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MEMORANDUM

TO: Snowmass Workshop Participants
FROM: Rob Stavins RS
DATE: August 15, 1998
RE: ***Carbon Sequestration***

Following my whirlwind (and, I suspect, barely intelligible) comments on Rob Mendelsohn's paper on "carbon sinks" at last week's NBER-Yale Global Change workshop in Snowmass, Colorado, a number of you asked me for copies of my slides.

So, here are the slides, plus a forthcoming article to which I referred in my comments on Rob's paper. And thanks again for participating in the workshop.

cc: JY
JH
SBF
[illegible]

Enclosure

Comments on

"Carbon Sinks: Management Tool or Bottomless Pit"
by Robert Mendelsohn

for

Workshop on Design of Climate-Change
Policy Instruments and Institutions
Yale University/NBER, Snowmass, CO, August 13-14, 1998

Robert N. Stavins
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Overview

- Topic is important: cost and feasibility of carbon sequestration policies
- Four Parts of Paper:

I. Examine two types of carbon sink programs

II. Provide cost estimates of *one means* of forest carbon sequestration: lengthening rotation lengths

III. Consider non-market effects

IV. Conclusions

I. Two Types of Sink Programs

- Two types: “Physics-Based” and “Official Projects”
- Neither is the Kyoto approach; it would be interesting to learn RM’s assessment of that.

1. Physics-Based Approach: Total Terrestrial Stock of Carbon as a Baseline

- RM describes how difficult this would be.
- But there’s no reason to consider it.
- Why worry about baseline of total stock of carbon in the biological case any more than in the fossil fuel case?
  - We don’t focus on estimating total coal, oil, and natural gas reserves; rather, we focus on estimating extractions.
- Seems obvious to look at flows, not stocks; for example, land-use *changes*

2. Policy-Based Program: Measure "official projects to store carbon"

- Contrast between #1 and #2: stock vs policy-based
- Better to think about: *stock* vs. *flow* vs. *policies* that produce flows (ala Cooper)
- RM identifies major disadvantage of #2 as difficulty of defining adequate baseline: "it's difficult to know what each country would have done in the absence of an explicit carbon program"
  - But baseline issue *not* a problem of carbon sequestration policy *per se*, but of voluntary opt-in (reduction credit versus "cap and trade;" or what H&S call poorly defined property rights)
  - No unobserved hypothetical with "cap & trade" or other targeted programs with carbon seq
  - Likewise, no unobserved hypothetical with Cooper's common actions (tax, tax credit)
  - For example, forested area increases, you receive a point/acre; forested area decreases, you lose a point/acre. (But not end of story)
  - Changes (flows) should be focus of policy attention; motivation need not matter

- So, RM "baseline critique" is *not* a critique of carbon seq at all
    - It's a well-known and reasonable critique of JI or any voluntary opt-ins of any env'tl policy
- RM claims there would be an incentive for countries to cut down trees and then enter bare land into programs.
    - No, baseline must be in past, not future, as with any environmental program.
- Another conclusion in paper: sink program would have (unfortunate) consequence of delaying time at which countries had to take serious carbon abatement actions.
    - True, but not a problem — allows energy-generating and energy-using capital-stock to turn over (Manne & Richels).

II. Cost Estimates

- RM says other studies find extensive sequestration at "low cost of $1 to $10 per ton" — major straw man
    - See table of some of best studies: AC: up to $70/ton; MC: up to $140/ton (Plantinga et. al. 1998: ME $225, SC $55; WI $90)
- Paper notes correctly that preventing deforestation may be better economically than forestation
    - But *eliminates* it as potential policy by stating there will be no significant deforestation in future.
    - World Bank, UN, others: deforestation will continue in developing world, due to demand for firewood, cropland, and pasture (& hardwood).
- Paper *eliminates* forestation as a potential policy route by stating that "costs of reforesting substantial amounts of temperate farmland are likely to be high."
    - See figure (AER). Not cheap, but should still be part of c/e portfolio, even in the U.S.
- Paper *eliminates* option of foresting marginal farmlands by noting that they produce less carbon.
    - But marginal lands also have lower opportunity cost.
    - It's an empirical question.

