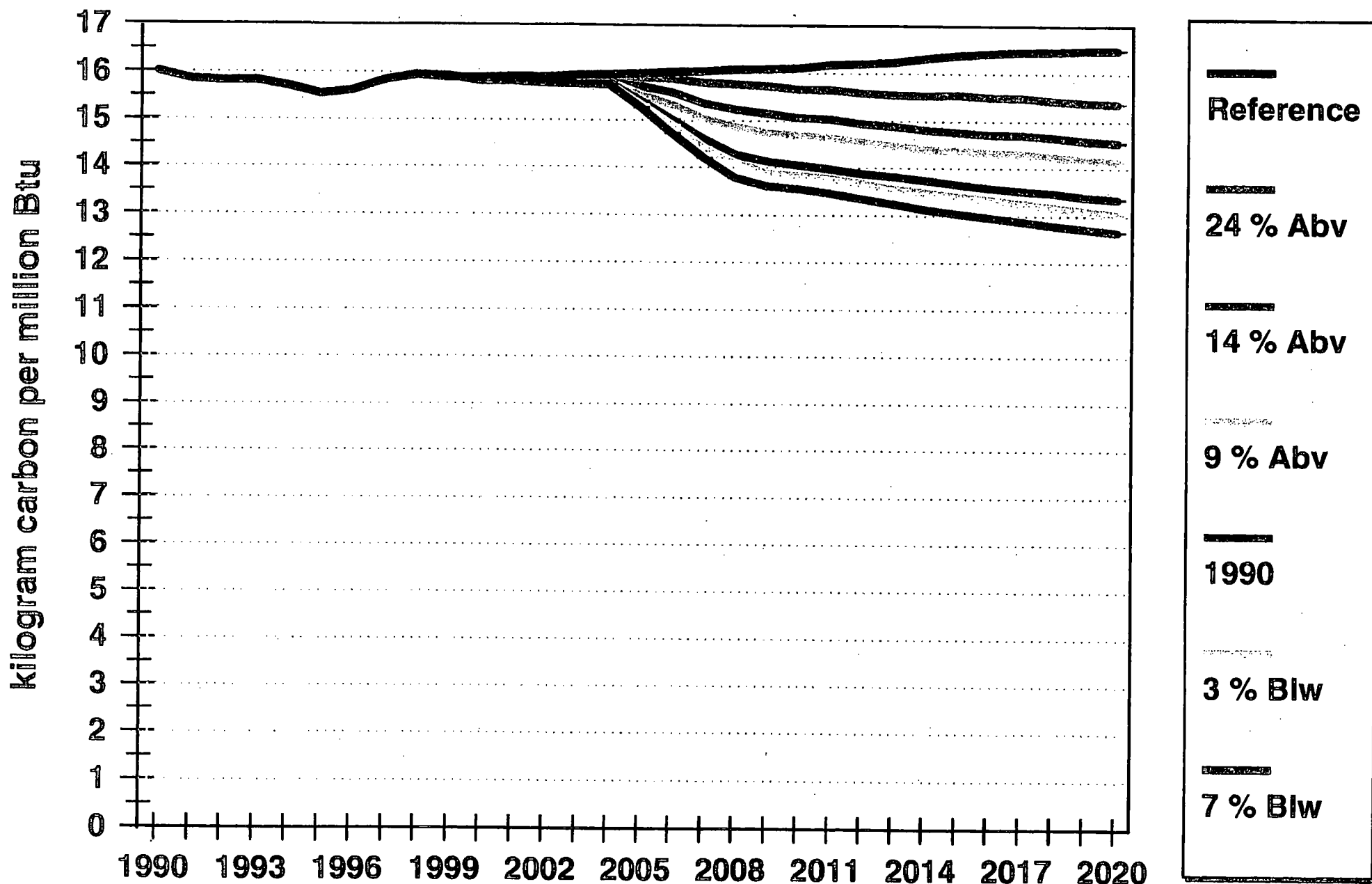
Renewable energy consumption in the reference and six target cases, 1990-2020



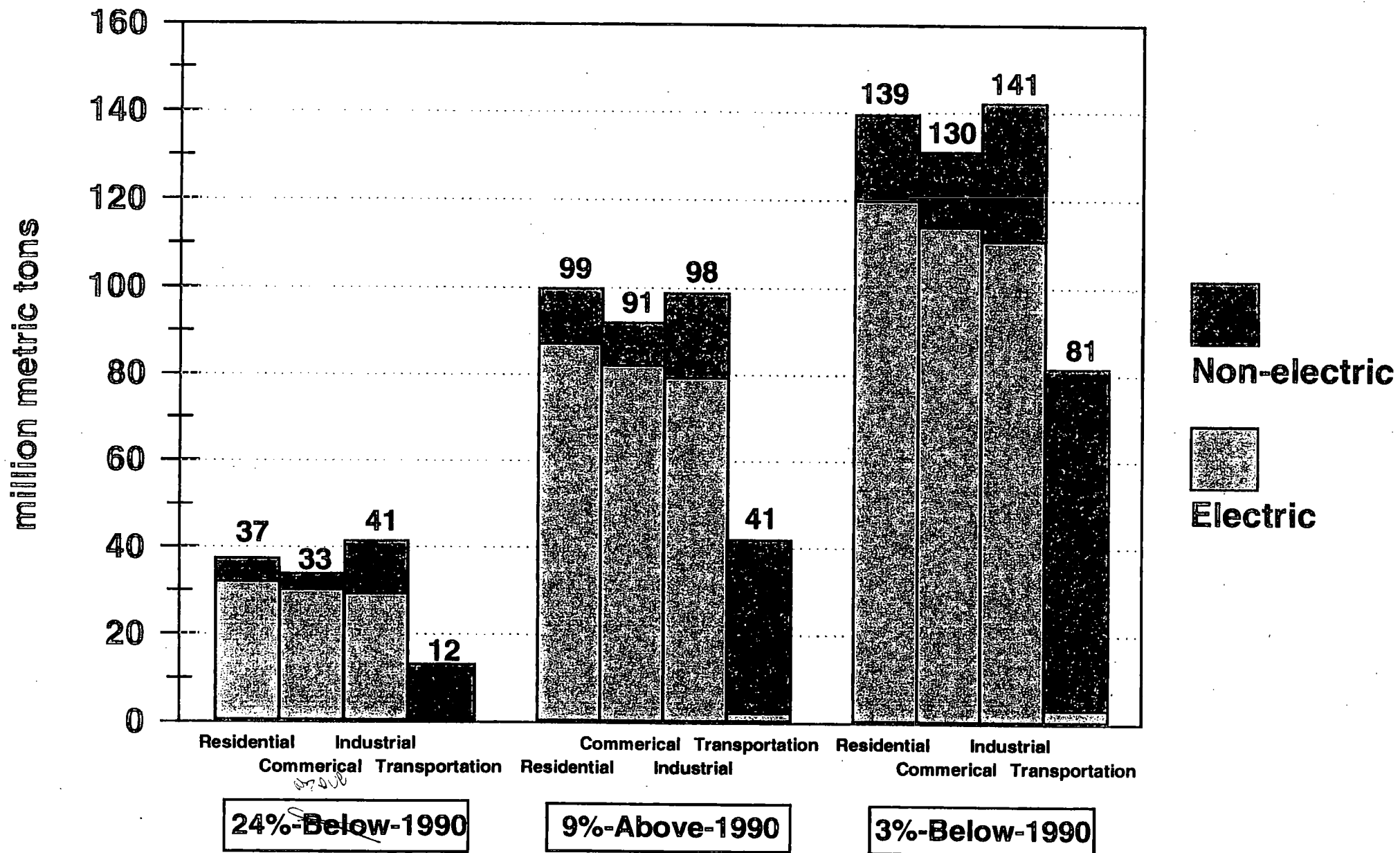
Energy consumption per unit of gross domestic product in the reference and six target cases, 1970-2020



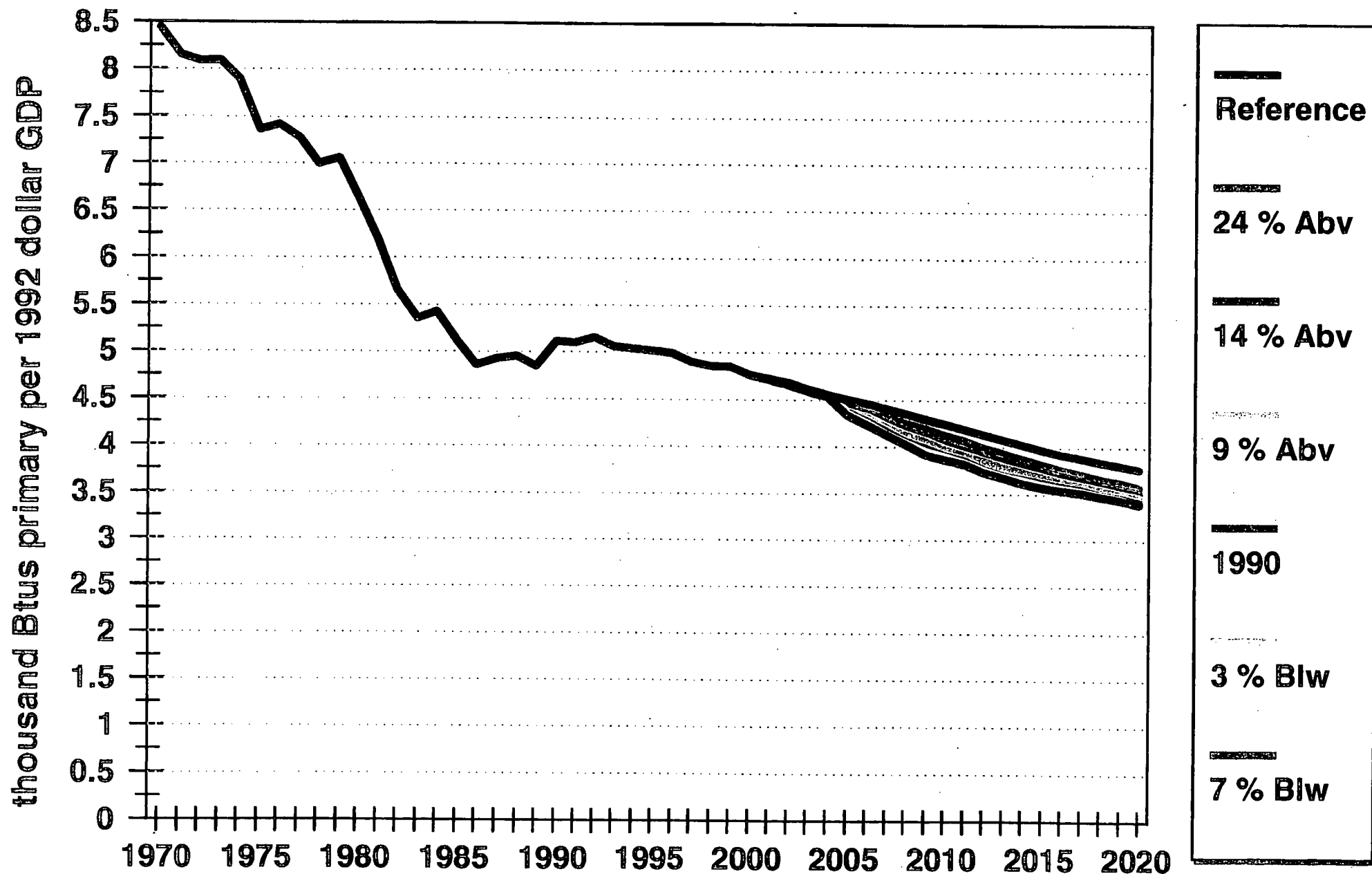
Carbon emissions per unit of primary energy consumption in the reference and six target cases, 1990-2020



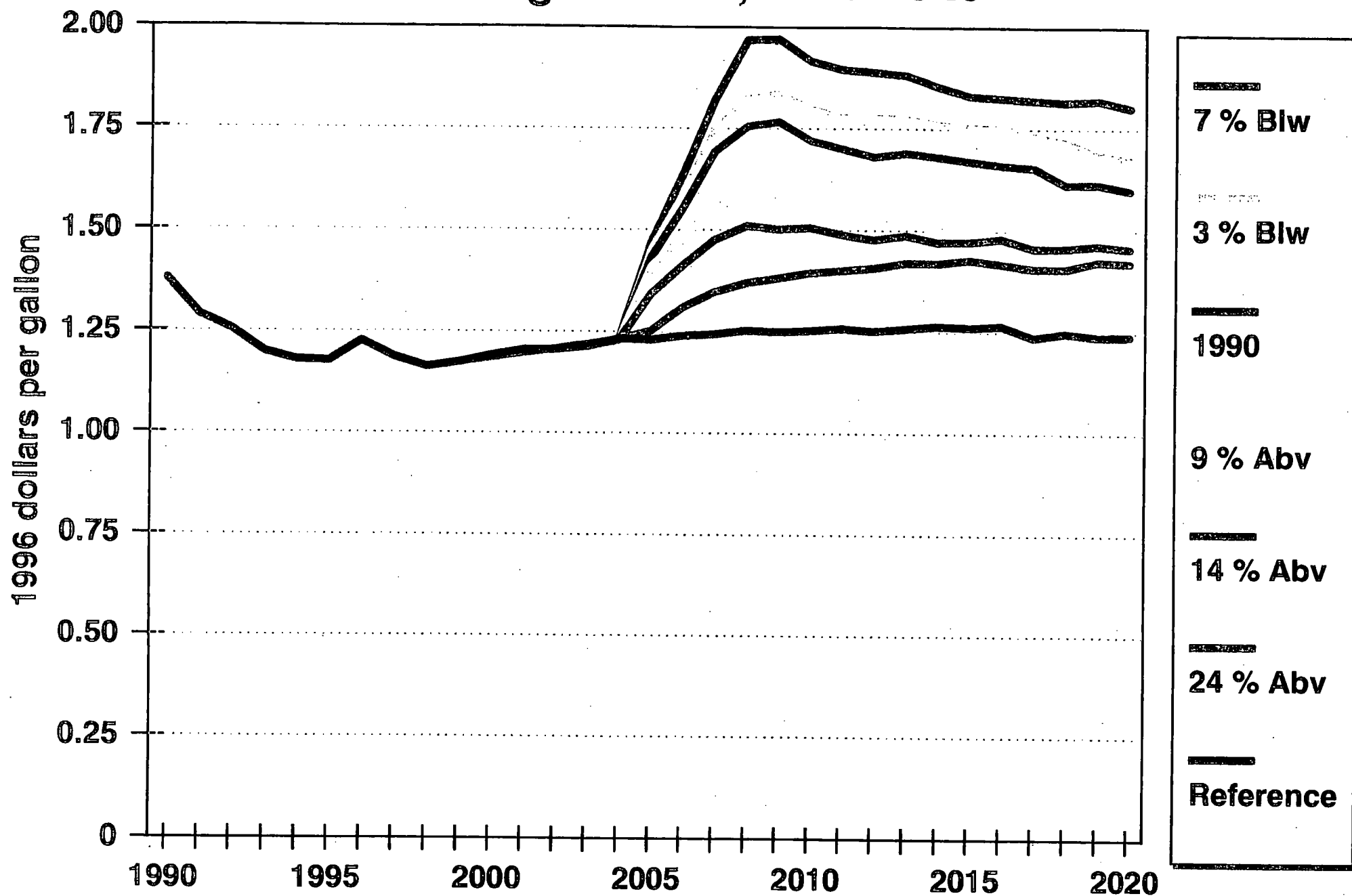
Carbon reductions by sector, 24%-above-1990, 9%-above-1990, and 3%-below-1990 cases, 2010



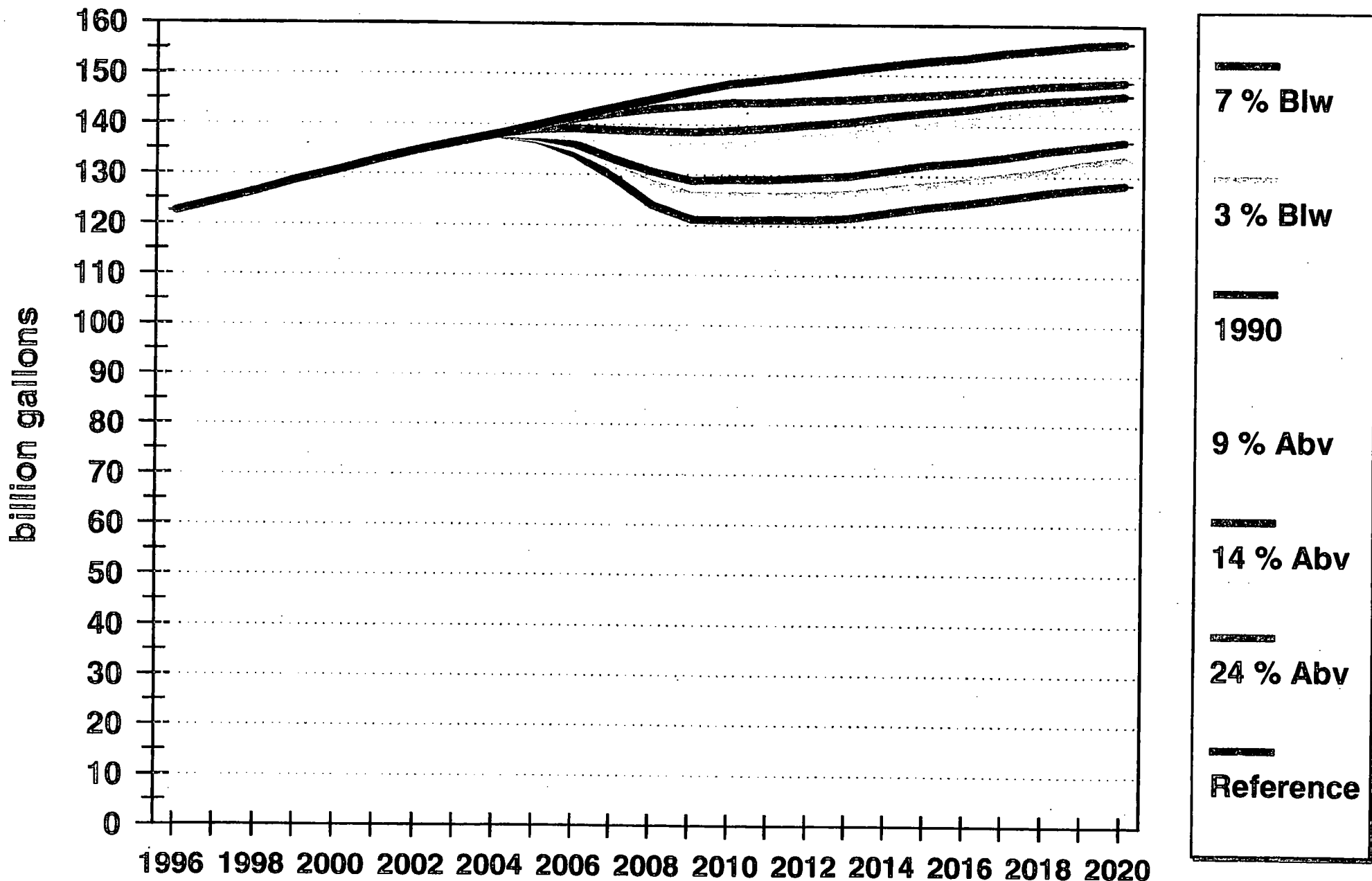
Industrial energy intensity in the reference and six target cases, 1996-2020



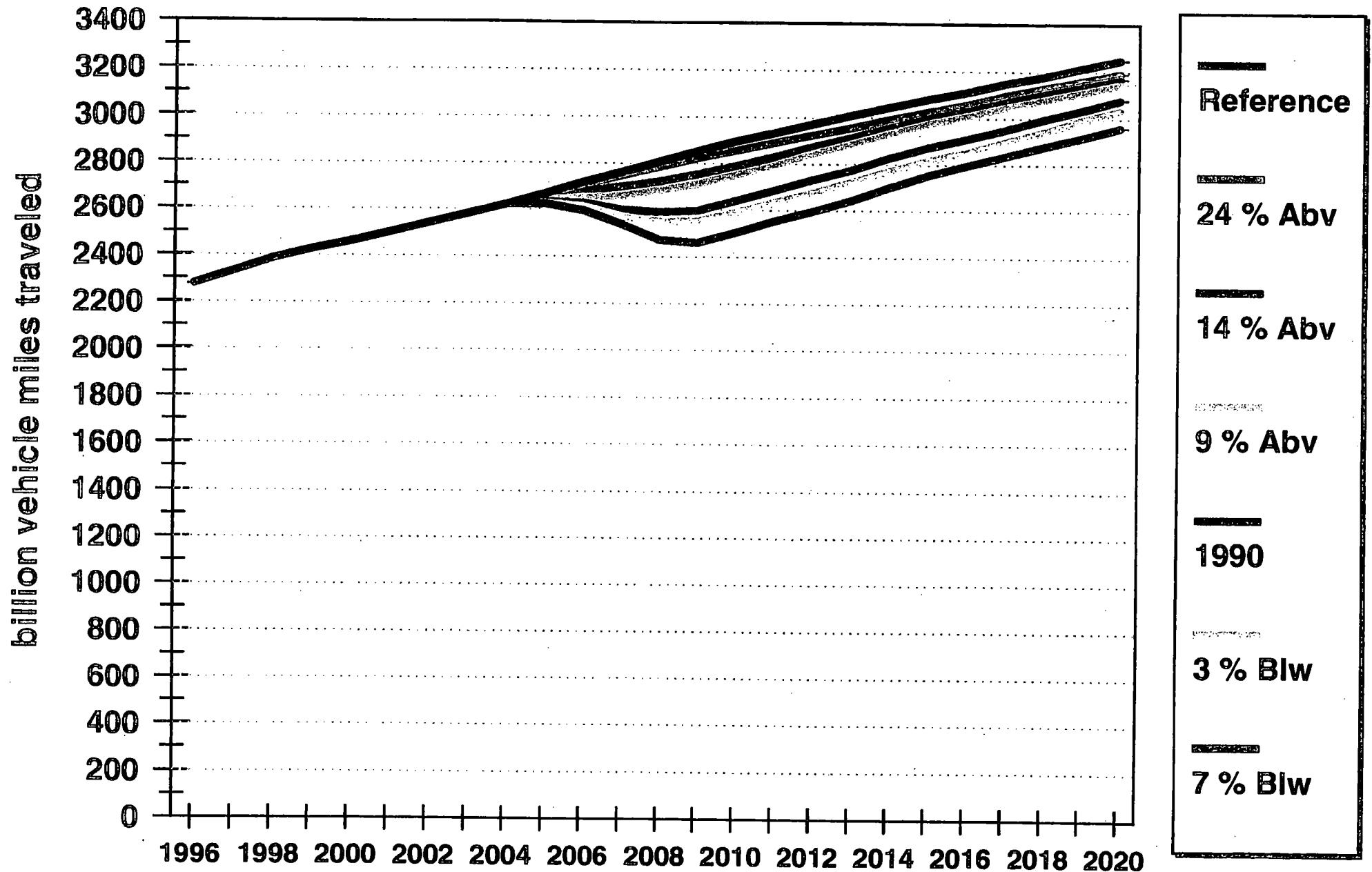
Motor gasoline price in the reference and six target cases, 1990-2020



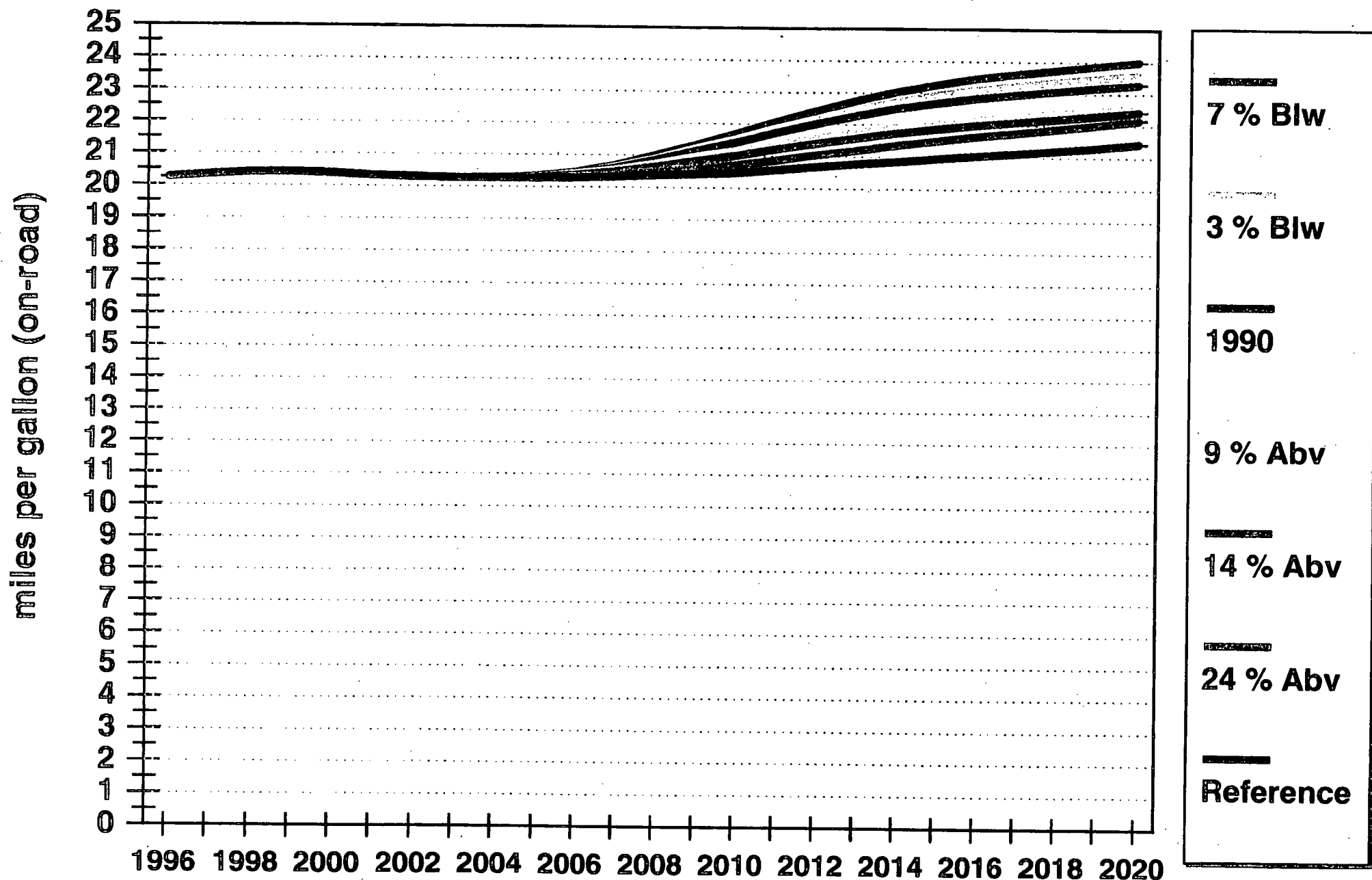
Motor gasoline consumption in the reference and six target cases, 1996-2020



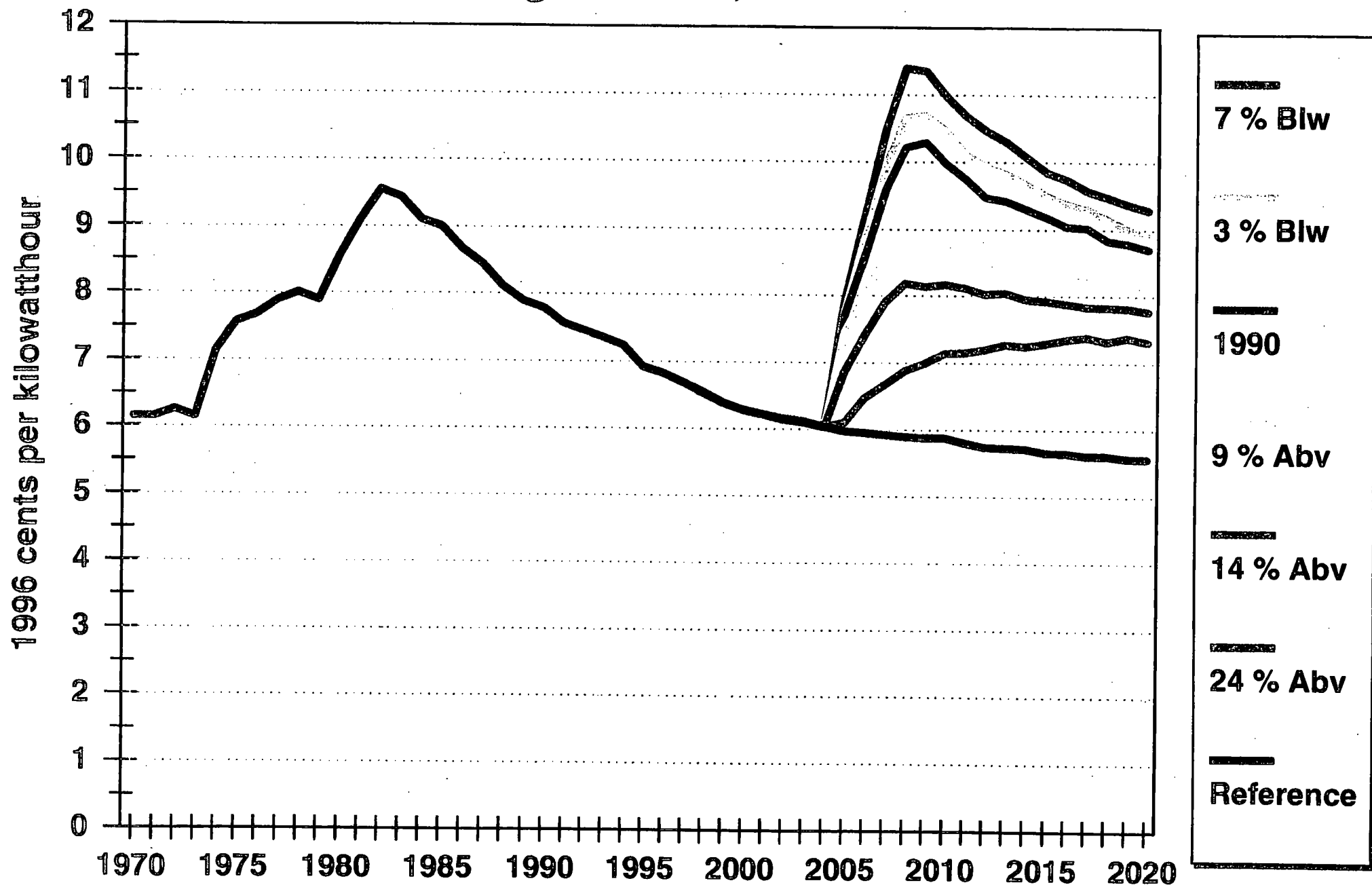
Light-Duty vehicle travel in the reference and six target cases, 1996-2020



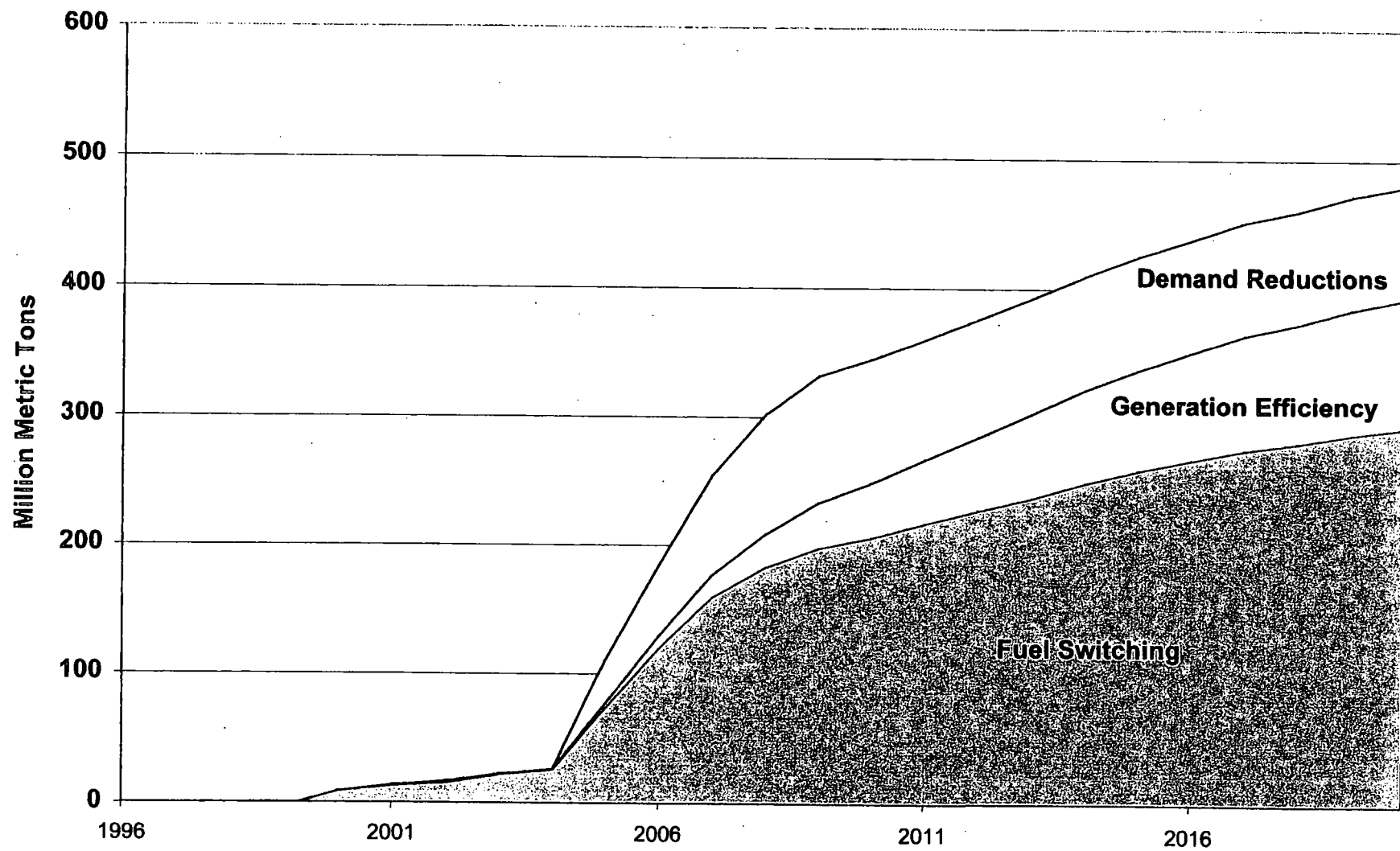
Light-Duty fleet efficiency in the reference and six target cases, 1996-2020



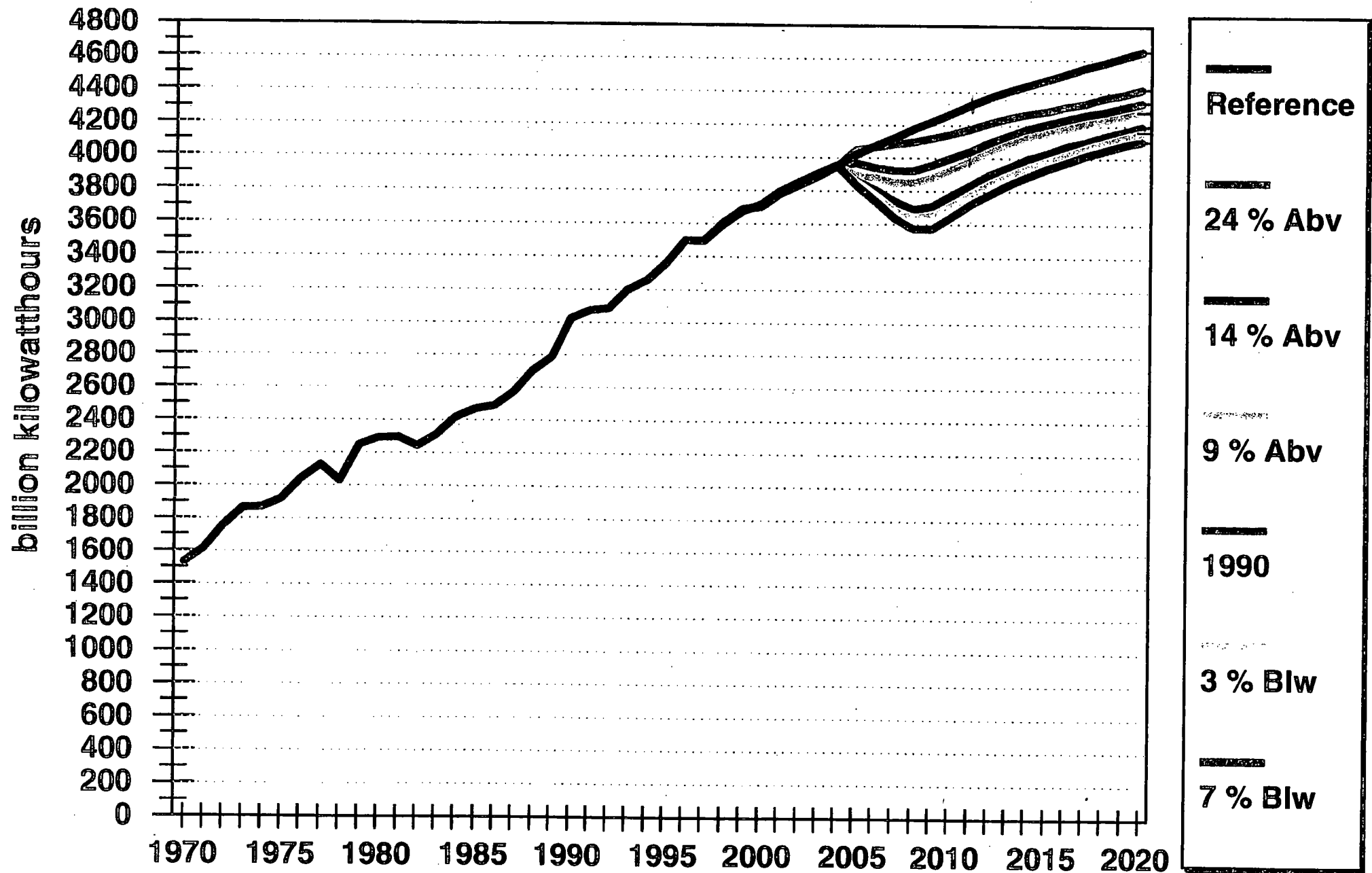
Electricity prices in the reference and six target cases, 1970-2020



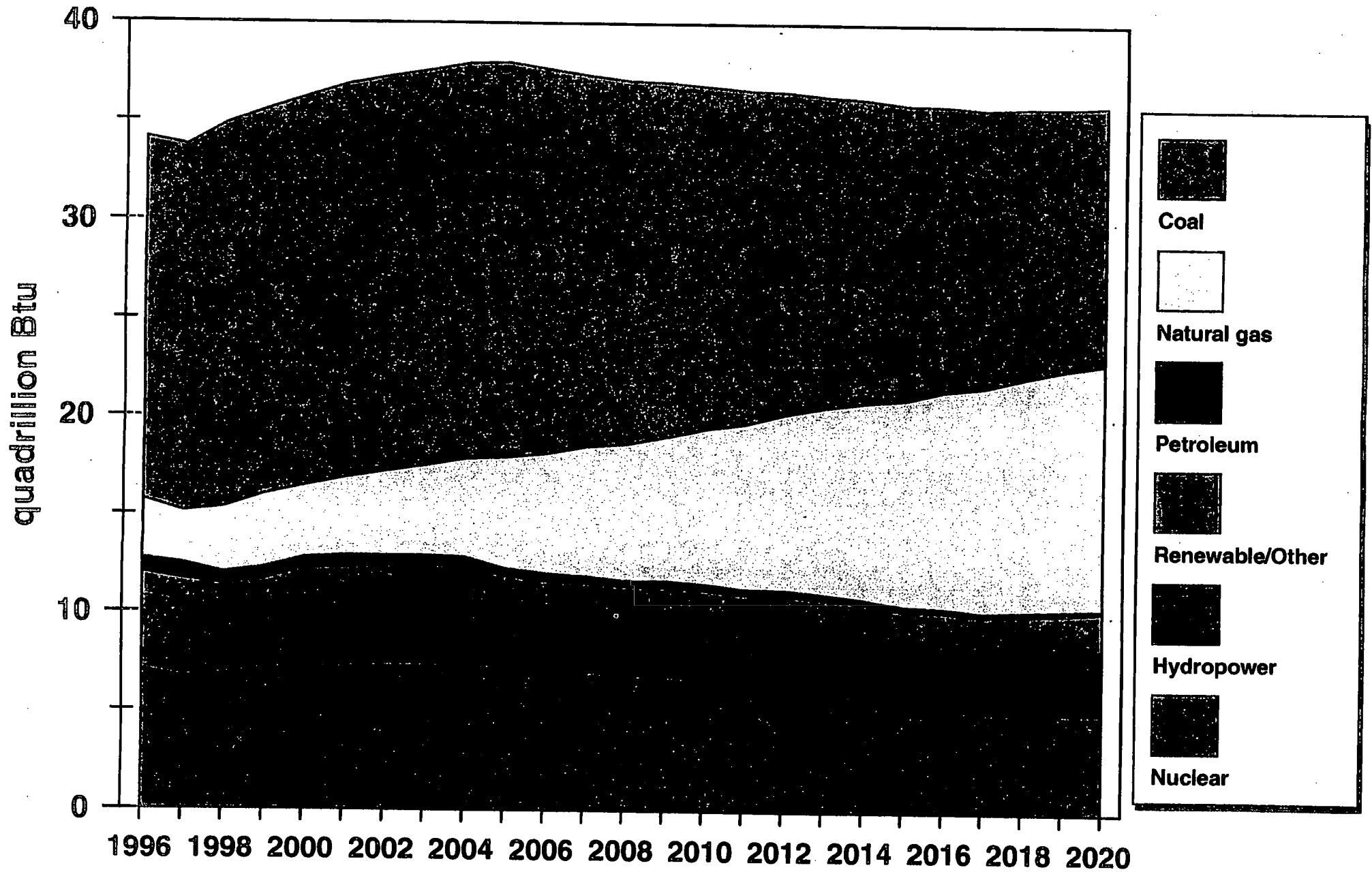
Electricity Sector Carbon Emissions Reductions by Source in the 1990-3% Case



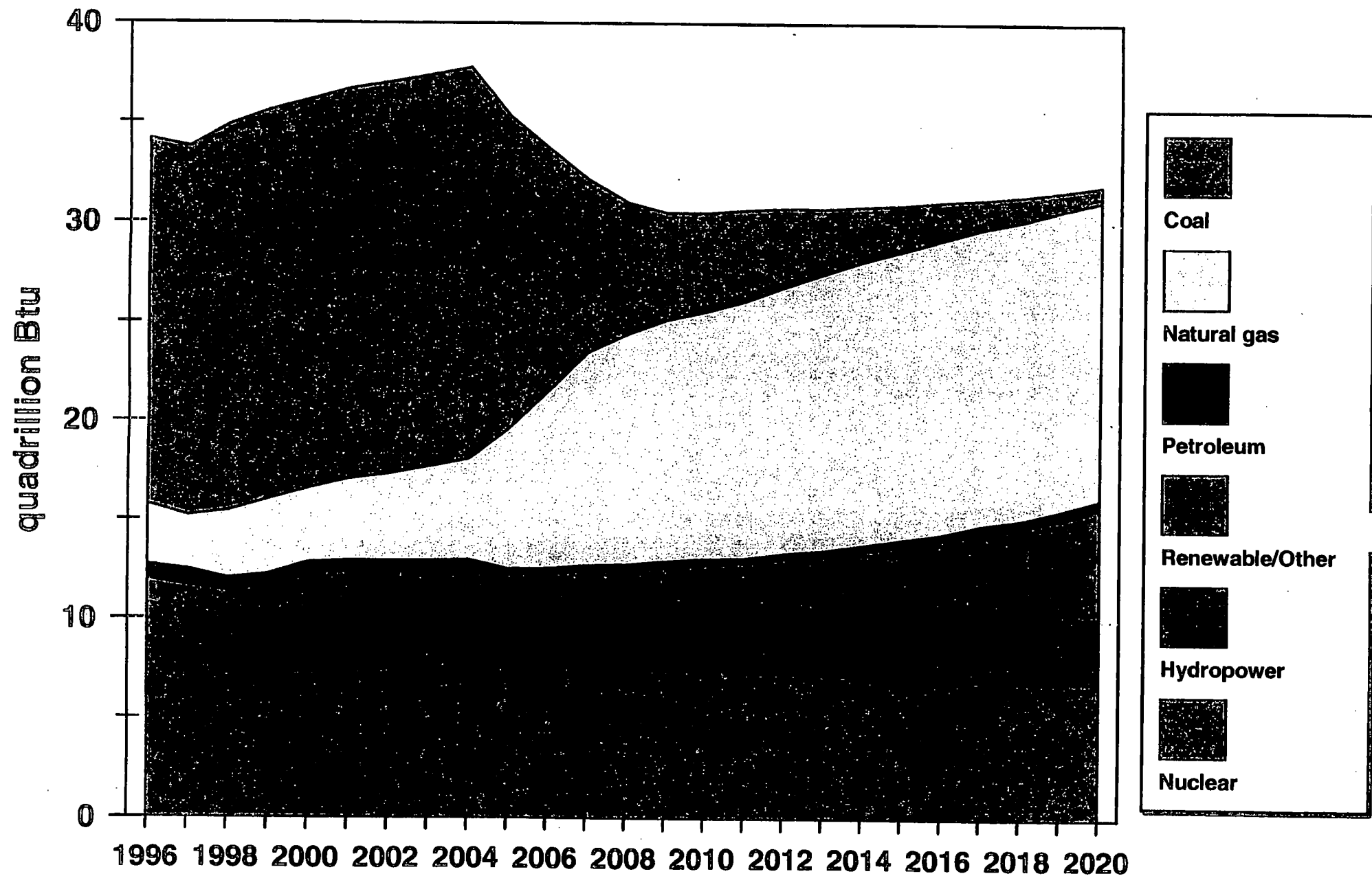
Electricity generation in the reference and six target cases, 1990-2020



Generation energy use by fuel in the 24%-above-1990 case, 1996-2020



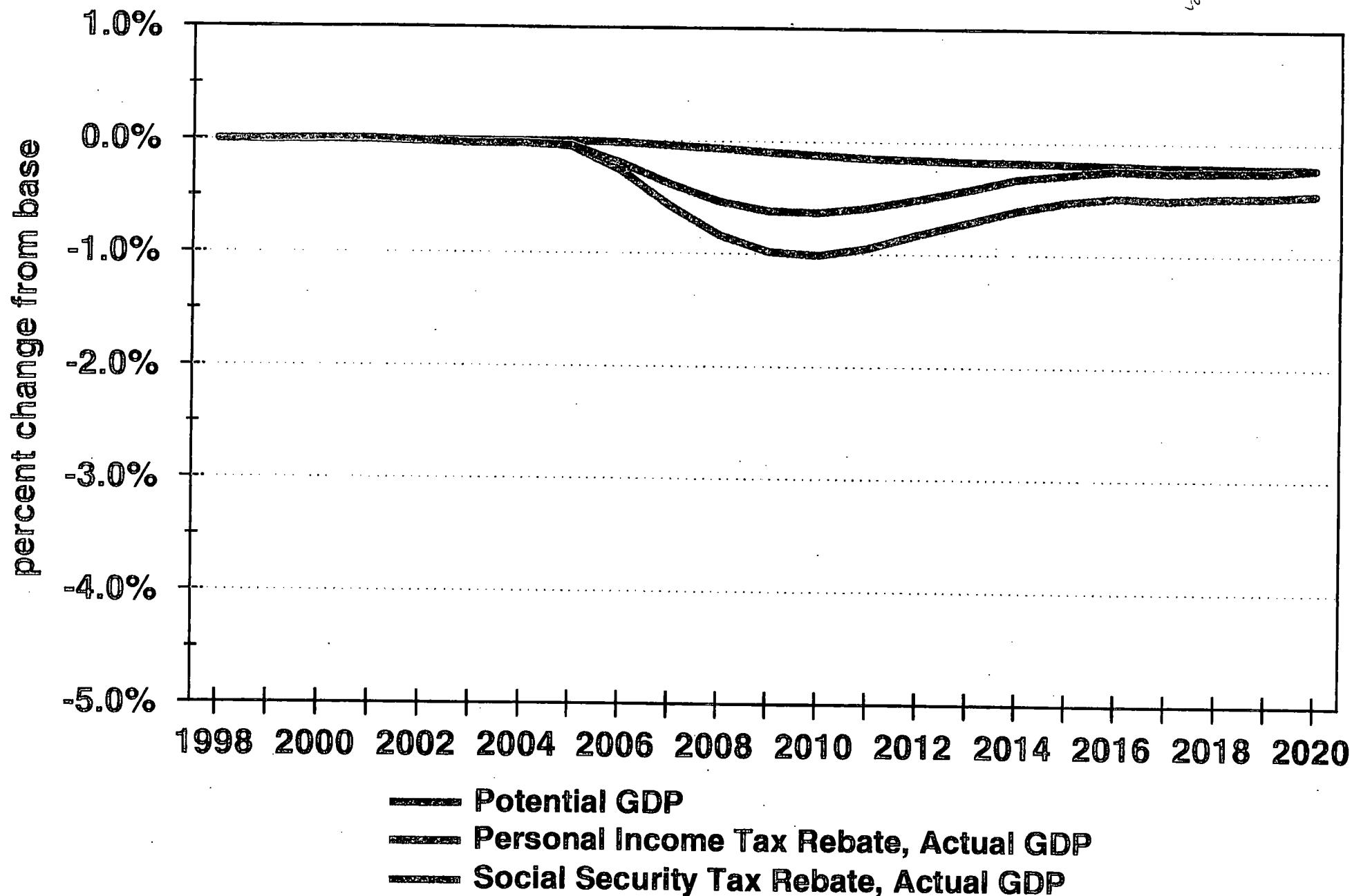
Generation energy use by fuel in the 3%-below-1990 case, 1996-2020



GDP with Alternative Fiscal Policies

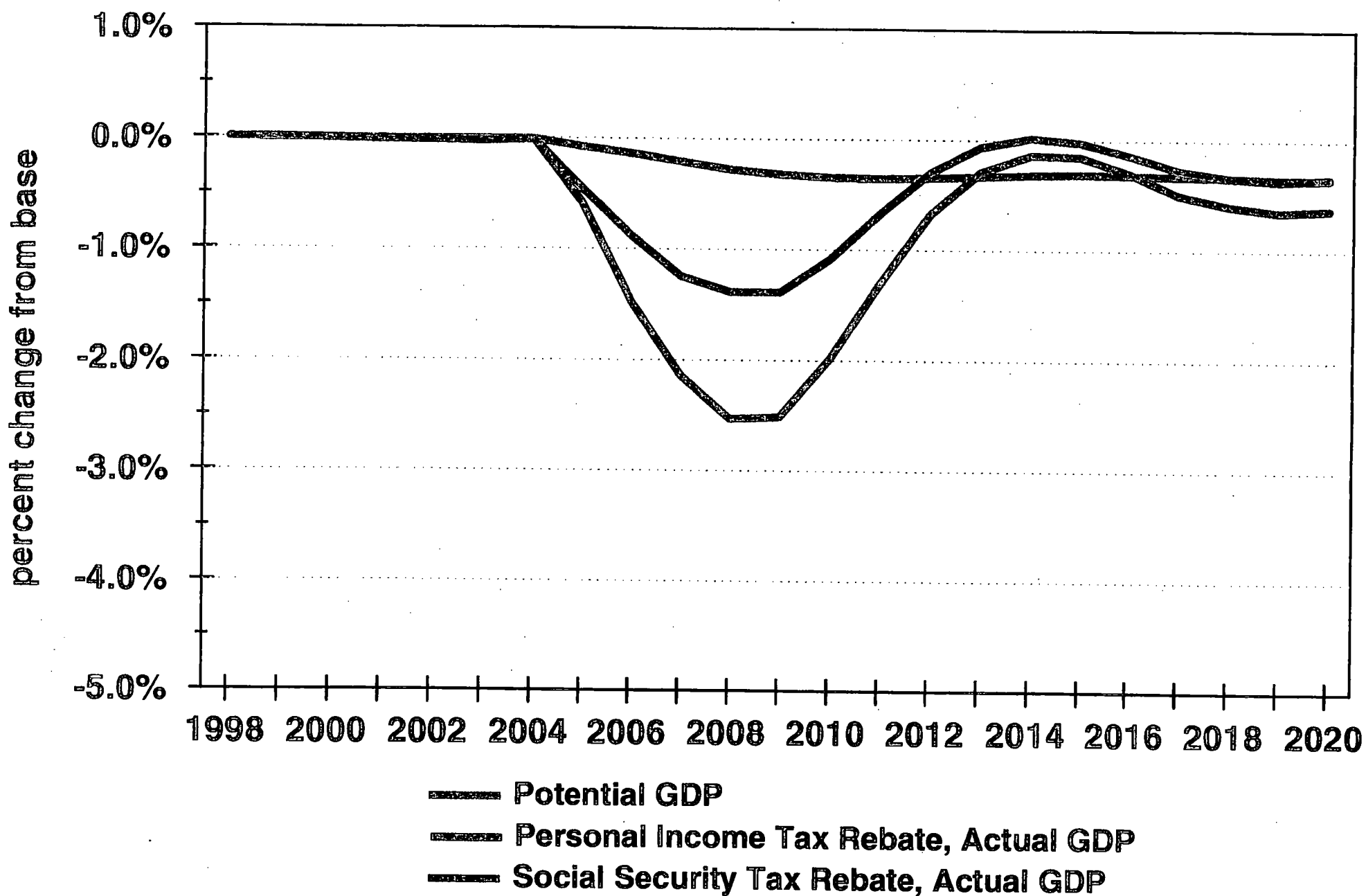
24% Above 1990

Uses 521 Macro Model



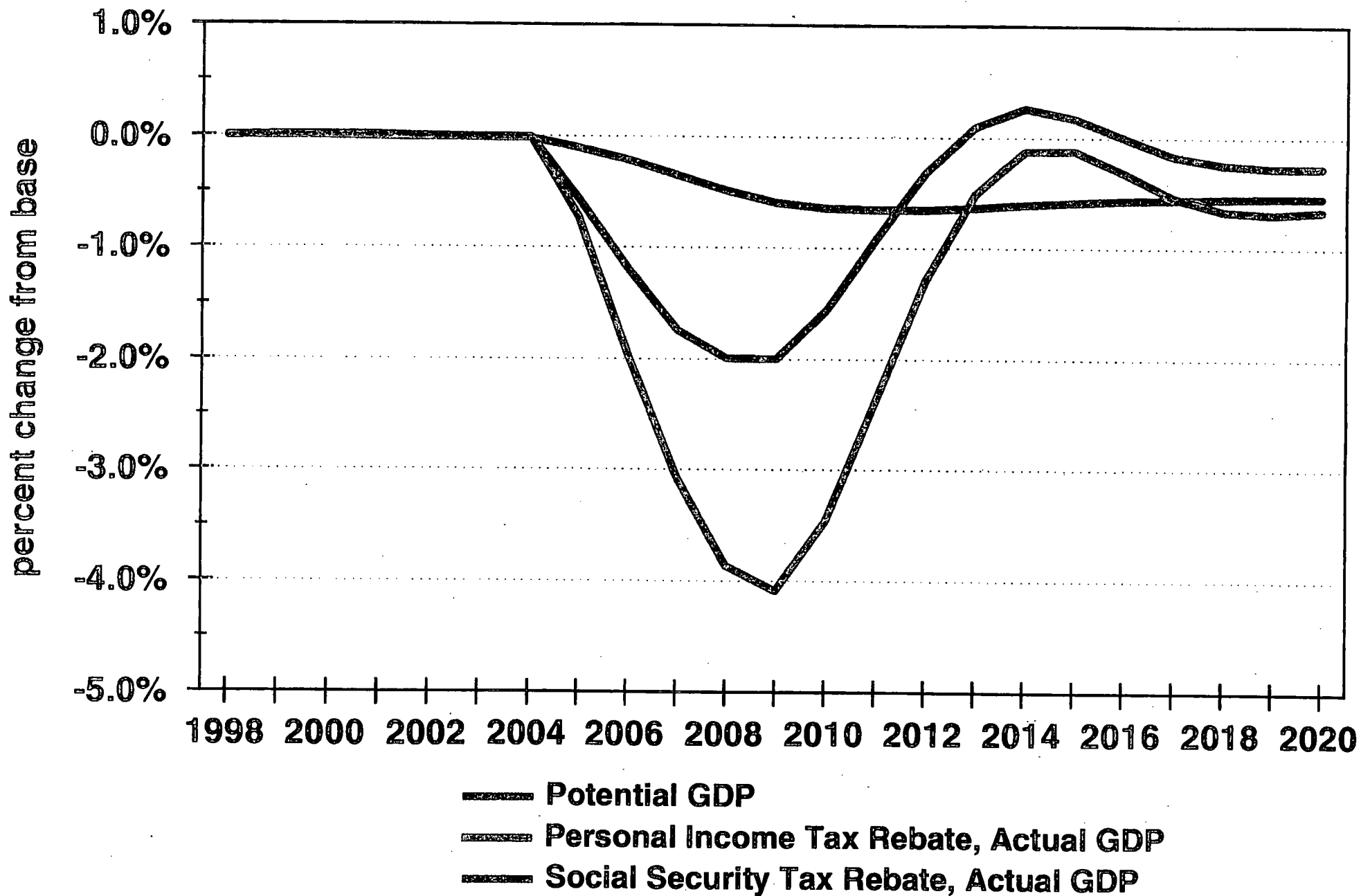
GDP with Alternative Fiscal Policies

9% Above 1990

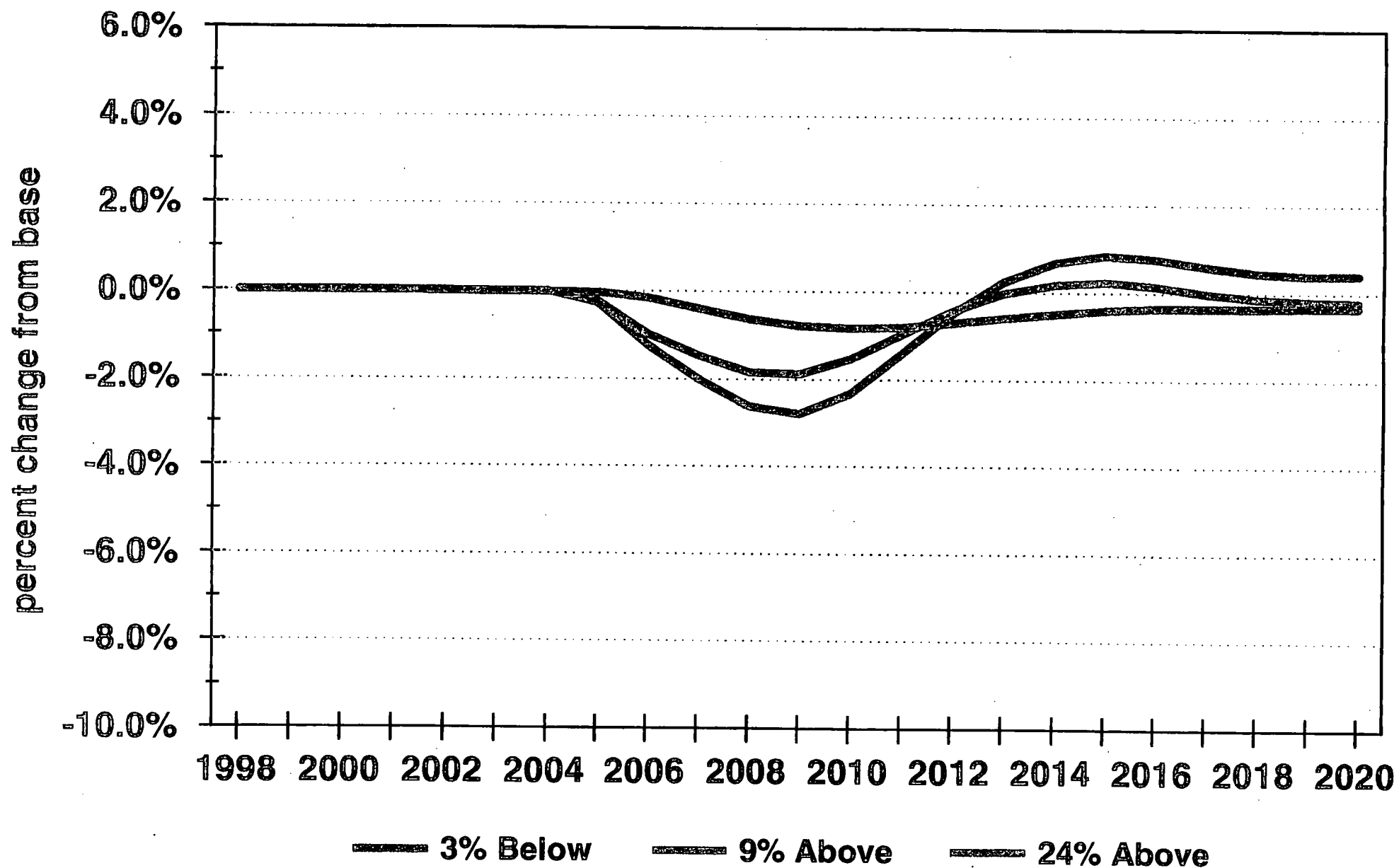


GDP with Alternative Fiscal Policies

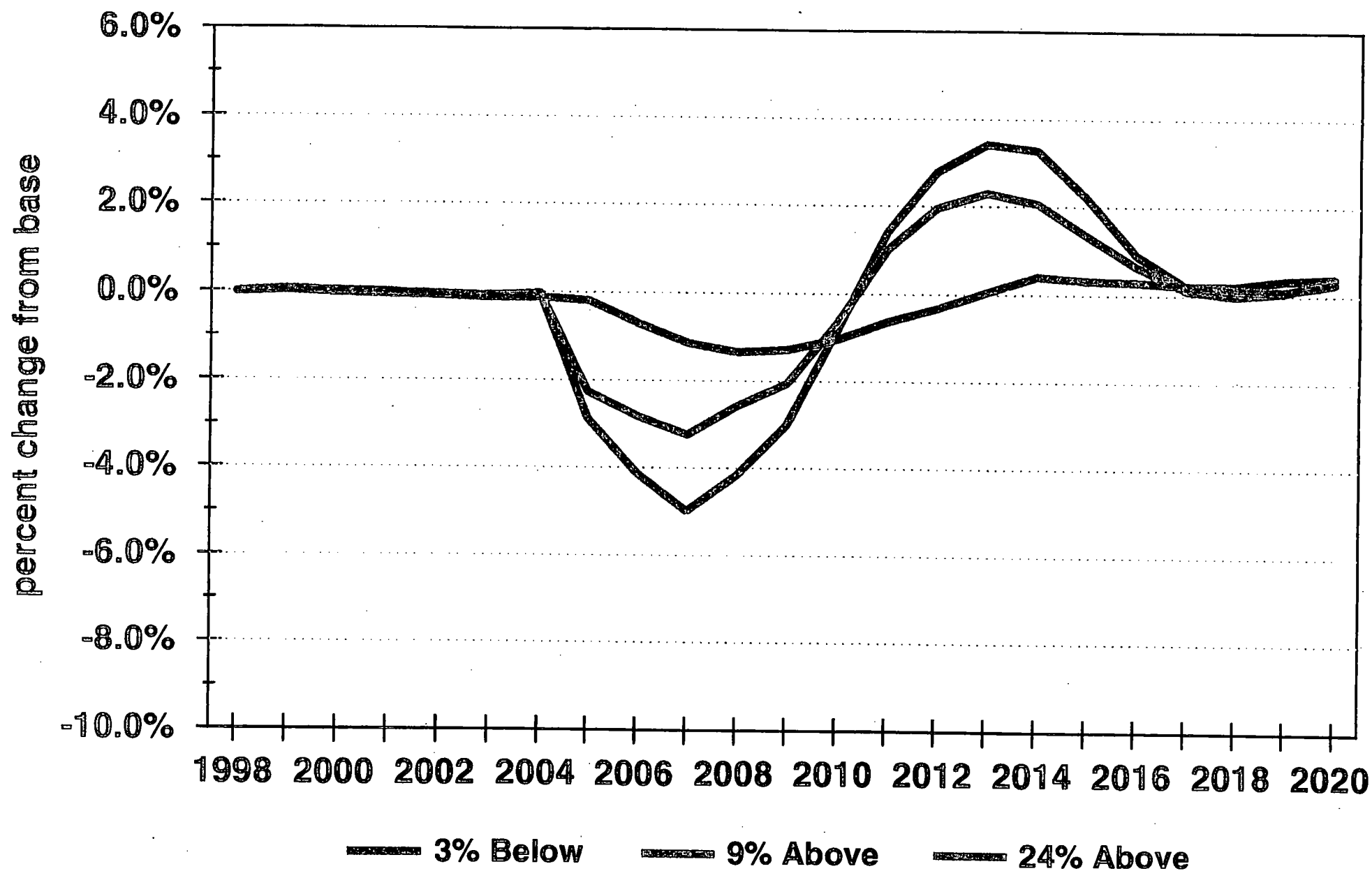
3% Below 1990



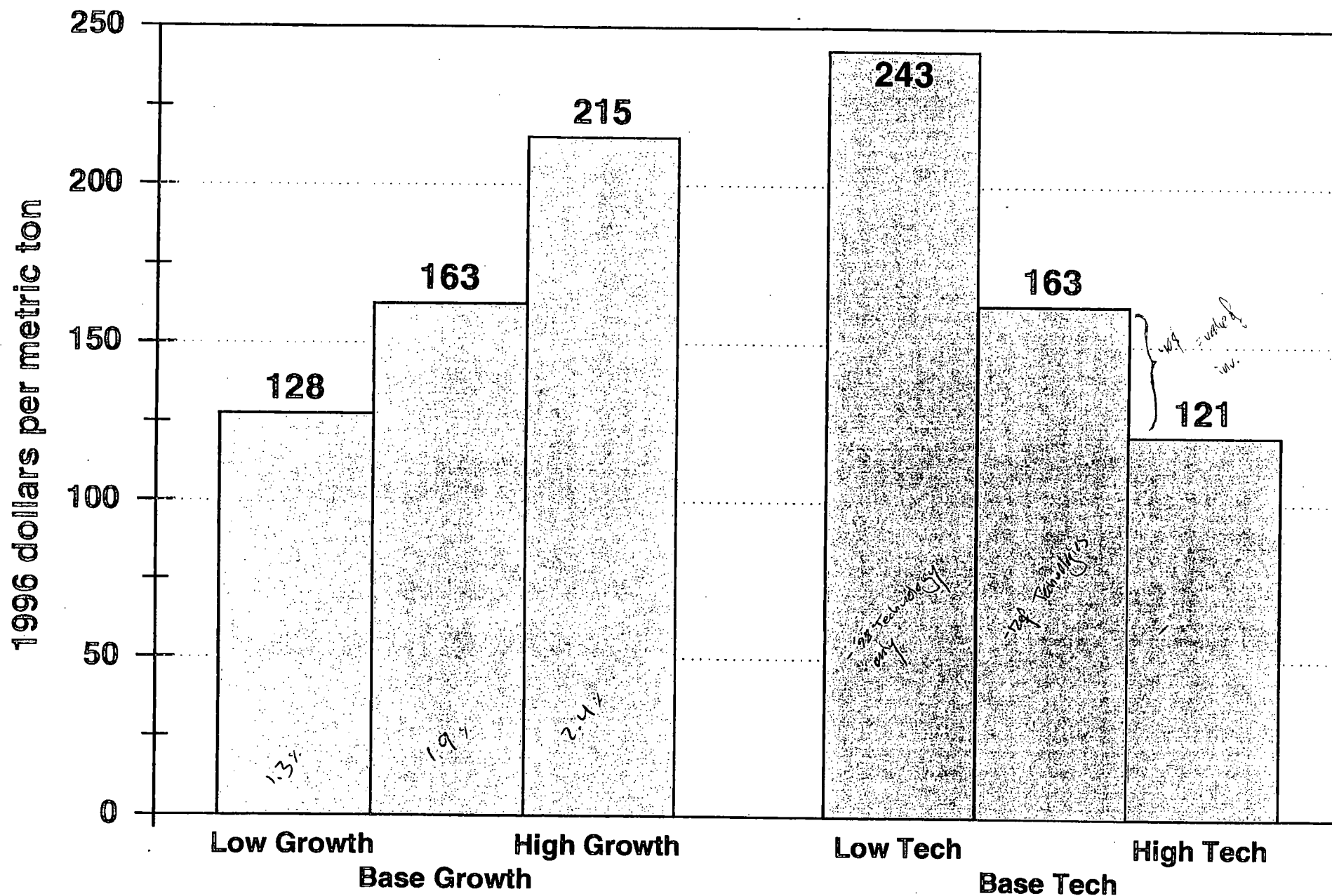
Real Consumption Personal Income Tax Rebate



Real Investment Social Security Tax Rebate



Carbon prices in the 9%-above-1990 sensitivity cases, 2010



Other Sensitivities

- Industrial Composition *Aggressive CBA
DPA has better input than*
- Competitive Pricing *- higher % competition (McRory)*
- Biomass Gasification
- Reducing the Impact on the Coal Industry

Economic Analyses of Emissions Trading and Joint Implementation

**IPIECA Global Climate Change Workshop:
Flexibility Instruments in the Kyoto Protocol
June 29, 1998**

**W. David Montgomery
Charles River Associates
Washington, DC**



Carbon Emission Trading Has Great Theoretical Appeal

- **Achieve carbon limits at minimum economic cost**
 - Information about costs at different sources is not required to find least-cost allocation of effort
 - Additional distortions of regulatory approaches are avoided
- **Allow flexibility in burden sharing**
 - Changing the distribution of permits changes who pays and who benefits without increasing total cost
- **Examples**
 - All economic studies assume domestic emission trading or an equivalent program
 - Studies of international trading conclude global trading could reduce costs by 2/3

Achieving Theoretical Potential Requires Strong Institutions

- **Monitoring**

- Emission limit
- Holding of permits
- Actual emissions

- **Enforcement**

- Detection of violations from monitoring data
- Adequate penalties for exceeding limits

- **Trading rules**

- Validity of emission permits

- **Markets**

- Will develop if *rules, monitoring and enforcement* are adequate

Proposals for Emission Trading in the United States

- **Permits to market**

- Draw a line near the refinery, natural gas gathering point, or coal mine
- Any BTU that crosses the line requires a permit
- Requires reporting of all energy purchases at some point in the distribution chain
- Limited number of players minimizes administrative costs but there are subtleties like feedstocks

- **Permits to emit**

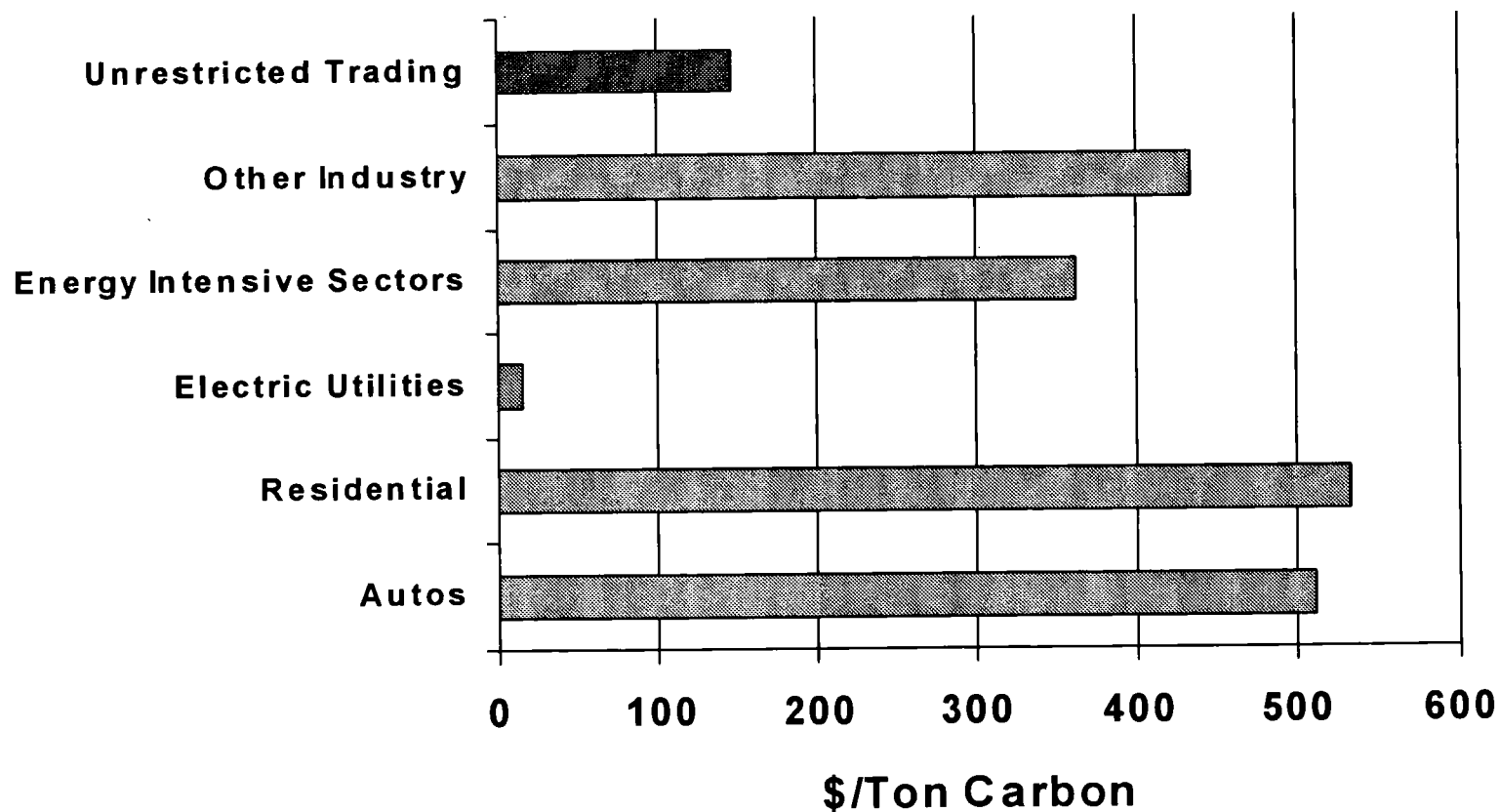
- All end users of energy require permits (rationing)
- Requires monitoring of fuel purchases or actual emissions
- Large number of transactions makes universal system prohibitively expensive

Proposals Differ Widely from the Theoretical Ideal

- **Examples include**
 - Heinz Foundation
 - Center for Clean Air Policy
- **Permits to emit: sector specific caps for utilities, large industry and automakers with limited trading across sectors**
- **Efficiency standards instead of emission trading for new cars, households and other end uses**
- **Potential cost increases**
 - Expected errors in setting sector specific caps
 - Added costs from reactions to regulatory approach

Sector Specific Caps Increase Costs

Marginal Cost of Holding Sectoral Emissions to 1990 Levels in 2010



Source: Autos8 Multi-Region Trade Model

CRA

Camouflaged Regulatory Approaches Increase Costs

- **“Permits to emit” are impossible to apply to small end users**
- **Costs will increase under proposals that substitute traditional regulations for emission trading in some sectors**
 - **CRA estimates CAFE standards are 5 times as costly as ideal trading system achieving same emission reduction from automobiles**
 - **Costs are due to “new source bias,” “take back effects” and other distortions generic to efficiency standards**
 - **Added costs can be estimated using standard techniques of “regulatory impact analysis”**

International Emission Trading Faces Even Greater Hurdles

- **Enforcement**
- **Institutions**
- **Participants**
- **Restrictions**

Requirements for Successful International Emission Trading

- **Binding caps for each country**
- **Monitoring of caps, permit holdings and emissions**
- **Enforcement and ability to impose penalties on countries and traders**
- **Institutions to handle transactions, information, and disputes**
- **Unrestricted trading among all regions**
- **“50 years from Bretton Woods to WTO”**

Status of International Emission Trading Under Kyoto

- **Trading within EU and among other Annex 1 countries authorized**
- **No role for developing countries except through CDM**
- **No enforcement provisions**
- **Rules and restrictions to be negotiated**

Negotiating Positions

- **U.S. desired outcome**

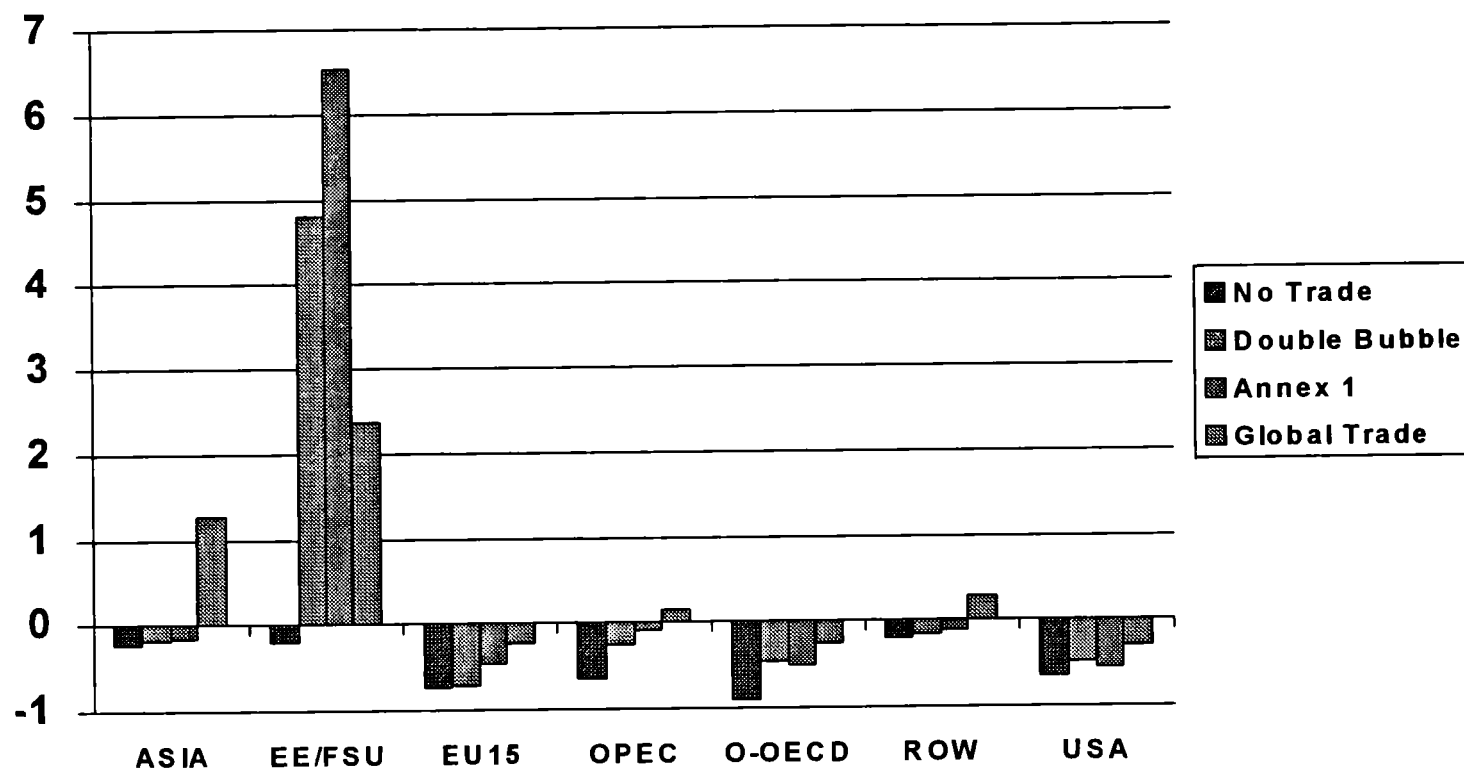
- Russia allowed to sell excess emission permits (“hot air”)
- No restrictions on the amount of a country’s obligation that can be satisfied through purchases
- Inclusion of developing countries in emission trading

- **Other countries’ positions**

- No sales of hot air
- Restrictions of purchases to 30% or less of obligation
- No participation of developing countries in emission trading

Costs of Kyoto under Different Ideal Trading Arrangements

(% Change in Present Value of Real National Income)



Source: Multi-Region Trade Model (MSMRT)

CRA

Cost Savings from Full Global Trading Unlikely to Be Achieved

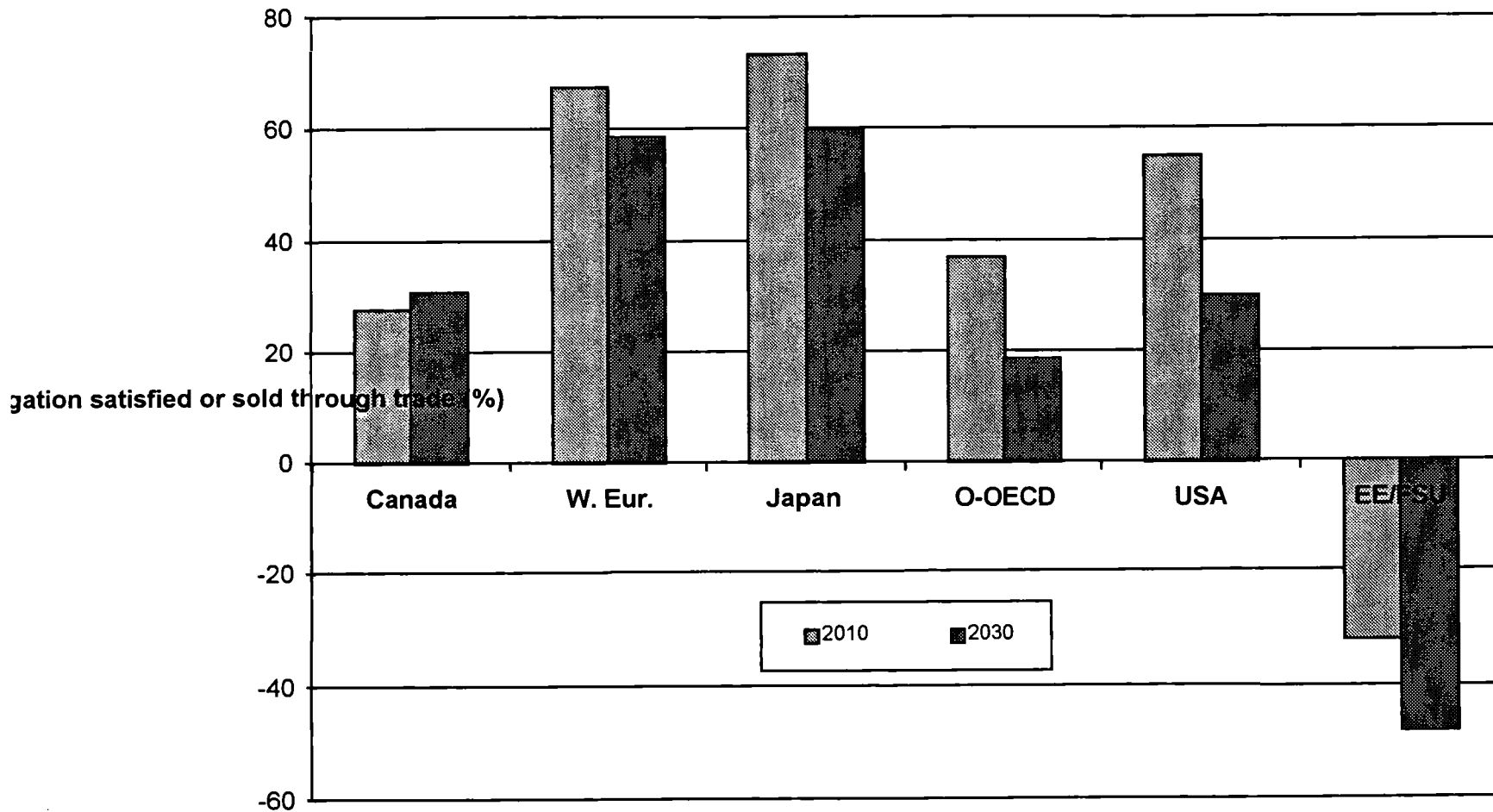
- **No provision for direct participation by non-Annex 1 countries**
- **CDM will have significant restrictions**
 - Layers of approval and requirement to spread investment across all non-Annex 1 countries
 - Possible project content restrictions (e.g. no nuclear)
 - Adjustment of credits for reductions included in baseline
 - Tax on projects for administrative costs and adaptation fund
- **Even well-designed CDM or JI does not achieve full economic benefits of trading**
 - Project orientation does not correct inequalities in energy costs between Annex 1 and non-Annex 1
 - Competitive imbalances remain producing carbon leakage and migration of energy intensive industry

CRA

Annex 1 Trading May Be Restricted

- **“Concrete ceiling” on permits that may be purchased**
- **Limits on Russia’s ability to sell permits in excess of baseline emissions**
- **Actions by Russia to restrict supply of permits and raise price**

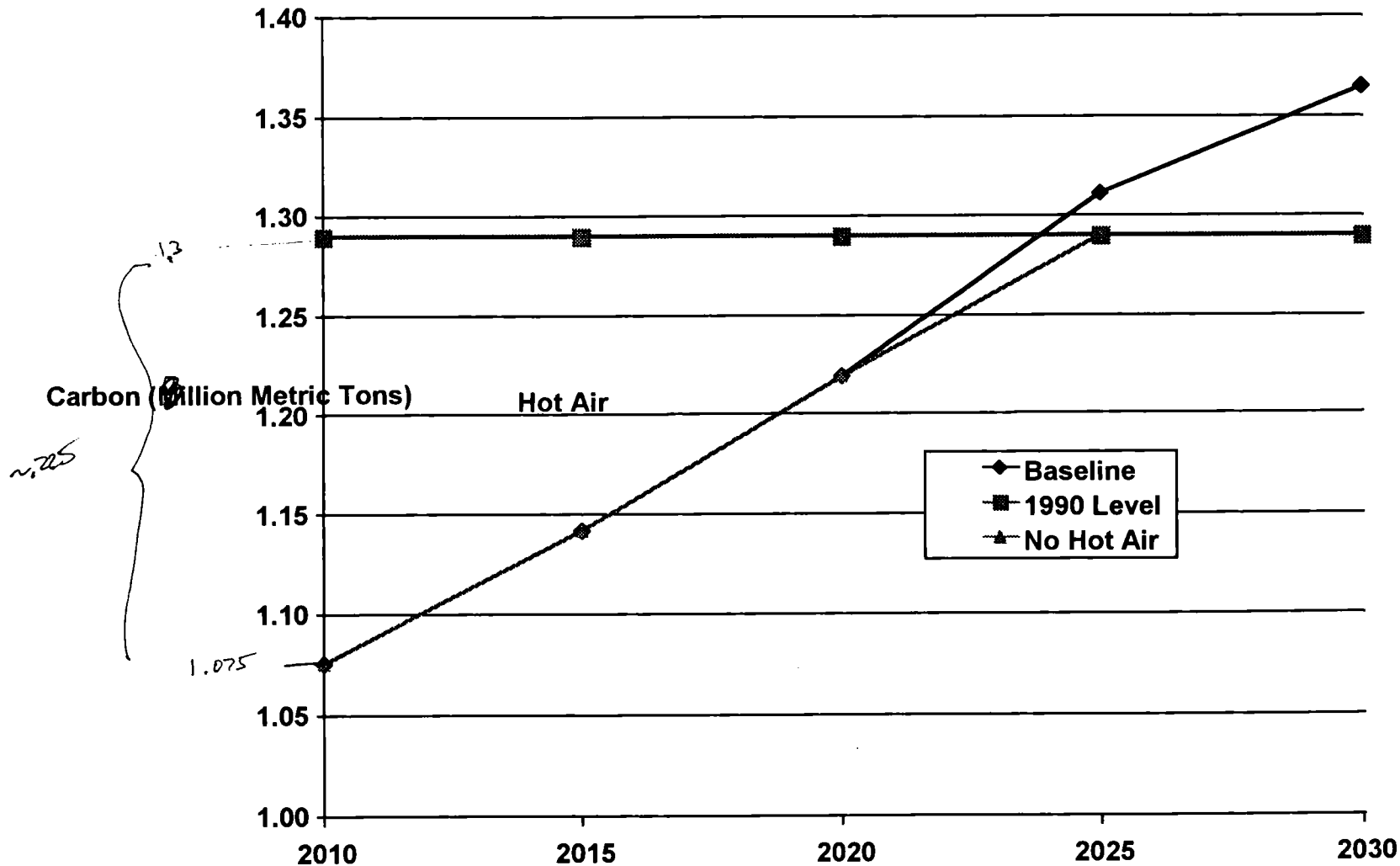
Purchases and Sales of Permits Under Annex 1 Trading



Source: Multi-Sector Multi-Region Trade Model

CRA

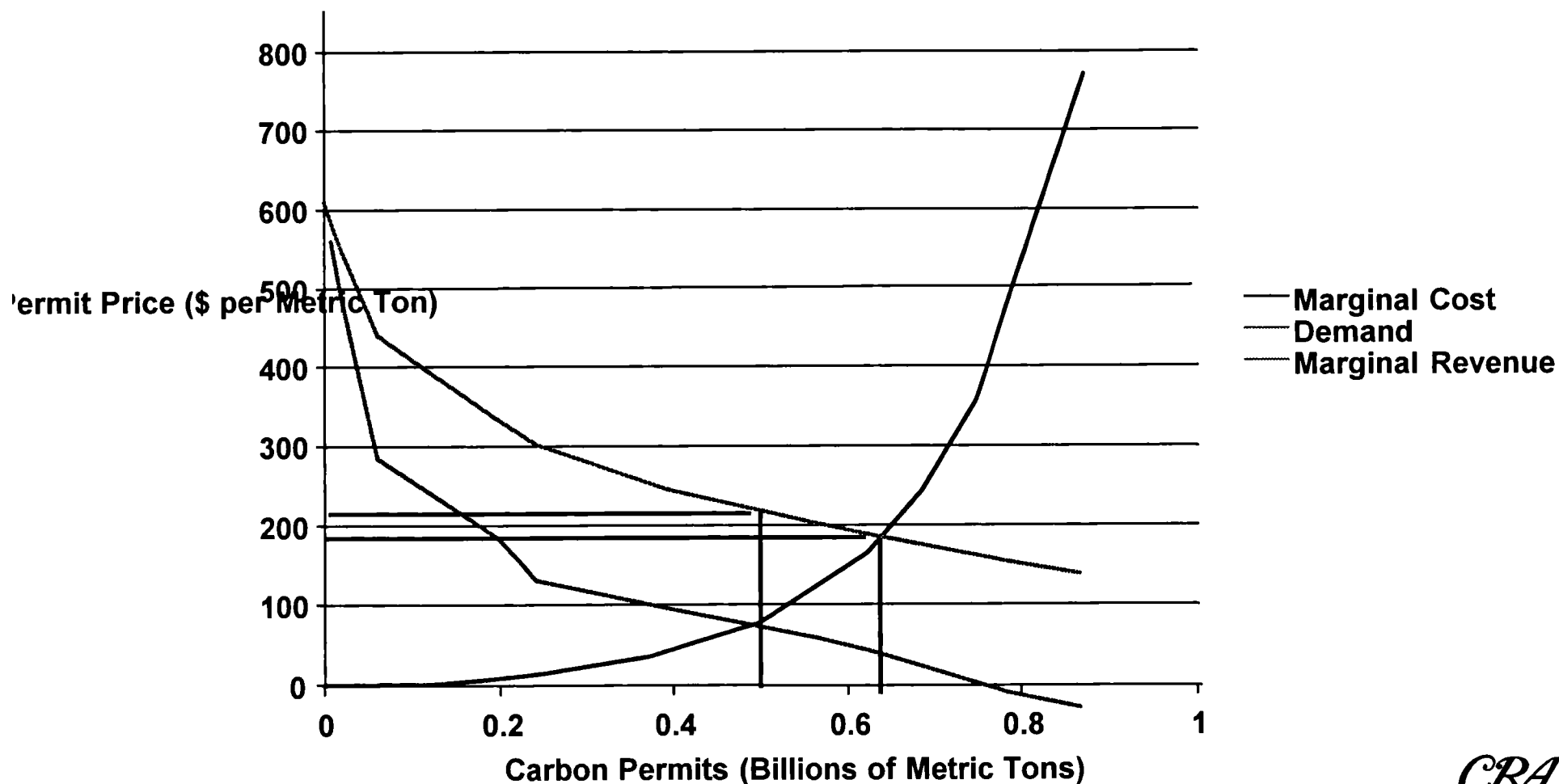
Russia's 2010 Target Exceeds Baseline Emissions



Source: Multi-Region Trade Model

CRA

Russia's Monopoly Power Could Raise Permit Prices



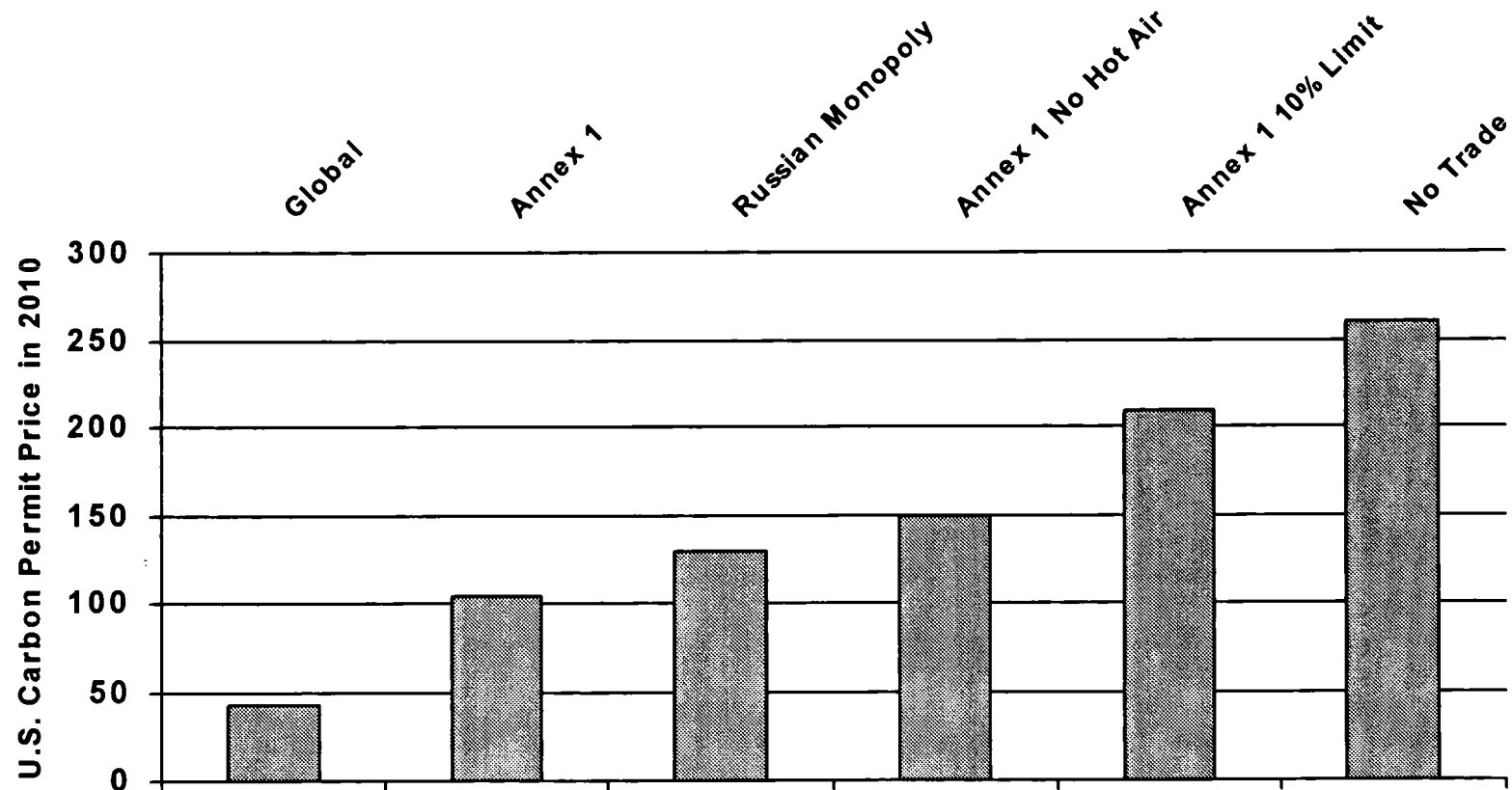
Source: CRA calculations based on Multi-Region Trade Model

CRA

Possible Outcomes of the Negotiations

- **Deadlock**
- **Annex 1 trading with significant restrictions**
- **Russian exercise of market power selling permits**
- **Annex 1 trading without restrictions**
- **Full global trading**

Permit Prices Under Different Trading Systems

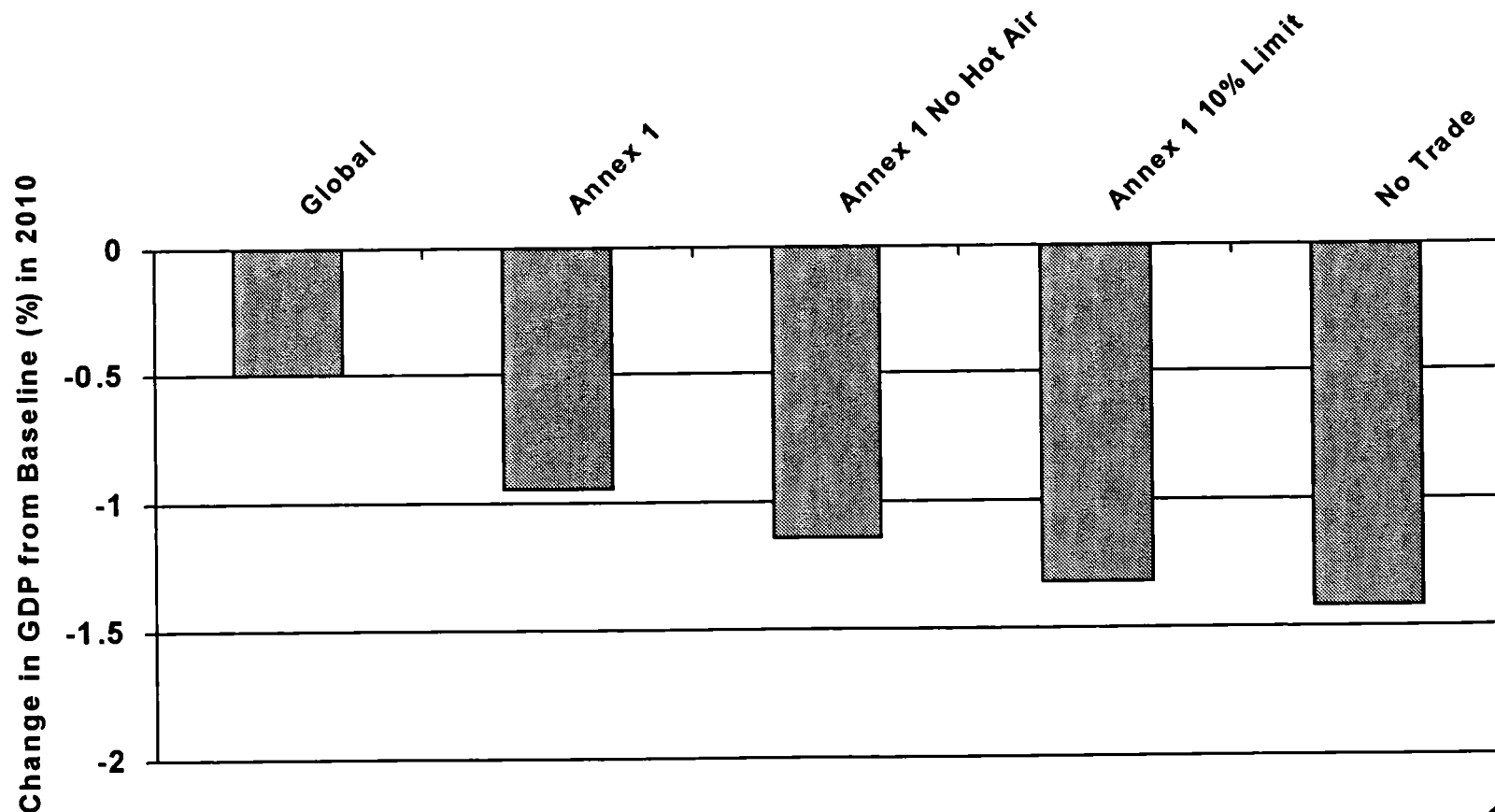


Source: Multi-Region Trade Model

CRA

Restrictions on Trading Raise Costs

% U. S. GDP Loss from Baseline in 2010

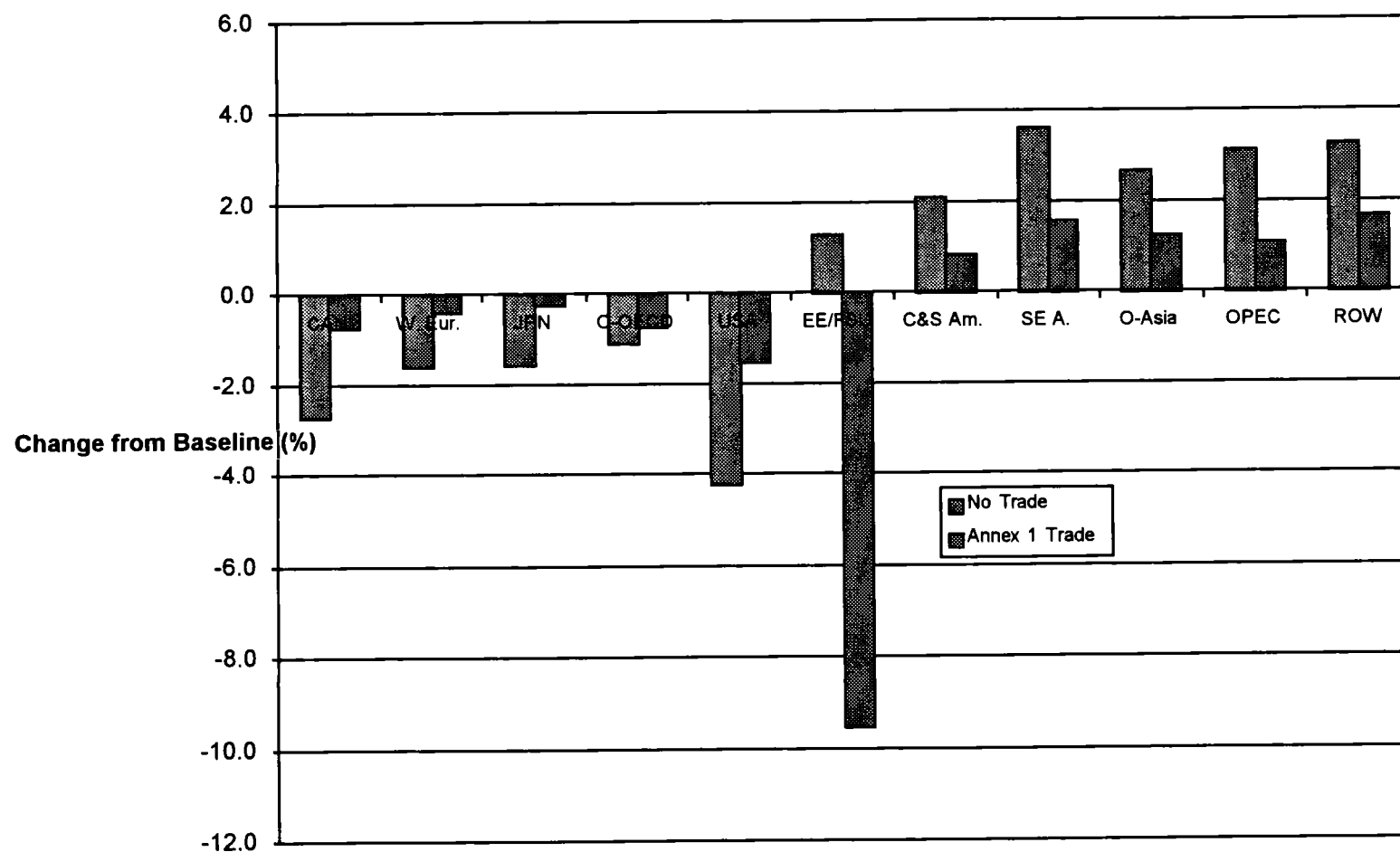


CRA

Source: Multi-Region Trade Model

Restricted Trading Leaves Competitive Distortions in Place

Output of EIS in 2010



Source: Multi-Sector Multi-Region Trade Model

CRA

Summary -- Emission Trading in Principle and in Practice

- **United States**

- Domestic emission trading or the equivalent is assumed in all economic studies
- Current proposals camouflage regulatory programs with limited emission trading and can have far higher costs

- **International**

- Ideal international emission trading can reduce costs dramatically
- Restrictions on trading could eliminate almost all potential benefits

NO TRADING	-1.4%
RESTRICTED ANNEX 1 TRADING	-1.2%
ANNEX 1 TRADING	-1.0%
ALL COUNTRIES TRADING	-0.5%

CRA

Table 28: Summary of Own Price and Income Elasticities

	Summary Statistics						Ylr		Source:	
	Range Per	Range Pir&Plr	Range Yer	Range Ylr&Ylr	Per	Plr	Yer	Ylr	Table	C or S
E	-.09/-52	-.04/-1.75	--	.27/1.14	<-0.3	<-0.5	--	1.05?--	1,2	S1,C1
E-r	-.15	.37/-66	1.17	.08/1.45	-0.15	<-0.5	--	?	2	C3
E-i	-.09/-66	.23/-99	--	.69/1	<-0.2	<-0.5	--	0.73?--	2	C6
E-ii	0/-1.09	0/-1.10	--	.89	--	--	--	--	2	C7
El	-.05	-.61/-1.31	--	--	?	-1	--	--	6	C8
El-r	+.57/-97	+.77/-2.2	-.02/.93	-.09/1.64	<-0.5	-.07/-0.9	<0.2?	<0.87?6,7	8	C9-11
El-c	0/-82	+3.36/-4.74	-.45/.26	-21.12/1.39	-0.22?	-0.82?	??	??	8	C12
El-i	+.06/-1.03	+17.4/-3.55	.01/.28	-1.01/1.44	-0.25?	-1.33?	.1?	?	8	C13
El-ii	-.03/-1.51	-.11/-2.5	-.1/.82	.25/1.63	--	<-.27?--	--	>.71?--	14	C14
Ng	--	-.03/-49	--	.62/.79	--	?	?	<.8	14,15	C16
Ng-r	+.02/-88	+1.86/-3.44	.01/.44	.06/.80	?	?	?	?	16	C17-20
Ng-c	-.16/-37	1.92/-2.68	-.33/.3	-2.19/1.95	-.26?	-.99?	?	--	16	C21
Ng-e	--	-.1/-1.89	--	--	--	-.72?	--	--	16	C22
Ng-i	-.26/-63	.71/-5.28	.13/.78	.46/3.08	-.51?	?	?	?	16	C23
Ng-ii	-.08/-1.63	-.12/-10.0	.14/1.74	.32/4.46	--	<-.9	--	--	16	C24
C-e	--	-.12/-9	--	--	?	?	--	--	18	C26
C-i	-.02/-1.62	+.08/-1.12	--	--	--	--	--	--	18	C27
C-ii	-.84	-.28/-2.52	--	--	?	>-.25?	--	>.70?	18	C28
O	-.04/-25	-.25/-94	--	0.31/1.13	?	?	--	?	20	C29-30
O-r	-.10/-59	-.62/-3.5	-.08/.21	-.28/2.28	<-.3	?	?	?	20	C31-32
O-c	-.07/-19	-.3/-3.5	.2	4.39	-0.13	?	?	?	20	C33
O-e	--	-.08/-3.11	--	--	--	?	--	--	20	C34
O-i	-.13/-21	-.08/-44	--	--	?	?	--	--	20	C35
O-ii	-.28/-58	-.36/-4.05	--	--	--	--	--	--	20	C36-39
O-ntr	.03/-19	.1/-2.35	.03/0.38	.82/1.47	-0.07?	-.65?	.21?	1.22?	20	C41
G	-.00/-36	.00/-1.99	.09/0.65	.09/1.22	-0.20	-0.60	<0.5	0.80?	23	C42-49
J	--	-.1/-39	--	.07/.68	--	-0.2--	--	0.36?--	23	C50
O-t	0/-0.14	0/-92	--	.63/1.1	-0.03?	-0.39?	--	1.06?	23	C51
VMT	.10/-22	0/-33	-.07/.39	-0.2/1.09	-0.14	-0.25	0.15	0.3?	25	C52
MPG	.00/.01	.03/.21	--	--	0	0.14	--	--	25	C54

For summary statistic, where results appeared fairly consistent and I feel the averages provide reasonable estimates for elasticities I include a point estimate or a range. If the averages appear reasonable with intermediate estimates between short and long run with no contradictions between categories, but with large variations across studies, I include the averages with a question mark behind them. Where averages appear unreasonable, studies are exceptionally erratic, or there are contradictions across categories I put only a question mark. If no estimates are surveyed for a category a dash is placed. For estimates on industries (-ii) only the range of elasticities across industries is included.