- Alternative to “retarded deforestation” and “forestation:” intensifying forest management — lengthening forest rotations, increasing stocking, stimulating growth

- Empirical analysis focuses exclusively on *lengthening rotations* beyond what is otherwise efficient

  - Present value numbers in text not in table. What’s the model? Can’t comment.

  - Also, difficult to assess MC numbers in table (expressed in $/MBD, not $/ton of carbon).

- Interesting aspect of MC in table: beyond a certain point, MC of lengthening rotations falls.

  - But there’s a problem.

  - RM seems to treat a unit of carbon seq. next year the same as a unit that occurs 60 years from now.

  - Can’t make reasonable c/e comparisons this way; they don’t have same benefits (damages)

  - Considerable literature on how to measure intertemporal carbon flows to calculate a MC (Richards *et. al.*)

    - Consensus: discount carbon quantities

    - Assumes b’s and c’s should be discounted at same rate, and mb constant over relevant range

III. Non-Market Effects

- There may be significant non-market (environmental) effects of changing land management
    - Paper suggests (without empirical information) that externalities are probably — on net — negative.
    - Maybe, maybe not (Hartman lit. may suggest otherwise)
- But RM may be correct that carbon seq would bring *negative* net non-climate effects, and that these should be counted in B/C calculations.
    - If so, then surely we should also include all of the non-climate, environmental *benefits* of carbon abatement programs, such as reduced SO_2, particulates, ambient ozone, congestion, etc.

IV. Conclusions

- Findings in parts I-III are very *negative*,

  .... but is the analysis compelling?

- Part IV ends with surprisingly upbeat conclusion:

  "Managing terrestrial stocks of carbon can contribute to greenhouse gas control in the long run, if the programs are carefully designed today."

Comments on conclusion:

1. Administrative costs of carbon sequestration policies are likely to be significantly *greater* than "equivalent" carbon abatement policies.

2. Carbon sequestration may still be part of cost-effective portfolio in many nations, particularly in *short run*.

3. It's hard to see how RM's final conclusion follows from the paper, but I think it's basically correct (in the short run).

THE COSTS OF CARBON SEQUESTRATION: A REVEALED-PREFERENCE APPROACH

Robert N. Stavins

John F. Kennedy School of Government, Harvard University
and
Resources for the Future

Forthcoming in the
American Economic Review

April 30, 1998

THE COSTS OF CARBON SEQUESTRATION: A REVEALED-PREFERENCE APPROACH

Robert N. Stavins*

The possibility of encouraging the growth of forests as a means of sequestering carbon dioxide has received considerable attention because of concerns about the threat of global climate change due to the greenhouse effect. Would this approach be as inexpensive as studies have suggested? A method is developed for estimating the costs of carbon sequestration by estimating the opportunity costs of land on the basis of econometric evidence of landowners' actual behavior. The marginal costs of carbon sequestration appear to be greater than previous studies have found. (JEL Q23)

Increased attention by policy makers to the threat of global climate change has brought with it considerable attention to the possibility of encouraging the growth of forests as a means of sequestering carbon dioxide (National Academy of Sciences (NAS) 1992; Bruce, Lee, and Haites 1996).[1] The Kyoto Protocol to the United Nations Framework Convention on Climate Change (1997), which establishes emission reduction targets for the United States and other industrialized nations, states that carbon sequestration can be used by participating nations to achieve their targets. Moreover, even before the Kyoto agreement, this approach had become an explicit element of both U.S. and international climate policies (U.S. Department of Energy 1991; William J. Clinton and Albert Gore 1993; United Nations General Assembly 1992). This high level of interest has been due, in part, to: suggestions that sufficient lands are available to use the approach to mitigate a substantial share of annual carbon dioxide (CO_2) emissions (Greg Marland 1988; Daniel A. Lashof and Dennis A. Tirpak 1989; and Mark C. Trexler 1991); and claims that growing trees to sequester carbon is a relatively inexpensive means of combating climate change (Dudek and Alice LeBlanc 1990; NAS 1992; Roger A. Sedjo and Allen M. Solomon 1989). In other words, the serious attention given by policy makers to carbon sequestration can partly be explained by (implicit) assertions about respective marginal cost functions.