For newer
price elastic
surveys. In
data they ar
slightly in

For Official Use

ECO/CPE/WP1(99)6



Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

OLIS : 17-Feb-1999
Dist. : 25-Feb-1999

Or. Eng.

PARIS

ECONOMICS DEPARTMENT
ECONOMIC POLICY COMMITTEE

ECO/CPE/WP1(99)6
For Official Use

*Background
• at ministerial (May)
• more progress in reporting
• more models
• LDC possible
• leakage*

Working Party No. 1 on Macroeconomic and Structural Policy Analysis

TAKING ACTION AGAINST CLIMATE CHANGE:
THE KYOTO PROPOSAL

This document has been prepared by the Economics Department for the Working Party No. 1 of the Economic Policy Committee.

Contact: Jean-Marc Burniaux tel: (33-1) 45.24.79.18
email: jean-marc.burniaux@oecd.org
or
Paul O'Brien, tel: (33-1) 45.24.87.64
email: paul.obrien@oecd.org

*John Weeks
- ECO Mission - US 97-*

*Green - Expand
Subs. - O'Brien
FSU Gen. - 10/11/99
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100*

74581

Document complet disponible sur OLIS dans son format d'origine
Complete document available on OLIS in its original format

Or. Eng.

TABLE OF CONTENTS

TAKING ACTION AGAINST CLIMATE CHANGE: THE KYOTO PROTOCOL	4
1. Introduction and summary	4
2. The Kyoto Protocol and the process of climate change.....	7
2.1 Climate change	7
2.1.1 The link between human activity and greenhouse gas emissions	8
2.1.2 The link between emissions and concentration levels.....	8
2.1.3 The determinants of climate change.....	9
2.2 Main features of the Kyoto Protocol	10
2.2.1 The flexibility mechanisms	10
2.2.1.1 Emission trading	11
2.2.1.2 Joint Implementation (JI) and the Clean Development Mechanism (CDM).....	11
2.2.1.3 Other aspects of the flexibility provisions	12
Supplementarity	12
Hot air	13
Banking	13
Substitution between greenhouse gases	13
Sinks.....	14
2.3 Some implementation issues	14
2.3.1 Ensuring compliance	14
2.3.2 Buyer or Issuer liability in permit trade?.....	15
2.3.3 Entity trading?.....	16
2.3.4 Monitoring and verification.....	17
3. Implications of Kyoto	18
3.1 Economic costs of the Kyoto commitments: the no-flexibility case	19
3.1.1 Emission reductions are substantial	21
3.1.2 Marginal abatement costs are high in OECD countries	21
3.1.3 Total economic costs remain low	21
3.1.4 Higher prices and lower output of energy	22
3.1.5 Oil prices will be hit but carbon leakage may not be a concern	23
3.2 Reducing the costs of Kyoto: making use of the flexibility mechanisms.....	23
3.2.1 "Where" flexibility	24
3.2.1.1 "Where" flexibility among Annex I Parties.....	24
3.2.1.2 Reasons why "Where" flexibility may be restricted.....	25
3.2.1.3 Trade segmentation.....	26
3.2.1.4 Trade restrictions	26
3.2.1.5 Market power.....	27
3.2.1.6 "Where" flexibility with the rest of the world	30
3.2.2 "When" flexibility	31
3.2.3 "How" flexibility	32
3.2.4 "What" flexibility	33
4. Beyond the first commitment period: extending Kyoto in time and space.....	34
4.1 Long-term aspects of the Kyoto Protocol.....	34

4.1.1	Long-term costs of the Kyoto targets	34
4.1.2	Impact on GHG concentration	35
4.1.3	The costs of "missing" Kyoto	36
4.2	Establishing a global agreement	37
4.3	Economic costs of stabilising CO ₂ concentration	40
4.3.1	Burden sharing	41
4.3.2	Economic costs	41
5.	Adapting to Climate Change	44
5.1	Anticipated climate change	44
5.1.1	North America	44
5.1.2	Temperate Asia	45
5.1.3	Australasia	46
5.1.4	Europe	47
5.2	Sectoral impacts	47
5.2.1	Agriculture	48
5.2.2	Fisheries	48
5.2.3	Transport	48
5.2.4	Water	48
5.2.5	Energy	48
5.2.6	Insurance	49
5.2.7	Tourism	49
5.2.8	Population movements	49
5.2.9	Health	49
5.2.10	Biodiversity	50
5.3	National "Impact assessments"	50
5.4	Adaptation, Costs and Catastrophe	51
5.4.1	Adaptation	51
5.4.2	Costs	52
5.4.3	Uncertainty	54
	GLOSSARY AND ABBREVIATIONS	55
	BIBLIOGRAPHY	57

Boxes

Box 1	The OECD's GREEN model	18
Box 2.	CO ₂ emissions in the Business as Usual scenario	20
Box 3.	How important is market power in the market for emission permits?	27
Box 4.	Establishing a global agreement -- the theory	37

TAKING ACTION AGAINST CLIMATE CHANGE: THE KYOTO PROTOCOL

1. Introduction and summary

1. Meteorological evidence points to a rise in the average global temperature over the past century. The trend towards warming is consistent with predictions from global climate models, that higher concentrations of so-called greenhouse gases trap increasing amounts of heat in the earth's atmosphere. Increased concentrations of greenhouse gases result to a large extent from emissions arising from human activity -- in particular the burning of fossil fuel. Against the background of increasing scientific consensus that man-made greenhouse gas emissions add to global warming, international efforts to reduce these emissions have thus far culminated in the Kyoto Protocol, agreed in December 1997.

2. The purpose of the current paper is fourfold, corresponding to its four main chapters. Chapter 2 describes some main aspects of the Kyoto Protocol and discusses some areas where choices in its implementation may have an impact on its success. The subsequent chapter quantifies the economic costs of implementing the Protocol under a variety of assumptions about how this will take place. Chapter 4 considers how, over the longer term, a credible effort towards stabilising concentrations of greenhouse gases can be made which includes participation by developing countries. The final chapter considers what kind of climate change is expected to occur over the next 50 to 100 years, which is largely independent of whether or not the Kyoto Protocol is successfully implemented, and discusses some aspects of the problems of adapting to such changes.

3. The Protocol contains targets for greenhouse gas emissions over the period 2008-12 for each so-called Annex I country; the countries involved include all OECD countries except Korea, Mexico and Turkey, and a number of economies in transition, most notably Russia. The targets are fairly ambitious in the sense that OECD emissions in 2008-12 will need to be some 20-40 per cent below the level they might be expected to reach without policy action. If countries were to respect their individual targets through domestic abatement measures, the annual cost to OECD countries may be of the order of magnitude of ½-1 per cent of GDP. This cost may appear small, but it should be borne in mind that it is a result from models that typically do not take into account the adjustment costs of shifting factors, especially labour, from more to less energy intensive sectors. And such shifts will be important, given that the marginal abatement costs can be thought of in terms of a carbon tax that would typically correspond to a doubling or tripling of the international oil price from its 1995 level. But the low cost for OECD countries also reflects that part of the cost will be borne by some non-OECD countries, not least as a result of lower demand for fossil fuel. On the other hand, the model simulations do not include the "ancillary benefits" of emission reductions, such as reduced local pollution levels, which may also be significant.

4. The Protocol includes a number of mechanisms to reduce the cost of meeting the emission targets -- and therefore increase the likelihood that the Protocol will be ratified and the targets met. The details of the Kyoto mechanisms, which include emission trading and the so-called Clean Development Mechanism, are not yet fully specified. It is important that the timetable, requiring agreement on details of the mechanisms by the end of year 2000, be met. The longer the delay, the later abatement measures are likely to be taken and, as illustrated by model simulations in Chapter 3, the higher the cost of meeting the emission targets is likely to be.

5. The costs of reaching the Kyoto targets can be significantly reduced by use of the flexibility mechanisms. Emission trading allows the marginal abatement costs in different Annex I countries to be equalised by trading emission permits so that emission reductions in one country, where they can be done relatively cheaply, may be counted against the target for another, where emission reductions are more costly. In the process, both countries can benefit. If trading succeeded in fully equalising marginal abatement costs across Annex I countries, the overall cost of meeting the targets could be approximately halved for OECD countries and become almost insignificant for all Annex I countries taken together, according to simulations with the OECD's GREEN model. Again, however, the strong assumptions behind and the uncertain nature of the model results should be borne in mind.

6. Emission trading raises a number of issues which need to be resolved for trade to deliver such efficiency gains. Some of these issues have a somewhat technical nature and relate to topics such as monitoring, verifying and enforcing compliance. The uncertainties in these areas have led to calls for restrictions on emission trading. Such restrictions, and the increased domestic action they imply, have also been justified with reference to the need for industrialised countries to show a good example which would induce developing countries to accept quantified emission limits too, as well as with reference to ancillary benefits of reduced domestic emissions (such as lower local pollution levels). If, against this background, a subset of Annex I countries were to impose unilateral restrictions on emission trading, their costs could go up while those of other Annex I countries might fall.

7. Two specific implications of the participation by transition economies in full emission trading are worth mentioning. First, part of the apparent gains from trading would come from higher overall emissions: emissions in Russia and Ukraine are likely to be considerably lower than the Kyoto target even in the absence of any abatement measures; by allowing emissions by OECD countries to rise by that amount, trading reduces the latter's costs. Restricting trading in this so-called "hot air" might reduce the gains from trade by about a fifth, based on the amount of hot air present in the baseline scenario with the GREEN model. Such restrictions would, however, be politically difficult and also ineffective in reducing atmospheric concentrations of greenhouse gases over the longer term, because another provision ("banking") of the Protocol allows unused emission quotas to be carried forward for use (or trading) later. Second, with Russia and Ukraine potentially the dominant suppliers in the market for emission permits, there is a risk that the market may be imperfectly competitive; if collusion allowed Russia and Ukraine to keep permit prices significantly above the competitive level, the gains from trade could be substantially reduced.

8. The Kyoto Protocol contains two mechanisms for project-based emission transfers between countries. While so-called Joint Implementation among Annex I countries resembles emission trading in that it leads to transfers of emission rights, the Clean Development Mechanism allows Annex I countries to gain emission rights from investments to cut emissions by developing countries. The latter do not have emission targets and the transfers of emission rights therefore have to be made with reference to agreed, project-specific, baselines for emissions. This makes it hard to assess how important the Clean Development Mechanism will be. Preliminary analysis has assumed that only a fraction of the potential for low-cost abatement in developing countries will be exploited and suggests that the gains from the mechanism will therefore be modest if it is introduced in conjunction with full emission trading among all Annex I countries.

9. In the context of attempts to reduce global warming appreciably, the Kyoto Protocol is best seen as a starting point for a long-term effort towards a significant reduction in global greenhouse gas emissions, and eventually stabilisation or reduction of atmospheric concentrations. Chapter 4 shows that, although the science is far from sufficiently well-developed to give definitive answers, action by Annex I countries alone will have only a marginal impact on concentrations, if emissions by non-Annex I countries grow as they are expected to without any constraint.

10. Inducing non-Annex I countries to accept such constraints is difficult, as evidenced by both the third and the fourth Conference of the Parties to the UN Framework Convention on Climate Change. This is not just because countries will be affected differently by climate change -- some developing countries are likely to be more severely affected by it than most OECD countries -- or because they have different valuations of these effects. Analysis in chapter 4 suggests that the likelihood of a large number of countries voluntarily agreeing to cut emissions may be small in the absence of side-payments. Furthermore, equity concerns may over the next half-century or so call for much larger cuts in emissions by Annex I countries than by developing countries, whose per capita emission levels are many times smaller. This, on the other hand, would conflict with concerns for global cost-minimisation.

11. Chapter 4 considers a number of global emission scenarios which are built on the notion that eventually per capita emission rights will have to converge across countries -- and, indeed, converge at fairly low levels in order to move the world towards a stable concentration of greenhouse gases in the atmosphere. With similar per capita endowments of emission rights but widely different abatement costs across countries, permit trading becomes a crucial instrument for keeping down costs. Depending on the degree of ambition with respect to emission paths, and assuming permit trading, annual discounted costs at the world level could be of the order of $\frac{1}{4}$ -1 per cent of GDP. However, revenues from permit selling may not provide sufficient incentives for all developing countries to participate in a global agreement, and chapter 4 also considers the possibility that Annex I countries provide financial transfers to induce participation. In this case, annual discounted costs to Annex I countries could be sizeable if an ambitious emission reduction strategy is aimed for -- the estimates range between $\frac{1}{2}$ and 2 per cent of Annex I GDP depending on the degree of ambition.

12. Despite the efforts being made in the context of the Kyoto Protocol and any likely follow-up agreement, some considerable further increase in atmospheric concentrations of greenhouse gases cannot be avoided. Chapter 5 notes that the resulting climate change is difficult to predict in the current state of knowledge, especially as regards precipitation patterns which, in many areas, will play a more critical role in determining the costs of climate change than changes in average temperatures. Few conclusions can therefore be drawn about the costs of climate change or about appropriate adaptation strategies in particular countries or for particular activities or sectors. Such studies of costs as have been undertaken appear to show relatively low costs over the next 50 to 100 years for most OECD countries. However, longer time horizons obviously matter -- as do concerns for non-OECD countries, many of whom seem likely to bear much higher costs. Moreover, what is of interest is not just the mean expected outcome but also the variation around it -- there may be a risk that beyond some concentration of greenhouse gases in the atmosphere, the associated climate change could be dramatic, with a substantial influence on the economy and society.

13. Whatever the change in climate may be, it is important that adaptation to it be as smooth as possible. To some extent, countries can learn from each other, given the wide differences that currently exist in climates. A number of countries also have some experience with adaptation, most prominently perhaps in the case of sea-level rise. In that area, because of externalities and perhaps also owing to economies of scale in information gathering, the public sector is typically involved in the necessary long-term planning and in resolving potential conflicts between different users of land. However, in many cases less rather than more public-sector involvement will be necessary to achieve smooth adaptation -- agricultural policy may be an example of this. At this stage it may be premature to draw very firm conclusions as to what type of policy change will be required to ensure smooth adaptation to climate change. Indeed, a general conclusion in the area of climate change is that there is a need for further knowledge. In particular, consideration of the accuracy of climate change forecasts, of the role of uncertainty and how fear of catastrophe should be valued (and indeed how a number of other aspects of climate change, such as species-loss and other irreversible changes, should be valued) is required if the benefits of the Kyoto Protocol and its successors are to be usefully compared with their costs.

2. The Kyoto Protocol and the process of climate change

2.1 *Climate change*

14. Since the last substantial analytical work on climate change was presented to WP1 (summarised in OECD, 1995), the issue has lost none of its importance. Meteorological evidence from the 1990s has reinforced the view that some global warming is already under way. Scientific research finds that this tendency increasingly corroborates predictions from global climate models which incorporate the greenhouse mechanism, whereby certain gases produced by human activity -- from industry, from households, from transport and from agriculture -- trap increasing amounts of heat in the earth's atmosphere and add to the "natural" greenhouse effect.

15. Despite the considerable attention being paid to this problem over the past ten years and the declarations arising from the 1992 UN Framework Convention on Climate Change (UNFCCC¹), current indications are that emissions of greenhouse gases (GHGs) are rising faster than expected, that the initial UNFCCC target for emissions for the year 2000 will be substantially exceeded in almost all OECD countries and that the date by which stabilisation of world emissions (let alone the necessary reductions) can feasibly be expected is receding into the future.

16. There are still uncertainties over precisely how much additional warming the greenhouse effect will produce, on the consequences of this for climates and the associated effects on human activity and well-being. There also remain minority scientific views that global warming is either not happening or is largely unrelated to human activity, or is anyway beneficial on average. These do seem to be very much non-mainstream views, however; the 1995 report from the Intergovernmental Panel on Climate Change (IPCC)² concluded that "the balance of the evidence suggests that there is a discernible human influence on global climate".

17. This was the background against which the parties to the UNFCCC met at their third conference (COP3), held in Kyoto in November-December 1997. The outcome of the meeting was the Kyoto Protocol, under which a number of countries have committed themselves to specific targets for emissions of greenhouse gases. However, many of its provisions left significant and essential detail to be agreed at subsequent Conferences of the Parties. COP4, in Buenos Aires in November 1998, made limited progress on these, but established a timetable for reaching agreement, with COP6, planned for late 2000, expected to settle any remaining implementation issues. The rest of this section reviews briefly the basic mechanisms through which human activity is thought to influence the climate and the next sections present some main features of the Kyoto Protocol.

1. Note that a short glossary is provided after chapter 5 to remind readers of the meaning of some of the terms and acronyms that occur in this paper.

2. The IPCC was set up in 1988 as a joint body of the United Nations Environmental Programme and the World Meteorological Office and monitors global climate developments and co-ordinates a programme of work aimed at improving scientific understanding of the mechanisms at work. Its assessment reports summarise the consensus view of the likely effect of current trends in emissions on future atmospheric concentration levels and the consequent effects on climate. The Second Assessment Report concluded, after a comprehensive survey of the scientific evidence and recognising that conclusive proof is not available, that there is a discernible influence of human activity on the climate, via the greenhouse effect; the report also investigated the properties of emission paths that would be necessary to stabilise atmospheric concentrations at various levels.

2.1.1 *The link between human activity and greenhouse gas emissions*³

18. There are a large number of greenhouse gases (GHGs), i.e. gases whose presence in the atmosphere reduces the rate at which heat is radiated from the earth. After water vapour, overwhelmingly the most important greenhouse gas is carbon dioxide (CO₂). The Kyoto Protocol includes a further five gases or groups of gases: methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride⁴. The last three do not spontaneously exist in nature, while emissions of CO₂, CH₄ and N₂O may be of either human ("anthropogenic") or natural origin⁵. After CO₂, methane is the most important anthropogenic GHG. The main sources of CO₂ are fossil fuel burning and deforestation; large sources of methane are animal husbandry, rice production and natural gas venting. The fluorine compounds' origin in the atmosphere is largely leakage from their main uses in refrigeration and from the manufacture of aluminium and magnesium. Emissions of chlorofluorocarbons, also greenhouse gases, have declined rapidly since the Montreal Protocol to phase them out came into force, and they are not covered in the Kyoto Protocol.

2.1.2 *The link between emissions and concentration levels*

19. In the short to medium term, and notwithstanding difficulties in establishing a precise relationship between emissions and concentration levels, the proportion of a given emission which remains in the atmosphere is thought to decline following a roughly exponential path over time as it is absorbed in the various "sinks" -- the oceans, the soil, forests. The oceans absorb gases in solution, and also through sedimentation on the ocean floor; the rate of absorption from the atmosphere depends importantly on circulation within the oceans themselves, which affect the rate at which gases absorbed at the surface are transported to deeper water. Forests in equilibrium are not thought to be an important sink, since the amount of CO₂ they absorb through photosynthesis is balanced by respiration and decay of vegetation. They are important sinks while they are reaching maturity, however, and also if they are harvested for long-lasting wood products. Soils too may not serve as sinks when in equilibrium, but may absorb carbon when, for example, reverting from agricultural use to natural vegetation (as occurs in "set asides" for example). An area of uncertainty for forests and soils is the carbon fertilisation effect. The rate of photosynthesis, and hence carbon absorption by many plants, including young trees, is known to increase in laboratory conditions as atmospheric CO₂ concentration increases, provided the plant is not constrained by lack of nutrients or water, and provided the temperature is not above a certain (species specific) threshold. The extent to which this is true in nature is uncertain, especially for mature trees.

20. The rate at which different greenhouse gases are removed from the atmosphere varies: methane is almost entirely removed in a decade (partly through conversion into CO₂) or so, whereas carbon dioxide may persist for 200 years, and certain perfluorocarbons for many centuries. In principle, knowledge about the rates of exponential decay can be used to project concentration levels based on assumed emission

3. Most of the information in this section is based on the IPCC (1996).

4. The contribution to global warming of a gas is a combination of its concentration in the atmosphere and its relative effectiveness in trapping outgoing radiation. CO₂ currently provides over 60 per cent of the total anthropogenic greenhouse effect, methane about 20 per cent, nitrous oxide about 6 per cent and the chlorofluorocarbons about 10 per cent. See IPCC (1996) Table 4, pp 92-93, and the accompanying text for details and qualification of these estimates.

5. In the scientific literature, "anthropogenic" refers both to that which is directly the result of human activity (e.g. burning fossil fuels for heat or transport) and to the results of natural processes which have been modified by human activity (e.g. planting forests). This meaning is that intended throughout this paper.

paths⁶. Establishing such projections is very complex, however, taking into account what is known about sources and sinks, as well as atmospheric (and, increasingly, oceanic) circulation, and the range of uncertainty is fairly large; uncertainty relates not only to the mechanisms involved but also the measurement of the basic magnitudes⁷.

2.1.3 *The determinants of climate change*

21. Notwithstanding these uncertainties, the scientific consensus seems to be that human activity has contributed to an accelerating increase in the concentration of carbon dioxide in the atmosphere, and that this increase has already caused average global temperatures to be higher than they would otherwise have been. Although over the last century records indicate that there have been periods when average global temperatures were falling (notably for about two decades after 1950), they do seem to have risen overall, and recently perhaps more rapidly than on average over the period; the melting of ice caps and retreating glaciers provide further evidence for this.

22. Increased concentrations have this effect because the GHGs absorb part of the long-wave radiation emitted by the earth's surface, reducing the proportion which escapes into space, thus increasing the equilibrium temperature required to maintain a balance between such outward radiation and incoming energy from the sun; provided temperatures have been at (or below) this equilibrium level in recent history, actual temperatures can be expected to increase.

23. There is further uncertainty when it comes to interpreting the implications of temperature changes for the climate itself. Generally speaking, increased average temperatures are expected to lead to an intensified hydrological cycle -- it will rain more. This is unlikely to be an evenly distributed increase, however; there may be increased frequency of both heavy rainfall in some places and droughts in others. In addition, average sea levels are likely to rise.

24. A principal force at work behind all climate patterns is the transfer of heat from the equatorial regions towards the poles. Higher overall temperatures can be expected to modify the associated atmospheric and ocean circulations. But detailed understanding of how these mechanisms work -- especially ocean circulation -- and their interaction with the nature of the land surface is relatively

6. The same relationships can be used in simple models to give an approximate idea of the effect on concentration of variations around the expected path of emissions, once a baseline (of historical and anticipated emissions and the resulting concentration levels) has been established (as in Chapter 4 below, for example).

7. See, for example, the assumed margins of error in the carbon "budget" estimate for the 1980s:

Sources and sinks of anthropogenic CO₂
annual averages 1980-89, gigatonnes of carbon per year

	amount	(confidence interval)
Sources		
Fossil fuel and cement production	5.5	(0.5)
Changes in land-use	1.6	(1.0)
Total	7.1	(1.1)
Sinks		
Atmosphere	3.3	(0.2)
Ocean	2.0	(0.8)
Northern hemisphere forest regrowth	0.5	(0.5)
Inferred sink	1.3	(1.5)

Source: IPCC, 1996, p. 17, Table 2.

limited at the moment, so precise predictions are unavailable. Even if greenhouse gas concentration levels stabilise relatively early (which seems unlikely) most projections imply that climate change will continue for some time. The slow adjustment towards "equilibrium" makes it difficult to speak of the properties of the "new" climate associated with a given concentration level since it will be changing continuously through time. Hence, it is necessary to look very far ahead to get a full picture of the impact of changes -- which, for a given region, could swing between positive and negative.

2.2 *Main features of the Kyoto Protocol*

25. The Protocol limits emissions from a group of countries known as "Annex I countries" (from the annex to the UNFCCC listing the original group, since expanded)⁸, currently comprising all OECD countries (except Mexico) and a number of economies in transition⁹. Relative to their emissions in 1990, Annex I countries committed themselves to reduce their total GHG emissions (expressed in carbon equivalent tonnes¹⁰), by around 5 per cent on average for the period 2008 to 2012. There is some differentiation of the target reduction in emissions among Annex I countries. These range from 6 per cent in Japan, Canada, Hungary and Poland to 8 per cent in members of the European Union and some eastern-European countries. The commitment for the Russian Federation and the Ukraine, as well as New Zealand, is to emissions no higher than their 1990 levels. Some countries are even allowed to increase their emissions relative to 1990 levels¹¹.

26. The Kyoto Protocol marked a retreat from one of the key initial aims of the UNFCCC -- for the industrialised countries to limit greenhouse gas emissions in the year 2000 to no more than their level of 1990. By comparison with this target, the emissions objective is tightened but put back by about a decade: as mentioned, quantitative commitments refer to the average for the years 2008-12. The magnitude of the task now appears greater for most countries because of increases in emissions since 1990. As far as the OECD is concerned, only a few countries (the United Kingdom and possibly Germany, Switzerland and the Netherlands) will meet the original target for the year 2000; most projections show that reaching the Kyoto targets for individual countries will require further policy action or making use of the flexibility mechanisms.

2.2.1 *The flexibility mechanisms*

27. Pursuing individual quantitative targets by domestic action only is a relatively costly way to reduce greenhouse gas emissions, since marginal costs of emission reduction may differ across countries as some have to take high-cost abatement measures while others do not fully exploit low cost ones. The so-

8. They should really be known as Annex B countries, since it is Annex B to the Protocol that lists the emission targets. Of OECD countries, Korea, Mexico and Turkey are not listed in Annex B.

9. Belarus, Bulgaria, Croatia, Estonia, Latvia, Lithuania, Romania, Russia, Slovakia, Slovenia and Ukraine. Liechtenstein and Monaco are also included. Turkey, while currently listed in Annex I, is not a Party to the Kyoto Protocol.

10. Conversion factors are based on the estimated impact of each gas in reducing outward radiation, relative to the impact of CO₂. Once converted to CO₂ equivalent, the measure itself is the weight of the carbon contained in the CO₂ equivalent; 1 tonne of CO₂ contains 0.27 (=12/44, the ratio of the atomic weight of carbon to the molecular weight of CO₂) tonnes of carbon.

11. Iceland (+10%); Australia (+8%); Norway (+1%). See Annex B to the Protocol. An internal EU ("burden sharing") plan to redistribute the quotas is allowed under the Protocol but has not yet been registered with the UNFCCC; under this EU agreement, country targets vary from -21% (Germany) to +27% (Portugal).

called flexibility mechanisms of the Kyoto Protocol allow a move towards alignment of marginal costs by providing ways in which emission reductions that take place in one country can be counted against another country's target¹². Three mechanisms are available: emissions trading, joint implementation and the clean development mechanism¹³. As with some other aspects of the Protocol, the text is not precise on how the flexibility mechanisms should be implemented. The intention is that rules and procedures for these mechanisms will be developed by future COP (and its "subsidiary bodies") meetings; at COP4 it was decided that these aspects are to be finalised at COP6 in late 2000¹⁴.

2.2.1.1 Emission trading

28. Article 17 of the Kyoto Protocol says that countries "may participate in emissions trading for the purposes of fulfilling their [2008-12 emissions target] commitments..." The intention is to allow Annex I countries which find it relatively easy to meet their Kyoto targets to reduce their emissions by more than is actually required, selling the surplus "permits" to countries whose abatement costs are higher¹⁵.

29. The relevant article of the Protocol states that emissions trading shall be "supplemental" to domestic action to reduce emissions. This reflected the desire of some of the participants to ensure that all countries took some measures to reduce domestic emissions and did not rely on buying "the right to pollute", but there is no consensus on what it will mean in practice. This, and other aspects of emissions trading, are taken up in more detail below.

2.2.1.2 Joint Implementation (JI) and the Clean Development Mechanism (CDM)

30. The Joint Implementation mechanism (Article 6 of the Kyoto Protocol) allows one Annex I country to sponsor an emissions-reduction¹⁶ project in another Annex I country and thereby acquire credit for the emission reduction, or part of it, as if it occurred in the sponsoring country, the same amount being deducted from the host country's allowed emission level. The important difference compared with direct trading of emission permits is the need to assess what emissions would have been without the project; the techniques for baseline definition are to be set by COP6. COP1 (1995) provided for an "Activities Implemented Jointly" (AIJ) scheme, and a number of pilot AIJ projects are already under way or planned¹⁷.

-
- 12. As recognised in the Protocol, a first-best policy to reduce emissions is to reduce subsidies to fossil fuel consumption.
 - 13. Found respectively in Articles 17, 6 and 12 of the Protocol.
 - 14. The Annex I Expert Group, which meets under OECD/International Energy Agency auspices, plays an exploratory role in this process.
 - 15. This paper refers to "permits" and "quotas", language not used in the Protocol but which is more transparent than that derived from the wording of the Protocol. Annex B to the Protocol defines the emissions target as a proportion of the total 1990 emissions, referred to as a QELRC or "Quantified Emission Limitation or Reduction Commitment"; from this can be calculated the emissions limit in terms of tonnes of carbon equivalent. Some papers refer to trading in "parts of Assigned Amounts", following language used in the Protocol itself, rather than in "permits".
 - 16. Projects which increase take-up by sinks are also eligible.
 - 17. 113 projects by June 1998. The hosts for these projects are either European transition countries or developing countries, the latter almost entirely in Latin America. See Joint Implementation Quarterly, September 1998.

31. The Clean Development Mechanism (Article 12 of the Protocol) is similar to JI, with the difference -- an important difference -- that the host country be a non-Annex I country¹⁸. This difference could have important implications. In JI any error in the baseline in favour of either the host or the sponsoring country is automatically offset as far as global emissions are concerned, since both countries are subject to emission limits (and provided these limits are respected). In the case of the CDM, errors in baseline calculations may lead to higher global emissions than without the project since non-Annex I countries have no initial emission ceilings. Errors could also go the other way, leading to lower global emissions, but both sides will have an incentive to exaggerate the impact of the project in reducing emissions by inflating baseline estimates. Reflecting these differences in incentives, the Kyoto Protocol foresees the establishment of a board to supervise the operation of the CDM, whereas the basic requirement for a JI project to be accepted is that both countries agree to it.

32. JI and the CDM are similar to emissions trading in that their aim is to make abatement where it is cheap but there are also some important differences. Being project based they are in the nature of investments and intended also to promote technology transfer, whereas trading allows for "spot" transactions. JI and the CDM are likely to have rather higher transactions costs, since they require the calculation of a baseline and approval of the projects on a case by case basis by the countries concerned, and possibly an international board as well. Various approaches to solving the problem of establishing baselines are under discussion¹⁹.

33. Certified emissions reductions from CDM projects obtained between the year 2000 and 2008 "can be used to assist in achieving compliance in the first commitment period" (quoting Article 13). This is potentially quite an important provision, giving an incentive to reduce global emissions before the first commitment period (2008-12). The Protocol also implicitly requires that the emissions reduction be long lasting, but it is not clear how many years' worth of reductions can be credited to the sponsoring party. This and other aspects of the CDM mechanism remain to be clarified.

34. The CDM may have spillover effects on emissions trading, with consequences for the pattern of global emissions. Although non-Annex I countries have low per capita emissions, their emissions per unit of GDP are generally very high, and the cost of reducing their emissions-intensity is low (relative to that in most OECD countries). The ease with which CDM projects can be approved and implemented will be crucial in determining their impact on emissions trading among Annex I countries: if the CDM were relatively friction free then the low cost of abatement in non-Annex I countries could put a low ceiling on the trading price of emissions permits, in turn meaning that actual reductions in emissions in Annex I countries would be relatively small (subject to supplementarity constraints, see below).

2.2.1.3 Other aspects of the flexibility provisions

Supplementarity

35. Not all countries who signed up to the Kyoto Protocol view the "flexibility" measures in the same way. The text of the Protocol reflects a certain tension between i) the idea that emissions should be reduced in countries where they are already very high on a per capita basis and ii) the idea that they should be reduced at least cost in foregone output. The flexibility options result from ii), but i) appears to be behind the introduction of the notion of "supplementarity".

18. The Protocol also provides for technological transfer and other assistance to non-Annex I countries.

19. See Puhl (1998).

36. Each of the Articles defining the three flexibility provisions discussed above carries wording on some kind of additionality condition²⁰. Emission trading, for example, is supposed to be supplemental to domestic action to meet the Kyoto targets. At one extreme this could be taken to mean that domestic action should be almost sufficient to meet the targets before any trading is permitted, in which case trading would not only be supplemental, but also largely pointless; at the other extreme it could be interpreted to require just some minimal domestic action. On the basis of this provision, there are suggestions that trading should be limited, for example, to a certain proportion of total allowances.

Hot air

37. Subsequent to the signing of the Protocol, a discussion has arisen over the issue of so-called "hot air". This refers to the possibility that some Annex I countries, notably some of the transition economies, might meet the Kyoto targets without any domestic action at all. In this case they would be able to sell their surplus emission allowance (the hot air) without incurring any abatement cost. Predictions as to how much hot air there may be are highly dependent on forecast output in the former Soviet Union, particularly Russia and the Ukraine. The present economic outlook for those countries suggests that there may be substantial amounts of hot air. However, it is likely to be a relatively short-term phenomenon that will not persist into the second commitment period. Chapter 3 discusses the impact of hot air and possible restrictions on trading it for overall abatement costs.

Banking

38. Article 3 of the Protocol also provides for carrying over unused permits into future commitment periods. In general this is likely to be little used as a deliberate policy, given positive time preference and to the extent there are expectations that abatement costs will diminish over time. The banking provision is relevant to the "hot air" issue, since if countries are prevented from selling "hot air" they will automatically be able to carry it over into the future. Banning hot air trading would in this case do nothing to reduce cumulative emissions, only delay them somewhat -- provided that assigned amounts for future commitment periods are not affected by actual emissions, which in practice they may well be given the sequential nature of negotiations.

Substitution between greenhouse gases

39. The Kyoto targets cover a "bundle" of gases. The target is expressed in terms of CO₂ equivalent, with the conversion factors for the different gases being given by their relative efficiency ("global warming potential") as a greenhouse gas²¹. This has implications for flexibility, since it potentially allows countries

20. ET: "Any such trading shall be supplemental to domestic actions for the purpose of meeting [the Kyoto targets]."

JL: "Any such project [must provide] a reduction in emissions, or an enhancement of removal by sinks, that is additional to any that would otherwise occur."

"The acquisition of emission reduction units shall be supplemental to domestic action...."

CDM: any reductions in emissions shall be "additional to any that would [otherwise] occur..." ;

21. Much less is known about the greenhouse properties of the non-CO₂ gases, especially the fluorine compounds, and the estimated warming potential may change as the state of knowledge advances. However, for the purposes of the first commitment period, the conversion factors are fixed at the global warming potential outlined in the Kyoto Protocol. Revisions in the light of further information will affect the relative weights of the gases only as from the second commitment period.

a wider choice of abatement strategies than those relating to CO₂ alone (provided their baseline emissions of the other gases are significant). Gielen and Kram (1998), in a study restricted to Europe, suggest that low-cost abatement options may be available, in particular for methane and nitrous oxide, such that a significant proportion of the necessary abatement in Europe could be achieved in the non-CO₂ gases, at lower cost than if CO₂ reductions were required for the full amount. Measurement of non-CO₂ emissions is subject to more uncertainty than for CO₂, however, and there are suggestions that measurement problems are a further justification for limits on the proportion of a country's commitment that can be met by trading (see below).

Sinks

40. In addition to widening the scope of emissions targets to cover non-CO₂ gases, the Kyoto Protocol also introduces sinks into the process. Sinks are largely natural processes -- not yet fully understood in many cases -- and any anthropogenic component is generally due to large scale land-use changes. The protocol allows changes in take-up of greenhouse gases by sinks, certified as resulting from direct human-induced activities occurring after 1990, to be treated as a credit in the first commitment period. The main policy leading to such changes is reforestation. In some countries reforestation is already leading to significant increases in take-up of CO₂, but this will be of rather little importance to start with because most of this is due to measures that were taken before 1990. Moreover, the carbon sequestration potential in forests is initially relatively low but then increases (up to a point, as previously mentioned) as they mature, so the importance of sinks may increase in future commitment periods.

2.3 Some implementation issues

41. Among the flexibility mechanisms, much interest has been devoted to permit trading. As discussed in chapter 2, permit trading has the potential to significantly reduce the economic costs of achieving the Kyoto targets. However, while the concept of emission trading is relatively simple in theory, there are many questions unanswered when it comes to setting up a trading system in practice. In particular, there are differing views on how compliance should be verified and enforced and who should be allowed to trade. This paper is not intended to recommend an appropriate structure for the trading system²², but, based on work carried out not least in the context of the Annex I Expert Group, this section highlights a number of issues that might affect trading and the overall aims of the Kyoto Protocol. Achieving early clarification on these issues will help implementing the Protocol in a cost-effective manner by creating a credible and predictable framework for forward-looking decisions by the private sector.

2.3.1 Ensuring compliance

42. Once in force, the Kyoto Protocol is a treaty commitment and governments will be obliged to ensure that it is respected. Nevertheless, elaboration of non-compliance responses is part of the mandate for COP6, and is important not least because of the inter-relation between compliance and permit trading: if compliance is not a constraint there is no incentive to buy permits; at the same time, some argue that the trading regime should be structured so as to encourage compliance²³. In the US sulphur dioxide trading regime, often used as a reference when discussing permit trading, the compliance problem is dealt with by

22. See, e.g., Mullins (1998), UNCTAD (1998) for a wider discussion of these issues..

23. E.g. Mullins (1998).

a credible external sanction, well above the marginal abatement cost²⁴. In principle, external sanctions could be imposed at an international level on countries exceeding their GHG emission limits, with trade policy sanctions, rather than fines, sometimes discussed as the instrument (though this would be unlikely to be consistent with WTO rules). However, political consensus on this is unlikely at least at the moment; there is certainly no precedent for such an international agreement²⁵. The maximum penalty considered in the Montreal Protocol on Ozone, for example, is the suspension of a country's rights under the Protocol, providing no material disincentive to "free-riding" other than the reputational cost of defaulting on a treaty commitment (which may, however, be large).

43. Using the emission trading system to strengthen compliance could take the form of suspending a country's right to trade permits as a penalty for non-compliance. At first glance, the effectiveness of this sanction might seem limited: if a country sells a lot of permits and is then found to be emitting more than allowed, removing the right to sell permits that have been already sold is not a strong sanction. However, this will be a "repeated game" so the inability to sell permits in the future may, in fact, be quite a strong sanction in some cases -- essentially for countries with substantially below average abatement costs, who could expect typically to be sellers. For countries likely to be net buyers of permits, the suspension of the right to buy permits might be an awkward penalty to impose for non compliance: by the time non-compliance for the first commitment period can be established (likely to be late 2013 at the earliest) purchasing permits will be the only way to come into compliance. Here the repeated game aspect does not help much: if a country's non-compliance is deliberate then preventing it from buying permits in the future might have little impact in that country but would reduce the price of permits to sellers and tend to increase global emissions. Furthermore, countries have an incentive to attempt to manipulate measurement of emissions (which will be based on self-reporting plus expert review by the UNFCCC). In general, then, compliance enforcement will depend very much on individual countries' desire to meet treaty commitments rather than on threats of punitive action²⁶.

2.3.2 *Buyer or Issuer liability in permit trade?*

44. Incentives for compliance are also involved in the discussion about buyer or issuer liability. The essence of the liability problem can be illustrated by an example in which country A has sold permits to country B; which country will be held responsible if, at the end of the commitment period, A is found to have emitted more than its reduced stock of permits allowed, but less than its original stock²⁷? Even where sanctions are not possible or not credible, liability rules can affect the incentives faced by different countries. Under Issuer²⁸ liability, any permits sold are sold irrevocably -- in this example, B has nothing to fear. The wording of the Protocol establishes the liability of sellers to ensure they remain within their reduced emission limits. Under Buyer liability, the permits (or some of them) bought by B could be invalidated and it would be B that is treated as non-compliant (provided that the permits bought from A were indeed required for B to meet its obligations).

24. Entities exceeding their allowed SO₂ emissions pay a fine of \$2 000 per ton, compared with a permit price of the order of around \$100 per ton.

25. The OECD Environment Directorate document ENV/EPOC(98)5/REV1 reviews the literature on this.

26. For non-compliance which is not deliberate, through miscalculation or mistaken policies for example, responses are likely to include assistance measures to help the country improve its policies, rather than punitive measures. These are found in the Ozone agreement, for example.

27. Among the current Annex I countries the most likely net sellers are some of the transition countries, notably Russia and the Ukraine.

28. Frequently this is referred to as "seller" liability. "Issuer" may be more appropriate since the idea is that liability rests with the country who was originally allocated the permit.

45. It is therefore argued that amending the Protocol to provide for Buyer liability would reduce the likelihood of this kind of non-compliance occurring, since the price of permits issued by potential non-compliers would be low, because of the risk that they will be unusable; hence countries wishing to sell permits would have an incentive to be compliant in order to increase their revenue, independently of whether they value the treaty commitment in itself. This presupposes that information about likely non-compliance is reasonably well available²⁹; in practice, there will be very little information initially, which may discourage trading altogether until countries have a track record -- not for some time. Until markets are deep enough, Buyer liability may increase the likelihood of market segmentation, which would reduce the efficiency of permit trading in reducing overall abatement costs.

46. Buyer liability may also be unrealistic if countries wish to link domestic cap-and-trade systems with the international permit trading system, with domestic penalties for non-compliance. Suppose, for example, a US enterprise purchases Russian permits and plans emissions on that basis, and some years later the permits turn out to be invalid because of excess emissions in Russia. Under Buyer liability the US enterprise is now in non-compliance and the US government should penalise it. Theoretically this should not be a problem because the US enterprise should have taken into account the probability that the permits would be invalid and planned its emissions in the light of the possible fine. In practice, however, this might be politically unacceptable, and could certainly generate quantities of litigation. Whether Buyer or Issuer liability³⁰ results in increased compliance will continue to depend on how seriously the different parties take their Kyoto commitments³¹.

2.3.3 *Entity trading?*

47. Just as international trading should allow greenhouse gas emission abatement to be carried out in countries where it is least costly, domestic trading systems should reduce average abatement costs within countries. This would require governments allocating some part of the national quota of permits, or assigned amount, to plants, enterprises or other entities. If these domestic trading systems were linked to the international system the number of agents in the global market would increase and hence market power would tend to fall, which should improve the overall efficiency of trading (see chapter 3 on the effects of market power).

48. It would not be possible to implement a domestic trading system covering all emissions of greenhouse gases, particularly those without point sources (such as methane but perhaps also household emissions of CO₂) where monitoring emissions is impossible and where there is not a fixed relationship between emissions and some measurable input or output. There would thus necessarily be a need for a mixture of policies, where some care would need to be taken to ensure that efficiency gains were not reduced by unnecessarily penalising or favouring particular kinds of emission.

49. The Kyoto Protocol does not expressly refer to entity trading (though it mentions legal entities or private entities in the context of JI or the CDM). However, even if there were opposition to entity trading under the Protocol itself, it would be relatively simple to link a domestic market to the international

29. This would lend increased importance to discussions on how and where to keep records of transactions in permits, how frequently they should be updated, and how public they should be.

30. Different combinations of Issuer and Buyer liability can also be imagined. If there were serious concern about trading increasing overall emissions, both Issuers and Buyers could be held fully liable.

31. It may also be noted that the options available could conceivably depend on whether trading was deemed by the WTO to be in a "commodity" or a financial instrument; in the former case permit trade would come under WTO rules and it might be difficult to use trade sanctions to encourage compliance. It would seem unreasonable, however, to classify emission permits as a commodity.

market: the government could regulate the supply of domestic permits as a function of its own holdings of international permits, operating on the domestic and international markets to keep the prices in line³². Allowing entities that are not themselves emitters to trade could also allow permit brokers to develop, potentially improving the functioning of the market.

2.3.4 Monitoring and verification

50. Another implementation problem, which has implications much beyond emission trading, is that emission volumes themselves can only be measured with uncertainty. The situation varies among the different gases. Measurement of anthropogenic emissions of CO₂ is thought to be fairly accurate, because emissions arise largely from combustion of fossil and biomass fuels. The resulting production of CO₂ is closely related to the (known) carbon content of each fuel, and does not vary much according to combustion technology³³. Provided use of such fuels can be measured, therefore, emissions can too.

51. Emissions of the other greenhouse gases are mostly related to industrial (for methane, mostly agricultural and waste disposal) processes or leakages from appliances either during use or on scrapping; emission rates vary, and vary considerably, according to the technology in use. Current estimates of emissions of these gases are subject to much greater relative margins of error than for CO₂. For some HFCs and SF₆ this may be up to a factor of 2 to 5; margins of error are lower for methane (+/- 25 per cent, i.e. a factor of 1.25) and nitrous oxide (a factor of 2) but are still substantial (Gielen and Kram, 1998).

52. Another area where there is considerable measurement uncertainty is sinks. COP4 agreed that the adjustment to a Party's assigned amounts shall be equal to verifiable changes in carbon stocks during the period 2008-12 resulting from direct human-induced activities of afforestation, reforestation and deforestation since 1 January 1990. Unless direct measurement of absorption by sinks is attempted, itself likely to be subject to sampling error, it will have to be estimated on the basis of information on the relevant forestation measures, along with estimates of the rate of absorption by each different type of forestation.

53. Basic "default" methodologies for measurement have largely been agreed under the UNFCCC, with countries being encouraged to use better methods where possible. Through the process of "national communications" (which contain estimates of emissions) and expert review teams (in which a member of the OECD Environment Department sometimes participates) measurement accuracy should be steadily improved (although the reviews do not directly check the accuracy of reported emissions figures). If the methodologies are inaccurate but unbiased then they may not lead to systemic excess emissions, unless the verification process is insufficient to detect possible "cheating." The incentive to cheat will be an increasing function of the sanction for non-compliance and the marginal abatement cost. Since trading will reduce the latter in net buyer countries and increase it in net sellers the overall outcome is not obvious *a priori*. Some have suggested that measurement inaccuracy justifies limiting trading in order to avoid excess emissions, or that participation in trading should be limited to countries whose data on emissions -- at a national level and by entities that might be involved in trade -- is reliable.

32. Such an arrangement might be known as the CO₂ Standard, or perhaps the Greenhouse Gas Board.

33. There is some variation, nevertheless, but errors are thought to be not more than +/- 2 to 5 per cent (Gielen and Kram, 1998).

3. Implications of Kyoto

54. This chapter aims to quantify some of the major aspects of the Kyoto Protocol in terms of emissions, concentration, economic costs, etc. As described in the previous chapter, the Protocol as it stands leaves many questions open. Without a clear idea on how it will be implemented in practice, any assessment of the economic impact of the Protocol will have to be tentative. Quantifying the effects under different assumption may, however, allow an assessment of the contributions that various aspects of the Protocol, not least the various flexibility provisions, can give to the achievement of a cost-effective implementation.

55. This chapter focuses on near-term aspects of the Protocol; that is, until the end of the first commitment period (2008-12). It is based on results from a range of econometric models which all embody a number of simplifying assumptions -- a prime simplification being the neglect of non-CO₂ GHGs. Among the model results considered are those obtained with the OECD's world general equilibrium model, GREEN (see Box 1)³⁴. The chapter first aims to identify the economic costs of the Protocol when countries and regions implement their emission targets individually -- what is referred to as the "no-flexibility case" -- and then analyses the impact of the so-called "flexibility mechanisms". Since it is unknown to what extent the flexibility mechanisms will be used, the approach is based on sensitivity analysis relative to a benchmark situation in which these mechanisms are applied without restriction. Aspects of the Protocol lying beyond the first commitment period, including its impact on atmospheric CO₂ concentration, are taken up in chapter 4.

Box 1 The OECD's GREEN model

The quantified scenarios in this paper have been elaborated using the Secretariat's GREEN model. GREEN is a multi-country, multi-sector, dynamic applied general equilibrium model which has been developed with the explicit aim of quantifying the economy-wide and global costs of policies to curb CO₂ emissions. In terms of the CO₂ issue, the model has a medium-term focus: it is simulated for the period up to 2050.

Because of the global nature of the GHG problem, specific attention is paid to the modelling of some key non-OECD regions. There are twelve detailed regional sub-models:

- four OECD regions (the United States, Japan, the EU and other OECD);
- eight non-OECD regions (the former Soviet Union, Eastern Europe, China, India, the energy-exporting LDCs, the Dynamic Asian Economies, Brazil and a Rest-of-the-World grouping).

GREEN has a simple recursive dynamic structure, in which saving decisions affect future economic outcomes through the accumulation of productive capital. In the version used here, capital accumulation is modelled in a putty/semi-putty fashion. Production sectors operate under constant return to scale and markets are assumed to be perfectly competitive. Production and consumption are specified using systems of embodied Constant Elasticities of Substitution (CES) functions. Consumers maximise their utility and allocate consumption according to an Extended Linear Expenditure System.

34. Other models are Worldscan (EPA), Energy Modelling Forum, MERGE, AIM, Capros, G-Cubed. For references see Glossary. Some of the models have an engineering based description of energy technology choices ("bottom-up approach") whereas others, including the Secretariat's GREEN model, put more emphasis on general equilibrium properties while treating energy technology in a more aggregate fashion ("top-down approach").

There are eleven production sectors in GREEN, chosen to highlight the relationships between resource depletion, energy production, energy use and CO₂ emissions. Since the main source of manmade CO₂ emissions is the burning of fossil fuels, a key focus is on the energy sectors. Three sources of conventional fossil-fuel energy -- oil, natural gas and coal -- and one source of conventional non-fossil (so-called "carbon-free") energy are distinguished. The carbon-free energy source includes nuclear, solar and hydro power. Both carbon-based and carbon-free backstop technologies are available for all conventional energy sources at exogenously given costs and introduction dates.

The production side of each regional model describes in a detailed way the supply of fossil fuels and the use of fossil and non-fossil energy inputs in the production process. Some allowance is also made for shifts in the composition of production by treating agriculture as a separate sector, and by distinguishing between two broad aggregates, energy-intensive industries and other industries and services.

Consumer demand is split between four broad aggregates: food and beverages, fuel and power, transport and communication and other goods and services. Saving is treated implicitly as a "fifth good", and shifts in energy prices therefore affect both the structure of consumer demand and the consumption/saving mix through changes in real income.

The version of the model used in this paper is updated and slightly modified compared to the one used in OECD's Model Comparisons Project (see Burniaux *et al.*, 1992a and 1992b and Lee, Oliveira-Martins and van der Mensbrugghe, 1994). It is based on 1995 data elaborated by the GTAP project (Hertel, 1997). Further planned model developments, financed by specific grants, include the introduction of two additional GHGs (methane and nitrous oxide) and an endogenous specification of the potential of carbon sinks through reforestation and slower deforestation.

3.1 *Economic costs of the Kyoto commitments: the no-flexibility case*

56. A first step in analysing the economic impact of the Kyoto Protocol is to consider the case where Annex I Parties meet their commitments individually. A scenario in which flexibility mechanisms play no role is a useful starting point for several reasons³⁵: first, there is uncertainty about the extent to which these additional mechanisms will be allowed to contribute to reduce emissions; second, there is little knowledge so far about some key technical aspects of some of these mechanisms -- such as the potential, measurement and costs of sinks enhancement and reductions of non-CO₂ gases; third, such a scenario provides an upper bound estimate of the costs of applying the Protocol and can be used subsequently as a benchmark to evaluate the effectiveness of the flexibility mechanisms in reducing costs.

57. In all cases, in these scenarios the required emission reductions have been fulfilled in terms of CO₂ alone -- none of the models allow for non-CO₂ GHGs. Where emissions of other gases can be reduced at lower cost, the scenarios therefore may exaggerate the costs of implementing the Kyoto Protocol. The simulated impacts fall within a rather wide range, not surprisingly given the differences in the model structures and some ancillary assumptions. Moreover, the simulated impacts of policies to respect the Kyoto targets depend on the emission paths in the absence of such policies. These so-called Business-as-Usual (BaU) scenarios differ between the various studies (the BaU with the Secretariat's GREEN model is described in Box 2). Nevertheless, despite these differences across studies, some insights appear robust.

35. Although the current US negotiating position implies that the Kyoto protocol would not be ratified in the absence of the flexibility mechanisms.

Box 2. CO₂ emissions in the Business as Usual scenario

The first step in quantifying the economic impact of the Kyoto Protocol is to derive a plausible projection of future emissions as they would be expected in the absence of any policy action to restrain their growth -- the so-called "Business-as-Usual (BaU) scenario. The emissions targets set in Kyoto are expressed relative to the Annex I countries' emissions levels in 1990. Thus, the future growth of emissions, as projected in the BaU scenario, is critical in determining the efforts required to meet the Kyoto commitments.

Main assumptions behind the BaU scenario comprise future GDP and population growth rates, as well as the future trend of the international oil price. In addition, the BaU scenario incorporates assumptions about future technological developments in the field of energy production, including the future rate of Autonomous Energy Efficiency Improvement (AEEI) and the emergence of alternative energy options (referred to as "backstop" technologies).

Projected GDP growth

The model has been calibrated so as to reproduce given trends in GDP. These trends combine population growths, as projected by the World Bank, with productivity growths from various sources. Over the medium term, GDP growth rates are drawn from *OECD Economic Outlook 63* and the associated Medium Term Projections. Longer term assumptions about GDP growth are drawn from Secretariat work on population ageing (see Turner *et al.*, 1998). Table 1 summarises GDP growth trends in the BaU scenario.

(Table 1. GDP projections underlying the BaU scenario in GREEN)

Energy related assumptions

Another important assumption is that each country/region has an annual autonomous energy efficiency improvement to be equal to 0.4 times its annual labour productivity growth. Moreover, the model considers three backstop energy sources: a carbon-based substitute to fossil fuels, a carbon-free substitute to fossil fuels and a carbon-free electricity source. These backstops are assumed to become available after 2030 at uniform prices across all regions. The prices have been set according to the Stanford Energy Modeling Forum (EMF) guidelines (7 333 1995 \$ per terajoule for the carbon-based fuel, 13 333 1995 \$ per terajoule for the carbon-free fuel and 27 778 1995 \$ per terajoule for the carbon-free electricity generation). Finally, the current version of the model assumes that existing differences in energy prices across countries reflect distortionary taxes and subsidies which are assumed to remain constant. Subsidy rates have been updated on the basis of various recent studies, including World Bank, 1997; OECD, 1997a and b; Michaelis, 1996. The international oil price is set to remain constant in real terms until 2000. Thereafter, it is endogenously determined, given the parameters of the reserve depletion function. These parameters have been calibrated on IEA medium-term projections and data from the World Energy Resources Program (USGS). As a result, the real world oil price increases by 1.85 per cent annually on average over the period 1995-2050.

CO₂ emissions in the BaU

Emissions projections depend on the above assumptions and their interactions through international energy prices. Thus, emissions are directly related to assumed future GDP growth. In addition, as oil and gas reserves are being depleted, energy demand shifts towards coal and the carbon-based fuel substitute. As the carbon content of these fuels is higher, this, in turn, tends to increase the

amount of CO₂ emitted per unit of energy consumption. Table 2 shows the future emissions trends as they are projected in the GREEN BaU scenario.

(Table 2. CO₂ emissions in the BaU scenario in GREEN)

3.1.1 *Emission reductions are substantial*

58. The Kyoto Protocol specifies the country-specific limitations on emissions in terms of 1990 emission levels. Expressed in this way, the Protocol implies what sounds like a rather modest reduction of about 5 per cent for Annex I countries as a whole. However, emissions have already risen relative to 1990 and, according to BaU scenarios, where no action is taken to curb emissions, seem set to rise further. When measured relative to a BaU, most Annex I countries will have to cut their emissions by 20 to 40 per cent in 2010 (see Table 3, first column)³⁶, an effort of an unprecedented magnitude which is likely to require major structural adjustments. Russia and Ukraine (referred to as the CIS in the following³⁷) are noticeable exceptions. Falling output, deregulation of energy markets and a substantial subsidy reductions, have brought emissions in the CIS below their 1990 levels. In 2010, CIS unconstrained emissions could be substantially below commitments: the BaU scenario in GREEN suggests a gap ("hot air") of more than 14 per cent of the CIS commitment, some 130 million tons of carbon.

(Table 3. Estimates of the economic costs of implementing the Kyoto Protocol without the flexibility mechanisms)

3.1.2 *Marginal abatement costs are high in OECD countries*

59. There are various ways to express the costs of reducing CO₂ emissions, the most straightforward being to calculate the marginal abatement costs for each Annex I Party. Table 3 shows that these marginal costs are likely to be rather high for OECD countries if they have to meet their target individually, possibly ranging between 100 to more than 300 1995 \$ per ton of carbon³⁸. Available studies in general point to higher marginal abatement costs in the European Union, Japan and the rest of the OECD region (grouping mainly Canada, Australia and New Zealand), than in the United States. In contrast, marginal costs are lower in Eastern Europe and zero in the CIS, where the limit decided in Kyoto is not a binding constraint.

3.1.3 *Total economic costs remain low*

60. The right-hand column in Table 3 indicates that the total economic costs -- expressed as percentage of GDP or total real income -- would be around 1 per cent of GDP annually in the European Union and below 1 per cent of annual GDP in other main OECD regions. Although not imposing any

36. For the sake of simplicity, and reflecting the structure of some of the models involved, the first commitment period is taken to correspond to its mid-point, i.e. 2010.

37. The Russian Federation and Ukraine only have signed the Kyoto Protocol. However, the current version of the GREEN model considers only one aggregate region -- called CIS -- which corresponds to the former Soviet Union.

38. For reference, the international oil price expressed in terms of carbon equivalent amounted to \$150 per ton in 1995.

carbon limitation³⁹, the CIS would lose from an adverse terms-of-trade effect due to reduced energy export revenues.

61. These global cost estimates may appear surprisingly modest in view of the size of emission cuts and their high marginal costs. Global economic models (like GREEN, MERGE or WORLDSCAN) provide cost indications which correspond roughly to the "dead-weight losses". Thus they consider the efficiency losses (in terms of producer and consumer surplus) which are associated with the resource reallocation resulting from a carbon limitation rather than the total abatement cost (as measured, for example, by the revenues of the carbon tax required to reduce emissions). Such models may underestimate the economic costs of carbon limitations, especially over the short and medium term, because they assume that factors are more or less mobile: they therefore fail to capture the transitory costs associated with the necessary reallocation of labour and capital⁴⁰. The simulations also assume that domestic implementation policies are cost-effective in the sense of raising marginal costs of CO₂ emissions by the same amount across sectors (even if pre-existing distortions are maintained, see section 3.2.3). Hence, these low cost estimates should not hide the fact that some sectors and some countries, including among non-Annex I parties, would be substantially affected. Secondly, as discussed later in the paper, the impact of this level of emission reductions on atmospheric concentrations and climate change will be small. To have a significant impact on the global warming process will require much greater efforts, involving a larger number of countries, and so the costs (and the gains to minimising them) will be correspondingly greater.

3.1.4 Higher prices and lower output of energy

62. Carbon taxes or prices of domestically traded permits in the range corresponding to the marginal costs reported in Table 3 are likely to generate sharp increases in energy product prices. Figure 1 reports the price increases simulated by the OECD GREEN model. The coal price in OECD countries would increase by 200 to 400 per cent (relative to the BaU scenario) leading coal output to fall by 30 to 50 per cent in 2010. Other energy prices would increase too: the average price consumers pay for energy services and transportation would increase by more than 50 per cent (except in Japan⁴¹). This substantial impact on consumers is partly offset by the assumption in the GREEN model that additional revenues from carbon taxation are redistributed to consumers in a lump-sum way⁴².

(Figure 1. Energy price increases in 2010 caused by the implementation of the Kyoto Protocol)

63. The output of energy producing sectors is reduced substantially in 2010 (see Figure 2), with coal output falling most while the production of electricity is reduced by less than 10 per cent or even increased in some countries/regions. There is widespread concern that energy-intensive industries (steel, cement, paper and pulp, etc.) could be adversely affected by the Protocol. This is an area where results differ somewhat. According to simulations with the MERGE model, production in these sectors in some Annex I Parties could fall by as much as 10 per cent in 2010 (Manne and Richels, 1998). Results from GREEN

39. Models reported in Table 3 show no carbon taxes in the CIS. The carbon reduction of 2 per cent reported by the GREEN model is the result of feedback effects from limitations in the other Annex I countries.

40. On the other hand, ancillary benefits, including economic ones, of action to reduce CO₂ emissions are not taken into account either.

41. The lower price effect in Japan reflects the large non-energy component in the average consumer price of energy services and transportation.

42. Alternatively, re-circulation of revenue could take place via reductions in distortive taxes, thereby reducing the overall economic costs of action to reduce CO₂ emissions.

suggest smaller impacts, with the production of energy-intensive sectors cut by 1 per cent only in Japan and the European Union, 3 per cent in the United States and 4 per cent in other OECD countries.

(Figure 2. Output changes in 2010 caused by the implementation of the Kyoto Protocol)

3.1.5 *Oil prices will be hit but carbon leakage may not be a concern*

64. Implementation of the Protocol is likely to have a large impact on the international market for crude oil. According to results with GREEN, reduced oil consumption by Annex I countries causes a real income loss of 3 per cent among the oil-exporting countries, proportionately much higher than any projected loss incurred by Annex I Parties. By contrast, some oil-importing developing countries (for instance, Brazil) may benefit from lower oil prices.

65. Such lower oil prices are likely to lead to "carbon leakage" whereby part of the emissions reduction achieved in Annex I countries could be offset by additional emissions in non-Annex I countries. This may occur through migration of energy intensive industries away from Annex I countries where they will become less competitive, though GREEN simulations suggest rather small reductions in such output, in the range of 1 to 5 per cent (see Figure 2), and thus a small carbon leakage effect from this source. More generally, carbon leakage will result from substitution towards cheaper energy in all non-participating countries (see, for instance, Shackleton, 1998).

66. Carbon leakage may be higher the higher the degree of international capital mobility, but model results indicate that this factor has little impact; it could even contribute to reduce leakages under certain circumstances (McKibbin, Shackleton and Wilcoxon, 1997; Burniaux and Oliveira Martins, 1999). The existence of economies of scale and imperfect competition, leading to international relocation of firms, are other factors which could potentially determine the magnitude of leakages, although their influence has not been quantified so far. On the whole, available simulations point to fairly moderate carbon leakage, although the range of estimates is proportionately rather large. In simulating the Kyoto Protocol, the MERGE model (Manne and Richels, 1998) and the G-Cubed model (Shackleton, 1998) show leakage rates (calculated as the ratio of additional emissions in non-Annex I countries to the total emissions reduction in Annex I countries) around 9 per cent, whereas the GREEN model estimates leakage rates below 4 per cent.

3.2 *Reducing the costs of Kyoto: making use of the flexibility mechanisms*

67. The scenario analysed in the previous section pointed to large differences of marginal abatement costs across Annex I Parties. This implies that the Protocol's provisions for flexible, market-based instruments may significantly reduce the cost of achieving the overall emissions reduction target. Drawing on chapter 2, this section reviews these flexibility instruments and attempts to quantify their potential to reduce the economic costs.

68. The mechanisms considered in the Protocol can be characterised in terms of three basic categories of flexibility⁴³: i) the "where" flexibility which allows emission reductions to be redistributed across Parties so as to minimise costs; ii) the "when" flexibility which permits the reallocation of emissions reductions over time; iii) the "what" flexibility which allows a choice between cutting six different gases and/or enhancing sinks instead of cutting emissions. The Protocol also leaves Parties free to choose how to implement their limitation domestically, for instance by applying taxes or imposing

43. This categorisation has been used by, e.g., Frankel (1998).

controls. As part of this "how" flexibility, this section also analyses the possibility that some Parties remove remaining subsidies in their energy markets.

3.2.1 "Where" flexibility

3.2.1.1 "Where" flexibility among Annex I Parties

69. Existing studies agree that the potential for cost saving by emissions trading (ET) and joint implementation projects (JI) is very substantial⁴⁴. For instance, the Stanford Energy Modeling Forum (EMF), by comparing the results from six world-wide models, has estimated that international trading would reduce the cost of meeting global emissions targets by nearly 60 per cent (Weyant, 1997). Table 4 suggests that "where" flexibility could reduce the marginal costs of meeting the Kyoto targets by more than half. Average costs could fall substantially too. Gielen and Koopman (1998) estimate that permit trading could reduce the total cost for Annex I countries of implementing the Kyoto Protocol from 0.25 per cent of real consumption to 0.10 per cent. Based on simulation results for the United States alone, Manne and Richels (1998) report economic cost falling from more than \$80 billions (1 per cent of US GDP) to \$50 billions (both at 1990 prices), a reduction of more than 40 per cent⁴⁵. Simulations with the OECD GREEN model suggest that the total real income loss for OECD could be approximately halved and that it could become virtually insignificant for Annex I countries as a whole (Figure 3). When interpreting this result, it should be borne in mind that it reflects both very substantial gains from trading, amounting to some 0.4 per cent of real income, and fairly low costs of 0.5 per cent of real income even in the absence of trading -- the latter result being due, not least, to substantial terms-of-trade gains among OECD countries due to lower energy prices.

(Table 4. Marginal abatement costs without and with emission trading
(Figure 3. Real income changes from alternative trading regimes in the Kyoto Protocol)

70. About 80 per cent of the gains from trading arise from greater efficiency -- GHG emission reductions are made where they are less costly, which in practice means mainly in the CIS. The remaining gains come from the fact that aggregate Annex I emissions are higher under a permit trading scheme than if countries meet their target individually, with the difference being equal to the gap between the CIS commitment and emissions levels in the BaU scenario. With less overall Annex I abatement, the aggregate cost is also lower. Scenarios with the GREEN model suggests that, by 2010, the CIS could sell some 130 million tons of carbon as "hot air" and about 280 million tons further as emission reductions, making the CIS the dominant seller in the permit market (some potential ramifications of this are discussed in sub-section 3.2.1.5 below).

71. ¹ Most Parties benefit from emission trading. GREEN results suggest that permit sales would give the CIS an inflow of \$39 billion (at 1995 prices) (12 billion of which come from selling hot air), whereas with individual implementation the CIS would lose because of falling revenue from energy exports. Indeed, ² more than 60 per cent of the overall gains from trading permits would accrue to the CIS (Figure 4). The European Union would come next with about a third of the gains. Both the European Union and Japan ³ would tend to meet a higher percentage of their obligation by buying permits and thus would benefit

44. Studies generally do not distinguish trading of emissions allowances from JI projects: they treat both instruments as if they had the same impact.

45. Part of the cost reduction in the scenario simulated by Manne and Richels comes from the implementation of the CDM.

relatively more from trading permits than other OECD Parties. According to these simulation results, the United States would not gain from trading⁴⁶

(Figure 4. Distribution of benefits and losses from permit trading under the Kyoto Protocol in 2010)

72. Gains from permit trading are not restricted to Annex I countries. As Figure 3 shows, non-Annex I countries lose somewhat less if permits are traded among Annex I countries than if they meet their commitments individually. The explanation is that permit trading changes the nature of the cut in energy consumption; it shifts part of the burden of this cut from imported oil to CIS coal production. As a result, oil exporting countries are much less affected by the emission reductions in Annex I countries. A related effect is that the leakage rate with tradable permits is likely to be lower than under the individual approach.

3.2.1.2 Reasons why "Where" flexibility may be restricted

73. The unlimited "where" flexibility is effective in lowering costs but also raises a number of questions and difficulties:

- First, there is no consensus among Annex I Parties on how to meet the targets, and some Parties may be politically disinclined to rely on market-based instruments such as permit trading. In the extreme, this could lead some countries or groups of countries to refrain from trading, which again could lead to some degree of market segmentation (section 3.2.1.3).
- Second, the proportion of trading relative to commitments may cause political concern. The full-trade scenario indicates that OECD countries would rely to a considerable extent on buying permits to satisfy their obligations: for example, the proportion of emission reductions met by purchasing permits could range from 32 per cent in Japan to 42 per cent in the European Union. This may fuel the feeling that OECD countries seek to transform the burden of mitigation into capital transfers to the CIS and may be thought to conflict with Article 17 of the Protocol which specifies that "trading shall be *supplemental* to domestic actions for the purpose of meeting quantified emission limitation and reduction commitments". These concerns could lead to general restrictions on how much individual countries can trade (section 3.2.1.4). lowest?
EU buys
more permits
- Third, the high proportion of the CIS Assigned Amount which is sold to other Annex I countries (43 per cent in 2010, according to the GREEN scenarios) may undermine the credibility of the Protocol if it turns out that these emissions reductions cannot be achieved or effectively verified. More generally, the measurement and other implementation problems discussed in chapter 2 may argue for some restrictions on trade.
- Fourth, the large amount of hot air may also create perception problems even if, as described in chapter 2, the banking provisions of the Protocol imply that this may have little impact on cumulative emissions over a longer time period.

46. Under the individual approach, the United States benefits from a term-of-trade improvement associated with the fall of the international oil price. As permits trading shifts the abatement effort of Annex I countries from oil to coal, the world oil price increases, leading to a deterioration of the US terms-of-trade which offsets the gain from buying permits.

- Fifth, the fact that the CIS taken as a whole would be the sole seller of allowances raises the possibility of monopolistic behaviour and associated efficiency loss in the market for permits (section 3.2.1.5).

Finally, developing countries typically refuse to consider quantitative emission limits which restrict their per capita emission rates to levels far below those of developed countries unless the developed countries are willing to show some commitment to reduce their own emissions. Taking this position as given, it may make sense to insist that Annex I countries do undertake "unnecessarily" high abatement costs in order to induce some major developing countries to accept quantitative limits (see further in chapter 4).

74. Against this background, the following three sub-sections review various possible departures from the full "where" flexibility and their impact on economic costs.

3.2.1.3 Trade segmentation

75. Trade segmentation refers to the possibility that some Annex I Parties do not participate in general permit trading even if they may trade among themselves in a separate trading area (a so-called "double bubble" scenario). Under this kind of scenario, there would be divergences between marginal abatement costs in the different segments of the permits market. Parties who would be net buyers of permits under full trading, but who do not wish to trade permits, have to abate more domestically and at a higher cost. Other net buyers would gain as the price of the permits would be lower than with full trade.

76. The "double bubble" scenario has been simulated using various models, for instance, by assuming that the European Union and Eastern European countries would not participate in permit trading⁴⁷. All results point to substantially lower efficiency gains with segmented trade than with full permit trading among Annex I countries. According to the GREEN model ("Umbrella" scenario in Figure 3), restricting permit trading to the so-called "umbrella countries" (North America, the Pacific countries and the CIS) would reduce the efficiency gains by 40 per cent (relative to the full Annex I trading scenario). The losses are concentrated in the European Union, which forgoes the benefit of buying permits from the CIS, and in Eastern Europe. On the other hand, countries of the "umbrella" group gain more than in the full trade scenario since the permit price is lower in the absence of the European Union as a large buyer on the market. Thus, by not participating in trading, Parties would tend to suffer higher costs (even relative to the no-trade situation) while conferring additional benefits on Parties which trade.

3.2.1.4 Trade restrictions

77. The condition in the Kyoto Protocol that emissions trading should be supplemental to domestic action raises the possibility that restrictions be imposed on the amount of emissions Parties can buy or sell. This again would cause marginal abatement costs among Annex I Parties to diverge. If a Party has a binding restriction on its purchase of permits, it may have to rely on further domestic reductions to meet its obligations and, as a result, its marginal abatement cost would exceed the transaction price of permits. As the demand for permits is reduced and the transaction price of permits falls (relative to the full trading scenario), this in turn benefits the unconstrained buyers of permits. The difference between the marginal abatement cost in the rationed countries and the international transaction price of permits corresponds to a

47. See Bollen *et al.*, 1998; Tulpulic *et al.*, 1998; Shackleton, 1998; Kainum *et al.*, 1998; US Administration, 1998.

rent which normally would accrue to the buying Party⁴⁸. A restriction on permit sales of an Annex I Party would have parallel effects.

78. Bollen *et al.* (1998) have simulated restrictions on permit purchases on the WorldScan model. Under the assumption that purchases of permits by Annex I Parties cannot exceed 10 per cent of their QERLCs, all OECD countries would be rationed buyers and their marginal costs would therefore differ (although to a lesser extent than with no trade). Manne and Richels (1998) have also simulated the impact of limitations on permit purchases and show that not allowing buyers to satisfy more than one third of their reduction commitment with allowances purchased from abroad could more than double the GDP loss incurred by the United States (relative to a full trade situation).

3.2.1.5 Market power

79. Concern about market power in the context of the Kyoto Protocol arises from the prospect that the CIS, taken as a unit, would be the largest, perhaps the sole, supplier of tradable permits. Perfect monopolistic behaviour under these circumstances would imply that the CIS set the transaction price of permits so as to maximise the sum of the revenues from permits sales minus its own abatement cost. The difference between the price at which the CIS sells permits and its own marginal abatement cost corresponds to the rent the CIS extracts from exerting its market power. Thus, here again, the rule of marginal abatement cost equalisation would be broken with the consequence that permit buyers would be forced to abate more than with full competitive trading (as, due to a higher permit price, they buy fewer permits) while the CIS would abate less (as it keeps more permits for its own use). As for the above cases, this market segmentation implies efficiency losses. In practice, and for the reasons discussed in Box 3, it is unclear to what extent the CIS could and would act as a monopolist. However, in the extreme case discussed in Box 3 where the CIS is able to exert full market power, the permit price in 2010 could be some 20 per cent higher than under perfect competition and OECD countries' gain from trading permits could be reduced by a fifth or more (Burniaux, 1998).

Box 3. How important is market power in the market for emission permits?

The simulation results on the effects of permit trading reported in the main text are predicted on the assumption of perfect competition in the market for permits. This assumption is not necessarily realistic. Concern about imperfect competition in permits trading arises from a result which has been confirmed by virtually all quantitative projections of the Kyoto protocol using models: permits trading under the conditions set up in Kyoto is likely to be overwhelmingly dominated by the Russian Federation and Ukraine (referred to as the CIS). Figure 5 (Parts a and b) shows the trade patterns obtained with the OECD GREEN model assuming that initial allocation of permits to each Party correspond to its QERLCs decided in Kyoto. Starting from 2000, the CIS would sell about 120 million tons of carbon to all other Annex I countries. This amount increases rapidly over time up to 450 million tons by the first budget period. An important part of these sales would be accounted for by hot air, especially during the early stage of the implementation of the Protocol (see Part b). Simulations extending the Kyoto commitments over a longer period show that the CIS would remain the major supplier of permits up to 2030, when the United States would emerge as another major permit seller. Thus, conditions exist for the CIS to behave monopolistically. This Box provides benchmark values for the impacts on trade and abatement costs under the extreme assumption that the CIS would be able to exploit fully its market power in permits trading.

(Figure 5. Permit trading by country/region under the Kyoto Protocol)

48. Alternative assumptions on how the rent accruing from trade restrictions is distributed matter for the impacts on real incomes (Manne and Richels, 1998).

A model of monopolistic competition in permits trading

The approach used here extends the specification model formulated by Hahn (1984) at the firm level to Annex I countries. It assumes that one dominant country has the ability to influence the price of permits. In the case of monopoly, this country sets the permit price at the level which corresponds to the maximisation of the difference between revenues from permits sales and its abatement costs. All other countries behave as price takers, i.e. they minimise their abatement/trading costs given the permit price set by the dominant country. There is one single transaction price for permits (thus, permits are traded as if they were homogenous goods). The country with market power is identified as the one which sells or purchases the largest share of permits in the corresponding competitive scenario (where all countries are price takers).

The first order conditions of the optimisation problem of the monopolistic country leads to the following specification for the permit transaction price (P) (see Burniaux, 1999, for further details) :

$$[1] \quad P = \frac{\left(L - \sum_{i=2}^m E_i(P) - E_1^0 \right)}{\sum_{i=2}^m E'_i(P)} - C'_1(E_1)$$

In equation [1], the price set by the monopolistic (or monopsonistic) country 1 (P) is calculated by adding a positive (or negative) mark-up to the marginal abatement cost of the country -- $C'_1(E_1)$. This mark-up, in turn, is a function of:

1. The excess demand for permits by country 1 relative to its initial permit allocation E_1^0 (as indicated by the numerator of the right-hand fraction with the emissions of country 1 being calculated as a residual between the total permits quota L and the total emissions from price-taking countries 2 m). In the case of monopoly, this excess demand is negative.
2. The inverse of the sum of first derivatives of demands for permits in the price-taking countries 2 to m (with $E'_i(P)$ being the first derivative of the demand for permits (or emissions) as a function of the permit price P in country i).

Equation [1] has the following implications:

1. If the price-setting country uses less permits than its initial allocation, then: $\left(L - \sum_{i=2}^m E_i(P) - E_1^0 \right) < 0$.

The country sells permits in excess at a price set above its marginal abatement cost (both $C'_1(E_1)$ and $E'_i(P)$ are negative). Compared with the competitive case, the monopolist sells fewer permits (but at a higher price) and, thus, abates too little.

2. If the price-setting country uses more permits than its initial permits allocation, then $\left(L - \sum_{i=2}^m E_i(P) - E_1^0 \right) > 0$. The country buys permits at a price set below its marginal abatement costs.

Relative to the competitive case, the monopsonist buys less permits (but at a lower price) and, thus, abates too much.

3. It follows from (2) and (3) that the total abatement cost is always larger than under the competitive scenario.
4. The price set by the dominant country -- and the resulting loss of efficiency relative to the competitive case -- depends on the amount of permits initially allocated to this country (E_1^0 in the numerator of the right-hand ratio). Thus, imperfect competition establishes a link between distributional aspects and overall efficiency. In other words, one initial allocation of emission rights may prove more or less costly than another. This contrasts with the competitive case where the total abatement cost is the same whatever the initial allocation of emission rights.
5. The deviation between the transaction price set by the dominant country and its marginal abatement cost depends on the price elasticity of demand for permits. Thus, the easier it becomes to substitute carbon-free energy sources for carbon-based ones -- for instance when backstop options become available -- the more difficult it becomes for the price-setting country to exert market power.

Main quantitative results

Based on simulations with the Secretariat's GREEN model, Figure 6 describes a scenario in which the CIS exerts its market power. It shows the evolution of the transaction price, i.e. the permit price set by the CIS (the bold line), compared with the permit price in the competitive scenario. In 2010, the permit price set by the CIS is 21 per cent higher than the corresponding competitive price (91 1995 \$ per ton of carbon compared with 75 1995 \$).

(Figure 6. Permit price in the Kyoto Protocol under alternative market structure)

At this higher price, the CIS would sell less permits and therefore abate less than in the competitive scenario. Thus, its marginal abatement cost -- represented by the dotted line in Figure 6 -- lies below both the marginal cost with perfect competition and the price at which permits are sold with imperfect competition. The wedge between the transaction price set by the CIS (in bold) and its marginal abatement cost (the dotted line) is the mark-up on permit sales; it reflects the market power of the CIS in permit trading. It also corresponds to the difference between marginal abatement costs in the CIS and in other Annex I countries (as other Annex I countries act as price takers and equalise their marginal costs with the permit price set by the CIS). This mark-up reaches a maximum in 2010 with a rate of 178 per cent (i.e. the permit price set by the CIS is almost three times its marginal abatement cost) and declines steadily thereafter (under the assumption the Kyoto targets remain unchanged).

Imperfect competition implies that the total emission reduction is achieved at a higher cost than in the perfectly competitive case. This results from the fact that the CIS (the low cost country) abates too little while the other Annex I countries (the high cost countries) abate too much compared with the competitive scenario. The total abatement cost in OECD countries is higher than in the competitive trade scenario, albeit much lower than in the no-trade situation (Figure 7). Price manipulation by the CIS would thus reduce the gains expected from permit trading. In 2010, competitive permit trading would cut the OECD cost by half (from 503 to 273 billions 1995 \$), but due to monopolistic price setting, this cost gain is reduced by a fifth (see the right-hand scale in Figure 7).

(Figure 7. Abatement costs of OECD countries under alternative market structure)

Simulations have been run to illustrate the impact on trade if the CIS would receive a larger allocation of permits than the one agreed upon in Kyoto, thereby increasing its potential. The gains from permit trading are obviously much larger with the second set of commitments than with the one decided in Kyoto (Figure 8). However, under this alternative allocation rule, monopolistic trade yields total cost

significantly in excess of the one obtained with the allocation rule derived from the Kyoto protocol (see the bold lines in Figure 8). For OECD countries, 24 per cent of the gains from trading are lost in 2010, compared with 18 per cent with the allocation decided in Kyoto. However, the loss could exceed 50 per cent of the gains over the longer run. This illustrates how important the initial allocation of commitments may be if some countries behave as price setters in the permit market.

(Figure 8. Abatement costs of Annex I countries under alternative permits allocation)

Summing up

The above results suggest that monopolistic trading of permits may reduce the total efficiency gains from trade by a third or more under some circumstances. Nevertheless, there is no possibility that monopolistic behaviour completely offsets the efficiency gains from trade. This analysis relies on three important -- and possibly questionable -- assumptions about the market structure for permits: first, that permits trading in the CIS is centralised rather than being pursued by individual countries and firms; second, that trade in other Annex I countries is performed by individual firms which have no market power; and, third, that the CIS does not take into account the effects of its monopolistic behaviour in the permits market on energy prices and thereby its terms of trade¹. In addition, it is assumed that firms have no market power on the goods market. It may seem unlikely that permit trading under the Kyoto protocol will fully correspond to this particular structure. The results might therefore best be seen as providing an upper bound estimate of the inefficiency which could be generated by price manipulation if the CIS were to exert monopolistic power in permits trading.

1. In the simulations, overall emission cuts are given. However, the price of permits will affect the fuel mix in individual countries and thereby the relative prices of different types of energy. This again may affect the terms of trade of the CIS which exports mainly oil and gas. This feedback effect will be assessed by introducing the model of imperfect competition in GREEN.

3.2.1.6 "Where" flexibility with the rest of the world.

80. The Clean Development Mechanism (CDM) allows Annex I countries to count emission reductions from projects implemented in non-Annex I countries as part of their obligation in the first commitment period (2008-12) as long as these reductions are "certified" (see discussion in chapter 2). In principle, CDM investments rely on the same economic incentives as emissions trading: investors will undertake projects in which the abatement cost is lower than in other locations -- including their own country. In that sense, the allocation of emissions reductions obtained with CDM is cost-effective. Quantifying the effects of CDM is difficult, however. First, CDM projects cannot be modelled in the same way as emissions trading because CDM, unlike emissions trading, is not subject to any kind of quota on host country emissions. Abatement is achieved through the replacement of existing capacity mostly or entirely paid for by the Annex I investor, while energy prices in the host country do not increase as they would with emissions trading. In consequence, the CDM is more likely to trigger carbon leakage than emissions trading (Bollen *et al.*, 1998). Second, the take-up of potential CDM projects is highly uncertain. As a result, assessments of the impact of the CDM have so far been illustrative only.

81. The potential for the CDM is sometimes assessed by first assuming that the total emissions reduction specified in the Protocol is spread over the world through a global system of permit trading. This gives an upper bound on the CDM's potential to reduce the abatement costs of Annex I countries. According to the MERGE model, with such full global trading US GDP would fall by only a quarter of what it would fall in the absence of trading (Manne and Richels, 1998). But the practical difficulties in

implementing the CDM and in certifying the emissions reduction from CDM projects make it unlikely that this potential, although very large, could be anywhere near fully exploited. Existing studies approximate these limitations by imposing arbitrary ceilings on the amount of emissions which can be acquired through CDM projects (10 per cent in Bollen *et al.*, 1998; 15 per cent in Manne and Richels, 1998; 20 per cent in US Administration, 1998). Results from Bollen *et al.* (1998) and US Administration (1998) suggest that if the CDM is additional to full emission trading among Annex I countries⁴⁹, the cost reduction obtained through the CDM with these restrictions is rather marginal. According to these scenarios, most projects undertaken under the CDM facility would take place in China.

3.2.2 "When" flexibility

82. The time frame over which the emissions reductions decided at Kyoto will be achieved is another source of uncertainty in assessing the economic costs. By setting the first commitment period some time into the future, the Protocol aimed to give Parties enough time to adopt gradual and credible paths for emission reductions. The fact that the targets are stated in terms of average emissions over a five-year period (2008-2012) confers an additional degree of flexibility, and the "banking" provision implies that over-fulfilment of the target will count against future emission targets. Against these measures in favour of credibility and commitment counts the fact that many aspects of the Protocol are not yet fixed, which together with the delay in ratifying the Protocol may encourage Parties to wait before making any serious adjustments. Details on the implementation of the flexibility mechanisms will now not be finally known until COP6 at the end of 2000. The Protocol itself will come into force only after a significant majority of signatories have ratified it⁵⁰ and the ratification process might be somewhat prolonged for some countries⁵¹. The earliest possible entry into force is thus 2001; even then some procedural hurdles will remain, such as setting up the necessary accounting and verification institutions.

83. The "when" flexibility in the Protocol implies some degree of freedom to pick a cost-effective time-path towards the Kyoto targets. First, abatement costs may fall over time as new sources of energy with lower or no carbon content become available at low cost. This argument calls for delaying abatement to the later years covered by the Protocol. On the other hand, delaying action increases the magnitude of the effort required to bring emissions down to the levels specified in the Protocol. Moreover, spreading the reductions over a longer time period would reduce costs by reducing the extent of "premature" retirement of existing capacity (though delayed, but credible and predictable adjustment may also reduce this problem). As well, to the extent technological development is endogenous, early abatement may reduce the cost of subsequent efforts. Finally, a gradual phasing in of the reductions may reinforce the credibility of future abatements.

84. Only some of these aspects are reflected in the GREEN model⁵². Nevertheless, for illustrative purposes the model has been used to simulate three alternative time-paths for different regions individually

49. For instance, according to the SGM model, full Annex I trading together with the CDM would cut the cost to the United States by 66 per cent. In comparison, trading among Annex I countries alone would reduce the US cost by 57 per cent.

50. Entry into force requires ratification by at least 55 countries, including Annex I countries whose emissions total at least 55 per cent of total Annex I CO₂ emissions in 1990.

51. The current US position is that ratification is contingent on there being no serious restrictions on emission trading, and on participation by some major developing countries. Judging by the discussion at COP4, the latter condition seems unlikely to be met in the near future.

52. The GREEN model takes into account that new back-stop technologies may emerge starting from 2010 and also embodies rigidities in capital turnover (through its putty-clay production functions). By contrast, the

to meet the Kyoto targets: i) a scenario in which emissions reductions are linearly spread over the period from 2000 to 2010; ii) a scenario in which the Kyoto targets are achieved by early action spread over the period 2000 to 2005; and, iii) a scenario in which late action during the period 2005 to 2010 brings emissions down to their commitment levels (Figure 9). For all regions, spreading the effort over a longer period of time is the least costly option. Reductions phased-in over shorter periods of time clearly generate additional costs associated with accelerated replacement of existing capacity. When considering on the time horizon of the Protocol, early and rapid action appears to be the most costly option. This reflects that not all the costs of late and rapid action appear within the Kyoto horizon. Looking instead at costs up to 2050, delayed action spread over a five year period unambiguously appears as the most costly option. Some countries, such as the United States, need very high carbon taxes to meet their commitments in time, suggesting that this later scenario may prove unfeasible in practice, given the available technological options⁵³. Thus, these results suggest that, within the context of the Protocol, gradually phasing in the reductions from an early date will minimise aggregate costs over time. A factor which crucially affects these results is the level of intertemporal preference⁵⁴. Even more important are the limitations of the model in terms of ignoring forward-looking expectations and endogenous determination of technological change. Against that background, the results should be seen as illustrative only.

(Figure 9. Alternative timepaths of implementing the Kyoto Protocol without trade)

3.2.3 "How" flexibility

85. The "how" flexibility refers to the freedom of Parties to choose among alternative instruments in order to meet their commitments. However, the Protocol specifies that Parties, while achieving their quantified emission limitation, should implement and/or further elaborate policies to progressively reduce or phase out market imperfections that run counter to the objective of the Protocol (Article 2, v). In particular, this involves the removal of subsidies to energy consumption. Some of the transition economies among Annex I Parties have traditionally applied very high subsidies for fossil fuel consumption. Despite recent reforms, these subsidies remain important in some cases. For instance, a recent study by the World Bank (1997) points to subsidy rates around 30 per cent in 1995 in the CIS and Eastern European countries.

86. Removing energy subsidies is a "no regret" measure in the sense that it brings economic benefits beyond the environmental achievement of reduced GHGs emissions (though it has distributional consequences including associated adjustment costs). Price distortions generate efficiency losses as producer and consumer decisions are made on the basis of prices which do not represent the economic opportunity cost of resources. It follows that the cost of implementing the Kyoto Protocol would be reduced by eliminating the remaining energy subsidies in the CIS and Eastern European countries. However, the gains would not be restricted to countries in which subsidies are removed. First, removing energy subsidies in the CIS, by reducing energy consumption, would increase the amount of permits that the CIS could sell to other Annex I countries if emission rights were tradable. Second, accelerated subsidy reforms in transition economies would reduce international energy prices and hence improve Annex I countries' terms of trade and thereby partly offset their cost of meeting the Kyoto targets.

87. Simulations with the GREEN model confirm that the removal of fossil-fuel subsidies lowers the aggregate economic costs for Annex I countries as a group (Figures 10 to 12). The resulting efficiency

model does not include forward-looking behaviour and the fact that the model solves in five year steps reduces the choice of potential time-paths that can be considered.

53. In particular, this reflects the assumption that no backstop energy sources are available by 2010.

54. These assessments have been made using a 3 per cent discount rate.

gain is, however, much less substantial than the one which would arise from making emission rights fully tradable. Both with and without permit trading, subsidy reform in the CIS and Eastern Europe may lower the aggregate cost of Annex I countries by about 15 per cent (from 27 to 23 billion 1995 \$ in the former case and from 107 to 91 billion 1995 \$ in the latter case).

(Figure 10. Impact of removing energy subsidies on the costs of the Kyoto Protocol)

(Figure 11. Distribution of real income gains from energy subsidy removal)
in the context of the Kyoto Protocol with no permits trading)

(Figure 12. Distribution of real income gains from energy subsidy removal)
in the context of the Kyoto Protocol with permits trading)

88. The distribution of the gains from energy market reforms in the CIS and Eastern Europe differs strongly with and without tradable permits. With no permit trading, the CIS is the largest gainer (accounting for 58 per cent of the gains) but there are still substantial positive spillover effects to the OECD countries accruing, not least, as a result of lower energy prices (Japan, the European Union and the United States together receive 44 per cent of the gains: see Figure 11). With permit trading, and assuming that this trade has a competitive structure, the efficiency gains from removing subsidies in the CIS are entirely "exported" to the other Annex I Parties as the CIS sells more permits (484 million tons of carbon instead of 440 million tons with no subsidy removal). These permits do not, however, provide any benefit to the CIS. As the aggregate demand for permits remains unchanged, additional supply lowers the permit price so that the revenues the CIS gets from permits sales is slightly lower than in the scenario with no subsidy removal.

89. Thus, these results suggest that the removal of remaining energy subsidies in transition economies may lower further the costs of emissions reductions. ~~The efficiency gains would not only benefit the countries which undertake the reforms. On the contrary, they would be spread over all OECD countries, in particular the United States and the European Union. Indeed, on some assumptions, the benefit to the countries undertaking reform may be so low as to raise questions about the incentives to do so.~~ } 87

3.2.4 "What" flexibility

90. "What" flexibility relates to the choice of which emissions to cut and whether to make use of "sinks". As discussed in chapter 2, the Protocol covers six different types of GHGs, and Parties are free to substitute reductions in emissions of one gas equivalent to increases in emissions in another. Some gases have a much larger warming potential⁵⁵ than others, and there may be large differences of marginal abatement costs across gases -- implying significant potential efficiency gains from equalising these marginal costs by substituting among gases. In addition, the Protocol includes net changes of emissions resulting from human-induced changes of forestry activities. Here again, Parties may choose reforestation options if they prove less costly than reducing emissions from industrial activities.

91. The evidence provided in the literature about the cost saving potential of these two options is fragmentary so far. As far as the Secretariat is aware, there are currently no models that deal with the other GHGs in a comprehensive way⁵⁶. Gielen (1998) estimates that other gases currently account for 21 per cent of total CO₂ equivalent emitted in Europe and this share is projected to decline up to 2010. According to the same source, the autonomous decline of these gases over time might reduce by 25 per cent the

55. For instance, the warming potential of SF₆ is 24 000 times higher than CO₂.

56. The MIT EPPA model contains all GHGs but no documentation on how non-CO₂ gases are taken into account in this model was available at the time of writing this document. } ?

corresponding cut of CO₂ emissions needed to meet the European Union target in 2010. Gielen also suggests that further abatement of non-CO₂ gases can be achieved at relatively low cost (25 ECU per ton of CO₂ equivalent). To the extent these results prove robust and generalise to other Parties, the costs of meeting the Kyoto targets could be significantly lower than suggested in this paper. However, measurement uncertainties for non-CO₂ gases will have to be reduced considerably; while they remain high, some limits on trading, particularly on sales by countries where non-CO₂ gases are a significant part of total emissions, may be thought necessary.

92. The sequestration potential and the economic effects of carbon sinks have not yet been systematically evaluated. Carbon emissions from land-use changes currently amount to 1.6 gigatonnes of carbon per year, compared to 6 gigatonnes of carbon from the burning of fossil fuel. Slowing the rate of loss and degradation of existing forests could reduce CO₂ emissions substantially but most of this potential concerns the tropics rather than Annex I countries. On the other hand, there is insufficient time for afforestation/reforestation to significantly change the amount of carbon sequestered above-ground before the first commitment period. Indeed, as Nilsson and Schopfhauser (1995) showed, the impact of mass plantation would be significant only after 40 to 50 years. In summary, the sequestration potential of enhancing carbon sinks is likely to be negligible within the current time limits of the Kyoto Protocol, but this potential may become more important if the Protocol is extended in time and country coverage.

4. Beyond the first commitment period: extending Kyoto in time and space

4.1 Long-term aspects of the Kyoto Protocol

93. The previous chapter focused on various aspects of the Kyoto Protocol up to the first commitment period of 2008 to 2012. Very few studies provide any quantified assessment of the Protocol beyond this period. Such assessment is very speculative at this stage as it has to be based on assumptions concerning the longer-term targets on which the current version of the Protocol contains no guidance. Despite this uncertainty, it is important that the Protocol be analysed in the context of the longer-term goal of the Framework Convention which is to stabilise the concentrations of GHGs in the earth's atmosphere. This section outlines the implications of an extension into the future of the Kyoto Protocol: i.e. the targets decided in Kyoto for Annex I countries are maintained unchanged over the longer term while no effort to mitigate emissions is undertaken in non-Annex I countries. The outcome of this scenario is that, in the longer term, the costs of maintaining the commitments decided in Kyoto are likely to grow while the potential for emissions trading to reduce these costs would diminish. At the same time, and based on a tentative analysis of the links between CO₂ emissions and atmospheric concentrations, it seems that stabilisation of Annex I emissions at the levels decided in Kyoto is far from sufficient to stabilise concentrations. This forms the background for the subsequent sections on issues involved in achieving a global agreement with the purpose of stabilising concentration levels. The analysis in both this and subsequent sections is couched exclusively in terms of CO₂ given the limited information on other GHGs.

4.1.1 Long-term costs of the Kyoto targets

94. Figure 13 reports the real income losses relative to the BaU scenario in 2050 under the assumption that Annex I countries individually keep their emissions from exceeding the targets set at Kyoto. The aggregate loss for the whole Annex I area reaches 1½ per cent annually (compared with ½ per cent in 2010). Although economic costs increase in all countries, Eastern Europe and the CIS are most affected. The shape of the BaU scenario including the existence of new sources of energy contribute to increase the costs. By 2050, shale oil with a high carbon content is projected to become cheaper than crude oil in the BaU scenario. Applied in this context, a carbon tax -- or, equally, a system of tradable permits --

would tax shale oil (which has a higher carbon content) more than crude oil. The shift in demand towards oil and the corresponding rise in the international oil price lead to a deterioration in Annex I countries' terms of trade. Energy exporters would gain, in contrast with their situation in 2010.

(Figure 13. Long-term costs of the Kyoto Protocol)

95. In contrast to the first commitment period, emission trading among Annex I Parties would not significantly reduce aggregate costs in 2050. There are two explanations for this, both related to the assumption that, by this time, alternative energy sources (referred to as "backstop technologies") would be available at some uniform price in all countries. First, by harmonising the marginal abatement costs among countries, backstop energy sources reduce the scope for efficiency gains from trading emissions. Second, benefits from trade disappear as increasing returns in abatement occur in high-cost countries (in which backstop energies are competitive) while low-cost countries still use traditional energy sources characterised by decreasing returns of abatement (see Annex 1).

4.1.2 *Impact on GHG concentration*

96. The UN Framework Convention on Climate Change (UNFCCC) calls for "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". The Convention however does not specify the concentration values which would correspond to this threshold. Nor has the scientific community determined such a level. Nevertheless, the threshold of 550 ppmv of CO₂ has often been considered as a target for stabilisation by the end of the 21st century. This level corresponds roughly to twice the CO₂ concentration in pre-industrial times⁵⁷. Projections reported in the Second Assessment Report of the IPCC have shown that stabilising CO₂ concentration at 550 ppmv by the end of the next century would require global emissions ultimately to fall to well below their current levels (IPCC, 1996).

97. In the light of the recent trends in CO₂ emissions, the question arises of whether the targets agreed upon in Kyoto are still in line with a stabilisation path to keep concentration below 550 ppmv or, alternatively, whether effectively this target is already out of reach. A recent study by the IPCC (Wigley, 1997) has shown that limitations of the magnitude decided in Kyoto⁵⁸ "would [not] lead to anything approaching CO₂ concentration stabilisation" with unconstrained growth of emissions in non-Annex I countries. The study concludes that "substantial global emissions reductions beyond those defined by the various emissions limitation proposals would be required". While this is not in dispute, several emission trajectories may lead to this outcome. On an optimistic note, Wigley (1997) argues that non-Annex I countries can wait several decades before their emissions need to depart significantly from their BaU trajectories, even in the context of stabilisation at 550 ppmv. Such optimism crucially relies on the assumption that world emissions can ultimately be reduced to a very low level (see Annex 2). In addition, these studies are based on a central BaU scenario (IS92a) which looks optimistic in the light of recent high emissions growth.

98. Linking past emissions to future concentrations is subject to a number of important uncertainties. First, the carbon cycle may be described by different models which imply different profiles of carbon decay in the atmosphere. There is little information on how the choice of model affects the results. Second, the predictive value of these models may fall for concentrations departing significantly from those observed in the past for the reasons described in chapter 2.

57. Corresponding to the end of the eighteenth century.

58. This study was made prior to the signing of the Kyoto Protocol. It analyses the implications of the proposals submitted by the Annex I countries to the COP3 meeting.

99. These uncertainties need to be borne in mind when interpreting the Secretariat's attempt to translate CO₂ emissions, as projected by the GREEN model, into future concentration levels (see Annex 3.2)⁵⁹. The results of this exercise roughly confirm the previous analysis made by the IPCC prior to the Kyoto meeting. As concerns action by Annex I countries alone, they can be summarised as follows:

- The CO₂ limits on Annex I countries set by the Kyoto Protocol, if extended beyond the first commitment period, will do little to stabilise CO₂ concentration (at least over the time horizon 1997-2200). At most, the targets decided in Kyoto might delay by about a decade the point in time when the 550 ppmv level would be reached.
- Any further effort by Annex I countries alone to reduce their emissions below the levels decided in Kyoto will have little impact on concentration, given their already rapidly declining share in global emissions.

4.1.3 *The costs of "missing" Kyoto*

100. These results could be interpreted as putting the merit of the Kyoto Protocol in doubt. Indeed, a priori, there is no guarantee that the Kyoto Protocol will be the first step of a cost-effective path towards a stable concentration level. In choosing the least-cost pathway, one has to balance the costs of early and more gradual action against the costs of later, more rapid, forced action (as was described in section 2.2.2 for the case of reaching the Kyoto targets). Reasons for delaying action involve: i) to give more time for the economic turnover of existing capacities; ii) to give more time to develop low-cost alternative carbon-free energy sources; and, iii) the effect of time discounting. Based on "integrated assessment" models, some authors have argued that the least costly way to achieve concentration stabilisation would be to let emissions continue unconstrained for a couple of decades, followed by drastic cuts later on (Wigley, Richels and Edmonds, 1996). In that sense, the reductions specified in the Kyoto Protocol would not be consistent with a cost-effective strategy to stabilise concentration (Manne and Richels, 1998).