We develop and demonstrate a method by which the costs of carbon sequestration can be estimated on the basis of evidence from landowners' behavior when confronted with the opportunity costs of alternative land uses. The simplest of previous economic analyses derived single point estimates of average costs associated with particular sequestration levels (Marland 1988; Sedjo and Solomon 1989; Dudek and LeBlanc 1990; Edwin S. Rubin et.al. 1992; Omar Masera, Mauricio R. Bellon, and Gerardo Segura 1995). Often it has been assumed that land (opportunity) costs are zero

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*John F. Kennedy School of Government, Harvard University, 79 John F. Kennedy Street, Cambridge, MA 02138, and Resources for the Future. Richard Newell supplied excellent research assistance; and valuable comments on a previous version were provided by Lawrence Goulder, William Nordhaus, Andrew Plantinga, Kenneth Richards, participants in seminars at the Universities of California at Los Angeles and Santa Barbara, Maryland, Michigan, and Texas, Harvard, Stanford, and Yale Universities, Resources for the Future, and the National Bureau of Economic Research, and two anonymous referees. The author alone is responsible for any errors.

[1] After fossil-fuel combustion, deforestation is the second largest source of carbon dioxide emissions. Estimates of annual global emissions from deforestation range from 0.6 to 2.8 billion tons, compared with slightly less than 6.0 billion tons annually from fossil-fuel combustion, cement manufacturing, and natural gas flaring, combined (R. A. Houghton 1991; T. M. Smith et.al. 1993).

(Robert K. Dixon et.al. 1994; New York State Energy Office 1993; J. K. Winjum, Dixon, and P. E. Schroeder 1992; G. Van Kooten, L. Arthur, and W. Wilson 1992). Another set of studies -- essentially "engineering/costing models" -- have constructed marginal cost schedules by using information on revenues and costs of production for alternative uses on representative types or locations of land, and then sorting these in ascending order of cost (Robert J. Moulton and Kenneth R. Richards 1990; Richards, Moulton, and Richard A. Birdsey 1993). Simulation models include a model of the lost profits due to removing land from agricultural production (Peter J. Parks and Ian W. Hardie 1995), a mathematical programming model of the agricultural sector and the timber market (Richard M. Adams et.al. 1993), a related model incorporating the effects of agricultural price support programs (J. M. Callaway and Bruce McCarl 1996), and a dynamic simulation model of forestry (Susan Swinehart 1996). Lastly, an analysis by Andrew J. Plantinga (1995) adopts land-use elasticities from an econometric study to estimate sequestration costs. We draw on some of the best features of the previous studies, including the carbon levelization method of Adams et.al. (1993) and Moulton and Richards (1990), and the intertemporal carbon yield curves of Richards, Moulton, and Birdsey (1993).

Nearly all of the previous analyses are potentially limited by their inability to reflect the actual preferences of landowners, as revealed -- for example -- by landowners' decisions regarding the disposition of their lands in the face of relevant economic signals.[2] There are a number of reasons why landowners' actual behavior might not be well predicted by "engineering" or "least cost" analyses: (1) land-use changes can involve irreversible investments in the face of uncertainty (Parks 1995), and so option values may be important (Robert S. Pindyck 1991); (2) there may be non-pecuniary returns to landowners from forest uses of land (Plantinga 1995), as well as from agricultural uses; (3) liquidity constraints or simple "decision-making inertia" may mean that economic incentives will affect landowners only with some delay; and (4) there may be private, market benefits or costs of alternative land uses (or of changes from one use to another) of which an analyst is unaware.