101. However, delayed action involves the risk that, as scientific information becomes available, more rapid reductions will become necessary, causing a premature retirement of future capacity. By explicitly taking account of both uncertainty and inertia in changing the productive system which generates GHGs, Ha-Duong, Grubb and Hourcade (1997) reach the conclusion that a strategy of early and modest abatements may prove less costly if there is a high risk of exceeding the stabilisation target or "if the BaU scenario is significantly higher over the coming years than the IS92a scenario used by the IPCC", as the projections from the GREEN model would suggest.

102. Both approaches mentioned above fail to take into account a number of additional factors. First, they neglect the role of early abatement in stimulating the process of learning-by-doing which, in turn, would lower subsequent abatement costs. Second, they do not take into account the equity aspects of the international negotiation process, which make non-Annex I countries reluctant to undertake emission reductions before Annex I countries have taken some action (see below). These arguments reinforce the view that early but moderate reductions, as those specified in the Protocol, are the best way towards an adequate response to the threat of climate change, given the uncertainty and the inertia which characterise both the energy system and the negotiation process.

59. The model used is derived from Wigley and is linear in that the carbon remaining in the atmosphere is expressed as a linear function (i.e. a fraction) of the initial emission.

4.2 *Establishing a global agreement*

103. Analysis of emission and corresponding concentration timepaths in Annex 2 establishes that to stabilise CO₂ concentrations, or even to delay significantly the date by which they reach double the pre-industrial level, will require the Kyoto Protocol to be extended after the first budget period to involve non-Annex I countries in a substantial mitigation effort. This section deals with the requirements for obtaining participation by non-Annex I countries and the implied economic costs.

104. The Kyoto Protocol was agreed on a *voluntary* basis. The countries which made commitments may be seen as having weighed the gains of being a free rider against the risk that no agreement would be struck. In this sense, the rationality which underlies the process of climate negotiation may be seen as at least partly related to economic incentives. Against this background, a growing game-theoretic literature analyses the formation of coalitions for environmental objectives such as to combat climate change. Box 4 reviews the main outcomes from this approach. In summary, these studies agree that a fully voluntary agreement would comprise at most a small number of signatories and, therefore, be insufficient to stabilise the climate. A main reason for this pessimistic conclusion is the strong incentive for countries to free-ride. The literature also suggests that if carbon leakages are significant, it may be even more difficult to reach wide agreement because incentives to free-ride become stronger. Conversely, the existence of local, ancillary benefits may strengthen the incentives of countries to participate in an agreement. Studies have also identified a number of possibilities to expand this small "self-enforcing" coalition, including by means of transfers to hesitant countries.

Box 4. Establishing a global agreement -- the theory

Game theory identifies the conditions for a coalition of countries taking policy action with a global environmental objective to exist and be stable: first, each participant in the coalition should gain compared with the initial situation where nobody co-operates; second, nobody should have an incentive to leave or to join the coalition. With these two conditions satisfied, the coalition is said to be "self-enforcing".

The problem of forming a self-enforcing coalition can be illustrated by comparing the net benefits of participant and non-participant countries under the assumption that all countries are symmetric (i.e. they have identical marginal abatement costs, damages and environmental preferences). Countries outside the coalition enjoy the global environmental benefit from the action undertaken by the co-operating countries without supporting any abatement costs. As a result, countries have an incentive to free-ride. This is illustrated in Figure 14a where the payoff of non-participants (i.e. their net welfare gain) always exceeds that of coalition countries whatever the size of the coalition. Payoffs increase monotonically with the size of the coalition, as the environmental gains rise with the number of participants. The figure also illustrates that there may be an equilibrium at which no country has an incentive to join the coalition (because its payoff outside the coalition is higher than the payoff it would have as a participant in an enlarged coalition) and no country has an incentive to leave the coalition (because its payoff in the coalition is higher than the payoff it would have outside a smaller coalition¹). This equilibrium determines the size of the self-enforcing coalition. It has been demonstrated that this size is typically small (Hoel, 1991; Barrett, 1992, 1994, 1997 and Carraro and Siniscalco, 1992). Botteon and Carraro (1998) have shown that this conclusion may hold when some types of asymmetries across countries are accounted for.

(Figure 14.)

In the context of climate change, an important factor in determining the size of a self-enforcing coalition is the magnitude of carbon leakages. High carbon leakages reduce the global environmental benefit so that coalition countries would pay the abatement costs without receiving the corresponding

benefits, thus reducing the incentive to form a coalition (with high leakage the coalition payoff may no longer be monotonically increasing as illustrated in Figure 14b). At the same time, non-participating countries get a higher payoff associated with the economic benefits of carbon leakages (lower energy prices, improved competitiveness of energy-intensive industries). Under these conditions, the size of the self-enforcing coalition is reduced or there may even be no incentive at all to form any coalition (see, for instance, Carraro and Moriconi, 1998). Here again, this conclusion may remain valid when countries are not identical² (Botteon and Carraro, 1998).

Action to reduce greenhouse gas emissions may have important local, ancillary benefits. These benefits will not accrue to free-riders and the diminished incentives for free-riding will tend to increase the size of the self-enforcing coalition. Whether in practice the effects from leakage or the effects from local ancillary benefits will dominate is unclear.

The size of an environmental coalition can be expanded in a number of ways. First, a system of transfers may be designed so that no country refuses to join a coalition. However, for such an outcome to be achieved, a group of "core" countries need to be committed to co-operation (Carraro and Siniscalco, 1993; Hoel, 1994; Carraro, 1998a). In that sense, the resulting agreement is no longer self-enforcing. Another way to expand a coalition is by "issue linkage": it has been suggested, for instance, to link environmental negotiations to negotiations on trade liberalisation (Barrett, 1995) or on R&D co-operation (Carraro and Siniscalco, 1995; Katsoulacos, 1997). But Carraro (1998a) shows that, by generating an incentive to exclude some countries from the agreement, issue linkage may not necessarily be successful in achieving the environmental objective. At the same time, such a strategy may imply risks of inferior outcomes in the linkage area.

Finally, the size and stability of the coalition may be influenced by the rules of the negotiation process and the behaviour of participants. For instance, the equilibrium coalition would be larger if countries correctly conjecture the consequences of their decision to leave or to join the coalition (Carraro and Moriconi, 1998). If more than a single agreement is allowed, the equilibrium outcome is characterised by several coalitions which implies that more countries undertake abatements although the total abatement is not necessarily higher (Carraro, 1998a and 1998b). Different membership rules leads to coalitions with different sizes. For instance, the equilibrium coalition would be larger if membership is subject to an unanimity rule -- i.e. that no entry or exit is allowed without unanimous consent of coalition members (Carraro and Moriconi, 1998). Here again, achieving the grand coalition (i.e. a coalition grouping all countries) would require some form of commitment.

To the extent that the Kyoto Protocol corresponds to the small self-enforcing coalition predicted by theoretical models, it has the implication that extending the Protocol could require additional provisions, covering, for instance, financial transfers and some form of commitment. The current process implies a complete re-negotiation of the agreement at the end of each budget period, including new membership and targets for emissions reductions, which, according to the game theoretic models, may imply insufficient commitment to expand the current coalition.

1. And assuming that its decision to leave the coalition does not influence the remaining participants in the coalition.
2. Botteon and Carraro (1998) also show that, with asymmetric countries, leakages reduce the size of the coalition when the initial coalition is small but increase the size of the coalition when the coalition is initially large.

105. It may be questioned whether simple theoretical models focusing on economic incentives have much predictive value as regards the current process of climate change negotiation⁶⁰. The models are generally not good at taking into account the asymmetric nature of climate change negotiations. A few studies have attempted to validate the results of the theoretical models in the case of heterogeneous participants (for instance, Botteon and Carraro, 1998). Although they seem to confirm the results from the simple model with identical countries, these approaches so far lack generality and hardly lead to any policy recommendation. Asymmetries are related not least to the fact that the impacts of climate change are likely to be very different across countries (see chapter 5). At the same time, countries' preference for and valuation of climate change, and actions against it, may differ. Thus, it is often argued that environmental protection may be considered a superior good. Following from this line of reasoning, the countries which made commitments under the Protocol might be thought to have a high preference for a clean environment but, on the other hand, to suffer relatively little from the consequences of climate change (in some cases, perhaps even to benefit). In contrast, developing countries would be more affected by climate change but might be relatively less concerned about this. The current stage of the negotiation process would, according to this view, reflect the low level of expected damages in industrialised countries, together with the low preference for climate stability in the developing world. As environmental concerns in the developing world increase together with real income levels, the current agreement would then gradually expand. However, this process might be slow and could, accordingly, result in an eventual very high level of concentrations. These considerations obviously take into account neither uncertainty nor the profile of risk, with some low-probability but disastrous outcomes.

106. More fundamentally, there is a question as to how far economic rationality is useful in describing coalition formation and the future of the negotiation process. Insofar as anthropogenic emissions of greenhouse gases have contributed to increased atmospheric concentration levels in the past, responsibility lies largely with the Annex I countries, whose emissions represented two-thirds of the total as late as in 1995. Against this background, and emphasising basic principles of fairness, most developing countries have been reluctant to accept restrictions on their own emissions, which are generally far below those in OECD countries measured on a per capita basis, at the same time as OECD countries are far richer than developing countries. Indeed, practically any scheme for reducing global emissions induces changes in the international distribution of income. In the context of tradable emission rights this effect is immediately apparent -- recipients of large quantities of emission allowances appear to be receiving transfers from those with little or no allocation. It is useful to consider this allocation problem from two different perspectives on property rights.

107. A first perspective is provided by considering the property rights that are implicit in the UNFCCC. The convention notes, *inter alia*, that climate change is a common concern of mankind, that efforts to deal with it should be based on a principle of equity, and that the parties to the convention are determined to protect the climate for both current and future generations. One might conclude from this that since the climate is a common concern, it is a common good, and that equity implies that each individual has an equal stake in it. From there it is a small step to argue that a neutral allocation is to give each individual an equal right to greenhouse gas emission permits -- equal rights to damage the climate.

108. Another perspective would be to consider the consequences of regime changes. Up to now, there has been no legal notion of greenhouse gas emissions as a bad⁶¹ and economic agents have not been

60. It may be argued that there are some signatories of the Kyoto Protocol -- Canada and the Russian Federation are possible examples -- which, according to the rationality of the game theory model, should never have joined an agreement to reduce emissions because they could stand to gain from a warming of the climate.

61. Not as such; ancillary damage due to local or other pollution effects has of course been recognised in various ways.

expected to act as if they were. Any legal change which discriminates on the grounds of past emissions may be inequitable in the sense of being a retrospective penalty. From here it is a small step to argue that equity requires grandfathering.

109. There is no obvious way to choose between these two interpretations. In practical terms, what is needed is a way of allocating emission allowances which encourages both current and future heavy emitters to participate. One way to do this might be to have a transition through time from allocations based on grandfathering to equal per capita allocations⁶². Consensus on such an allocation scheme might induce non-Annex I countries to adopt voluntary tradable emissions limits for the first commitment period, without weakening the overall constraint on emissions imposed by the Kyoto Protocol -- no hot air would be generated. It would avoid penalising Annex I countries so heavily that they would be likely to reject the whole process. It may not, on the other hand, give non-Annex I countries sufficient incentive to participate.

110. This review does not offer any clear indications how to bring non-Annex I countries to agree to emission constraints in the near future beyond certain generalities: reliance on perceived self-interest will be insufficient; some notion of equity will need to be satisfied; some financial transfers will probably be necessary to bridge the gaps between different ideas of what of equity implies. The next section considers some of these issues and attempts to quantify their importance.

4.3 *Economic costs of stabilising CO₂ concentration*

111. This section presents some illustrative quantifications of the costs to Annex I countries of global agreements to achieve stabilisation of concentration levels, including the role of financial compensation to induce non-Annex I countries to participate.

112. A variety of emissions pathways may lead to stable concentration levels by the end of the 22nd century. Here, however, the focus is on a shorter horizon -- from the first commitment period (2008-12) to 2050. Accordingly, the scenarios analysed below may be characterised better in terms of different degrees of risk aversion rather than stabilisation per se. The large uncertainties involved in "translating" emission paths to concentration levels also points to an emphasis on risk aversion rather than targeting of concentration levels. The analysis considers three global emission scenarios which imply different degrees of emission reductions but have in common that participation by non-Annex I countries is required to achieve the limitations:

- A first scenario is based on the premise of low risk aversion: emission reductions are phased in so as to let concentration rise towards 550 ppmv of CO₂ in 2080 (the "low cost 550 ppmv" scenario in Figure 15) and then broadly stabilise at that level.
- Alternatively, a scenario corresponding to high risk aversion would imply more drastic emissions reductions in order to keep concentration well below 550 ppmv over the next century (the "high cost 550 ppmv" scenario in Figure 15).
- In the third scenario, concentration rises to 740 ppmv with stabilisation achieved only by the middle of the 22nd century (the "740 ppmv" scenario in Figure 14).

(Figure 15. Alternative CO₂ concentration pathways)

62. This notion of convergence through time in per capita emissions was discussed at COP4, see IEA/SLT(98)49.

4.3.1 *Burden sharing*

113. There is also a wide variety of ways to share the burden of these reductions between Annex I and non-Annex I countries. One possible development of an equity rule is that non-Annex I countries join the coalition to reduce emissions, i.e. become subject to constraints, when their emissions per capita reach the same level as those in Annex I countries (see Annex 2)⁶³. In this case, the size of the coalition gradually increases over time; moreover, by fixing their own targets, Annex I countries determine the pace at which the coalition expands. This allocation scheme for emissions (referred to as the "egalitarian" scenario) is simulated for each of the three global emission scenarios "low cost 550 ppmv" (Figure 16b), "high cost 550 ppmv" (Figure 16c) and "740 ppmv" (Figure 16d). The non-Annex I commitments in these three scenarios are endogenously determined by the emission reductions in Annex I countries which again are set so as to reach the three global emission scenarios. All three scenarios thus imply an increase in the share of non-Annex I countries in total emissions.

(Figure 16. Burden-sharing in alternative emission scenarios)

114. The opposite extreme case is that allocation of future emission rights represents some kind of "grandfathering" of current emissions⁶⁴. For this position to lead to a global coalition would require non-Annex I countries to accept that their emissions per capita remain much below those in Annex I countries. This case is represented by a scenario in which the "low cost 550 ppm" stabilisation path is combined with constant emission shares starting from 2030 (see Figure 16e).

115. The scenarios involve two types of financial flows between countries. First, each of the scenarios described above is simulated under the assumption of either no or full permit trading among all countries⁶⁵. In the latter case, financial flows arise as counterparts of emissions trading. Second, transfers are used to induce participation by those non-Annex I countries which would otherwise have an incentive to free-ride. Each scenario is simulated with the additional assumption that non-Annex I countries which lose from participating in the common action, even taking account of the proceeds from permit sales, would be compensated by financial transfers from Annex I countries⁶⁶.

4.3.2 *Economic costs*

116. Figure 17 compares the average annual discounted⁶⁷ costs at the world level over the period from 2010 to 2050 of the various scenarios, including that discussed in section 4.1 of extending the Kyoto targets forever. All alternatives are much more costly than the extended Kyoto Protocol, which is not

63. This rationale may partly explain why the Russian Federation and Ukraine signed the Kyoto Protocol. According to GREEN data, the emissions per capita ratio in the CIS region in 1995 was equal to 2.6 tons of carbon against 2.7 in the EU and 2.4 in the other OECD region.

64. This view is illustrated by the US position which subordinates the ratification of the Protocol to some commitment from non-Annex I countries.

65. In the egalitarian cases, countries that do not reach Annex I emission levels per capital, and therefore are not subject to an emission constraint, are allowed to sell emission permits based on their BaU emissions. This aims at approximating the full potential of the CDM.

66. This roughly approximates the costs of a stable grand coalition. However, it may be a lower bound estimate as it does not take into account the existence of possible carbon leakages, which would imply a need for larger inducements to avoid free-riding. Local, ancillary benefits, however, may point in the opposite direction, i.e. to this being an upper-bound cost estimate.

67. Assuming a discount rate of 3 per cent per year.

surprising given that the extended Kyoto Protocol comes nowhere near to stabilising concentrations. The least cost stabilisation option is to aim for a concentration level of 740 ppmv, and allow full permit trading among all countries: this would cost about a third of one per cent of world real income annually. The "high cost 550 ppmv" is much more costly with an average loss of almost 1 per cent of annual real income.

(Figure 17. Average costs of alternative scenarios to stabilise CO₂ concentration: world)

117. In all scenarios, permit trading reduces the costs substantially. However, the gains from permit trade are larger with egalitarian than with grandfathering burden sharing. The explanation is that, with the egalitarian rule, non-Annex I countries receive more emission rights and the potential for exploiting their low-cost abatement options through permit trade is therefore higher than with the grandfathering rule. Conversely, if permits are not or only partly tradable, the grandfathering burden-sharing rule is substantially less costly to the world as a whole than the egalitarian one (which commits high cost Annex I countries to undertake a larger share of abatements). Thus, the current negotiation process -- to the extent that it implies that developing countries are unwilling to make any abatement unless industrialised countries have achieved substantial reductions i.e. leading towards an egalitarian burden sharing -- is unlikely to yield a cost-effective outcome, unless accompanied by provisions allowing trade of substantial amounts of emissions and thereby allowing low-cost emission cuts in non-Annex I countries.

118. Figure 18 shows the results for Annex I countries. In most cases, stabilising concentrations is relatively costly when Annex I countries are not allowed to trade (i.e. buy) emission rights. The lowest estimate is for the "grandfathering" stabilisation at 550 ppmv (around 1 per cent of real income per year). In contrast, real income losses in the scenario describing the high cost pathway to stabilise at 550 ppmv amount to some 1.5 per cent per year. In this case, emissions trading does little to reduce costs: first, because marginal abatement costs at such high levels of reductions tend to converge across countries to the price levels set by available backstop energy sources, thus reducing the potential efficiency gains from trading permits; second, due to the shape of the cost curves when backstop energy sources are available⁶⁸.

(Figure 18. Average costs of alternative scenarios to stabilise CO₂ concentration: Annex I)

119. Figure 18 also reports the average costs to Annex I countries if they engage in transfer payments to compensate non-Annex I countries for any real income loss incurred from their participation in emissions reductions⁶⁹. In the scenario where concentrations are kept significantly below the 550 ppmv threshold during the next century (i.e. the "high cost 550 ppmv" scenario), Annex I countries would suffer an average loss of 1¼ per cent of real income annually. Losses incurred in the less stringent scenarios with compensating transfers amount to around 0.7 per cent of real income per year⁷⁰.

68. It may happen that the marginal cost gain obtained by buying permits is offset by the term-of-trade deterioration induced by buying large amounts of permits. See Annex 2.

69. Account being taken of the proceeds from permits sales.

70. These are lower bound estimates as they do not incorporate potential carbon leakages. The assumption made here is that non-Annex I countries receive funds corresponding to their loss relative to the BaU real income level. However, this may not entirely offset the incentive for free-riding since non-participating countries may gain by staying outside a coalition due to spillover effects through trade and energy prices. In principle, the compensation payment to guarantee the stability of the grand coalition should be calculated as the difference between the real income level if the country stays outside the coalition (which may be higher than the BaU real income) and the corresponding real income if the country participate to the grand coalition. According to GREEN, however, carbon leakages are not very important, especially when the acting coalition involves all countries except one. However, local ancillary benefits may reduce the need for financial transfers to induce participation.

120. For non-Annex I countries, the real income effects range from losses of 2 per cent in the "high cost 550 ppmv" scenario to gains in scenarios involving financial compensations (Figure 19)⁷¹. In general, non-Annex I countries would benefit from trading permits to a larger extent than Annex I countries (in particular, in the most stringent "high cost 550 ppmv" scenario). For non-Annex I countries too, the egalitarian burden-sharing paradoxically appears relatively more costly than grandfathering in the absence of tradable permits. For both sets of countries, the variation in economic outcomes as a result of differences in burden sharing is less than the variation due to different degrees of ambition -- or risk aversion -- concerning concentration profiles. In particular, the high risk-aversion scenario appears very costly, raising the question whether the benefits exceed the costs. The next chapter takes up the issue of costs of living with climate change.

(Figure 19. Average costs of alternative scenarios to stabilise CO₂ concentration: non Annex I)

71. These gains arise because the countries whose emissions are capped by either the egalitarian or the grandfathering rules receive compensation for any losses they incur, whereas the countries that are not capped can improve real income by selling permits based on their baseline emissions (the CDM mechanism).

5. Adapting to Climate Change

121. According to consensus forecasts, some climate change is inevitable and is likely to continue over a long period, possibly several centuries. Although climate forecasting models are very complex, they give only relatively crude indications of how climates may change in specific regions. At the moment it is technically impossible therefore to run simulations to match a particular assumed path of greenhouse gas emissions with the consequent change in climate through time, even for broad regions of the globe, let alone individual OECD countries.

122. It is virtually impossible for countries to assess how their climate is going to change and already plan accordingly, even if somehow a convincing global agreement on the future path of emissions had been reached. There is consensus, however -- as reflected in a recent IPCC report -- on the likely nature of climate change and the consequent environmental impacts in different regions of the world, over the next 50 to 100 years (i.e. the short to medium term), under a particular set of assumptions about the effects of emissions. This chapter summarises that consensus. For a small number of countries national reports provide more detailed estimates. It then considers which economic sectors appear most sensitive to climate change impacts. The possible costs and benefits of these changes, and adaptation to them, are then discussed, along with the influence of uncertainty on how these issues are viewed.

5.1 *Anticipated climate change*

123. The following paragraphs are derived from the 1997 special IPCC report on the regional impacts of climate change (IPCC, 1998). That publication distinguishes 10 regions, of which five do not contain any OECD country⁷² and to which less attention is given here⁷³. The regional reports do not all use precisely the same assumptions about global warming or sea-level rise, though they are broadly standardised on a doubling of the CO₂ concentration by the second half of next century, with a projected global temperature increase of 2.5°C (range 1.5-4°) and sea-level rise of 0.5 metres (0.2-1).

5.1.1 *North America*

124. North America covers a wide range of climatic types, and variability of the weather is already a factor. Climatic change in the twentieth century has seen average temperatures peak in the 1940s before decreasing up to the 1970s, increasing again subsequently, being now around the level of the 1940s. Average precipitation gradually increased during the century, but there have been falls in some areas -- mainly California and the Northern Rocky Mountain states. There has also been an overall trend towards an increasing proportion of precipitation from extreme events, though not in Canada. Although the sea level has been rising in general, it has been falling in some areas (for the most part owing to post-glacial rebound).

125. The IPCC reports that forecasts for average temperatures vary quite considerably, while there is more consensus on precipitation. A doubling of CO₂ concentration will increase winter temperatures by more than summer ones, but the range of forecasts is quite wide (1.4-4.8°C for the winter and 0-2.6°C for the summer). A further increase in the proportion of precipitation that comes from extreme events is expected, though there is disagreement on whether this would imply more storms, or more intense ones.

72. Africa; Middle East and Arid Asia; Tropical Asia; Small Island States; The Arctic and Antarctic.

73. For Mexico, Japan and Korea, little specific information can be deduced from the regional reports since they are geographically small parts of the relevant regions (Latin America and Temperate Asia).

The existing regional variation in sea-level rise is expected to continue, with the level rising fastest in the Gulf of Mexico and the mid- and southern-Atlantic coast.

126. Models can give only broad indications as to the potential, let alone the likely, response to forecast trends. The suitable area for forests will generally increase, but there is a big difference between the suitable area and actual forest cover because of human intervention. Forest types would generally need to migrate northwards. This may not happen easily because of gaps in forest cover and also because the movement of suitable zones is likely to be faster than many species could actually migrate naturally; on the other hand, human intervention could allow faster migration. Tundra and peatland will migrate northwards too, with the affected regions perhaps changing from being a net sink to a net source of carbon. Ice jam patterns will change, generally so as to reduce frequency or intensity, but with possible increases in some areas.

127. Overall, agricultural productivity in North America would benefit from this projected climate change: more CO₂ and warming with more rain gives higher output, and there would be some gain even with moderately less rain; there may be some offsetting costs from possible increased variability, and from more frequent or more intense extreme events, however. Some areas, including Mexico, where water shortages already constrain agricultural output and where precipitation may fall, may see lower productivity, even before accounting for extreme events.

128. A 0.5 metre rise in sea level is estimated to threaten⁷⁴ between 8 500 and 19 000 km² of dry land in the United States and Canada, of which between a fifth and a quarter is developed land. The same rise would result in a net loss of between 17 and 43 per cent of coastal wetlands. River systems may be significantly affected: the possibility of lower summer precipitation, and the probability of higher evapo-transpiration, will make river transport more difficult to manage, and there may be more frequent or more severe floods.

5.1.2 *Temperate Asia*

129. This region includes China, which dominates it; little specific information on Japan and Korea is presented. The average temperature in the region has risen 1°C over a century, though not uniformly; this is due largely to higher winter temperatures, with only very slight increases in the other seasons. The increase has been faster since the 1970s. As for average precipitation, it has risen in Korea, but fallen in Japan (over a century, +10 to +20 per cent and -10 to -20 per cent respectively).

130. The regional mean temperature is expected to increase by between 1° and 3.5°C by 2100, but confidence in the sub-regional forecasts is very low. An important source of uncertainty is the influence of aerosols (deriving largely from sulphur-related emissions); some simulations imply summer cooling in parts of China. The importance of the monsoon, of typhoons and of the El Niño/La Niña phenomenon adds much uncertainty to precipitation forecasts; although a fall is generally expected, rises may also occur.

131. In Russia the tundra zone would decrease significantly with related expansion of grass and shrublands, as well as northern migration of forests in both Russia and China. The impact on agricultural productivity is uncertain, yields may fall without adaptation, especially if water shortages materialise as they may in China, but these may be more than offset by the carbon fertilisation effect.

74. In the sense that this amount of land is less than 0.5 metres above current high tide levels.

132. Sea level rises may have important consequences in Japan. The IPCC report notes that three major economic centres of Japan -- Tokyo, Osaka and Nagoya -- have large low-lying coastal areas. Two million people currently live below mean high-water level. If the sea level rose one metre (the upper end of the range usually quoted for the second half of the 21st century) this number would rise to 4.1 million; the same rise would increase the flood-prone area to 8 900 km² from 6 270 currently⁷⁵. According to the report, a 30cm rise in sea level would eliminate more than half of Japan's sandy beaches, and a 1 metre rise would eliminate nearly all of them; over the past 70 years, about one third, measured by area, have disappeared. Significant parts of the Chinese coastline are also threatened.

133. On extreme events, while they may increase in the future (the report notes no strong evidence for such an increase in temperate Asia) deaths from typhoons, for example, have been decreasing since the second world war, as a result of both mitigation and warning measures.

5.1.3 Australasia

134. This region covers Australia, New Zealand, and their outlying islands. It may be noted that in the current climate the variability of Australia's rainfall (especially in the north) is among the greatest in the world. The frequency and duration of drought (with flooding at other extreme) is great. To the extent that there is a tendency for other OECD countries' climates to move in this direction, Australia may be in a position to provide useful lessons on mitigation and adaptation to other countries.

135. Australasia has been warming a bit faster than the world average, and the highest rates of increase have been recorded since 1950. The diurnal range has been falling, as elsewhere. Rainfall seems to have increased in general, both on average and in the frequency of heavy rainfall events. In Australia, the largest increases have been on the east coast, with some decreases in the south-west and some inland areas. Heavy rainfall events are strongly related to El Niño fluctuations. The sea level has risen by around 2mm per year over the last 50 years.

136. For 2030, temperature increases of between 0.3 and 1.4°C are forecast for Australia and New Zealand, twice that for 2070. Precipitation for Australia seems uncertain, it may rise or fall, with the balance of probability thought to be for a fall. For New Zealand increases in the frequency of the prevailing westerly wind may increase precipitation in the west and reduce it in the east⁷⁶.

137. More frequent high-rainfall events will cause flooding but are unlikely to improve the general water situation in Australia. In New Zealand, higher temperatures and higher atmospheric CO₂ concentration will generally increase yields. In forested areas there may be higher growth rates, while vulnerability to fire will certainly increase, so the net effect on forest cover is uncertain.

138. The most acute problems with sea level rise are on outlying islands, though there are many urban and beach areas, and at least one national park area, that would be threatened. Increased flooding may result more from high-rainfall events. There is a wide range of estimates for changes in runoff rates, and higher variability is expected. Both Australia and New Zealand are expected to suffer losses of snow cover.

75. The report also notes that assets located in the respective areas are worth \$450 billion and \$908 billion, but the basis of this valuation is not clear. More meaningful might be the estimated \$80 billion necessary to modify relevant flood protection schemes to protect the expanded area.

76. It is interesting to note that the previous set of IPCC forecasts for New Zealand foresaw the opposite -- a reduction in the frequency of westerly winds and thus a reduced imbalance between precipitation in the east and the west. The change is due to the availability of more detailed models of ocean circulation.

5.1.4 *Europe*

139. Europe (whose eastern boundary is given by the Ural mountains and the Caspian Sea) has much intra-regional climate variation. It also has a rather varied experience of climate change over the past century: There has been some warming almost everywhere, though a few places have cooled a little (Greece and some parts of eastern Europe); a belt extending from Spain through central Europe to Russia has warmed a lot. Precipitation has generally risen in the north and fallen in the south.

140. Forecasts are not thought to be very reliable. An overall increase in winter temperatures is expected, by between 1.5° and 4°C according to the area and the model used. Summer temperatures may increase by up to 4.5°C, with a wider range of uncertainty than for the winter. The effect of aerosols is particularly important (and uncertain) in central Europe -- it might offset half the temperature increase due to CO₂. Precipitation overall also is expected to increase, particularly winter precipitation in the north. For the summer, some models show an increase, some a decrease⁷⁷.

141. Agricultural productivity would probably be positively affected overall, though not necessarily everywhere; the interaction of changes in temperature and changes in average rainfall and its timing will be crucial. Growth rates in forests would probably increase (some predicted increases in growth rates already seem to be occurring), though the zones suitable for different types of trees may shift faster than the forest types can migrate, and some areas will become more vulnerable to fire. Peat producing areas will produce less peat and bogs may turn into fens. Many wetlands may change from being carbon sinks to sources. A number of areas of coast and coastal wetland are vulnerable.

142. Many glaciers will completely disappear and reductions in winter snowcover will affect many areas. The main impact of changes in precipitation is likely to be reduced summer runoff and increased winter runoff, even with higher annual precipitation -- most of any increase in precipitation will come in the winter and evapo-transpiration⁷⁸ will increase. This will lead to increased problems with flooding, particularly since most floodplains are already "overpopulated"; coastal flooding due to storm surges will also increase with a higher sea level and a probable increase in frequency of storms.

5.2 *Sectoral impacts*

143. The degree of imprecision with respect to forecasts of even basic climate parameters is such that very little can be said with certainty about impacts on particular sectors, with the exception of impacts associated with rising sea levels. This section nevertheless considers what kinds of impacts one might expect, and where uncertainties may lie.

144. In all these areas there is a striking gap between the generally somewhat speculative, often qualitative rather than quantitative, predictions available and the kind of information needed to assign shadow prices (which may vary according to the different situations and preferences of different countries) to these impacts in order to refine the cost-benefit analysis of climate change and mitigation policies.

77. Climate change in Europe would be much more dramatic and could be sudden if the north Atlantic thermohaline ocean circulation (which brings the Gulf Stream to the coasts of north-western Europe) were to cease or diminish substantially. The probability of this is thought to be very low for the degree of climate change thought likely over the next century or so.

78. Evaporation of water directly from the ground and via plant activity.

5.2.1 *Agriculture*

145. In most OECD countries (Australia may be an exception) warmer weather is likely to mean higher crop yields unless water availability is a constraint. The latter depends very much on the geographical and seasonal pattern of precipitation, as well as on temperature itself (which affects the rate of evapo-transpiration), forecasts for which are very uncertain. The rate of photosynthesis increases quite substantially in many crops (and trees) as the atmospheric CO₂ concentration increases. Drier and hotter conditions in some areas may nevertheless result in losses of agricultural land, but the northern retreat of tundra and permafrost zones in Canada, northern Europe and Russia will presumably extend the northern margin of cultivated land. For the United States and Canada, and possibly for most of Europe, Japan, Korea and New Zealand, agricultural yields seem on average (with much local variation, no doubt) more likely than not to increase in response to climate change. Any increase in the frequency of extreme events (storms, floods, heatwaves, droughts) might work against this.

5.2.2 *Fisheries*

146. The most important impact on coastal fisheries is the potential loss of coastal wetlands, which are nurseries and nutrient suppliers, from sea-level rise. To a large extent, the amount of such wetlands that are lost will depend on choices about how to manage rising sea levels since for the most part they would naturally migrate inland as water levels rise. While species may migrate as water temperatures rise, there is no expectation of adverse effects on other fisheries. As the IPCC report notes, over-fishing and human intervention will probably have more influence on fisheries than climate change.

5.2.3 *Transport*

147. Only water transport seems likely to be directly affected by climate change. Changes in precipitation and its variability would affect river and canal transport; IPCC projections for north America and Europe suggest higher rainfall in spring and lower rainfall for the rest of the year, a pattern that would reduce the capacity of inland waterways. Sea-level rise will of course over a long period flood many existing port facilities. Ports currently suffering from closure or disruption by seasonal ice will generally benefit, however.

5.2.4 *Water*

148. Where higher temperatures are accompanied by lower precipitation, pressure on water supply, both quantity and quality, may increase. For most OECD countries this will be a purely domestic problem, though water rights can be a cross-border issue, as between Turkey and Syria, for example, and the countries bordering on the Rhine in Europe. In some areas, tension between domestic, industrial and agricultural (see above) uses for water may increase. As for agriculture, changes in the geographical distribution of precipitation could have important effects, but little is known about such changes.

5.2.5 *Energy*

149. One can confidently predict relatively less demand for energy for space heating and rather more for refrigeration and air conditioning. Compared with trends generated by changes in tastes, wealth and technology, these shifts will be insignificant. Changes in precipitation patterns may affect hydroelectric generation, most likely to reduce potential if there is indeed a trend towards increased spring precipitation

but less at other times of the year; a temporary, but possibly prolonged, benefit may arise from increased flows due to glaciers melting.

5.2.6 *Insurance*

150. The insurance industry exists because of uncertainty. If global warming does increase weather variability, particularly the incidence of storms and floods, the insurance industry may face increased demand⁷⁹. As patterns change, however, the industry will have to pay particular attention to methods of calculating risks -- historical averages on their own may be misleading.

5.2.7 *Tourism*

151. Tourism is most likely to be affected by the reduced amount of snow for winter sports. Significant rises in sea level will reduce available beaches, depending on the extent to which they can, or are allowed to, migrate landwards. Again it seems unlikely that these changes could be fast enough to be noticeable compared with shifts likely to come on the demand side.

5.2.8 *Population movements*

152. Since some coastal and estuarial locations would become submerged sea-level rise would necessitate some movement of population. Over the next 100 years the maximum expected rise of 1 metre would not result in much such pressure within OECD countries themselves, however. Potentially more important might be pressure for immigration from non-OECD countries suffering relatively more from climate change. There is little information from which to predict such pressures however; Africa contains a number of regions where populations may be most vulnerable to climate change but while IPCC projections imply warming throughout Africa there is no indication whether rainfall will increase or decrease. Also, IPCC notes that current agricultural yields are only about half of potential, implying that a fall in the latter is not necessarily associated with a fall in actual yields. As concerns population movements in response to sea level rises, Bangladesh may be thought particularly vulnerable.

5.2.9 *Health*

153. The only likely systematic health impact from warming may be an increase in the geographical spread of vector borne diseases as climates become more hospitable to mosquitoes and other disease-carrying insects. While one might expect warming to result in fewer winter-related deaths and more due to things like heat-stress, this is not clear since they are provoked more by variations in temperature than by average levels. It is also argued that there would be a larger increase in heat-related deaths than fall in winter deaths since the former are more closely related to temperature than the latter (Kupnick, 1998).

154. To judge by apparent preferences for vacations and, at least in North America, retirement, most people in temperate OECD countries prefer warmer weather. Unless this is more a relative than absolute

79. IPCC (1998) reports that the cost of insured catastrophes in Australia is at least 12 per cent of the costs of non-life premiums, compared with 2.5 per cent in the rest of the world -- the result of relatively high frequency of climatic and other natural hazards. This is despite the unavailability of private flood insurance for dwellings and small business. Some of this difference could of course be due to attitudes to risk and the structure of the insurance industry, rather than due to different or higher risks

preference, it may be supposed that warming in itself will improve well-being for many people, perhaps offsetting some of the higher health risks.

5.2.10 Biodiversity

155. The influence of global warming itself (as opposed to that of economic growth, industrialisation of agriculture, etc.) on biodiversity is not obvious (though it may be noted that biodiversity itself affects the ability of ecosystems to adapt to climate change). Where habitats are destroyed (as may be the case for some coral reefs and some forested areas) there will be losses but it is hard to say to what extent these may be offset by species migration and adaptation.

5.3 National "Impact assessments"

156. To provide more detailed indications of likely weather patterns in particular regions or countries a higher degree of geographical resolution is needed than is feasible using the global climate models on which the previous paragraphs are based. One way of doing this is to use more detailed models restricted to one region, constraining them to reproduce the results of a global model around the boundary of the region in question. Using this approach, more detailed, but still preliminary, impact assessments have recently been produced for France and the United Kingdom⁸⁰. It is noticeable that few other countries have produced such assessments -- at least to the knowledge of the Secretariat.

157. The UK report -- based on a "business as usual" scenario for emissions -- suggests a general northward movement of temperature patterns, with the south of the country experiencing, by around 2050, temperatures similar to those of the present day south of France. But while more rain is expected overall, the already (relatively!) dry south east could have much less summer rain; combined with higher temperatures and stronger winds this could dramatically change the landscape, increasing susceptibility to soil erosion and also damaging the foundations of many existing buildings. The UK report also draws attention to likely inundation of land along coasts and, perhaps more importantly, losses of low-lying high-grade agricultural land due to increased salinity. Not only agricultural land would be affected -- most of the United Kingdom's petroleum refineries and nuclear power stations are vulnerable to rising sea levels. Many ecological systems would be threatened partly because of the speed of the projected changes and also because species migration is hampered. Greater damage from storms and other extreme events is also foreseen. At this stage, the report does not attempt to assess the overall economic costs of these projected developments.

158. The French report, whose climate simulation does not cover overseas departments and territories, also predicts some regional variation in impacts due largely to precipitation, while temperature zones move more or less systematically northwards (although differences between average temperatures in the south and the north may increase slightly). Agricultural output may increase overall, though crop patterns would have to adjust while being subjected to increased frequencies of storms and droughts. Temperature changes imply that forest types should migrate northwards, but some would be inhibited by lack of water; the Mediterranean zone would see an increased sensitivity to fire risk. Drier soils in summer, autumn and winter (higher soil moisture in spring is expected) will increase vulnerability to soil erosion as well as tending to deplete underground aquifers. Although tourism would be affected, particularly by a reduced Alpine skiing zone, the report does not suggest that the tourist industry would necessarily be damaged, though the relative attraction of different areas would no doubt change.

80. Mission interministérielle de l'effet de serre, 1998, and Department of the Environment, Transport and the Regions, 1998, respectively.

159. Both reports note that health is likely to be affected by climate change, though it is difficult to assess whether the overall impact would be beneficial or not. Illnesses associated with colder weather would obviously diminish, while other risks would increase. Higher temperatures will certainly favour increased vector-borne and infectious diseases in all countries, and illnesses associated with atmospheric pollution would also almost certainly increase (the production of ozone, which favours such illnesses, increases with higher temperatures).

5.4 *Adaptation, Costs and Catastrophe*

160. Climate change will certainly impose economic costs on some sectors, even though it may benefit others. Faced with prospective costs, it may be worth spending some resources either on trying to reduce emissions so as to stabilise the climate, or on adapting to the changed climate to reduce its impact. Chapters 3 and 4 have discussed the former, this section discusses adaptation.

5.4.1 *Adaptation*

161. The benefits of reducing emissions are public goods, with a strong presumption in favour not only of government intervention but of internationally co-ordinated government intervention. On the other hand, market forces may be better able to handle adaptation in many cases. There are grounds for public intervention, however, where externalities exist, and policy may need to facilitate market-led adaptation by ensuring that public policy does not unnecessarily distort price signals. Even where "market type" decisions are feasible in principle, in practice the necessary time horizon may be so long that public intervention may be necessary to some degree. In any case, to ensure that markets do react, public policy needs to provide a stable framework in which private long-term decisions will not be subject to excessive risk.

162. Agriculture and water supply (including for agriculture) are areas where some existing policies in some countries may well inhibit optimal adaptation. Adaptation in agriculture will include changing crop patterns as well as possibly ceasing to cultivate some land. The benefits of agricultural support policies that are tied to particular crops or which prevent land use changes will have to be weighed against the possible higher costs they impose on adaptation to climate change. Water supply charges will need to be allowed to evolve in a way that reflects changing overall or seasonal supply patterns. Adaptation in the energy market, tourism, insurance and many other sectors can probably safely be left to market mechanisms, though public policy may have some parallel adaptation to do, for example ensuring that prudential provision of the insurance sector is evolving appropriately. Moreover, it will be important to avoid public policies that attempt to support activities that are ultimately not sustainable but which may enjoy political leverage.

163. One area where public intervention is already prevalent is coastal management in the face of sea level rise. Sea levels have been rising in many areas for some time, and some coasts suffer erosion even without such rises. Much experience has therefore accumulated in this area.

164. Three different types of strategy for coastal management in the face of sea level rise can be distinguished: accommodation, planned retreat, and protection⁸¹. The first consists of making no attempt either to protect existing installations or to influence the rate of erosion, installations and facilities are adapted while possible and abandoned as they become unusable. The third consists of fully protecting existing installations through sea walls, flood barriers and so on, while the second, planned retreat, allows

81. See, for example, IPCC (1997) pp 173-174 and pp 302-303.

natural processes to continue, withdrawing or abandoning some installations in advance, protecting others where cost calculations suggest it is worthwhile, and possibly preventing development of some areas likely to be vulnerable or needed for adaptation in the future.

165. While planned retreat sounds the natural choice, its use in practice has been rare⁸². It requires a lot of information, including projections of sea level rise but also information on local interdependencies -- for example between coastal wetlands which may diminish if dry land is protected, and fisheries which often depend on wetlands, as well as information on economic variables such as expected asset lives and necessary lead times for investment. Conflicts of interest are likely, and the legislative framework may need to be adapted⁸³.

166. Coastal management also provides a precedent in terms of legislation to encourage forward planning. Most maritime countries have legislation that requires states or districts to draw up programmes to address rising sea levels⁸⁴.

167. While projected temperature changes alone may not merit such comprehensive public sector involvement as in coastal management, the example may be useful in the case of water resources, both where supplies may diminish substantially and where increased frequency of extreme events may have implications for floods, landslides etc. Urban planning, construction standards and transport policy may all play a role in reducing future vulnerability to these changes. Where there is no obvious role for public sector action, it may be worthwhile verifying that public policy does not inadvertently restrict the ability of individual agents to adapt.

168. An important aspect of adaptation is the speed at which climate change may occur. Warming of 2 to 3 degrees and sea-level rise of around 0.5 metres by the second half of the 21st century should not produce dramatic short-term adjustment problems for economic infrastructure. For example, the IPCC reports lead times of 10 years for planning and construction of major facilities in Australia, e.g. dams and flood protection facilities; this seems a relatively short time, relative to the expected rate of change of the climate. Further, "The time frame for response to sea-level rise is, in principle, sufficient to allow for the development of suitable coastal policies..."⁸⁵. These conclusions may be cause for optimism, but while they suggest that mitigation and adaptation strategies are feasible, they do not in themselves imply that the costs will be low.

5.4.2 Costs

169. Since future emission paths are unknown, and since, even if they were known, the detailed consequences for climate and climate variability are unknown, calculating the costs of climate change is a very hypothetical exercise. In many areas, for example coastal management and water resources, fisheries, the pressure on resources of climate change may in any case be very small relative to existing and future pressures from population growth and economic development.

82. IPCC (1997) mentions experiments in eastern England where sea walls have been deliberately breached, turning previously protected farmland into coastal wetlands; this is intended to relieve pressure on the sea defences, to provide flood alleviation benefits and to help restore natural balance in estuaries. See IPCC (1997) p 174.

83. Some measures by US states to restrict the rights of owners of coastal land to prevent the inland migration of beaches and wetlands have had to be modified after court challenges. See IPCC (1997) p 303.

84. E.g. The US Coastal Zone Management Act, the New Zealand Resource Management Act.

85. IPCC (1996) p 133.

170. A certain number of attempts to make such calculations for countries or regions as a whole have been made, however, based on particular assumptions about emissions or climate change. The complexity of this task has ruled out model-based approaches up to now; rather, groups of experts collaborate on committee-type assessments⁸⁶ or secondary sources are used for costs in different sectors of the economy⁸⁷. These exercises, which by their nature are of uncertain reliability, suggest that for most OECD countries the identified costs of climate change, up to the end of the 21st century, will be moderate. Thus, one estimate is that the costs of a doubling of CO₂ concentration for most OECD regions would be between 1.5 and 2 per cent of GNP, rather higher for Australasia, and that they could be between 5 and 10 per cent of GNP in Asia and Africa⁸⁸. Other studies have results of a similar order of magnitude. Even the latter figures, when compared with possible productivity increases, do not seem enormous⁸⁹. It is interesting that these estimates seem to be of the same broad order of magnitude as the estimated costs of stabilising concentration levels by the end of the 22nd century provided that the path towards stabilisation is not overly ambitious (see chapter 4).

171. These estimates provide useful benchmarks, and mark an essential starting point in the search for quantification of the effects of climate change. But they are open to question. The figures are generally based on heroic assumptions about the unit cost of particular aspects of change, the various figures then being summed. Lacking more complete models of the links between climate and the economy (in both directions) it may not be possible to do much better.

172. One possible alternative is the so-called "Ricardo" approach, which looks at agriculture using cross-section data on farm performance across climate zones, attempting to correct for various influences such as the level of the capital stock and soil type, to isolate the influence of climate on agricultural productivity. Such studies for India, Brazil and the United States confirm suggestions that, if no account is taken of carbon fertilisation, the impact on developing country agriculture would generally be more severe than on that in OECD countries, and that adaptation can reduce estimates of damage by one third or one half; they also suggest that when the carbon fertilisation⁹⁰ effect is taken into account, the impact on developing country agriculture may be close to zero in aggregate (for particular areas, the impact may of course be severe)⁹¹. Another interesting result is that the sensitivity of farm results to climate change does not depend on capital intensity.

173. It may be possible to adapt this methodology to other economic sectors, or to the economy as a whole, although agriculture may be unique in the wealth of the necessary highly geographically-disaggregated data available. No such studies have been attempted so far.

86. E.g. Mosley, M.P., ed., *Climate Change in New Zealand*, 1990, quoted in IPCC, 1998.

87. Fankhauser (1995) (and Fankhauser and Tol (1997) and Fankhauser, Tol and Pearce (1998)) takes into account the costs of coastal defences, loss of dry land and of wetlands, loss of ecosystems, the effect on agriculture and forestry, the energy and water sectors, the cost of mortality changes and those of air pollution, migration and hurricane damage. In principle, the estimates assume that optimal adaptation responses are forthcoming. Some indication of the importance of this assumption can be found in studies of the impact on agriculture which show that "welfare losses" are frequently reduced by half, relative to a no-behaviour-change baseline, when adaptation is assumed (Reilly *et al.* (1993)).

88. Fankhauser, Tol and Pearce, 1998, quoting earlier work by the same authors.

89. The IPCC regional reports do not systematically give similar estimates of costs, although some quote the figures in Fankhauser and Tol (1997). The one country-specific study reported is of Finland, which may benefit by about 1 per cent of GDP (Kuoppomaeki (1996), quoted in IPCC(1997)).

90. See glossary.

91. See Mendelsohn *et al* (1994), Dinar *et al* (1998). A study covering a number of European and Mediterranean countries is currently under way.

5.4.3 Uncertainty

174. A potentially more serious objection to both of these approaches is that they ignore the impact of uncertainty on the assessment of costs. In particular, the probability distribution of impacts is almost certainly highly skewed: there are a number of unlikely but potentially catastrophic scenarios even in the medium term. Two that might concern most OECD countries are a collapse of part of the Antarctic ice shelf which could raise sea levels by several metres relatively quickly (compared with the usually assumed scenario of a rise of up to one metre over the next century), and severe disruption of the thermohaline circulation⁹² in the north Atlantic and north Pacific, which could lead to a large and rapid cooling of climates on the north-east coasts of these oceans.

175. Although there is no easy approach to potential events whose probabilities are unknown and where even the consequences are hard to define, some account needs to be taken of them⁹³. Even though the true probabilities are unknown, certain influences on them are known, so strategies that tend to reduce them can be undertaken. The Framework Convention on Climate Change is itself an example of action taken partly on these grounds, at least by a number of Parties for whom the apparently most likely consequences of climate change may be negative but not very serious⁹⁴.

176. Influenced by the UNFCCC and by rising public awareness and concern, countries are moving towards more co-ordinated research into climate change impacts. For example, the United Kingdom established a Climate Impacts Programme in, France set up the Mission Interministérielle de l'Effet de Serre. These programmes should in the future provide more complete pictures on which to base analysis.

92. See glossary.

93. One way of looking at the long term impacts of climate change policies is the so-called Tolerable Windows Approach. This is based on an inverse modelling concept where one decides on what represents an unacceptable future risk, as a function of future greenhouse gas concentration levels and then works backwards to look at feasible paths for emissions paths. The costs of policies to establish such paths can then be assessed against the degree of risk that is thereby avoided. This does not avoid the problems caused by our considerable ignorance about future climate change, but has the advantage of focusing attention on reducing risk (or indicators of risk) and the costs of so doing. See Toth *et al.* (1998), one conclusion which is that while different short-term emission paths may not make much difference to the costs of eventual climate change, they can have an important impact if the rate of change of climate matters.

94. There are many other reasons, including altruism vis-à-vis countries who expect to suffer more.

GLOSSARY AND ABBREVIATIONS

Assigned Amount

Permitted emissions for the period 2008-12 in tonnes of carbon equivalent.

Carbon fertilisation

The rate at which photosynthesis proceeds, and hence the rate of plant growth, in most plants is, in laboratory conditions, an increasing function of the amount of CO₂ in the air, at least up to a certain point and provided growth is not constrained by lack of nutrients or too high temperatures. The extent to which this would be true in practice is uncertain, especially for mature trees.

Commitment Period

Period for which actual emissions are compared with the Assigned Amount to assess compliance with emission limits. The first is 2008-12, the expectation is that the next would be 2013-17.

Evapo-transpiration

Water vapour gets into the atmosphere from the ground either through direct evaporation or through being taken up by plants and subsequently being emitted through their leaves; the combination of these processes is evapo-transpiration.

Thermohaline ocean circulation

Flows between the equatorial and polar regions, driven largely by relative salinity, carrying heat towards the polar regions. The most important is in the North Atlantic, of warm (near surface) water flowing north and cold (deep) water south. Without this flow the "Gulf Stream" would not have its moderating effect on the climate of western Europe.

COP

Conference of the Parties (to the UNFCCC).

IPCC

Intergovernmental Panel on Climate Change. Established in 1988 as a joint body of the United Nations Environmental Programme and the World Meteorological Office.

MOP

Meeting of the Parties (to the Kyoto Protocol); = COP with non-ratifiers of the Protocol as observers. MOP does not effectively occur until the Kyoto Protocol has been ratified.

QELRC

Quantitative Emission Limitation or Reduction Commitment: permitted emissions for 2008-12 expressed as a percentage of the 1990 level.

UNFCCC

United Nations Framework Convention on Climate Change. Established in 1992 in Rio de Janeiro.

Models

The paper refers to a number of models used in assessing aspects of climate change and policies:

AIM (Asian-Pacific Integrated Model): integrated assessment model including a recursive general equilibrium model of the world economy, a warming forecasting model and a warming impact model. This model has been developed by the National Institute for Environmental Studies and the Faculty of Engineering of the Kyoto University.

EMF 16: the Energy Modeling Forum (EMF) was established in 1976 at Stanford University to provide a structural framework within which energy experts, analysts, and policy makers could meet to improve their understanding of critical energy problems. The forthcoming sixteenth EMF study (EMF-16) will focus on "Integrated Assessment of Climate Change : Post-Kyoto analysis".

G-Cubed: a multi-region, multi-sector intertemporal general equilibrium model initially developed by W. McKibbin and P.J. Wilcoxon (McKibbin and Wilcoxon, 1995) and currently used by the US Environmental Protection Agency (EPA) (McKibbin, Shackleton and Wilcoxon, 1998).

GEM-E3: a general equilibrium model for the EU-14 (Capros *et al.*, 1997).

GTEM (Global Trade and Environment Model): dynamic general equilibrium model of the world economy developed by the Australian Bureau of Agricultural and Resource Economics (ABARE: see the web site www.abare.gov.au).

MERGE (a Model for Evaluating the Regional and Global Effects of greenhouse gas reduction policies): an intertemporal market equilibrium combining a bottom-up representation of the energy supply together with a top-down perspective on the remainder of the economy, developed by A. Manne (Stanford University) and R.G. Richels (EPRI). See www.stanford.edu/group/MERGE or Manne, Mendelsohn and Richels, 1995.

POLES: a world energy system model used by the European Commission (Criqui *et al.*, 1996).

PRIMES: a partial equilibrium model of the European energy system (Capros *et al.*, 1996).

WorldScan: a multi-sector, multi-region, recursively dynamic applied general equilibrium (AGE) model of the world economy, used in a project funded by the Dutch Ministry of Environment (VROM), the Netherlands Bureau of Economic Policy Analysis (CPB), and the National Institute of Public Health and the Environment (RIVM). For a model description, see Geurts *et al.* (1997).

BIBLIOGRAPHY

- Barret S. (1992), "Conventions on Climate Change: Economic Aspects of Negotiations", OECD, Paris .
- Barret S. (1994), "Self-enforcing International Environmental Agreements", Oxford Economic Papers , No: 46 , pp. 878-94.
- Barret S. (1995), "Trade restrictions in International Environmental Agreements", London Business School.
- Barret S. (1997), "Heterogeneous International Environmental Agreements", in C. Carraro (ed.), *International Environmental Agreements: Strategic Policy Issues*, E. Elgar, Cheltenham.
- Bollen J., A. Gielen, H. Timmer (1998), "Compliance with the Kyoto Protocol", in Economic Modelling of Climate Change, OECD Workshop Report, 17-18 September.
- Botteon M., Carraro C. (1998), "Environmental coalitions with heterogeneous countries: burden-sharing and carbon leakages", *Nota di Lavoro* 24.98, March.
- Burniaux J.M. (1998), "How important is market power in achieving Kyoto: an assessment based on the GREEN model", in Economic Modelling of Climate Change, OECD Workshop Report, 17-18 September.
- Burniaux J.M., J. Oliveira-Martins (1999), "Carbon Emission Leakages: An analytical General Equilibrium view", forthcoming draft.
- Capros P. (1998), "Economic and energy system implications of European CO₂ mitigation strategy: synthesis of results from model based analysis", in Economic Modelling of Climate Change, OECD Workshop Report, 17-18 September.
- Carraro C., D. Siniscalco (1992), "Transfers and commitments in international environmental negotiations", forthcoming in KG. Mäler (ed.), *International Environmental Problems: an Economic Perspective*, Kluwer Academic Publishers: Dordrecht.
- Carraro C., D. Siniscalco (1993), "Strategies for the International Protection of the Environment", *Journal of Public Economics*, No. 52, pp. 309-28.
- Carraro C., D. Siniscalco (1995), "Policy coordination for sustainability: commitments, transfers and linked negotiations", in I. Goldin and A. Winters (eds.), *The Economics of Sustainable Development*, Cambridge University Press, Cambridge.
- Carraro C., Moriconi F. (1998), "Endogenous formation of environmental coalitions", draft, January.
- Carraro C. (1998a), "The Structure of International Environmental Agreements", *Nota di Lavoro* 12.98, January.

- Carraro C. (1998b), "Beyond Kyoto: A game theoretic perspective", in Economic Modelling of Climate Change, OECD Workshop Report, 17-18 September.
- Department of the Environment, Transport and the Regions (1998), "Climate Change Impacts in the UK", London.
- Dinar, A., R. Mendelsohn, R. Evenson, J. Parikh, A. Sanghi, K. Kumasr, J. McKinsey, S. Lonergan (1998), "Measuring the Impact of Climate Change on Indian Agriculture", *World Bank Technical Paper* No. 402.
- Enting I.G., T.M.L. Wigley, M. Heimann (1994), "Future emissions and concentrations of carbon dioxide: key ocean/atmosphere/land analysis", CSIRO division of atmospheric research technical paper, CSIRO, Australia.
- Fankhauser S. (1995), *Valuing Climate Change. The Economics of the Greenhouse*, London, Earthscan
- Fankhauser, S. and R. Tol. (1997), "The social costs of climate change: the IPCC Second Assessment Report and beyond", *Mitigation and Adaptation Strategies for Global Change*, Vol. 1, No. 4, pp. 385-403.
- Fankhauser, S., R. Tol and D. Pearce (1998), "Extensions and alternatives to climate change impact valuation: on the critique of IPCC Working Group III's impact estimates", *Environment and Development Economics*, Vol. 3, pp. 59-81.
- Gielen A., C. Koopmans (1998), "The economic consequences of Kyoto", *CPB report*, Vol. 98, No. 1, pp. 30-33.
- Gielen D., Kram T. (1998), "The role of non-CO₂ Greenhouse Gas in meeting Kyoto Targets", in Economic Modelling of Climate Change, OECD Workshop Report, 17-18 September.
- Grubb, M., A. Michaelova, B. Swift, T. Tietenberg, Z. Zhang and F.T. Joshua (1998), *Greenhouse Gas Emissions Trading: defining the principles, modalities, rules and guidelines for verification, reporting and accountability*, UNCTAD.
- Ha-Duong M., M.J. Grubb, J.C. Hourcade (1997), "Influence of socioeconomic inertia and uncertainty on optimal CO₂ emission abatement", *Nature*, Vol. 390, pp. 270-73.
- Hoel M. (1991), "Global environmental problems: the effects of unilateral actions taken by one country", *Journal of Environmental Economics and Management*, Vol. 20, No. 1, pp. 55-70.
- IEA (1998), "Standing Group on Long-Term Co-Operation, COP4 Outcome", IEA/SLT(98)49, OECD, Paris, 23rd November.
- IPCC (1996), "Climate Change 1995: the science of climate change. Contribution of Working Group 1 to the Second Assessment Report of the IPCC", J.J. Houghton, L.G. Meiro Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (eds.), *Cambridge University Press*, Cambridge.
- IPCC (1998), "The Regional Impacts of Climate Change: An Assessment of Vulnerability". A Special Report of IPCC Working Group II.
- Joint Implementation Quarterly (1998), Joint Implementation Network, Netherlands, September.

- Mullins, F. (1998), "International Emissions Trading under the Kyoto Protocol", OECD Information Paper.
- OECD, "Ensuring Compliance With A Global Climate Change Agreement", ENV/EPOC(98)5/REV/1.
- Puhl, I. (1998), "Status of research on Project Baselines under the UNFCCC and the Kyoto Protocol", OECD and IEA Information Paper.
- Jain A.K., H.S. Kheshgi, M.I. Hoffert and D.J. Wuebbles (1995), "Distribution of radiocarbon as a test of global carbon cycle models", *Global Biogeochem. Cycles*, No. 9, pp. 153-66.
- Katsoulacos Y. (1997), "R&D spillovers, R&D cooperation, innovation and international environmental agreements", in C. Carraro, (ed.) *International Environmental Agreements: Strategic Policy Issues*, E. Elgar, Cheltenham.
- Kupnick, A. (1998), "Climate Change Health Risks and Economics", *Resources for the Future*, Washington.
- Manne A., R.G. Richels (1998), "The Kyoto Protocol: a cost-effective strategy for meeting environmental objectives?", in *Economic Modelling of Climate Change*, OECD Workshop Report, 17-18 September.
- Manne A., R.G. Richels (1998), "The Kyoto Protocol: a cost-effective strategy for meeting environmental objectives?", in *Economic Modelling of Climate Change*, OECD Workshop Report, 17-18 September.
- McKibbin W., R. Shackleton, P.J. Wilcoxon (1997), "The International Trade and Financial Impacts of Carbon Emissions Reductions", draft, August.
- McKibbin W., R. Shackleton, P.J. Wilcoxon (1998), "The potential effects of international carbon emissions permit trading under the Kyoto Protocol", in *Economic Modelling of Climate Change*, OECD Workshop Report, 17-18 September.
- Mendelsohn, R., W.D. Nordhaus and D. Shaw (1994), "The Impact of Global Warming on Agriculture: a Ricardian Analysis", *American Economic Review*, Vol. 84 pp. 753-71.
- Mission interministérielle de l'effet de serre (1998), "Impact potentiel du changement climatique en France au 21ème siècle, Paris.
- Mosley, M.P (1990) (ed.), "Climate Change in New Zealand", New Zealand Ministry of Environment.
- Nilsson S., W. Schopfhauser (1995), "The Carbon-Sequestration Potential of a Global Afforestation Program", *Climatic Change*, No. 30, pp. 267-93.
- Siegenthaler U., F. Joos (1992), "Use of a simple model for studying oceanic tracer distributions and the global carbon cycle", *Tellus*, No. 44, pp. 186-207.
- Toth, F.L., G. Petschel-Held and T. Bruckner (1998), "Kyoto and the long-term climate stabilisation, in *Economic Modelling of Climate Change*", OECD Workshop Report, 17-18 September.
- Tulpulé V., S. Brown, J. Lim, C. Polidano, H. Pant and B.S. Fisher (1998), "An economic assessment of the Kyoto Protocol using the Global Trade and Environment Model", in *Economic Modelling of Climate Change*, OECD Workshop Report, 17-18 September.

US Administration (1998), "The Kyoto Protocol and the President's Policies to Address Climate Change", draft, July.

Wigley T.M.L., R. Richels, J.A. Edmonds (1996), "Economic and environmental choices in the stabilization of atmospheric CO₂ concentrations", *Nature*, Vol. 379, 18 January.

Wigley T.M.L. (1997), "Implications of recent CO₂ emission-limitation proposals for stabilization of atmospheric concentrations", *Nature*, Vol. 390, 20 November.

Wigley T.M.L., A.K. Jain, F. Joos, B.S. Nyenzi and P.R. Shukla (1997), "Implications of proposed CO₂ emissions limitations", Intergovernmental Panel on Climate Change.

Wigley, T.M.L. (1993), "Balancing the global carbon budget. Implications for projections of future carbon dioxide concentration changes", *Tellus*, Vol. 45, pp. 45-48.

World Bank (1997), "Expanding the Measure of Wealth: Indicators of Environmentally Sustainable Development", *Study and Monography Series*, No. 7, pp. 40-65.



ECONOMICS DEPARTMENT
ECONOMIC POLICY COMMITTEE

For Official Use
ECO/CPE/WP1(99)6/ANN1

Cancels & replaces the same document:
distributed 25-Feb-1999

Working Party No. 1 on Macroeconomic and Structural Policy Analysis

**TAKING ACTION AGAINST CLIMATE CHANGE:
THE KYOTO PROTOCOL**

ANNEX 1: TABLES AND FIGURES

This document has been prepared by the Economics Department for the Working Party No. 1 of the Economic Policy Committee.

Contact: Jean-Marc Burniaux tel: (33-1) 45.24.79.18

email: jean-marc.burniaux@oecd.org

or

Paul O'Brien tel: (33-1) 45.24.87.64

email: paul.obrien@oecd.org

74808

Document complet disponible sur OLIS dans son format d'origine
Complete document available on OLIS in its original format

English text only

Tables and Figures

Table 1.	GDP projections underlying the BaU scenario in GREEN
Table 2.	CO ₂ emissions in the BaU scenario in GREEN
Table 3.	Estimates of the economic costs of implementing the Kyoto Protocol in 2010 without the flexibility mechanism
Table 4.	Marginal abatement costs without and with emission trading
Figure 1.	Energy price increases in 2010 due to the Kyoto Protocol
Figure 2.	Output changes in 2020 caused by implementation of the Kyoto Protocol
Figure 3.	Real income changes from alternative trading regimes in the Kyoto Protocol, 2010
Figure 4.	Distribution of benefits and losses from permit trading under the Kyoto Protocol in 2010
Figure 5.	Permit trading by country/region under the Kyoto Protocol
Figure 6.	Permit price in the Kyoto Protocol under alternative market structure
Figure 7.	Permit price in the Kyoto Protocol under alternative market structure
Figure 8.	Abatement costs of Annex I countries under alternative permits allocation
Figure 9.	Alternative timepaths of implementing the Kyoto Protocol without trade
Figure 10.	Impact of removing energy subsidies on the costs of the Kyoto Protocol
Figure 11.	Distribution of real income gains from energy subsidy removals in the context of the Kyoto Protocol with no permits trading
Figure 12.	Distribution of real income gains from energy subsidy removals in the context of the Kyoto Protocol with permits trading
Figure 13.	Long-term costs of the Kyoto Protocol
Figure 14.	Payoff curves at different coalition sizes
Figure 15.	Alternative CO ₂ concentration pathways
Figure 16.	Burden-sharing in alternative emission scenarios
Figure 17.	Average costs of alternative scenarios to stabilise CO ₂ concentration: world
Figure 18.	Average costs of alternative scenarios to stabilise CO ₂ concentration: Annex I countries
Figure 19.	Average costs of alternative scenarios to stabilise CO ₂ concentration: Non Annex I countries

Table 1. GDP projections underlying the BaU scenario in GREEN
average yearly growth rates, per cent

	1995-2000	2000-2005	2005-2010	2010-2030	2030-2050
United States	2.9	2.5	2.0	1.6	1.4
European Union	2.4	2.6	1.5	1.2	0.5
Japan	0.7	2.2	1.5	0.9	0.6
Other OECD	3.1	3.1	2.1	1.7	1.4
CIS	-2.5	3.5	4.5	4.0	3.5
Eastern Europe	3.6	4.6	4.1	3.6	3.1
Annex 1	2.1	2.6	1.8	1.5	1.2
China	7.7	5.6	5.0	4.8	4.0
India	5.4	4.4	4.2	4.2	3.0
Dynamic Asian Economies	2.5	4.8	4.8	4.2	3.2
Brazil	1.7	3.1	2.9	2.8	2.0
Energy exporters	2.0	2.2	2.2	2.2	2.9
Rest of the World	2.7	3.2	3.0	3.0	2.9
Non-Annex1	3.1	3.7	3.6	3.5	3.2
World	2.3	2.8	2.2	2.0	1.8

Table 2. CO2 emissions in the BaU scenario in GREEN

	average yearly growth rates, per cent					
	1990-1995	1995-2000	2000-2005	2005-2010	2010-2030	2030-2050
United States	1.3	2.2	2.0	1.9	0.9	0.9
European Union	-0.3	1.4	1.4	0.9	0.6	0.5
Japan	1.6	1.7	1.7	1.5	-0.9	0.2
Other OECD	1.6	2.4	2.3	2.0	1.4	1.3
CIS	-7.4	-2.0	2.7	3.4	2.9	2.6
Eastern Europe	-3.1	1.2	1.8	2.0	2.6	2.3
Annex 1	-1.1	1.2	2.0	1.9	1.2	1.4
China	4.8	5.5	5.5	5.2	5.2	3.1
India	6.4	3.5	3.8	3.8	3.9	3.0
Dynamic Asian Econom	8.8	3.0	3.3	3.2	2.2	2.5
Brazil	3.9	1.9	1.7	1.6	1.3	1.9
Energy exporters	3.8	1.9	2.2	2.2	2.2	2.1
Rest of the World	0.1	4.8	1.3	1.2	1.6	2.9
Non-Annex1	4.6	3.9	3.8	3.7	3.9	2.9
World	0.8	2.2	2.7	2.7	2.6	2.3

Table 3. Estimates of the economic costs of implementing the Kyoto Protocol in 2010 without the flexibility mechanisms

	emission reduction (in per cent) relative to the BaU in 2010	marginal cost in 1995 \$ per ton of carbon	total cost as percentage reduction of real income in 2010	
United States				
WorldScan ⁽¹⁾	-28	41	-0.2	(GDP)
GREEN	-36	231	-0.3	(HEV)
G-Cubed ⁽²⁾	-29	63	-0.3	(GNP)
EMF16 ⁽³⁾	na	140 - 340	na	
Merge ⁽⁴⁾	na	274	-1.0	(GDP)
AIM ⁽⁷⁾	-25	166	na	
POLES ⁽⁵⁾	-23	90	-0.2	(GDP)
GTEM ⁽¹⁰⁾	-28	369	-2.0	(GDP)
Western Europe				
WorldScan ⁽¹⁾	-29	83	-0.3	(GDP)
GREEN	-22	189	-0.8	(HEV)
POLES ⁽⁵⁾	-22	141	-0.1	(GDP)
G-Cubed ⁽²⁾⁽⁶⁾	-25	167	-1.4	(GNP)
AIM ⁽⁷⁾	-18	214	na	
PRIMES ⁽⁸⁾	-13	72	na	
GEM-E3 ⁽⁹⁾	-15	218	na	
GTEM ⁽¹⁰⁾	-25	762	-0.9	(GDP)
Japan				
WorldScan ⁽¹⁾	-22	93	-0.8	(GDP)
GREEN	-32	182	-0.2	(HEV)
G-Cubed ⁽²⁾	-29	252	-0.8	(GNP)
AIM ⁽⁷⁾	-22	253	na	
POLES ⁽⁵⁾	-27	260	-0.3	(GDP)
GTEM ⁽¹⁰⁾	-22	739	-0.7	(GDP)
Eastern Europe				
WorldScan ⁽¹⁾	-10	4	0.0	(GDP)
GREEN	0	82	0.1	(HEV)
GTEM ⁽¹⁰⁾	-24	43	-0.5	(GDP)
CIS				
WorldScan ⁽¹⁾	0	2	-1.1	(GDP)
GREEN	4	0	-1.7	(HEV)
AIM ⁽⁷⁾	0	0	na	
GTEM ⁽¹⁰⁾	1.6	0	0	(GDP)

1. Emission reductions and economic costs are from Gielen and Koopmans (1998); carbon taxes are from Bollen, Gielen and Timmer (1998).

2. McKibbin, Shackleton and Wilcoxon in OECD, 1998, p. 71.

3. Figures quoted by J. Edmonds reporting on the results of the EMF16.

4. Manne and Richels in OECD, 1998, p. 19.

5. Figures from POLES are based on interpolations made on the basis of Figure 2, p. 35 and Figure 3, p. 36 of Capros in OECD, 1999.

6. Includes Europe, Canada and New Zealand.

7. Kainuma, Matsuoka and Morita in OECD, 1998 p. 167.

8. Figures from PRIMES refer to EU8 and are interpolations made on the basis of Figure 4, p. 41 of Capros in OECD, 1998.

9. Figures from GEM-E3 refer to EU14 and are interpolations made on the basis of Figure 5, p. 43 of Capros in OECD, 1998.

10. Tulpulé et al. in OECD, 1998.

Table 4. Marginal abatement costs without and with emission trading

	without trade	with trade
United States		
WorldScan ¹	41	18
GREEN	231	90
G-Cubed ²	63	37
EMF16 ³	140 - 340	21-160
Merge ⁴	274	113
AIM ⁵	166	67
GTEM ⁶	369	122
Western Europe		
WorldScan ¹	83	18
GREEN	189	90
G-Cubed ²	167	37
AIM ⁵	252	67
GTEM ⁶	762	122
Japan		
WorldScan ¹	93	18
GREEN	182	90
G-Cubed ²	252	37
AIM5	253	67
GTEM6	739	122

65%

52%

50%

1. Bollen, Gielen and Timmer in OECD, 1998.
2. McKibbin, Shackleton and Wilcoxon in OECD, 1998, p. 71.
3. Figures quoted by J. Edmonds reporting on the results of the EMF16.
4. Manne and Richels in OECD, 1998, p. 19.
5. Kainuma, Matsuoka and Morita in OECD, 1998, p. 167.
6. Tulpulé *et al.* in OECD, 1998.

**Figure 1. Energy price increases in 2010 due to the Kyoto Protocol
(with no trade)**

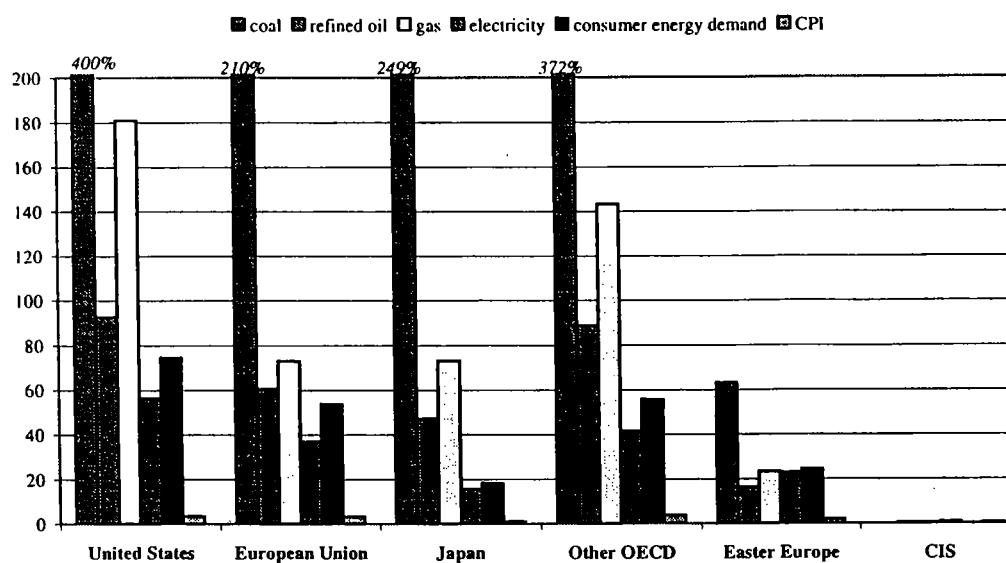


**Figure 2. Output changes in 2010 caused by implementation of the Kyoto Protocol
(with no trade)**

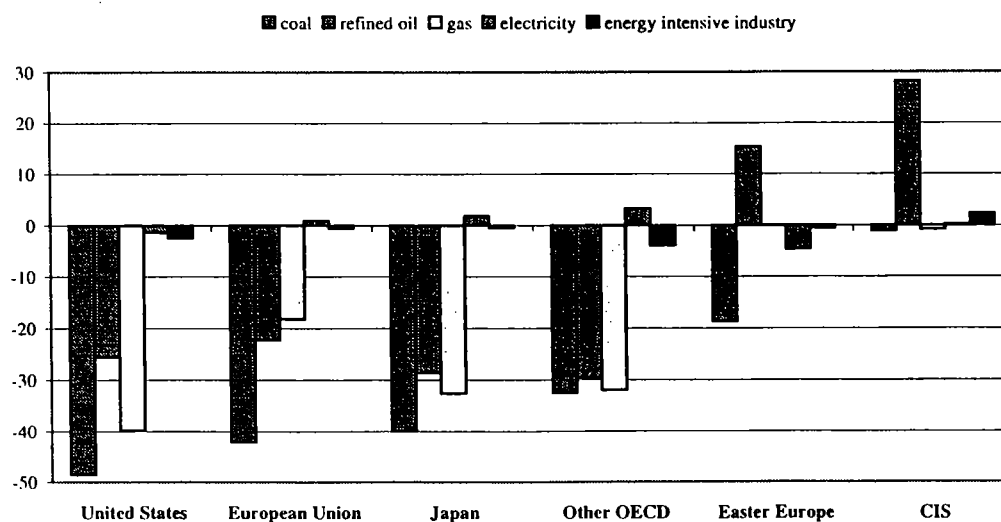


Figure 3. Real income changes from alternative trading regimes in the Kyoto Protocol, 2010

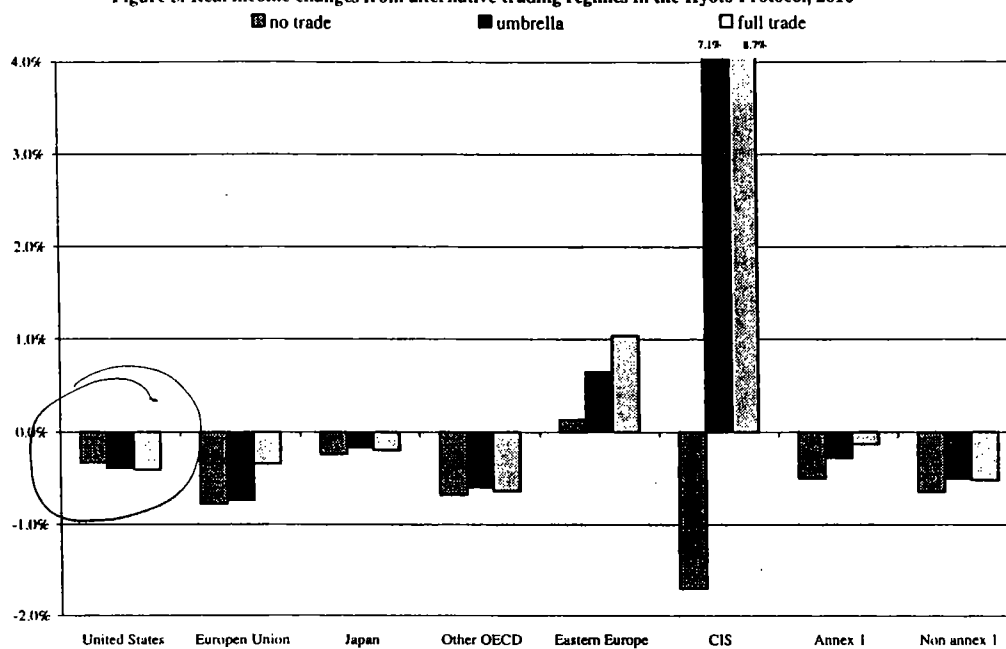
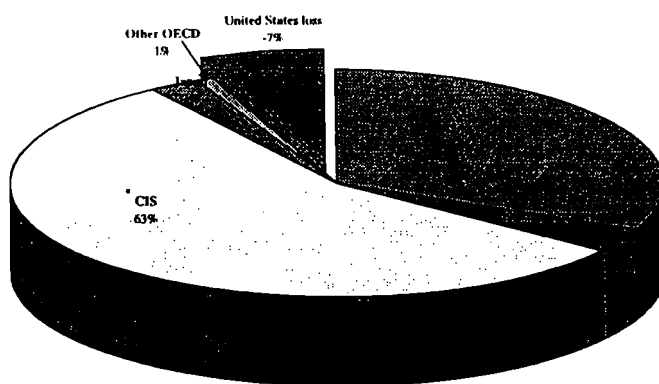


Figure 4. Distribution of benefits and losses from permit trading under the Kyoto Protocol in 2010



*Trading
prior to 2008?*

Figure 5. Permit trading by country/region under the Kyoto Protocol

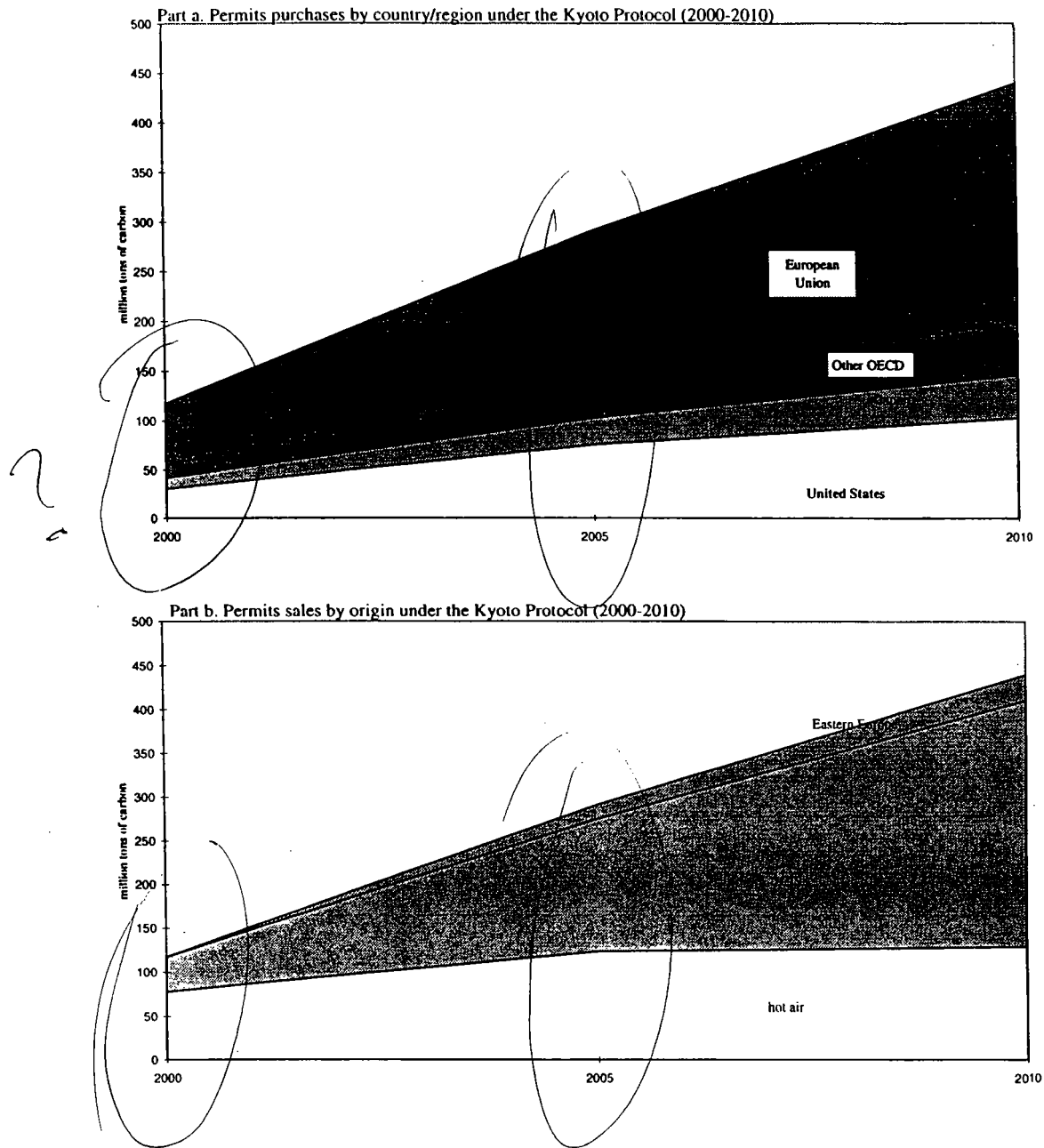


Figure 6. Permit price in the Kyoto Protocol under alternative market structures

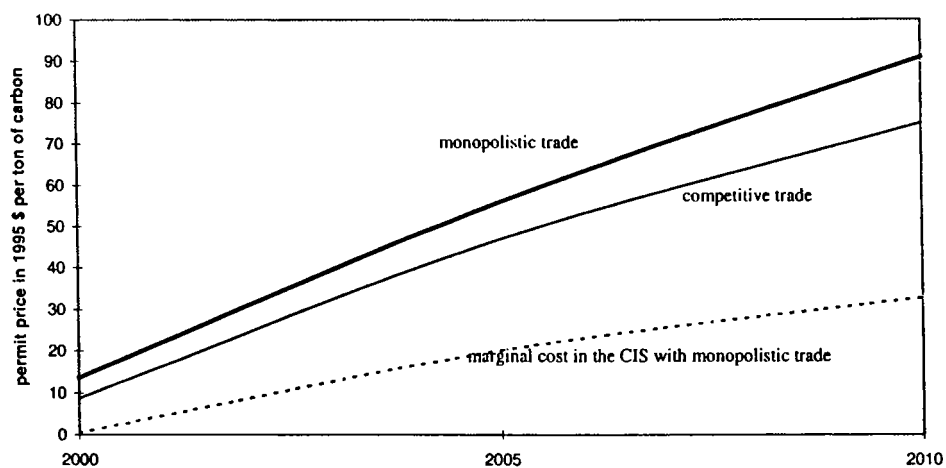


Figure 7. Permit price in the Kyoto Protocol under alternative market structures

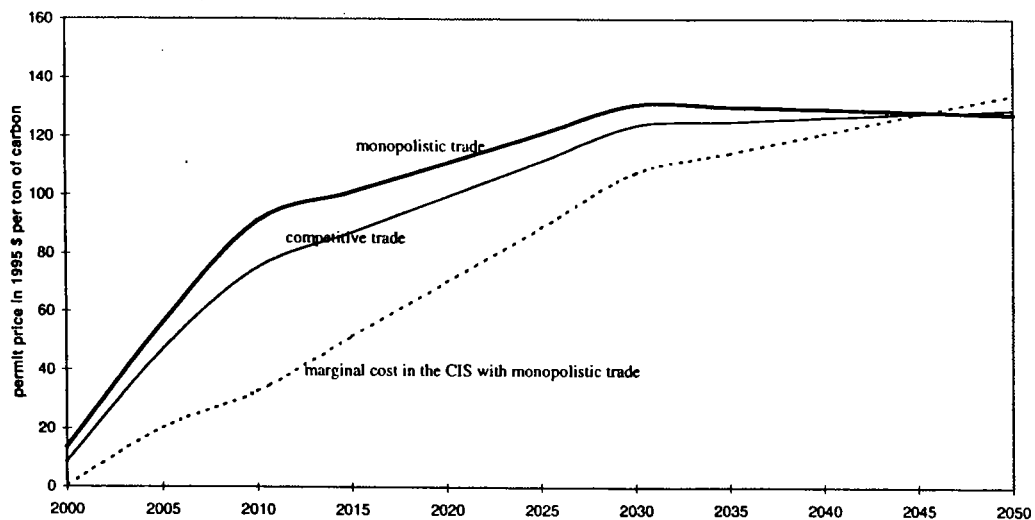
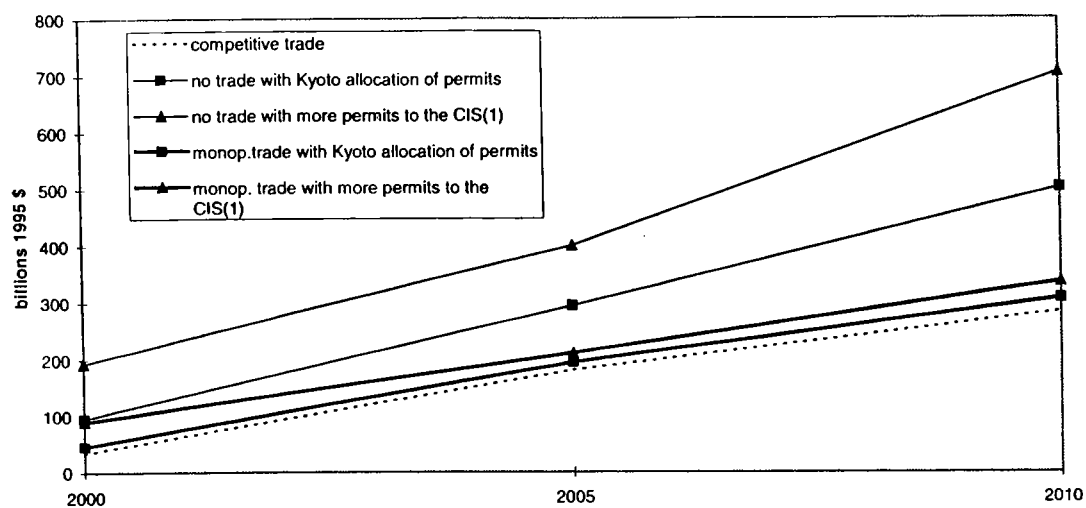


Figure 8. Abatement costs of Annex I countries under alternative permits allocation



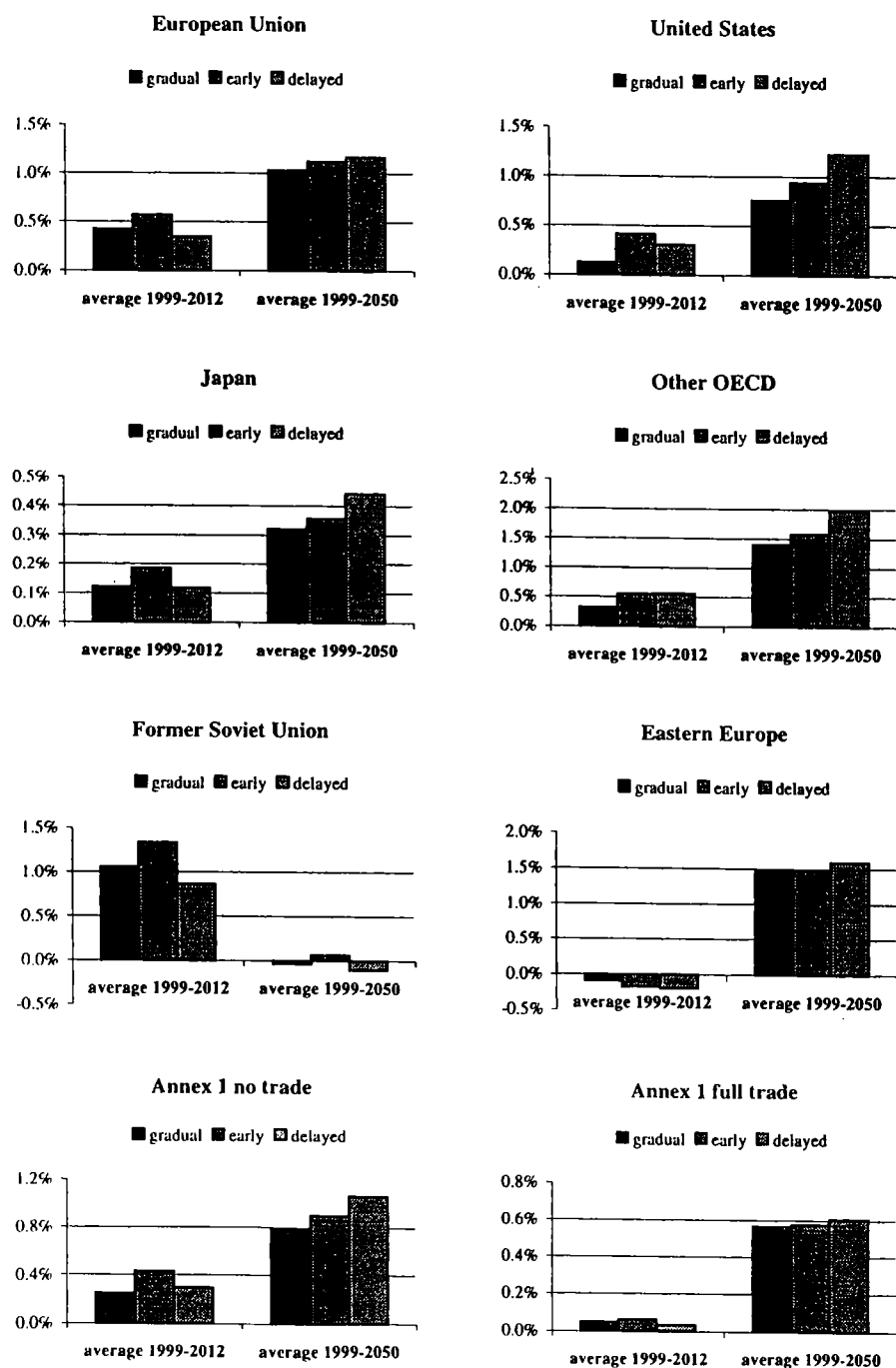
1. The amount of permits allocated to the CIS grows by 1 per cent annually in excess to the commitments decided in Kyoto.

Figure 9 : Alternative timepaths of implementing the Kyoto Protocol
(average discounted¹ real income losses)

Gradual: implementation from 1999 to 2010

Early: implementation from 1999 to 2005

Delayed: implementation from 2005 to 2010



1. The discount rate is 3 per cent.

**Figure 10. Impact of removing energy subsidies on the costs of the Kyoto Protocol
(real income changes relative to BaU in 2010)**

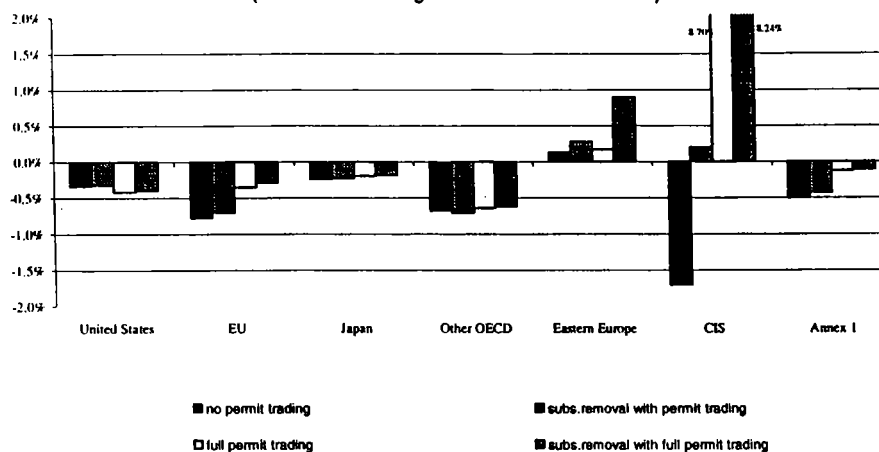


**Figure 11. Distribution of real income gains from energy subsidy removals
in the context of the Kyoto Protocol with no permits trading**

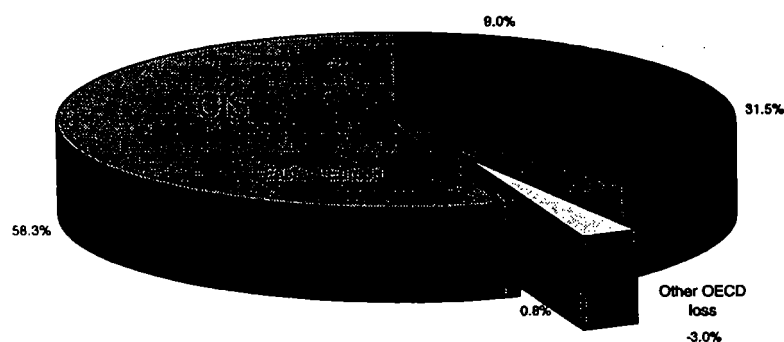


**Figure 12. Distribution of real income gains from energy subsidy removals
in the context of the Kyoto Protocol with permits trading**

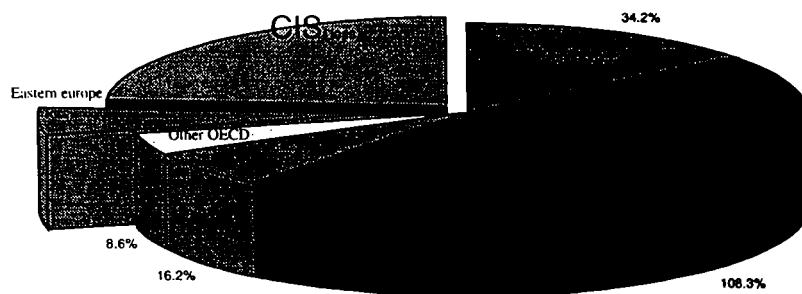


Figure 13. Long-term costs of the Kyoto Protocol
(real income losses in per cent relative to the BaU)

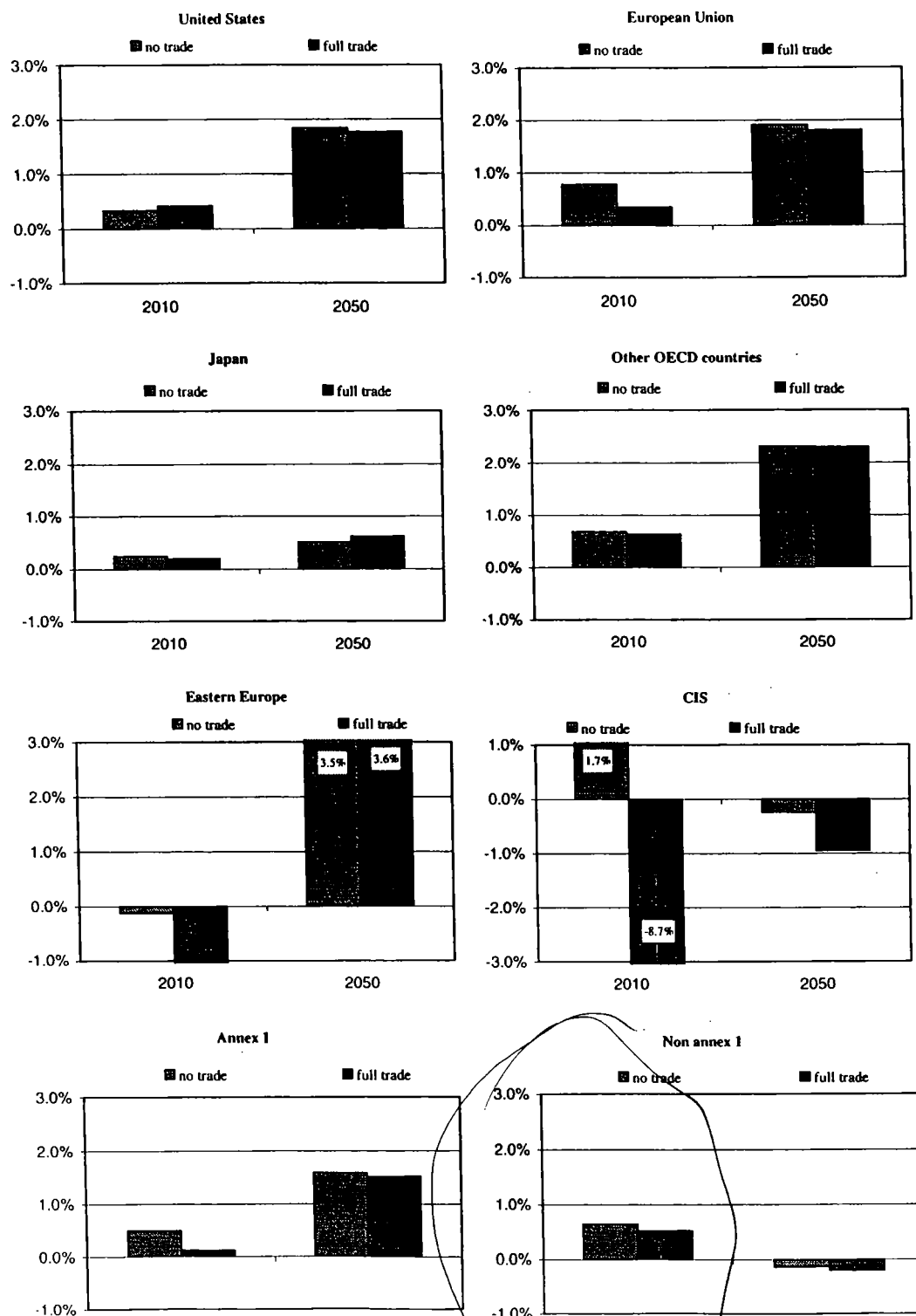
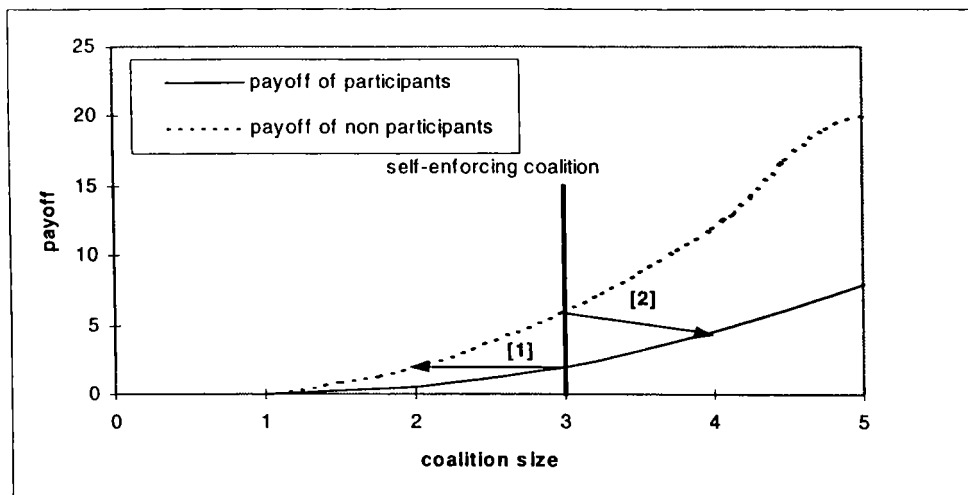


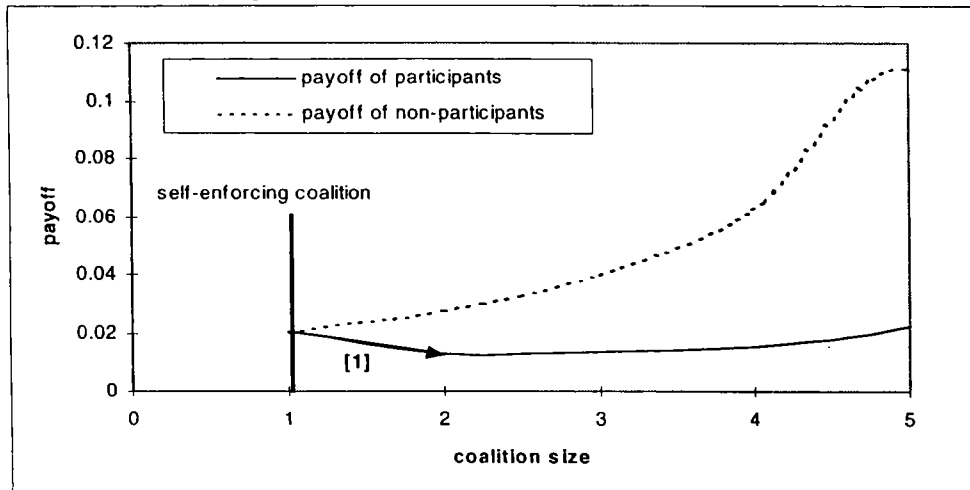
Figure 14. Payoff curves at different coalition sizes

Part a: with no carbon leakage



1. Internal stability: no participant has incentive to leave the coalition.
2. External stability: no non-participant has incentive to join the coalition.