We seek to address at least some of these problems by employing an econometric model to derive the costs of carbon sequestration. The paper is intended to be illustrative of how econometric analyses of land use, which already exist for a number of countries, can be used to develop better region-specific estimates of the marginal costs of carbon sequestration.[3] In Part I of the paper, we describe an econometric model of land use; in Part II, we develop a simulation model of carbon sequestration; in Part III, we derive our marginal cost results; in Part IV, we compare our results with other estimates of carbon-sequestration costs and with estimates of the cost of abating carbon emissions through fuel switching and energy-efficiency enhancements; and in Part V, we offer some conclusions.

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[2] Plantinga's (1995) analysis of southwestern Wisconsin is an exception; it is similar in some respects to our method, although the former model requires information on land characteristics (quality) *within* counties, whereas our approach is based upon an econometric model in which the unobserved heterogeneity of land is parameterized and thus estimated simultaneously with other structural parameters. Thus, the potential advantage of the present approach is simply that its data requirements are less, which could be important if a nationwide land-use analysis were carried out.

[3] Another possibility — in theory — would be to employ land sale price data, reflecting anticipated values of net returns to alternative uses. But useful price data are not available for sufficiently diverse geographic areas over time.

I. Econometric Model of Land Use

In previous work with a distinctly different policy motivation, a dynamic optimization model was developed of a landowner's decision of whether to keep his or her land in its status quo use or convert it to serve another purpose (Robert N. Stavins and Adam B. Jaffe 1990; Stavins 1990). Landowners are assumed to observe current and past values of economic and other factors relevant to decisions regarding the use of their lands for forestry or agriculture,[4] and on this basis form expectations of future values of respective variables. Landowners are assumed to attempt to maximize the expected long-term economic return to their land. Thus, a risk-neutral landowner will seek to maximize the present discounted value of the stream of expected future returns:

$$\max_{\{g_{ijt},v_{ijt}\}} \int_0^\infty \left[(A_{it}q_{ijt} - M_{it})(g_{ijt} - v_{ijt}) - C_{it}^{\alpha P_{it}} g_{ijt} + f_{it}S_{ijt} + W_{it}g_{ijt} - D_{it}v_{ijt}\right] e^{-r_t t}\,dt \tag{1}$$

$$subject\ to: \qquad \dot{S}_{ijt} = v_{ijt} - g_{ijt} \tag{2}$$

$$0 \leq g_{ijt} \leq \bar{g}_{ijt} \tag{3}$$

$$0 \leq v_{ijt} \leq \bar{v}_{ijt} \tag{4}$$

where *i* indexes counties, *j* indexes individual land parcels, and *t* indexes time; upper case letters are stocks or present values; and lowercase letters are flows. The variables are:

A_{it} = present value of typical expected agricultural revenues per acre in county *i* and time *t*;

q_{ijt} = index of feasibility of agricultural production (including effects of soil quality and moisture);

g_{ijt} = acres of land converted from forested to agricultural use (deforestation);

v_{ijt} = acres of cropland returned to a forested condition (forestation);

M_{it} = expected cost of agricultural production per acre, expressed as present value of future stream;

C_{it} = average cost of conversion per acre;

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[4] In both industrialized nations and in developing countries, nearly all deforestation is associated with conversion to agricultural use (C. J. Jepma et. al. 1996). The previous work by Stavins and Jaffe (1990) focused on forested wetlands, but that quantitative analysis was of all forested areas.