Part b: with carbon leakage



1. Nobody has any incentive to form a coalition; the equilibrium coalition is a singleton.

Figure 15. Alternative CO2 concentration pathways

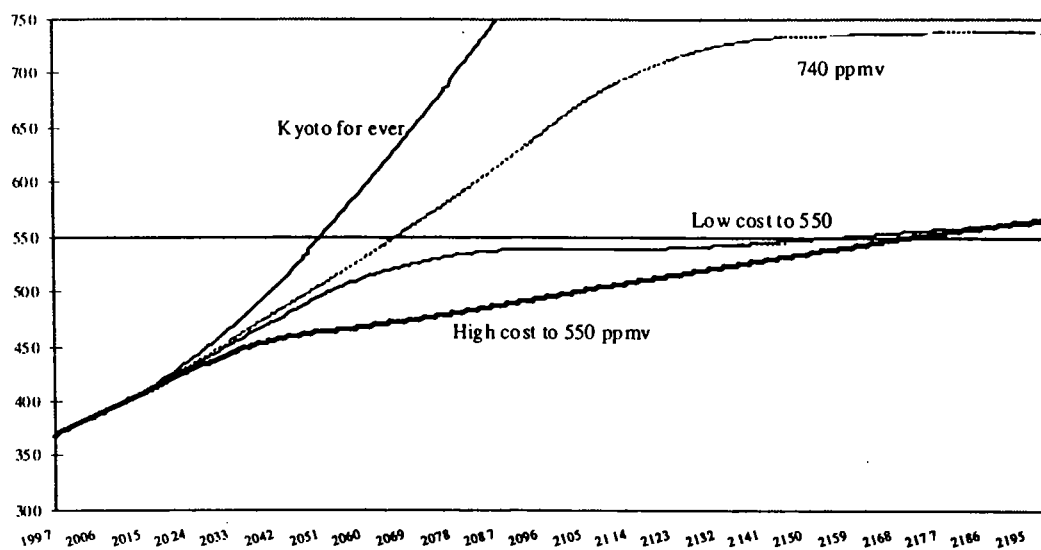
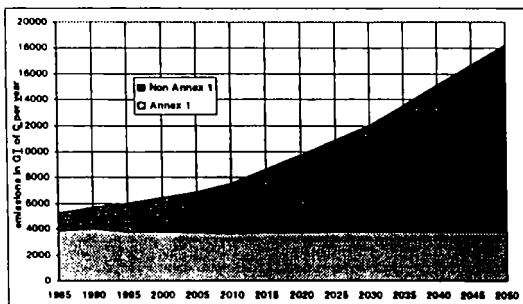
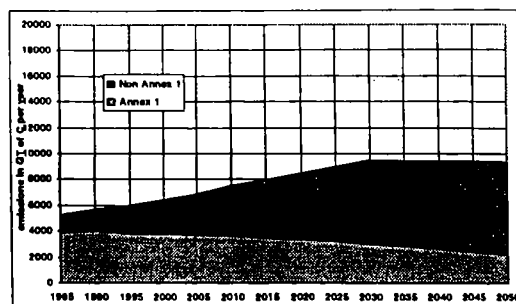


Figure 16. Burden-sharing in alternative emission scenarios

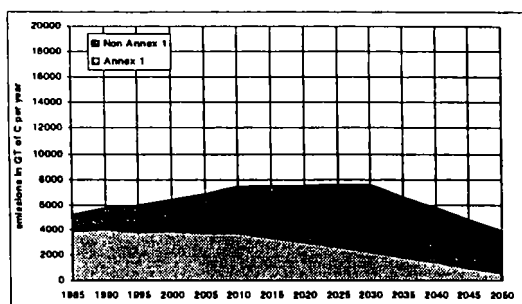
Part a: Kyoto for ever



Part b: low-cost timepath to stabilise concentration around 550 ppmv



Part c: High-cost timepath to keep concentration below 550 ppmv (egalitarian allocation of emission rights)



Part d: timepath to stabilise concentration around 740 ppmv (egalitarian allocation of emission rights)

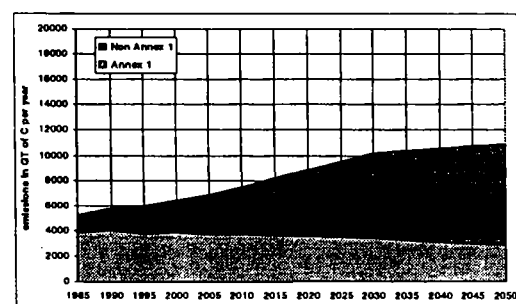
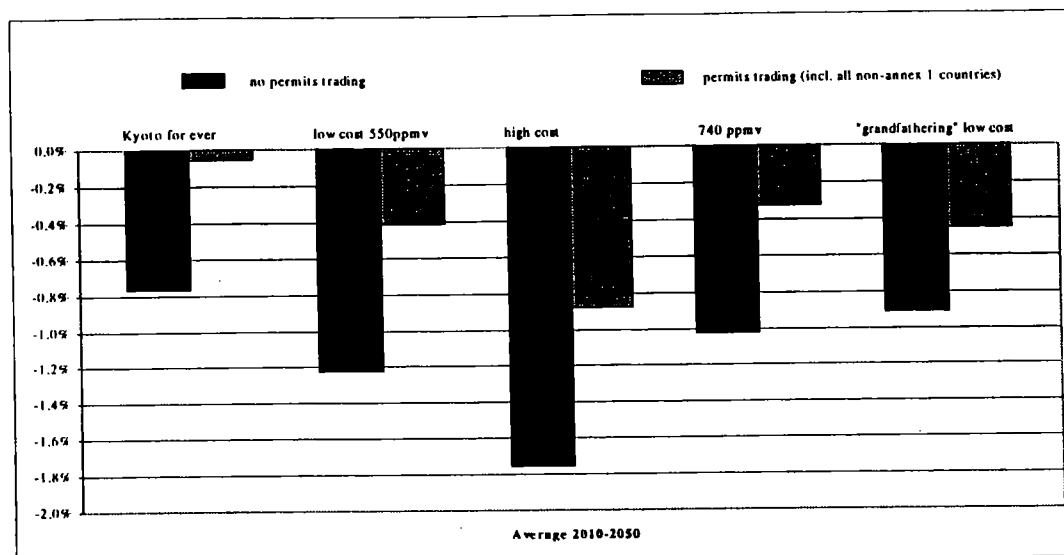
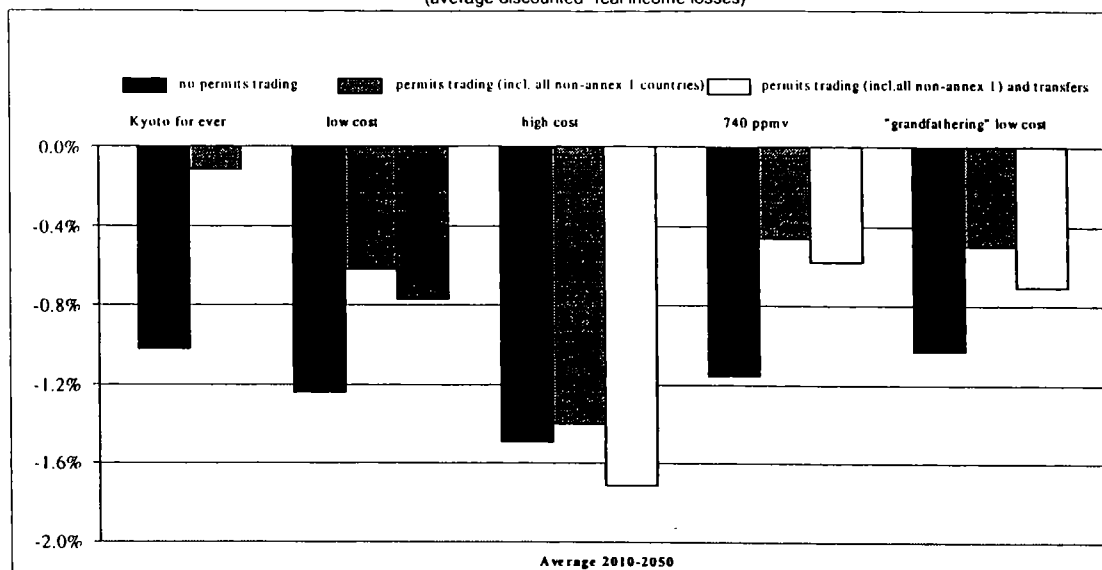


Figure 17. Average costs of alternative scenarios to stabilise CO2 concentration: World
(average discounted¹ real income losses)



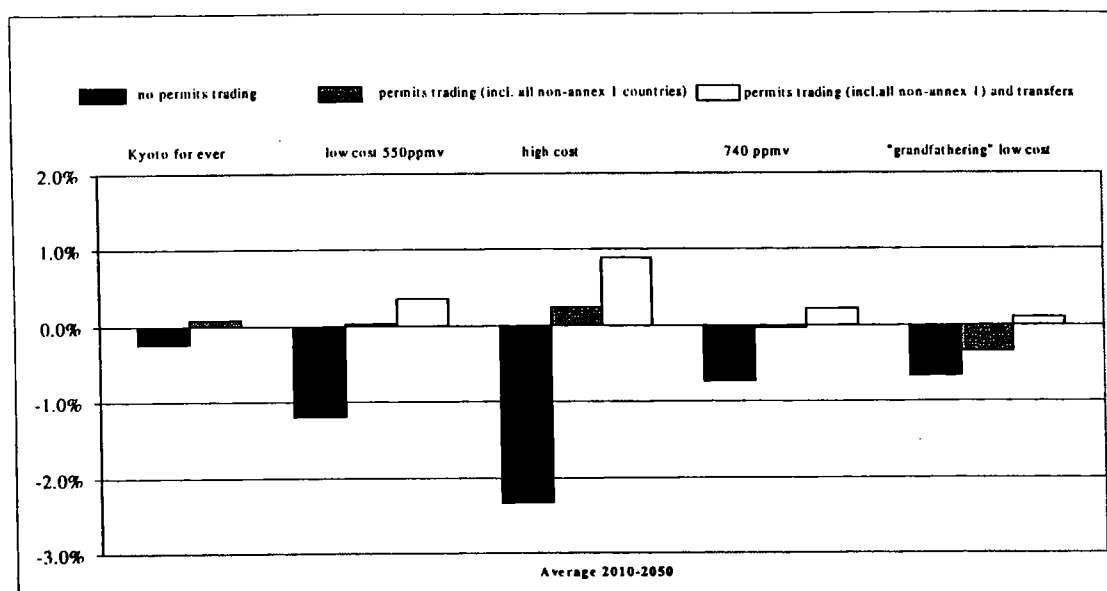
1. The discount rate is 3 per cent.

Figure 18. Average costs of alternative scenarios to stabilise CO₂ concentration: Annex I countries
(average discounted¹ real income losses)



1. The discount rate is 3 per cent.

Figure 19. Average costs of alternative scenarios to stabilise CO2 concentration: Non Annex I countries
(average discounted¹ real income losses)



1. The discount rate is 3 per cent.

EPRI

August 20, 1998

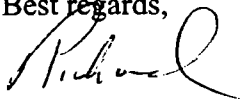
Dr. Jeffrey Frankel
Council of Economic Advisers
Old Executive Office Building
Washington, DC 20502

30:54
JA
SP
QF

Dear Jeff:

Alan Manne and I thought you might be interested in the enclosed draft "The Kyoto Protocol: A Cost-Effective Strategy for Meeting Environmental Objectives?". The paper results from our involvement in the ongoing Energy Modeling Forum-16 study on the impacts of proposals for dealing with the threat of global climate change. Any comments or suggestions would be most welcomed.

Best regards,



Richard Richels
Director, Global Climate Change Research

The Kyoto Protocol: A Cost-Effective Strategy for Meeting Environmental Objectives?

Alan S. Manne, Stanford University

Richard G. Richels, EPRI

July 27, 1998

This research results from our involvement in Stanford University's Energy Modeling Forum 16 Study. The authors are indebted to James Deaker and Robert Parkin for their research assistance. We have benefited from discussions with Jae Edmonds, Henry Jacoby, David Montgomery, William Nordhaus, Stephen Peck, Thomas Rutherford, and John Weyant. Funding was provided by EPRI. The results presented here are solely those of the individual authors.

1. Introduction

The Kyoto Protocol represents a milestone in climate policy.¹ For the first time, negotiators have attempted to lay out emission reduction targets for the early part of the 21st century. The goal is for Annex 1 (developed countries plus economies in transition) to reduce their aggregate anthropogenic carbon dioxide equivalent emissions by at least 5 percent below 1990 levels in the commitment period 2008 to 2012. The Protocol, however, has yet to enter into force. To do so will require ratification by 55 countries representing 55 percent of total Annex 1 CO₂ emissions in 1990.

As each country considers ratification, important questions will arise. High up on the US list is the issue of economic costs. The Senate, for example, has stated that “any Protocol should be accompanied by a detailed financial analysis of impacts on the economy.”² Not surprisingly, US negotiators had hardly returned from Kyoto before the first hearings were scheduled on Capitol Hill. Although the issue of costs is but one of many important considerations, policy makers are keenly interested in the economic implications of ratification.

This paper is intended to help clarify our understanding of compliance costs. The focus is on three questions, which we believe to be of particular relevance: What are the near-term costs of implementation? How significant are the so-called “flexibility provisions”? And, perhaps most importantly, is the Protocol cost-effective in the context of the long-term goals of the Framework Convention?³

Unfortunately, the answers to these questions will not come easily. It has always been difficult to calculate the economic costs of implementing climate policy. Kyoto has done little to simplify matters. Indeed, it raises at least as many questions as it resolves. These questions fall into two categories: those related to the near-term implementation of the Protocol and those related to the evolution of climate policy over the longer term.

The Protocol is unclear on a number of topics. These include the rules governing emission trading, joint implementation (JI), the Clean Development Mechanism (CDM), and the treatment of carbon sinks. In addition, there is a weak knowledge base regarding the costs of sink enhancement and of controlling several of the relevant trace gases. Until these issues are clarified, analyses will be highly speculative.

Calculating the costs of Kyoto is also complicated by the issue of “what happens next?” Energy sector investments are typically long-lived. Today’s investment decisions are not only influenced by what happens during the next decade, but also by what happens thereafter. In order to estimate the costs of implementing emission cuts in the first commitment period, assumptions are required concerning the longer-term requirements. Unfortunately, the international negotiation process offers little guidance on this issue. This further complicates the process of analysis.

We do not wish to suggest that economic analysis is premature at the present time. Uncertainty is rarely an excuse for paralysis. It does mean, however, that we must be

careful to highlight the tentative nature of the projections and focus, to the extent possible, on the insights for decision making. Here, sensitivity analysis can be particularly useful. For example, in the case of several of the flexibility provisions (emission trading, joint implementation and the Clean Development Mechanism), we explore a variety of scenarios regarding constraints on the purchase of carbon emission rights. While the exact magnitude of the benefits will continue to be debated, the insights, nevertheless, appear to be quite robust.

We also examine the Protocol in the context of the longer-term goal of the Framework Convention, i.e., the stabilization of greenhouse gas concentrations in the earth's atmosphere. A particular concentration goal can be reached through a variety of emission pathways. Considerable effort has been devoted to trying to understand the characteristics of cost-effective pathways.⁴ It is interesting to examine Kyoto in the context of this work. The price tag for moving forward may be formidable. Consistent with the Framework Convention, it is essential that "policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible costs."⁵

2. The model

This analysis is based on MERGE (a model for evaluating the regional and global effects of greenhouse gas reduction policies).^{6,7} MERGE is an intertemporal market equilibrium model. It combines a bottom-up representation of the energy supply sector together with a top-down perspective on the remainder of the economy. Savings and investment decisions are modeled as though each of the regions maximizes the discounted utility of its consumption subject to an intertemporal wealth constraint. Each region's wealth includes not only capital, labor and exhaustible resources, but also its negotiated international share in carbon emission rights.

For the present version of the model, known as MERGE 3.0, we have adopted 10-year time intervals through 2050 and 25-year intervals through 2100. Geographically, the world is divided into nine geopolitical regions: 1) the USA, 2) OECD (Western Europe), 3) Japan, 4) CANZ (Canada, Australia and New Zealand), 5) EEFSU (Eastern Europe and the Former Soviet Union), 6) China, 7) India, 8) MOPEC (Mexico and OPEC) and, 9) ROW (the rest of world). Note that the OECD (regions 1 through 4) together with EEFSU constitute Annex 1 of the Framework Convention.

Particularly relevant for the present analyses, MERGE provides a general equilibrium formulation of the global economy. We model the possibility of international trade in carbon emission rights. This is sometimes known as "where" flexibility. It would allow regions with high marginal abatement costs to purchase emission rights from regions with low marginal abatement costs. In addition, MERGE can be used to examine the related issue of "when" flexibility - intertemporal transfers of carbon emission rights.

We also model international trade in oil, natural gas, and energy-intensive basic materials. We are therefore able to examine issues related to "carbon leakage". Such leakage can occur through a variety of pathways. For example, Annex 1 emission

reductions will result in lower oil demand, which in turn will lead to a decline in the international price of oil. As a result, non-Annex 1 countries may increase their oil imports and emit more than they would otherwise.

The present version of the model includes the notion of endogenous technical diffusion. Specifically, in the electric sector, the near-term adoption of high-cost carbon-free technologies leads to accelerated future introduction of lower cost versions. The model also includes both price-induced and non-price conservation. For most regions and time periods, the AEEI (autonomous energy efficiency improvement) rate is taken to be 40% of the rate of GDP growth. By 2100, this leads to regional energy-GDP ratios that are much closer to each other than they were in 1990.

In calibrating MERGE for the present analysis, several supply- and demand-side parameters were adjusted so that the global emissions baseline would approximate the Intergovernmental Panel on Climate Change (IPCC) central case “no policy” scenario (IS92a).⁸ Figure 2.1 shows carbon emissions for each region in the reference case scenario. For more on the model and its key assumptions, see our website:

<http://www-leland.stanford.edu/group/MERGE/>

3. Treatment of sinks and non-CO₂ greenhouse gases

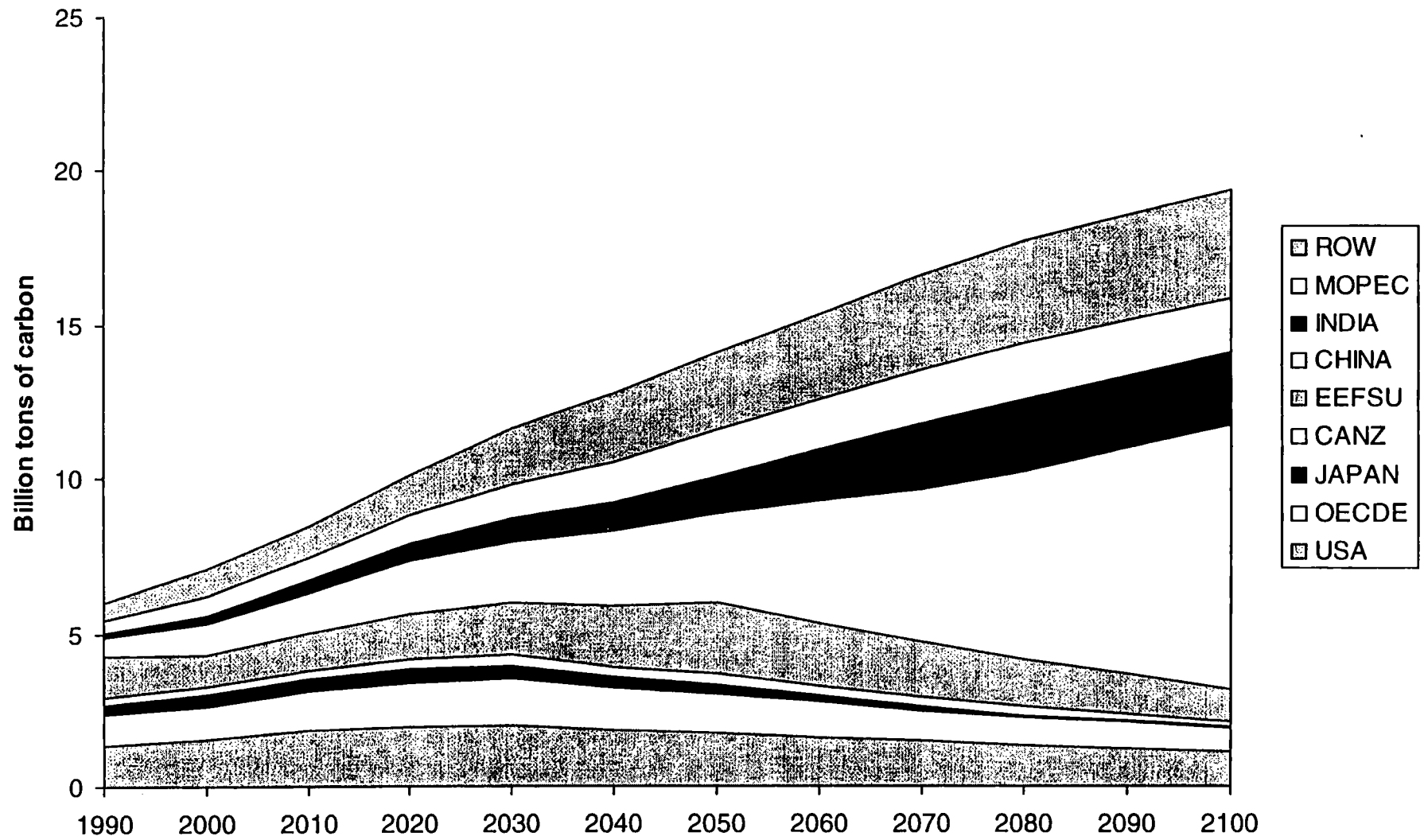
Few issues have engendered as much confusion as that of carbon sinks. Key questions include their definition, the extent to which they are included in the Protocol, the amount currently being sequestered, their time profile, and the costs of sink enhancement.

The Protocol states that Annex 1 commitments can be met by “the net changes in greenhouse gas emissions from sources and removal by sinks resulting from direct human-induced land use change and forestry activities limited to afforestation, reforestation, and deforestation since 1990, measured as verifiable changes in stocks in each commitment period.”⁹ The confusion results from alternative interpretations regarding the treatment of soil carbon, an issue flagged for further study in the Protocol. Their inclusion may result in large increases in the international legal definition of sink potential.

The quality of the data is uneven. The supply curves for sink enhancement are particularly questionable. The degree of confidence concerning current and predicted future levels of carbon sequestration varies enormously across regions of the globe. Not surprisingly, information is most reliable (albeit still poor) for Annex 1 countries. Comparatively little effort has been made to collect such data elsewhere.

As placeholders, we have adopted the values shown in Table 1. To provide some perspective, in order for the US to reduce industrial carbon emissions by 7% below 1990 levels in 2010, it would have to reduce emissions by approximately 550 million tons below its reference trajectory. Sink enhancement would satisfy 9 percent of this

Figure 2.1 Regional Carbon Emissions -- reference case



obligation. For purposes of the present analysis, we assume that this sink enhancement is costless.

Table 1. Sink Enhancement (million metric tons of carbon annually)

USA	50
OECD	17
Japan	0
CANZ	50
EEFSU	34

CO₂ is by far the most important of the greenhouse gases. In addition, the Protocol includes five other trace gases (methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride). Given the scarcity of reliable emissions and cost data, the treatment of the non-CO₂ greenhouse gases is also problematic. For purposes of the present analysis, we assume that each gas is reduced proportionately. With this proportionality assumption, the inclusion of the non-CO₂ greenhouse gases does not affect the requirements for CO₂ reductions.

As with our treatment of sinks, we do not include the costs of abating the non-CO₂ greenhouse gases in our estimates of the costs of complying with the Protocol. Clearly, an important next step would be to develop supply curves for the cost of abating non-CO₂ greenhouse gases and for sink enhancement. Neither of these costs is included in the present version of MERGE.

4. "Kyoto Forever"

We begin with an examination of a "Kyoto Forever" scenario. This is a case in which the Kyoto constraints on Annex 1 countries are maintained throughout the 21st century. With regard to non-Annex 1 emissions, we assume they will continue to be bounded by their business-as-usual baseline (Figure 2.1). The latter constraint is imposed in order to prevent carbon leakage. Later on, we will explore the impact of relaxing this constraint.

Numerous studies have shown that global mitigation costs can be reduced substantially by allowing emission reductions to take place wherever it is cheapest to do so - regardless of geographical location.¹⁰ The Kyoto Protocol includes several provisions allowing for a limited amount of "where" flexibility. These include emission trading and joint implementation among Annex 1 countries. They also include provisions for a Clean Development Mechanism (CDM) that is intended to facilitate joint implementation between Annex 1 and non-Annex 1 countries.

As with the definition of sinks, the Protocol leaves many critical details unresolved. For example, it remains unclear whether there will be limits on the extent to which a country can rely upon the purchase of emission rights to satisfy its obligations. The Protocol states that "the Conference of the Parties shall define the relevant principles, modalities, rules and guidelines ..."¹¹ Similar ambiguity surrounds the Clean Development

Mechanism. Again, the elaboration of “modalities and procedures” is left to a future meeting of the Conference of the Parties.¹²

In this section, we explore three scenarios: 1) no trading, 2) Annex 1 trading plus CDM, and 3) full global trading. These three options are representative of alternative implementations of the Kyoto Protocol. Each has its own advocates and opponents, but we do not consider them equally likely. In our opinion, there is little likelihood of enticing all major countries to participate in a global market in emission rights during the initial commitment period (2008-2012).

The full global trading scenario places an upper bound on the CDM’s potential to reduce GDP losses. In calculating the potential size of the contribution from a CDM, we therefore calculate this upper bound on the export of emission rights from non-Annex 1 regions. Because of the difficulties in implementation of the CDM, however, we assume that only 15% of the potential would be available for purchase through this mechanism. This is a highly subjective estimate. Given the complexities of the CDM, however, we are not inclined to assign a higher value

Figure 4.1 reports the incremental value of carbon emission rights to the US in 2010 and 2020. We focus first on 2010. In the most constrained scenario, the US must satisfy its emission reduction requirements within its own geographical boundaries. In this case, the value of emission rights approaches \$240 per ton. With Annex 1 trading plus CDM, the value drops to slightly less than \$100 per ton. As might be expected, the value of emission rights is lowest with full global trading. Here, it falls below \$70 per ton.

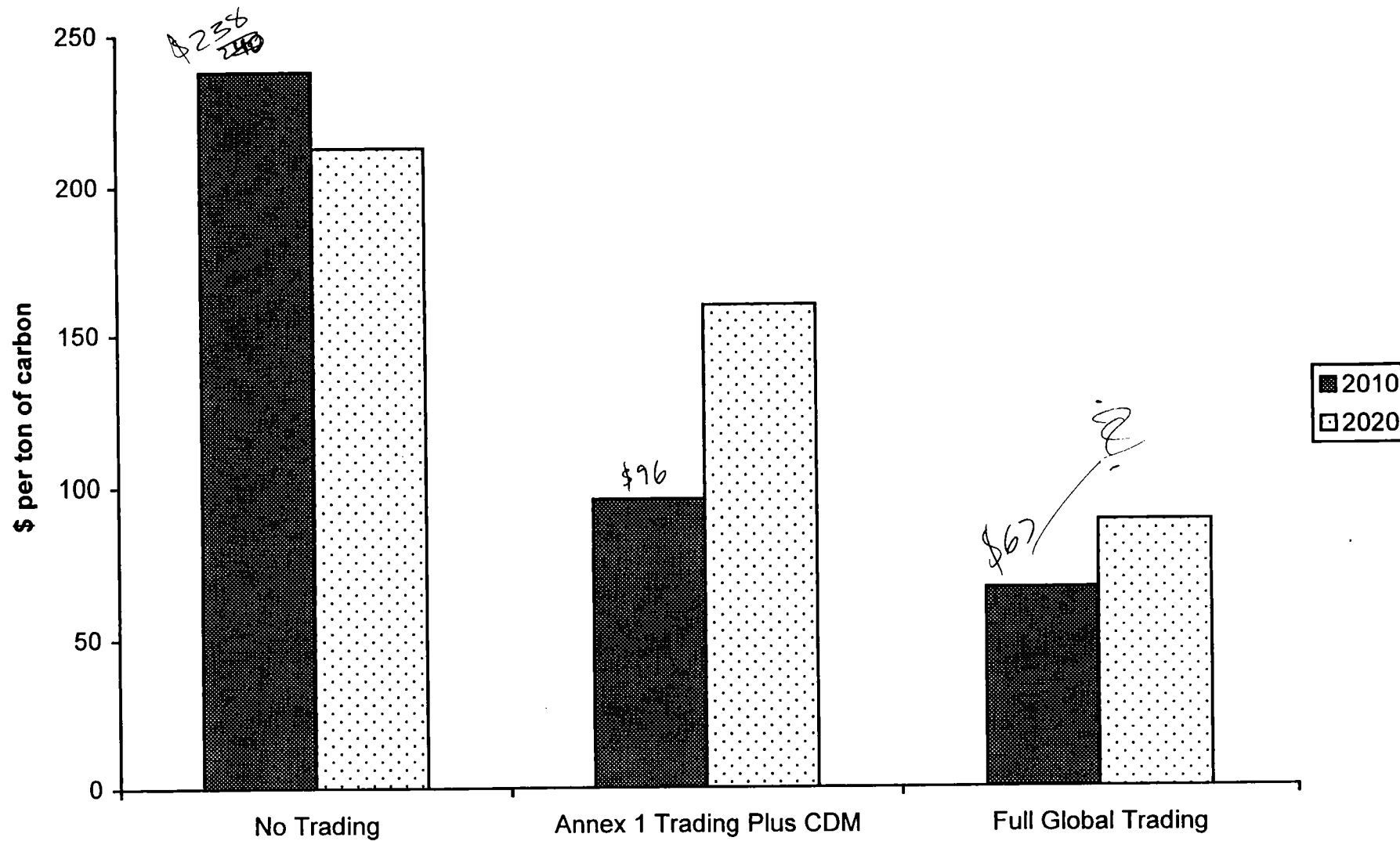
For the two scenarios in which trading is permitted, the value of emission rights increases in 2020. This is because EEFSU’s projected emissions lie below its negotiated constraint for 2010. It has been allocated more emission rights than it needs to satisfy its internal obligations. By 2020, however, EEFSU’s economic growth is expected to be such that it no longer enjoys an excess of emission rights. As a result, there is more competition for emission rights in the international marketplace, and there is an increase in their price.

Another way to view the costs of abatement is to show the GDP losses. Figure 4.2 contains those for the US. Losses are highest in the absence of trade. Here, they exceed \$80 billion dollars in 2010. This is approximately one percent of US GDP. To the extent that trade is introduced, losses decline. In the most optimistic scenario (full global trade), losses are approximately \$20 billion or one-quarter of one percent of GDP in 2010.

Of the three scenarios, “Annex 1 trading plus the CDM” is most consistent with the Protocol as it currently stands. However, the US Senate has stated that the US should not be a signatory to the Protocol if it does not mandate specific commitments for developing countries.¹³ If this were to result in full global emission trading, we move in the direction of the right-most bar of Figure 4.2.

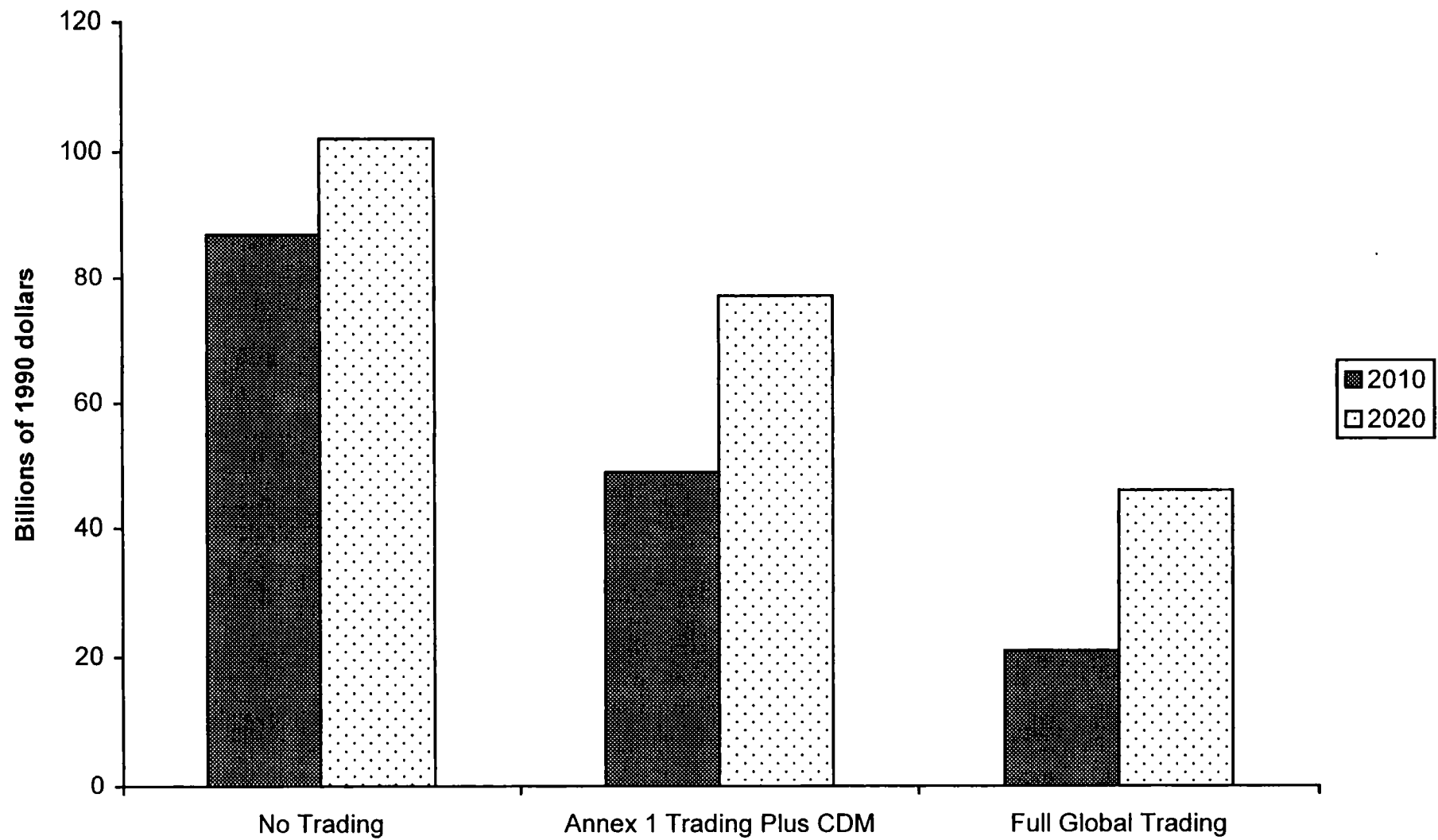
There is, however, strong sentiment among many parties to the Framework Convention to substantially limit the extent to which Annex 1 countries can meet their obligation

Figure 4.1 Incremental Value of Carbon Emission Rights in US Under Kyoto Forever



CDM ~~is~~ mostly changes
anything

**Figure 4.2 Annual US GDP Losses Under Kyoto Forever
(\$ billions)**



through the purchase of emission rights. Several influential developing countries have expressed strong opposition to the concept altogether. Figure 4.2 shows the costs of the no trading scenario. We now turn to the case where trading is permitted, but with limitations on the purchase of emission rights.

5. Limits on the purchase of carbon emission rights

Figure 5.1 shows our estimates of the percentage of the US emission reduction obligation that would be satisfied through the purchase of emission rights under base case assumptions. With full global trading (the least-cost of our three scenarios), trading is used to satisfy more than 50% of the US obligation. But suppose that limits are placed on the purchase of emission rights? For example, suppose that international negotiators agree that Annex 1 buyers can satisfy only one-third of their obligation through this means. What would be the impact on GDP losses?

Figure 5.2 compares three cases. All assume full global participation in an international market for carbon emission rights, but only the first assumes no limits on the amount a country can buy. The second and third case are based upon the one-third limitation. We further make the distinction between a buyers' market and a sellers' market. With the former, sellers of emission rights are price takers. Buyers exert sufficient market power to hold the international price to the marginal cost of abatement in the selling countries. However, since a country is only able to satisfy one-third of its obligation through the purchase of emission rights, it must eventually rely on its own domestic marginal abatement capabilities to meet its obligations. Hence, there is an important distinction between the international price and the domestic price. Conversely, with a sellers' market, buyers face but one price. Here, the rents accrue to the sellers.

Figure 5.3 shows the GDP losses associated with the three scenarios. Note that losses in 2010 are two and one-half to three times higher with the constraint on the purchase of carbon emission rights. That is, the benefits from "where" flexibility are greatly diminished. The message is clear. Developing country participation in the market for carbon emission rights is a necessary, but by no means a sufficient condition for reaping the full benefits of "where" flexibility. To achieve a cost-effective solution, buyers must also be unconstrained in the manner in which they fulfill their obligation.

Also note that the distribution of the rents makes a difference to GDP losses. US losses are 25% higher in 2020 when market power resides with the sellers. The analysis provides an additional message for Annex 1 buyers. If at a given point in time, low-cost sellers are concentrated among a few countries (e.g., EEFSU), they may have considerable potential for extracting monopoly rents.

6. The issue of carbon leakage

The Kyoto Protocol refers specifically to the period centered about 2010. During this period, the onus for emission reductions falls on Annex 1. No specific obligations are imposed on countries outside Annex 1, and there is the possibility of "leakage". That is,

Figure 5.1 Percent of US Obligation Satisfied Through the Purchase of Emission Rights

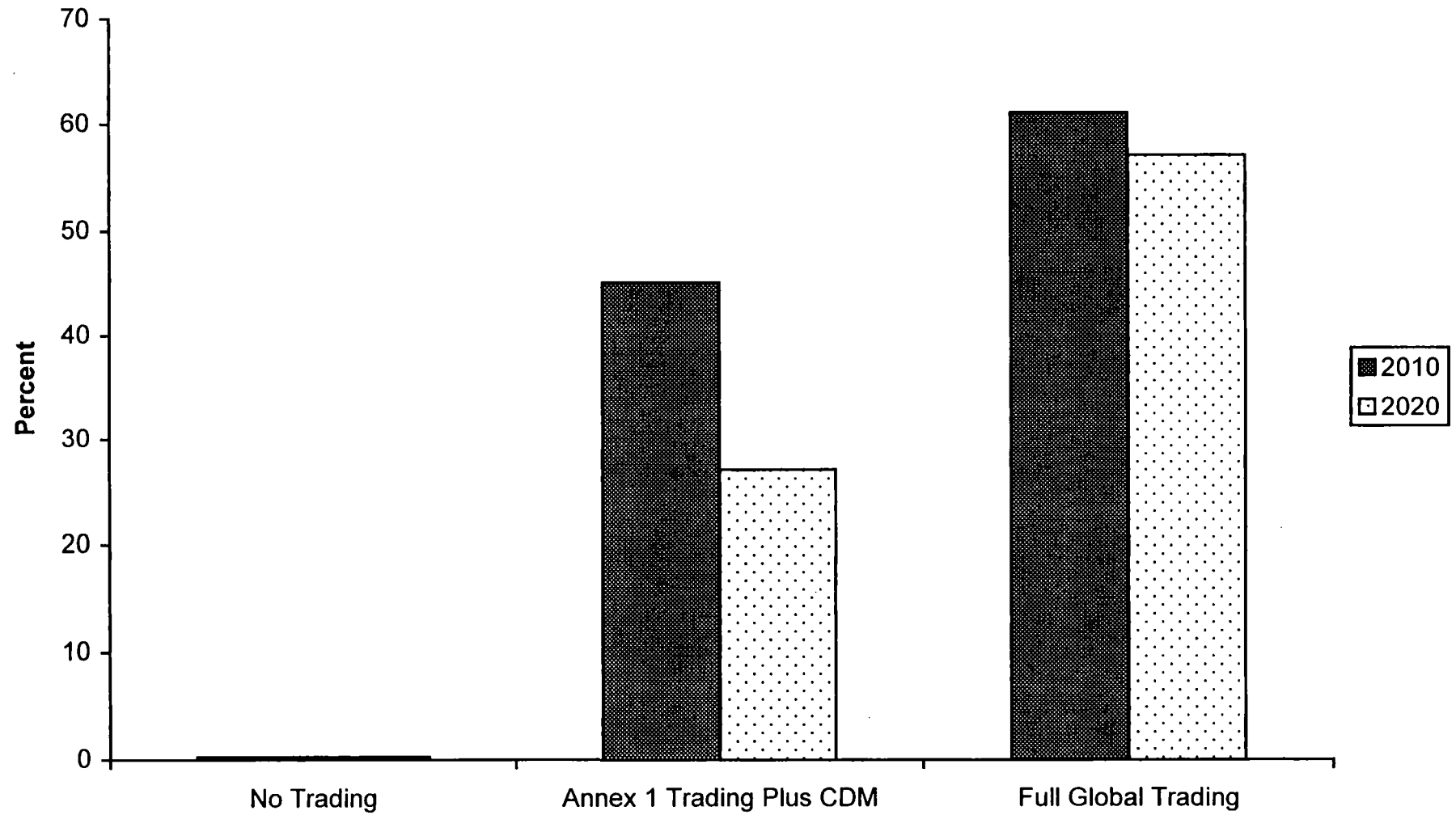


Figure 5.2 Incremental Value of Carbon Emission Rights With and Without Limits on the Purchase of Emission Rights -- Kyoto Forever

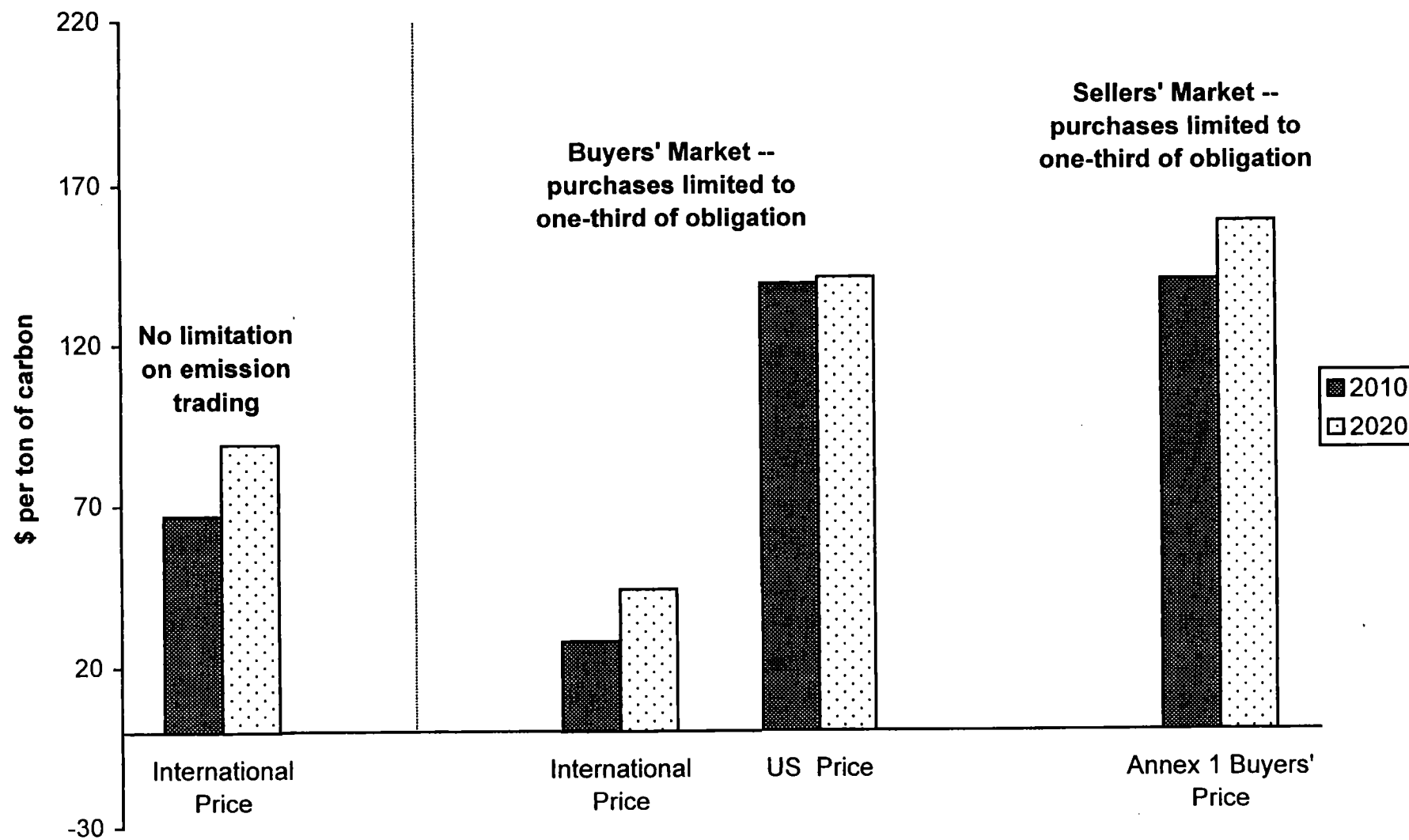
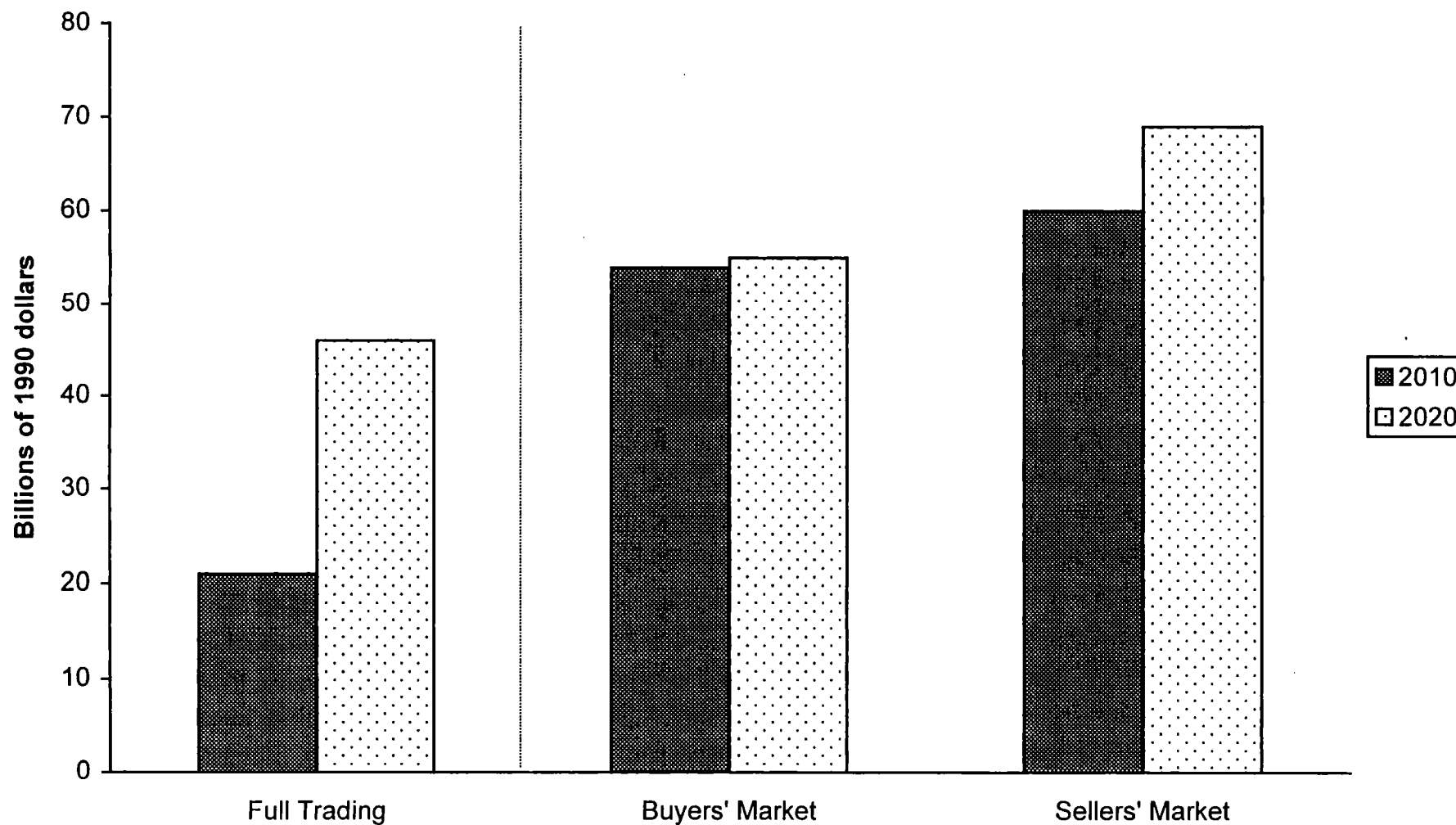


Figure 5.3 Annual US GDP Losses with Full Trading - Annex 1 May Satisfy Only One-Third of Obligation Through the Purchase of Emission Rights -- Kyoto Forever



the reductions in Annex 1 might be partially offset by increased emissions from China, India, Brazil and other countries that do *not* belong to Annex 1.

In this section, we examine the potential for leakage through international fuel markets and through the migration of energy-intensive industries. We therefore drop the assumption that non-Annex 1 countries are constrained to their reference case emissions. Two variants on the reference scenario are reported. In the first, the only trade impact of the Protocol consists of limiting the ability of the Annex 1 countries to import oil and gas. There is a lower international price of these goods, and there is a modest increase in price-induced demands by non-Annex 1 countries. However, there is no international trade in carbon emission rights, and there is no international migration of production within the energy-intensive sectors (EIS).

The second alternative is the same as the first, except that we now permit EIS trade. For a description of how the model has been modified to account for international trade in the energy-intensive sectors, see Appendix A. Figure 6.1 summarizes the overall results. According to this figure, neither of the two trade alternatives leads to a dramatic increase in carbon emissions outside Annex 1. Apparently there is an international leakage problem, but it appears to be of manageable dimensions.

Figure 6.2 suggests a somewhat different interpretation. Here we report the EIS trade scenario, and we compare the impact upon production-consumption ratios in each region. Under the reference case, these ratios are close to unity (the horizontal line) in most regions. The bars in Figure 6.2 show that the Protocol could lead to serious competitive problems for EIS producers in the USA, Japan and OECD Europe. The Protocol would lead to significant reductions in their output and employment, and there would be offsetting increases in regions with low energy costs. One can easily anticipate calls for protection against “unfair competition”. In its present form, the Protocol could lead to acrimonious conflicts between those who advocate free international trade and those who advocate a low-carbon global environment.

7. Evaluating Kyoto in the context of the longer-term goal

The objective of the Framework Convention is “the stabilization of greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system.”¹⁴ The drafters of the Protocol focused exclusively on the initial steps to be taken by Annex 1 countries. Little attention was paid to the ultimate goal. We now examine the Protocol in the context of a long-term stabilization objective.

From Figure 2.1 it is clear that the “Kyoto Forever” scenario will fail to stabilize global emissions and concentrations. A particular concentration target can be achieved through a variety of emission pathways. In this section, we explore three pathways for stabilizing concentrations at 550ppmv (twice preindustrial levels) by 2100. We stress, however, that the issue of what constitutes “dangerous interference” has yet to be determined. Indeed, it is likely to be the subject of intense scientific and political debate for decades to come. Hence, our choice of a target is meant to be purely illustrative.