P_{it} = Palmer hydrological drought index (to allow precipitation and soil moisture to influence conversion costs);

f_{it} = expected annual net income from forestry per acre (annuity of stumpage value);

S_{ijt} = stock (acres) of forest;

r_t = real interest rate used by landowners for investment decisions, linked with their private pre-tax rate of return;

W_{it} = net revenue per acre from one-time forest harvest (prior to conversion to agricultural use);

D_{it} = expected present discounted value of loss of income (when converting to forest) due to gradual regrowth of forest (first harvest occurs in year $t + R$, where R is rotation length);

$\bar{g}_{ijt}$ = maximum feasible rate of deforestation; and

$\bar{v}_{ijt}$ = maximum feasible rate of forestation.

As is described in by Stavins and Jaffe (1990), application of control theoretic methods yields a pair of necessary conditions for changes in land use. Forestation (conversion of agricultural cropland to forest) occurs if a parcel is cropland and:

$$(F_{it}^{*} - A_{it} \cdot q_{ijt} + M_{it}) > 0 \tag{5}$$

where F_{it}^{*}, delayed net forest revenue, equals F_{it} - D_{it}, and $F_{it} = f_{it}/r_t$. That is, a parcel of cropland should be converted to forestry use if the present value of expected net forest revenue exceeds the present value of expected net agricultural revenue. On the other hand, deforestation occurs if a parcel is forested and:

$$(A_{it} \cdot q_{ijt} - M_{it} - C_{it}^{\alpha P_{it}} - FN_{it}) > 0 \tag{6}$$

where FN_{it}, net forest revenue, equals F_{it} - W_{it}. That is, a forested parcel should be converted to cropland if the present value of expected net agricultural revenue exceeds the present value of expected net forest revenue plus the cost of conversion.

Inequalities (5) and (6) imply that all land in a county of given quality will be in the same use in the steady state, but, in reality, counties are observed to be a mix of forest and farmland. Although this may partly reflect deviations from the steady state, it is due largely to the *heterogeneity* of land, particularly in regard to its quality (suitability) for agriculture. Such unobserved heterogeneity can be parameterized within an econometrically estimatable model so that the *individual* necessary conditions for land-use changes (equations (5) and (6)) aggregate into a single-equation model, in which the parameters of the basic benefit-cost relationships and of the underlying, unobserved heterogeneity can be estimated simultaneously:

$$FORCH_{it} = FORCH^{a}_{it} \cdot D^{a}_{it} - FORCH^{c}_{it} \cdot D^{c}_{it} + \lambda_{i} + \phi_{it} \tag{7}$$

$$FORCH^{a}_{it} = \gamma_{a} \cdot \left[d_{it} \cdot \left[F \left[\frac{\log(q^{y}_{it}) - \mu(1 + \beta_{2} E_{it})}{\sigma(1 + \beta_{3} E_{it})} \right] \right] + (1 - d_{it}) - \left[\frac{S}{T} \right]_{i,t-1} \right] \tag{8}$$

$$FORCH^{c}_{it} = \gamma_{c} \cdot \left[d_{it} \cdot \left[1 - F \left[\frac{\log(q^{x}_{it}) - \mu(1 + \beta_{2} E_{it})}{\sigma(1 + \beta_{3} E_{it})} \right] \right] + \left[\frac{S}{T} \right]_{i,t-1} - 1 \right] \tag{9}$$

$$d_{it} = \left[\frac{1}{1 + e^{-(N_{i} + \beta_{1} E_{it})}} \right] \tag{10}$$

$$q^{y}_{it} = \left[\frac{F^{*}_{it} + M_{it}}{A_{it}} \right] \tag{11}$$

$$q^{x}_{it} = \left[\frac{FN_{it} + M_{it}}{A_{it} - C_{it}^{\alpha P_{it}}} \right] \tag{12}$$