**Figure 6.1 Carbon Emissions Outside Annex 1 --
Alternative Leakage Scenarios**

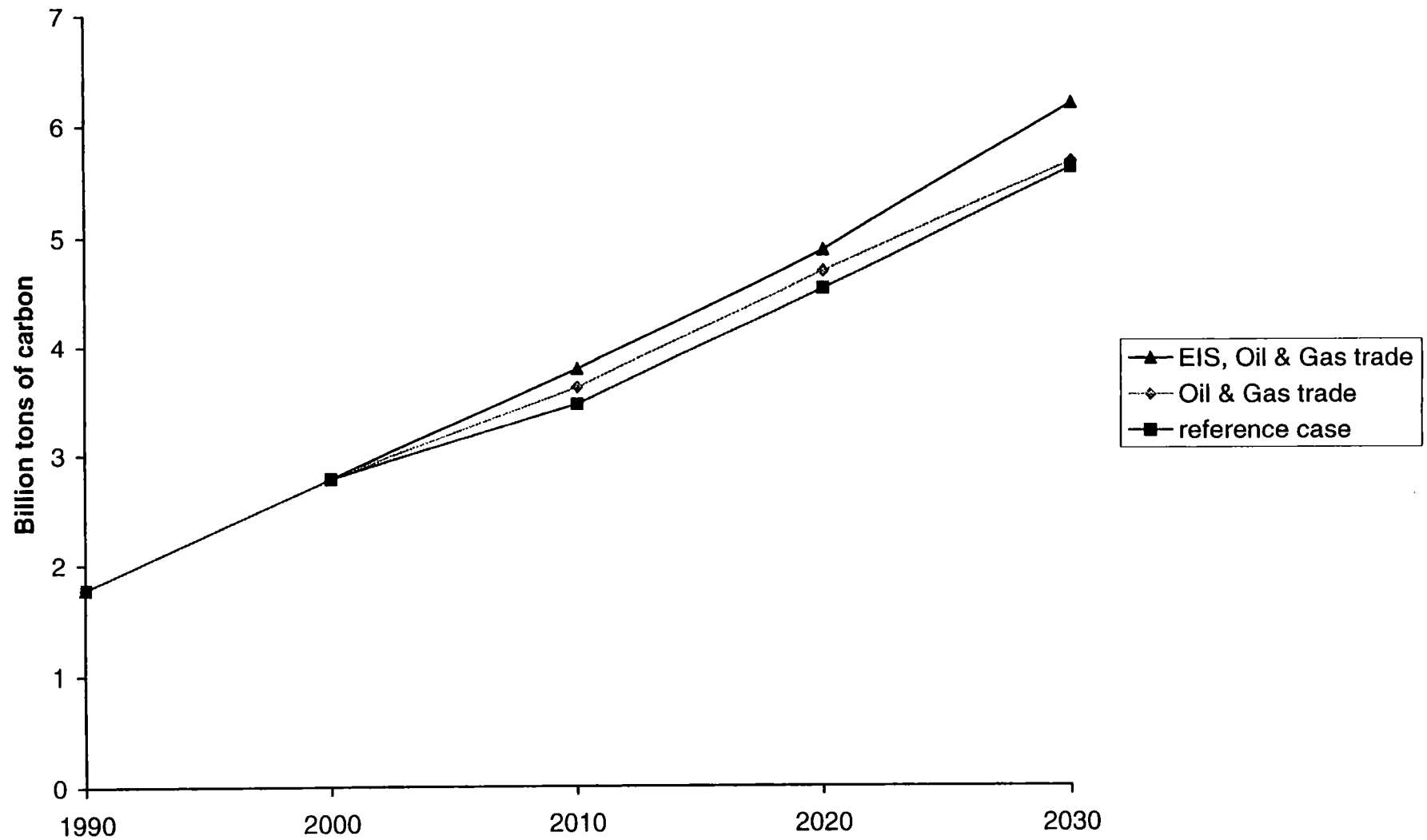
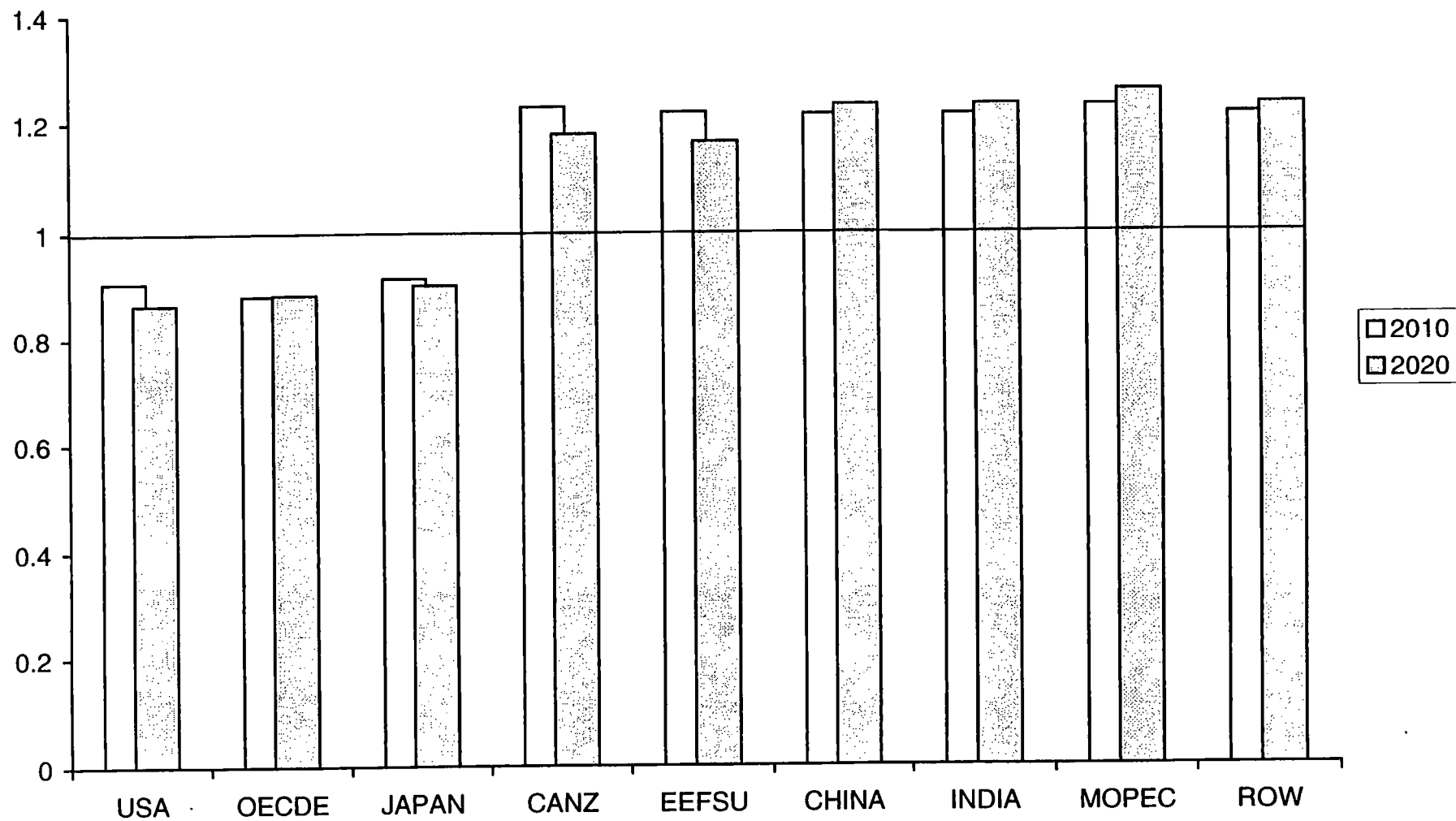


Figure 6.2 Ratios of Domestic EIS Supplies to Demands -- Kyoto with Leakage



Our three pathways are intended to illustrate the benefits of “when” flexibility. They are titled: 1) “Kyoto followed by arbitrary reductions”; 2) “Kyoto followed by least-cost”; and, 3) “least-cost”. As their names imply, the first two are designed to be consistent with the Protocol during the first commitment period. The third assumes a clean slate in the choice of emissions pathway throughout the 21st century.

For the first scenario, we assume that Annex 1 countries reduce emissions through 2030 at the same rate as the OECD during the first decade of the 21st century (2% per year). During this period, non Annex-1 countries are permitted to emit up to their reference case levels. By 2020, emissions in the developing nations are larger than those in Annex I. We then choose a pathway to stabilization which represents a relatively smooth transition to the target. As for the post-2030 burden-sharing scheme, we assume that between 2030 and 2050 all regions move to equal per capita emission rights (based on their 1990 population). Equal per capita emission rights have been proposed as one approach to international fairness, but there are others that might also serve to separate the issue of equity from that of economic efficiency.

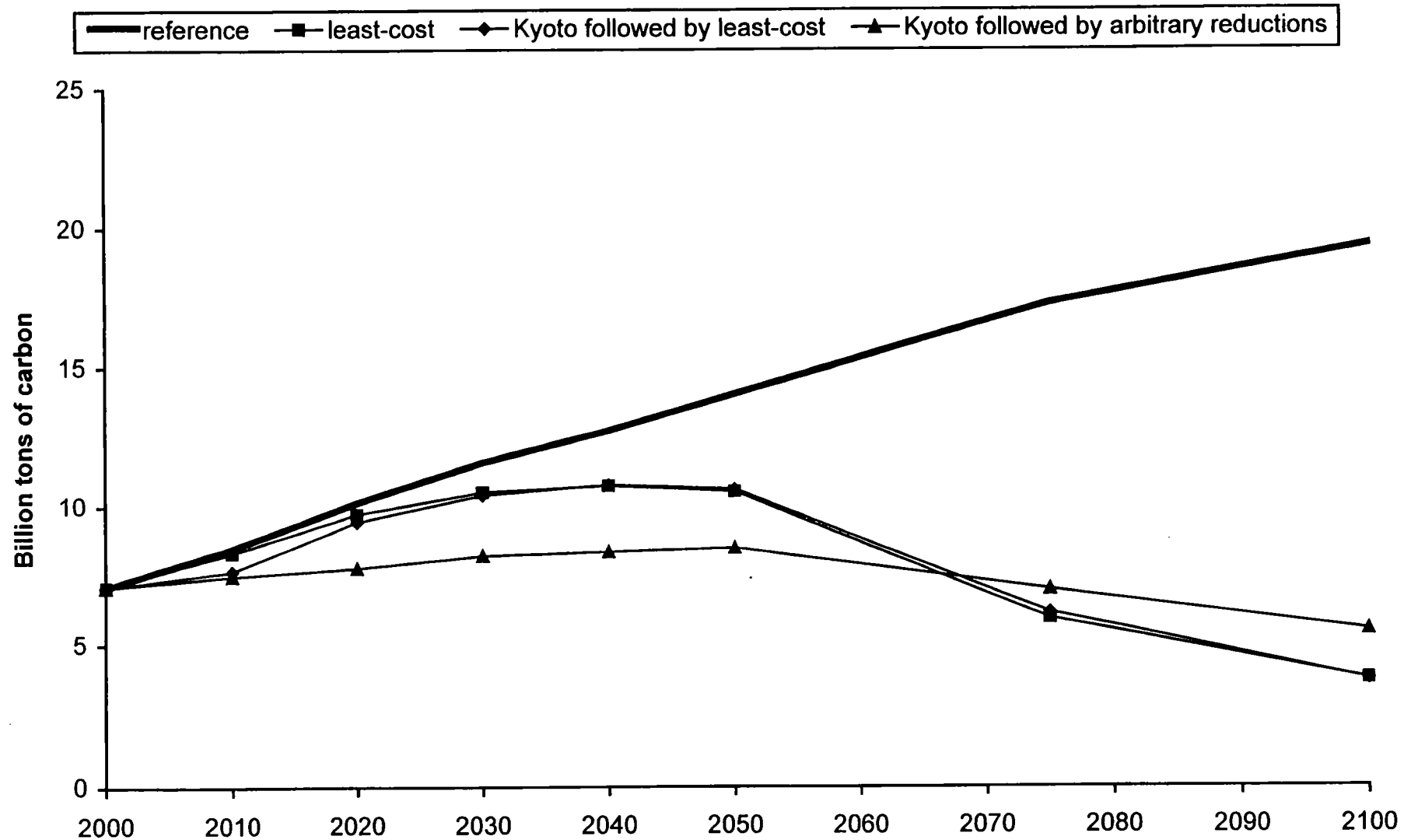
With “Kyoto followed by least-cost”, the Protocol is adopted for the initial commitment period. Thereafter, the most cost-effective pathway is followed for stabilizing concentrations at 550ppmv. With “least-cost”, the most cost-effective pathway for stabilizing concentrations at 550ppmv is followed from the outset. The latter two scenarios adopt the same proportionate burden-sharing scheme as the first.

All three scenarios assume Annex 1 trading plus the CDM. However, they differ as to the timing of developing country involvement in the international market for carbon emission rights. By definition, least-cost assumes that emission reductions will be made where it is cheapest to do so, regardless of the geographical location. Hence, in the least-cost scenario, we assume global emission trading from the outset. In the case of “Kyoto followed by least-cost”, we assume that global emission trading is delayed until after the first commitment period. With “Kyoto followed by arbitrary reductions”, global emission trading does not begin until 2030, the year that developing countries agree to lower their emissions below business-as-usual.

Global carbon emissions. Figure 7.1 shows global carbon emissions for the reference case and the three stabilization scenarios. Following a least-cost strategy from the outset results in an emissions pathway that tracks the reference path through 2010 and then departs at an increasing rate thereafter. There are several reasons why a gradual transition to a less carbon-intensive economy is preferable to one involving sharper near-term reductions.

Concentrations at a given point in time are determined more by cumulative, rather than year-by-year, emissions. Indeed, a concentration target defines an approximate carbon budget, i.e., an amount of carbon that can be emitted between now and the date at which the target is to be reached. At issue is the optimal allocation of the budget. Reasons for relying more heavily on the budget in the early years include: 1) providing more time for the economic turnover of existing plant and equipment, 2) providing more time to

Figure 7.1 Global Carbon Emissions -- Reference Case and Three Alternative Emission Pathways for Stabilizing Concentrations at 550ppmv



develop low-cost substitutes to carbon-intensive technologies, 3) providing more time to remove carbon from the atmosphere via the carbon cycle, and 4) the effect of time discounting on mitigation costs.¹⁵

We next turn to the two scenarios where we adopt the Protocol for the first commitment period. Notice that the two emission pathways behave quite differently post-2010. “Kyoto followed by least-cost” follows the least-cost pathway once the Protocol’s constraints are relaxed. “Kyoto followed by arbitrary reductions”, on the other hand, bears no resemblance to the least-cost pathway. What is striking about Figure 7.1 is that with a 550ppmv target, the Protocol is inconsistent with the most cost-effective mitigation pathway, i.e. “least-cost”. Indeed, it appears that the ultimate target would have to be considerably lower than 550ppmv for the Protocol to be justified in terms of cost-effectiveness.

Near-term losses. It is instructive to look at the incremental value of emission rights for the three stabilization scenarios (Figure 7.2). With the least-cost path, the value is relatively low in the early years (\$11 per ton of carbon in 2010), and it rises gradually over time. With “Kyoto followed by least-cost”, the value is \$130 per ton in 2010 and then tracks the least-cost path thereafter. In the case labeled “Kyoto followed by arbitrary reductions”, the incremental value of emission rights starts at about \$160 per ton and it remains high.

Figure 7.3 shows US GDP losses in 2010 and 2020 under the three stabilization scenarios. Notice that GDP losses in 2010 differ for the two scenarios involving the initial adoption of the Protocol. Because of the long-lived nature of energy investments, investors are concerned both with what happens in the initial commitment period and what happens thereafter. In the case of the more rapid transition away from the baseline (“Kyoto followed by arbitrary reductions”), investors will be forced to invest more heavily in high-cost substitutes in the early years. With “Kyoto followed by least-cost”, they will have more flexibility.

It is striking by how much GDP losses can be lowered under the “least-cost” scenario. This strategy involves a more gradual transition away from the baseline in the early years. It relieves much of the pressure for premature retirement of existing plant and equipment and for dependence on high-cost substitutes (both on the supply- and demand-sides of the energy sector). Relative to the reference case, the US also receives some benefits as an oil importer. Recall that a carbon constraint decreases the overall demand for oil and lowers its price on the international market.

Global losses. Finally, it is instructive to examine losses from a global perspective (Figure 7.4). For purposes of the present comparison, we focus on the present value of consumption losses over the 21st century discounted to 1990 at 5 percent. The relative magnitude of the cumulative losses for the three stabilization scenarios comes as no surprise given the previous discussion. “Kyoto followed by arbitrary reductions” is by far the most expensive of the three paths. “Kyoto followed by least-cost” is a considerable

Figure 7.2 Incremental Value of Carbon Emission Rights under Three Alternative Emission Pathways for Stabilizing Concentrations at 550ppmv -- Global Trading

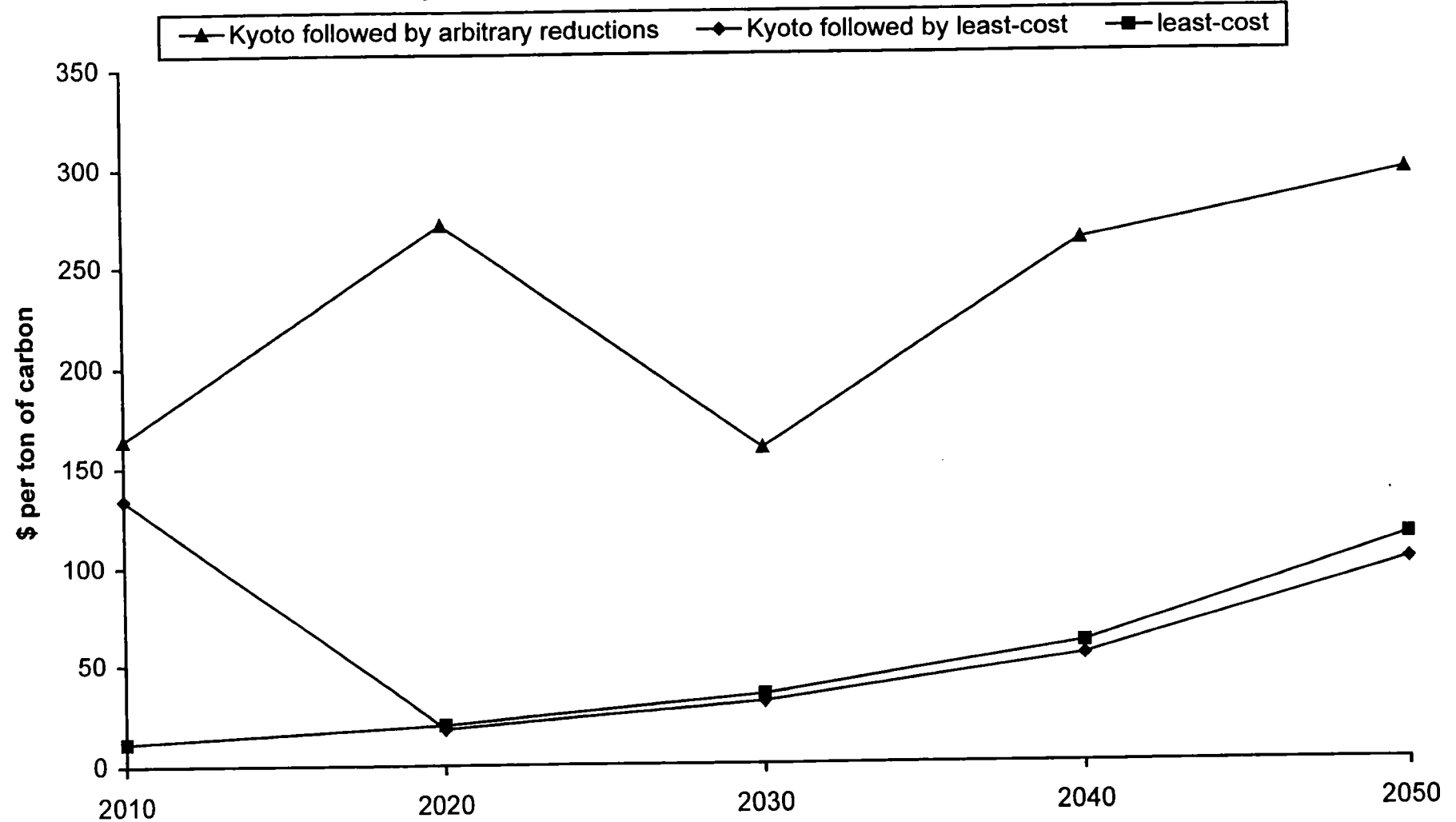


Figure 7.3 US GDP Losses Under Alternative 550ppmv Stabilization Scenarios

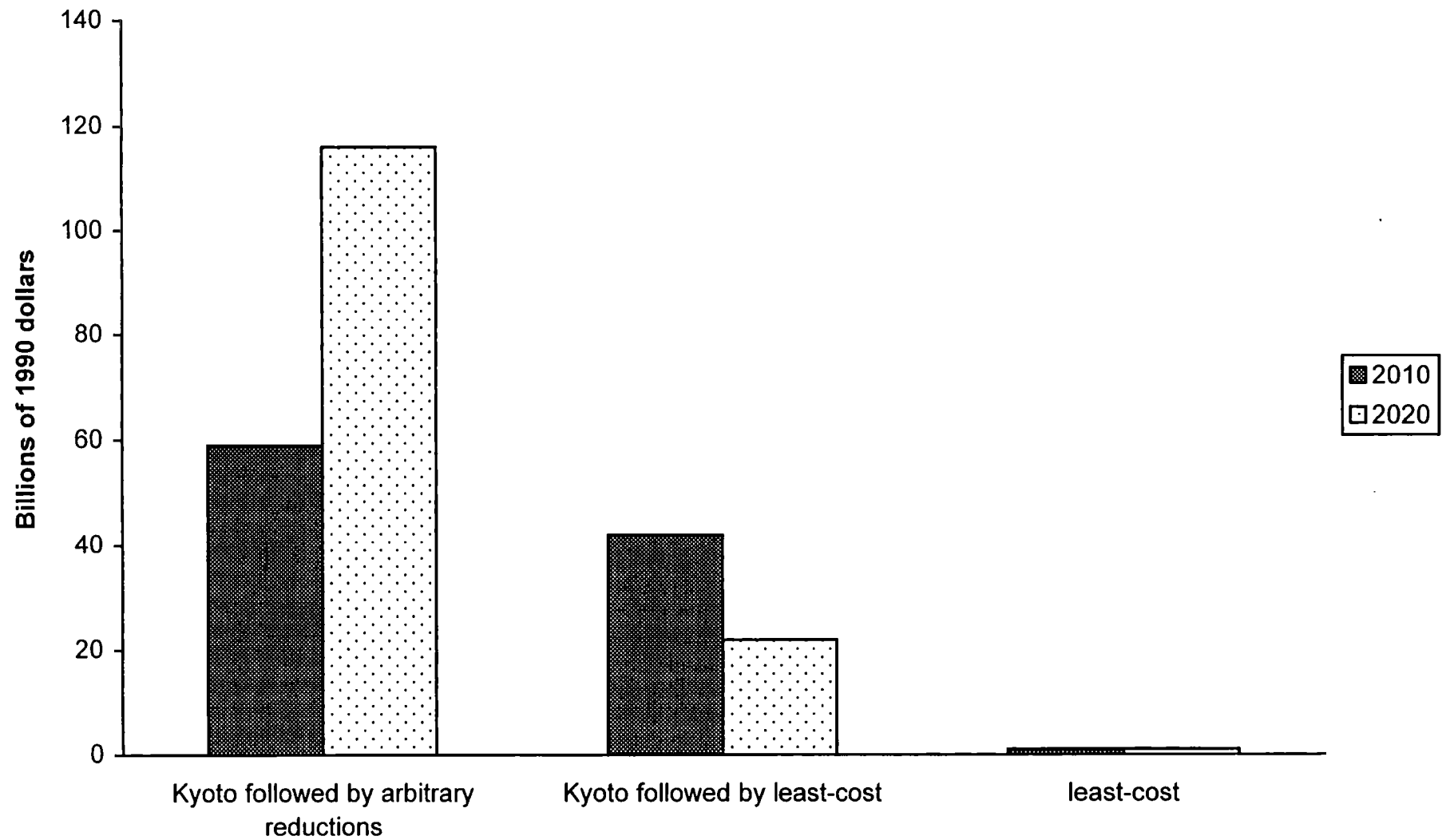
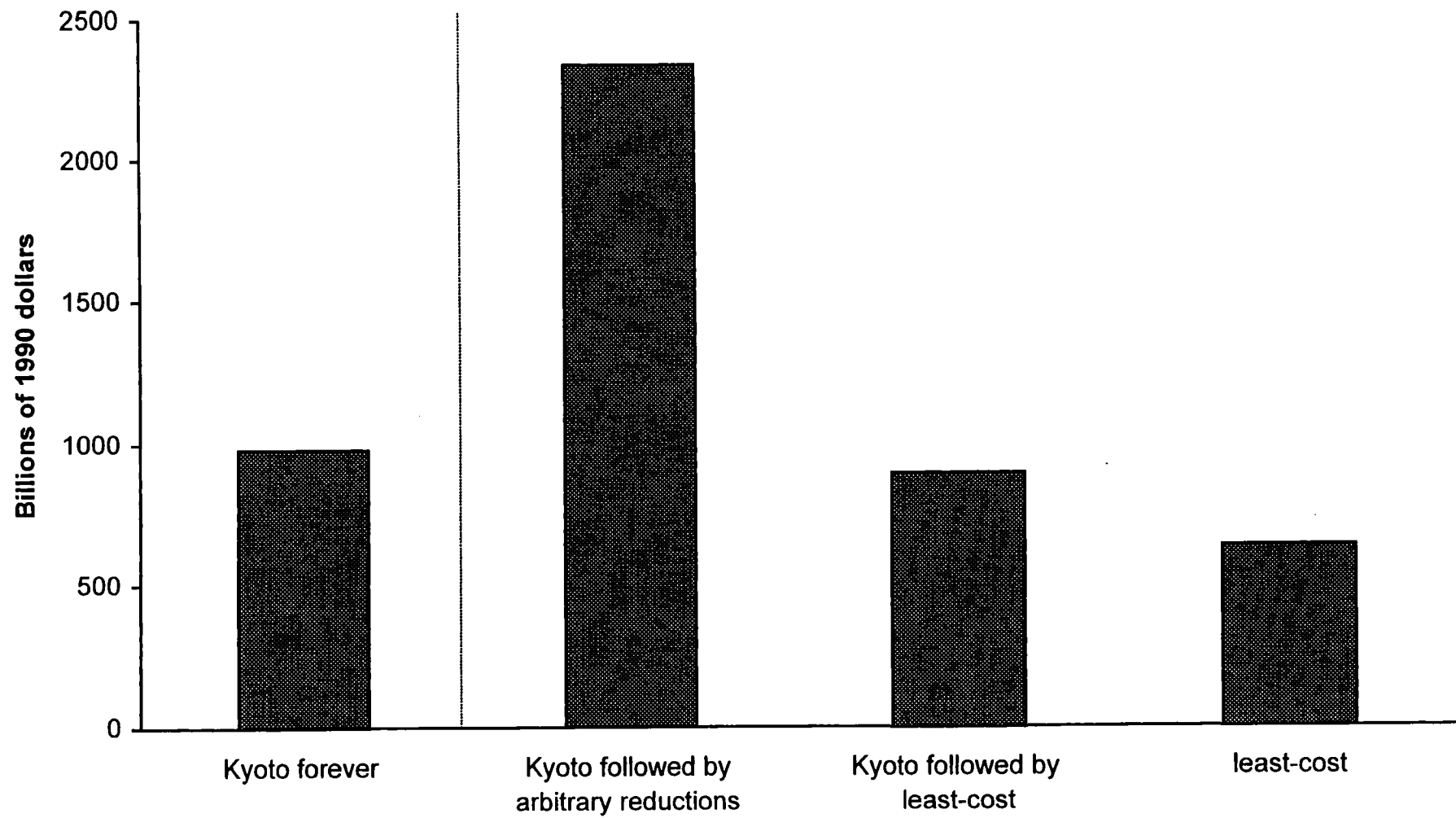


**Figure 7.4 Global Consumption Losses through 2100 Discounted to 1990 at 5% --
Kyoto Forever vs. Three Scenarios for Stabilizing Concentrations at 550ppmv**



improvement, but is still 40% more expensive than embarking on the most cost-effective mitigation pathway from the outset.

What is surprising is that “Kyoto Forever” turns out to be more expensive than “Kyoto followed by least cost” or “least cost”. “Kyoto Forever” results in sharper global emission reductions during the early decades of the 21st century. It does not, however, succeed in stabilizing emissions, much less concentrations. By contrast, the other scenarios all lead to stabilization at 550ppmv. In other words, “Kyoto Forever” ends up costing more, and it buys less long-term protection.

8. Further comments

Some suggest that models such as MERGE tend to *overestimate* the costs of mitigation. They argue that, when prospects for technical progress are incorporated, the costs of a carbon constraint, even a sharp near-term constraint, will be minimal. We, too, are optimistic about the outlook for technical innovation. Indeed, such innovation is embedded both in our reference case and in the policy scenarios. The disagreement is over the rate at which such progress will occur. We do not believe that economically competitive substitutes will become available at such a rate as to trivialize the costs of a Kyoto-like Protocol.

A more valid concern may be that we are *underestimating* the costs of a carbon constraint. There are several reasons why this may be the case. To begin with, optimization models assume that decision makers have perfect foresight. That is, they assume that investors are fully informed about the nature of future constraints, and act accordingly. Given the present state of uncertainty, this is highly unlikely. Models such as MERGE also tend to ignore short-term macro shocks. For example, the higher energy prices brought about by a carbon constraint are likely to be inflationary. If this leads to higher interest rates, investment may be dampened. The result would be a slowdown in economic growth.

In addition, we assume that policies will be efficient. That is, market mechanisms will be chosen over “command and control” approaches to accomplishing environmental objectives. Whereas, in recent years, there has been an increasing trend toward market mechanisms, the approach to be taken with climate policy is by no means assured. Moreover, even if such a commitment were made, we have no assurances that the requisite international institutions will be available when needed.

Although it is easy to quibble over the numbers, the real value of analyses lies more in insights than in numerical values. And, indeed we believe that the current exercise has yielded several insights that may be of value to those charged with interpreting the current proposal. Here, we summarize what we have learned:

- First, it is extremely unlikely that a “Kyoto Forever” scenario will stabilize emissions -- much less concentrations. Non-Annex 1 emissions are quickly overtaking those of the OECD and the economies in transition. Hence, meeting the stabilization goal of

the Framework Convention will eventually require the participation of developing countries.

- International cooperation through trade in emission rights is essential if we are to reduce mitigation costs. The magnitude of the savings will depend on several factors. These include the number of countries participating in the trading market, the shape of each country's marginal abatement cost curve, and the extent to which buyers can satisfy their obligation through the purchase of emission rights.
- With regard to the latter, limitations on the purchase of emission rights may be especially costly. In the example explored here, limiting purchases to one-third of a country's obligation increased GDP losses by a factor of at least two and one-half in the year 2010. If proponents of such limitations are successful, they may seriously reduce the benefits from "where" flexibility.
- The issue of monopoly power in markets for emission rights may turn out to be important. This is most likely to occur if trading is limited to Annex 1 and the majority of inexpensive emission rights are concentrated in a small number of countries. If these countries were successful in organizing a sellers' cartel, they might be able to extract sizable rents.
- The near-term costs of the Protocol will depend on expectations regarding the future. Energy investments are typically long-lived. Today's investment decisions are not only influenced by what happens during the next decade, but also by what happens thereafter. Hence, analyses which focus solely on 2010 may be underestimating the costs of Kyoto.
- Finally, and perhaps most importantly, unless the concentration target for CO₂ is well below 550ppmv, the Protocol appears to be inconsistent with a cost-effective long-term strategy for stabilizing CO₂ concentrations. Rather than requiring sharp near-term reductions, it appears that a more sensible strategy would be to make the transition at the point of capital stock turnover. This would eliminate the need for premature retirement of existing plant and equipment and would provide the time that is needed to develop low-cost, low-carbon substitutes.

References

- ¹ Conference of the Parties (1997). "Kyoto Protocol to the United Nations Framework Convention on Climate Change", Third Session Kyoto, 1-10 December.
- ² 105th Congress, 1st Session (1997), S. Res. 98.
- ³ Intergovernmental Negotiating Committee for A Framework Convention on Climate Change (1992). Fifth Session, Second Part, New York, 30 April-9 May.
- ⁴ IPCC (1997). "Stabilization of Atmospheric Greenhouse Gases: Physical, Biological and Socio-Economic Implications", Technical Paper III.
- ⁵ Intergovernmental Negotiating Committee for A Framework Convention on Climate Change (1992), op. cit.
- ⁶ Manne, A., Mendelsohn, R., and Richels, R. (1995). "MERGE: a model for evaluating regional and global effects of GHG reduction policies", *Energy Policy*, 3 (1).
- ⁷ Manne, A., and Richels, R. (1995). "The Greenhouse Debate: economic efficiency, burden sharing and hedging strategies", *The Energy Journal*, 16 (4).
- ⁸ IPCC (1994). *Climate Change 1994*, Cambridge University Press.
- ⁹ Conference of the Parties (1997). "Kyoto Protocol to the United Nations Framework Convention on Climate Change", op. cit.
- ¹⁰ Richels, R., Edmonds, J., Gruenspecht, H., and Wigley, T. (1996). "The Berlin Mandate: The Design of Cost Effective Mitigation Strategies", EMF-14, Working Paper 3, Stanford University, Stanford, CA.
- ¹¹ Conference of the Parties (1997). "Kyoto Protocol to the United Nations Framework Convention on Climate Change", op. cit.
- ¹² Conference of the Parties (1997). "Kyoto Protocol to the United Nations Framework Convention on Climate Change", op. cit.
- ¹³ 105th Congress, 1st Session (1997), S. Res. 98.
- ¹⁴ Intergovernmental Negotiating Committee for A Framework Convention on Climate Change (1992), op. cit.
- ¹⁵ Wigley, T., Richels, R., and Edmonds, J. (1996). "Economic and Environmental Choices in the Stabilization of Atmospheric CO₂ Concentrations", *Nature*, Vol. 379, 18 January.

Appendix A. Modeling international trade in the energy-intensive sectors

MERGE 3.0 has recently been modified to include the possibility of trade in EIS (energy-intensive sectors). EIS is an aggregate including ferrous and non-ferrous metals, chemicals, nonmetallic minerals, paper, pulp and print. This aggregate does not include the energy-intensive industry of petroleum refining. The model may be run either with or without EIS trade.

The new feature is introduced in a way that preserves the basic simplifying characteristics of the ETA-MACRO submodel. That is, energy, capital and labor are substitutes that enter into an aggregate production function. They produce a numeraire good which may be used for consumption, investment and interindustry payments for energy costs.

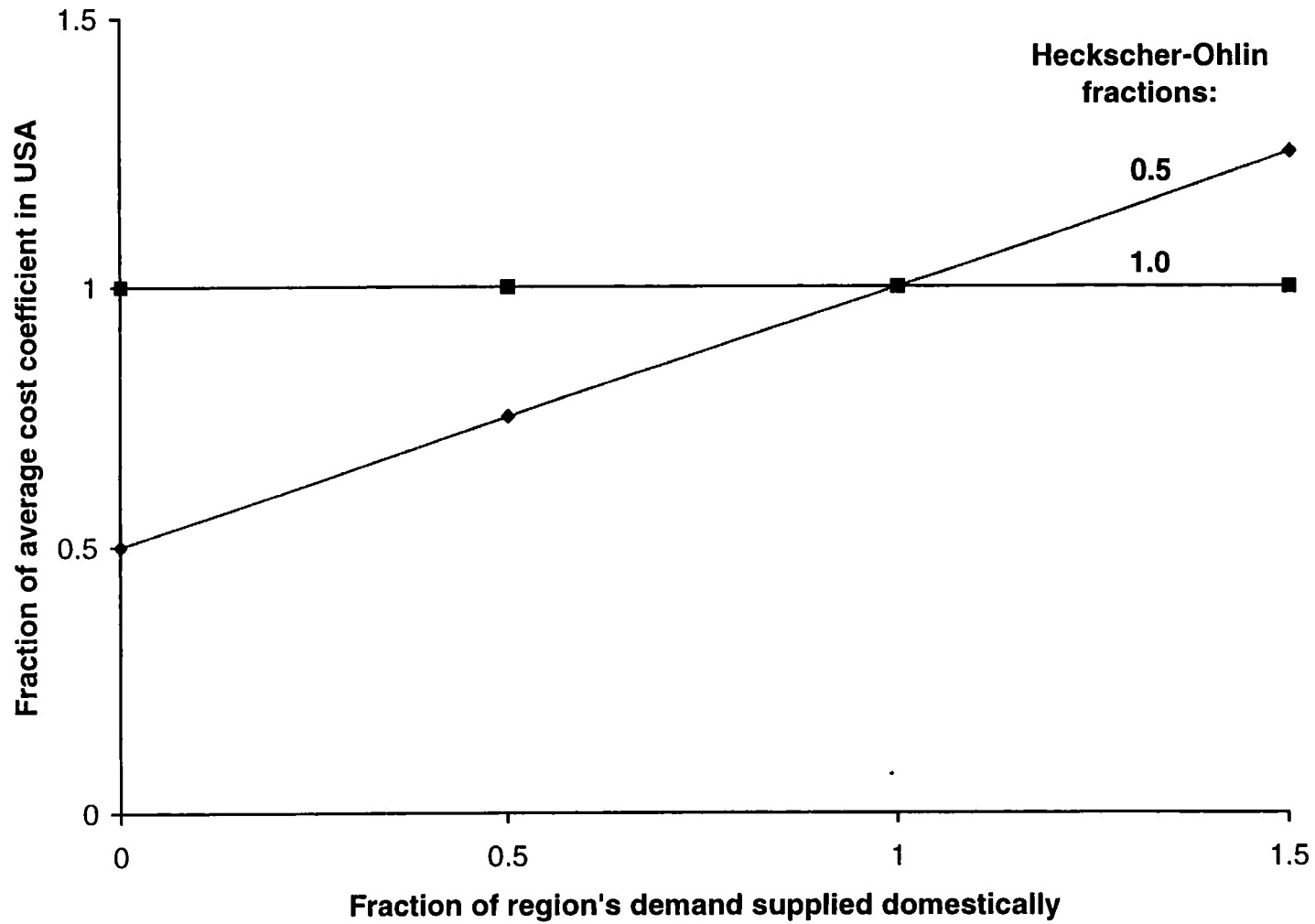
It is assumed that trade will continue to represent a relatively small amount of each region's total internal demand for EIS. The GTAP (General Trade Analysis Program, 1992) data base is employed to estimate each region's EIS demands. In all other respects, the model is the same as MERGE 3.0.

For projecting the impact of the Kyoto protocol, each region is taken to be self-sufficient at base year energy prices. Changes in the location of production are attributed primarily to changes in the cost of energy. At base year prices in the USA, 85% of the cost of EIS consisted of non-energy inputs (labor, shipping, capital, iron ore, etc.), and 15% of the cost consisted of energy inputs (half electric and half non-electric). Under these conditions, a doubling of energy prices would imply only a 15% increase in the cost of EIS. This is why it is assumed that the demand for EIS is inelastic with respect to the price of energy. For projecting future demands, the income elasticity is taken to be 0.5.

For modeling purposes, we have supposed that the marginal supplies of EIS in all regions are determined by the same international technology that prevails in the USA. Each region has the same energy-EIS production ratio. For non-energy inputs, each supply curve is linear. Its positive slope serves the same purpose as an Armington elasticity describing substitution between foreign and domestic goods. This is the way in which we avoid penny-switching as a characteristic solution mode.

The slope of the non-energy supply curve is described as a Heckscher-Ohlin fraction. If this fraction is unity, EIS is viewed as a perfectly homogeneous commodity. Small changes in energy costs will then lead to large changes in the international location of production. If this fraction is less than unity, the supply function is less elastic, and the changes in location will be less dramatic. (See Figure A.1.)

**Figure A.1 EIS Supply Curves --
Marginal Cost of Non-Energy Inputs to EIS**



July 3, 1997

To: Janet Yellen, Alicia Munnell

Cc: Jay Shogren, Mark Mazur,
Tom Rhoads, Cristian Santesteban, Quindi Franco

From: Jeff Frankel

Re: Climate Change, "Technology", and Prices

It appears that two engineering-based studies have just been, or are about to be, released -- both fitting into our "wishful thinking" category. They are being widely touted. Janet: Jack Gibbons asked me to pass on to you the enclosed one-pager on the DOE/Labs study. The other study, co-sponsored by Alliance to Save Energy, Tellus and others, was touted by John Holdren at a recent State Department lunch (a summary from Quindi and Tom is enclosed). The Vice President mentioned one of these studies to me at my swearing-in.

Meanwhile, I have had Quindi and Cristian doing some econometrics on Energy Efficiency Improvement numbers (memo enclosed, though I am not sure whether it is in final form). It seems to support my prior expectations, that **we can claim to be technology optimists, in the sense of the EEI bang one gets per change in energy prices**. It's just that we don't think you get much without a change in price. (Let me remind you that this definition of technology is not remotely what economists would call technological change. In addition to true innovation, it includes dissemination of existing technology, substitution among well-known technologies, the switch from manufacturing to services, and energy conservation. In short, it is everything.)

- ? (
- * The point estimate of the truly autonomous component of EEI is only .54-.63 per cent per year, generally not statistically significant, but near the .6-.7 range that our outside reviewers cite.
 - * The price elasticity is highly significant.
 - * Adjustment is gradual, so that the long-run elasticity is 20 times the one-year elasticity.
 - * When one includes government spending on energy R&D, its effect on EEI is insignificant.
 - * The "simulation" that Quindi and Cristian carried out (see graph at the back) suggests that under our assumptions, we get a slightly more rapid path of energy saving for a somewhat lower carbon tax than in the IAT results. The main point is that we think that our relative emphasis on the price component vs. the truly autonomous component of EEI is based on better economics, and is more likely to lead to good policy, than some others'. But it is nice that the bottom line is one that our green friends should like!

I think we want to verify and refine these results a bit more before using them, but I hope you agree that they are very suggestive.

Re: DOE/Labs Study

Attachment 2.

U.S. CARBON REDUCTIONS BY 2010 AND BEYOND

The Potential Impact of Energy-Efficient and Low-Carbon Technologies

CONCLUSION: Technology can lower the cost of stabilizing carbon emissions at 1990 levels in the medium term (i.e. 2010) to \$10 billion a year or less (0.1% of GDP). The study did not consider international trading or more flexibility in meeting the stabilization target, which could reduce costs by another 50% or more. The study assumes penetration of technologies from expanded Administration initiatives, such as the Partnership for a New Generation of Vehicles.

BACKGROUND: Five DOE national laboratories led by Oak Ridge and Lawrence Berkeley labs have conducted a comprehensive, peer-reviewed, 9-month "bottom-up" analysis of the role technology can play in stabilizing U.S. carbon emissions. It is the most authoritative and documented study of this subject since the National Academy of Sciences report in 1992 and the Office of Technology Assessment Report in 1991. The study documents in detail how four key sectors of the economy—buildings, transportation, industry, and electric utilities—could respond to the same climate scenario being modeled by the interagency team: a climate treaty is launched in the year 2000 with a goal of stabilizing in 2010, and a cap and trade system is phased in with gradually rising permit prices. The lab study examined what an aggressive program of research, development, and deployment of clean technologies could have combined with a marginal permit price of \$50/ton of carbon (the average permit price is much lower).

RESULTS: The study concludes that energy efficiency and low-carbon technologies have a very large potential to cost-effectively reduce U.S. carbon emissions while meeting the full energy needs of U.S. businesses and families. Many consumers will save money. Current projections suggest that a carbon emissions reduction of 380 million metric tons (MMT) is required to stabilize U.S. emissions in 2010 at 1990 levels. Under moderate technology and market assumptions, energy efficiency technologies alone can reduce emissions in 2010 by 120-190 MMT. This level of carbon reductions estimated to be possible at little or no net cost—that is, the energy bill savings exceed the investments required to achieve the carbon savings. Under more aggressive assumptions, a combination of energy efficiency, low-carbon technologies and relatively inexpensive coal power plant conversions to natural gas can reduce 2010 emissions by 340-390 MMT. The net cost of reductions of this magnitude is estimated to be on the order of \$10 billion per year in 2010 (0.1% of GDP). These low costs are due to the net savings resulting from investments in many of the technologies considered.

METHODOLOGY: In contrast to the current top-down economic modeling of the interagency team, the five laboratory study uses a bottom-up technology-by-technology assessment as well as a top-down engineering-economic modeling approach. It draws upon a wide variety of technology cost and performance information to assess potential impacts. It has been peer-reviewed by industry experts. A utility sector analysis quantifies the impacts of end-use efficiency improvements on utility carbon emissions, potential emissions reductions through operations changes, and the costs of converting coal power plants to natural gas. Finally, a number of promising very low carbon technologies are examined to determine their potential for emissions reductions, including advanced gas turbines in industry, biomass/biofuels energy, and improved aluminum smelting.

TOTAL BENEFITS EXCEED TOTAL COSTS: In the long term, these climate change mitigation actions will provide additional benefits not fully considered in the study—reductions in criteria air pollutants (i.e. ozone and fine particles), decreased dependence on foreign oil, greater industrial productivity, and U.S. leadership in technologies likely to be a major source of international trade and jobs in the next century.

CHOOSING OUR ENERGY FUTURE

The Present Path

National energy consumption rises from 85 Quads in 1990 to 105 Quads in 2010 and 119 Quads in 2030.

Economic growth averages 2.2% per year under *Present Path* assumptions.

In spite of economic growth, many job opportunities are lost due to energy waste and rising oil imports.

National energy bill rises to \$650 billion in 2010 from \$540 billion in 1990.

Fossil fuels, which account for 85% of U.S. energy use today, still account for 85% in 2010.

The United States remains fossil-fuel dependent for the foreseeable future, with renewable resources meeting only 11% of our energy needs in 2030.

Petroleum use rises from 17 Mbd (million barrels of oil per day) to 21 Mbd in 2010 and 25 Mbd by 2030.

U.S. oil import bill rises to \$104 billion annually by 2010, continuing to add to our trade deficit and drain the economy.

Energy intensity of the U.S. economy declines at 1.1% per year.

Air pollution from nitrogen oxide (NOx) emissions persists with little change from present level of 20 million tons per year.

Sulfur dioxide (SO₂) emissions decline only slowly, from 19 million tons annually today to 13 million tons by 2010.

Global warming emissions of carbon dioxide (CO₂) rise steadily from 1338 MTc (million metric tons of carbon per year) in 1990 to 1621 MTc in 2010 and 1892 MTc in 2030.

The Innovation Path

National energy consumption held to 89 Quads in 2010 and is cut to 69 Quads in 2030.

Economic growth averages 2.2% per year under the *Innovation Path*.

Energy savings result in job creation, with a net employment boost of nearly 800,000 jobs nationwide by 2010.

National energy bill held to \$560 billion in 2010. Net savings amount to \$530 per household per year in 2010.

Fossil fuel dependence drops to 79% by 2010 and down to 68% by 2030.

The country starts a clear transition toward renewable resources, which meet 14% of U.S. energy use needs by 2010 and 32% by 2030.

U.S. petroleum use trimmed to 16 Mbd by 2010 and then drops to 12 Mbd by 2030.

Oil import bill cut to \$83 billion by 2010, saving \$21 billion per year that would be otherwise largely lost to the economy.

U.S. energy intensity declines at 1.9% per year, falling 32% by 2010.

NOx air pollution is reduced 24% below the 1990 level by 2010, falling to 15 million tons per year.

SO₂ pollution is reduced 64% below the 1990 level by 2010, dropping to 7 million tons per year.

U.S. CO₂ emissions are cut to 1207 MTc; 10% below the 1990 level, by 2010 and reductions continue, pushing emissions down to 728 MTc, or 45% below the 1990 level, by 2030.



Memorandum

To: Jeff Frankel, Jason Shogren
From: Quindi Franco, Tom Rhoads
Date: July 2, 1997
Subject: **Review of *Energy Innovations, A Prosperous Path to a Clean Environment*¹**

Summary

This summary is based on the executive summary (full report is scheduled for release sometime mid-July). As such, specifics on the analysis are superficial at best. The study shows that CO2 emissions by 2010 can be reduced to 10 percent below 1990 levels at a net benefit to the economy, reducing annual energy costs by \$530 per household and creating nearly 800,000 net jobs. All of this by enhancing energy efficiency, using new technologies, and tapping into domestic renewable resources through a set of sector specific, revenue neutral policies.

The "Innovation Path" -- Policies & Technologies

The study analyzes a set of policies that can "put the U.S. on an innovative, prosperous path leading to an economically and environmentally sustainable future... The approach involves setting fair performance standards, creating incentives, providing better information, and reducing transaction costs in order to foster investments in clean and efficient technologies." The set of policies does not include an economy wide carbon or energy tax. Rather, the policies are sector specific (transportation, buildings, electricity, industry), and present no net increase in taxes or fees within any sector.

Examples of Sectoral Policies:

- Renewables Content Standards A credit-trading system requiring increasing percentages of electricity & motor fuels to come from renewable sources.
- Emissions Performance Allowances Caps on emissions of sulfur dioxide, nitrogen oxides, and carbon dioxide, with emissions allowances allocated to generators in proportion to their electrical output.
- Advanced Vehicles Initiative Stronger fuel economy and emissions standards, backed by rebates paid for by fees on gas guzzlers, market introduction programs and technology R&D.
- Investment Tax Credit 10 percent tax credit for investments in new manufacturing equipment, paid for by fees on purchased energy.

¹ "Energy Innovations, A Prosperous Path to a Clean Environment," by Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, Tellus Institute, and Union of Concerned Scientists, June 1997.

- Market Introduction Incentives Technology demonstrations, manufacturer incentives, consumer education, and “market innovations” to reduce transactions costs.

Technologies Developed: fuel cells, advanced gas turbines, integrated green building designs, membrane technology, fuels and electricity from biomass, advanced wind turbines, photovoltaic modules.

Analysis

The National Energy Modeling System (NEMS) and the Long-range Industrial Energy Forecasting (LIEF) model were used to represent the different energy sectors. Results were then fed into a macroeconomic model (IMPLAN) to project GDP, wage, and employment impacts. NEMS and IMPLAN are federal government models. *Details as to how energy diffusion and innovation (and the costs associated with them) were modeled are unclear from information released so far.*

Results:

Along the “innovation path” (full adoption of the policy approaches described above), primary energy consumption is 15 percent lower than the present path by 2010, and 42 percent lower by 2030. CO₂ emissions are 10 percent below 1990 levels by 2010. Oil and coal use decline, and an increasing share of energy is supplied from renewable sources (14% of energy need by 2010, almost doubling energy output from renewable sources). Wages, GDP, and employment all improve in the innovation path over the baseline.

Economic Benefits of “Innovation Path” (\$1993, versus business as usual)

	2000	2010
Incremental Investments (B\$)	28	73
Fuel Cost Savings (B\$)	38	131
Net Savings per Household (\$)	100	530
Avoided Petroleum Imports (B\$)	5	21
Cumulative Investments (B\$)	89	588
Cumulative Savings (B\$)	96	1005
Cumulative Benefit/Cost Ratio	1.1	1.7
Net Employment	n/a	773,000
GDP (B\$)	n/a	2.8
Income (B\$)	n/a	14

Memorandum

TO: Jeffrey Frankel, Jason Shogren
FROM: Quindi Franco, Cristian Santesteban
DATE: July 2, 1997
RE: Energy Efficiency, Energy Prices & AEEI Revisited

As you requested, we ran a series of regressions to look at the relationship between energy efficiency (E/GDP), energy prices, energy R&D, and time. We then constructed a small scenario to illustrate differences between our estimates and those of the IAT. After re-running the numbers in the scenario, our results have changed significantly from a previous memo (June 30). We are confident the numbers presented below are accurate. In brief, we find that while the total (price and time) impact of the our estimates is similar to the IAT results, the portion due to prices (and therefore the costs involved) is much greater.

Analysis of Historical Data

Geometric Lag Regression:

$$\ln(E/GDP_t) = \beta_0 + \beta_1 \ln(\text{Energy Price Index}) + \beta_2 \ln(E/GDP_{t-1}) + \beta_3(\text{Time})$$

Where the energy price index is a relative index of the CPI Energy Price Index over the general CPI. Data from 1959 through 1995.

Variable	Coefficient (std. error)
Price Elasticity (β_1) Short Run	-0.03855 (0.008)
Long Run	-0.76832
Lagged Energy Efficiency (β_2)	0.949 (0.042)
Time Trend (β_3) Short Run	-0.00031 (0.0006)
Long Run	-0.00627
$R^2 = .99$	

AEEI = 6.3 %/yr

Energy R&D:

$$\ln(E/GDP_t) = \beta_0 + \beta_1 \ln(\text{Energy Price Index}) + \beta_2 \ln(E/GDP_{t-1}) + \beta_3(\text{Energy R\&D Intensity}) + \beta_4(\text{Time})$$

Where Energy R&D intensity is government funded Energy R&D over total R&D. Various forms of Energy R&D data (real R&D expenditures, and various lag times) generate roughly the same non-statistically significant results. This could be because our aggregate energy R&D

figures include substantial funding for energy production technologies; we are not isolating the component of Energy R&D that is specifically efficiency related.

Variable	Coefficient (std. error)
Price Elasticity (β_1) Short Run	-0.03075 (0.014)
Long Run	-0.71051
Lagged Energy Efficiency (β_2)	0.9567 (0.043)
Energy R&D (β_3) Short Run	-0.00619 (0.00878)
Long Run	-0.14307
Time Trend (β_4) Short Run	-0.00024 (0.00062)
Long Run	-0.00544
$R^2 = .99$	

Scenario:

CEA CASE A \$100 per ton carbon tax is levied on all fuels in 1995; we assume this causes a 30% increase in energy prices (range in literature is 15% to 200%). Initial E/GDP of 13.45 (000btu/\$) in 1995, and a time horizon of 1995-2010. The long-run impact of the price increase is fully incorporated by 2010. The simulation uses the original regression estimates excluding energy R&D (lines 1 and 6 in the graph). Over this time period, the CEA estimated time effect is equivalent to an annual AEEI of 0.23 percent.

IAT CASE IAT results are from the most recent Markal-Macro simulations for stabilization at 1990 levels by 2010 under a 1.25% annual AEEI (5). This is a complex policy scenario and should only serve as a rough comparison to our simulation (the model estimates an implicit carbon tax of \$144 in 2010). The impact of the IAT AEEI assumptions (1.0% -- #2, 1.25% -- #3, and 1.75% -- #4) have been modeled continuously throughout the period (some IAT runs assume the rate starts at 1% in 2000, and increases to 1.25/1.75 by 2010).

Component	Drop in E/GDP (percent)	
	CEA	IAT
Time Effect (AEEI)	0.45 (23%) (1) in graph	2.31 (67%) (3) in graph
Price Effect (CEA)	3.1 (87%) from regression	-
Price + Other	-	1.14 (33%) implicit
Total	3.55 (6) in graph	3.45 (5) in graph

PHIL
TSENG
DOE
586-
3892

Energy Efficiency Improvements