where all Greek letters are parameters that can be estimated econometrically; $FORCH_{it}$ is the change in forest land as a share of total county area; $FORCH_{it}^{a}$ is forestation (abandonment of cropland) as a share of total county area; $FORCH_{it}^{c}$ is deforestation (conversion of forest) as a share of total county area; D_{it}^{a} and D_{it}^{c} are dummy variables for forestation and deforestation, respectively; λ_{i} is a county-level fixed-effect parameter; ϕ_{it} is an independent (but not necessarily homoscedastic) error term; γ_{a} and γ_{c} are partial adjustment coefficients for forestation and deforestation; **F** signifies the cumulative, standard normal distribution function; q_{it}^{y} is the threshold value of (unobserved) land quality (suitability for agriculture) below which the incentive for forestation manifests itself; q_{it}^{x} is the threshold value of land quality above which the incentive for deforestation manifests itself; T_{it} is total county area; N_{i} is the share of a county that is naturally protected from periodic flooding; E_{it} is an index of the share of a county that has been artificially protected from flooding by Federal programs (by time t); μ is the mean of the unobserved land-quality distribution; and σ is the standard deviation of that distribution.

Using panel data for 36 counties in Arkansas, Louisiana, and Mississippi, during the period 1935-1984, the parameters of the model embodied in equations (7) through (12) were estimated with nonlinear least squares procedures (Stavins and Jaffe 1990).[5]

II. Simulation Model of Carbon Sequestration

The initial step -- conceptually -- in moving from an estimated model of historical land use to a model of carbon sequestration involves introducing relevant silvicultural elements: (1) the possibility of "tree farming," that is, intensive management of forests, which brings with it significant costs of establishment; (2) alternative species, in particular, mixed stands and tree farms (pine plantations); and (3) alternative management regimes. Whereas the historical analysis assumed that all forests were periodically harvested, one might also consider the possibility of establishing "permanent stands" of biomass that are never harvested.

Next, simply as a means to generating a forest acreage supply function, consider a two-part policy that combines a subsidy on the flow of newly forested land with a tax on the flow of (new) deforestation. As a first approximation, the two price instruments can be set equal, although this is not necessarily efficient. We can treat the subsidy as an increment to forest revenues in the forestation part of the model (equation (8)) and treat the tax payment as an increment to conversion or production costs in the deforestation part of the model (equation (9)). Letting Z_{it} represent the subsidy and tax, the threshold equations ((11) and (12)) for forestation and deforestation, respectively, become:

$$q^{y}_{its} = \left[\frac{(F^{*}_{its} + Z_{it}) + M_{it} - K_{it}}{A_{it}} \right] \tag{13}$$

$$q^{x}_{its} = \left[\frac{FN_{its} + (M_{it} + Z_{it})}{A_{it} - C_{it}^{\alpha P_{it}}} \right] \tag{14}$$

where F_{its}^{*} = delayed net forest revenue ($F_{its} - D_{its}$), now subscripted by s to indicate species (mixed stand or pine), and set equal to zero for the case of permanent (unharvested) stands;

K_{it} = establishment costs associated with planting a pine-based tree farm.

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[5] The time dimension of the panel had observations every five years; hence, the time series contained ten periods, and the entire panel contained 360 observations. Estimated parameters were all of the expected sign, and nearly all estimates were significant at the 90, 95, or 99 percent level. Both parameter and standard error estimates were robust with respect to modifications of the specification, and the dynamic goodness-of-fit, based upon Henri Theil's (1961) measure, was 0.675.

A dynamic simulation, based upon equations (7), (8), (9), (10), (13), and (14), in which the variable Z is set equal to zero, will generate a baseline quantity of forestation/deforestation over a given time period. By carrying out simulations for various values of Z over the same time period, and subtracting the results of each from the baseline results, we can trace out a forest acreage supply function, with marginal cost per acre (Z) arrayed in a schedule with total change in acreage over the time period, relative to the baseline.[6]

Now we need to link carbon sequestration (and emissions) with forestation (and deforestation). Figure 1 provides a representation of the time path of carbon sequestration and emission linked with a specific forest management regime. In the example depicted in the figure, the time profile is of cumulative carbon sequestration associated with establishing a *new* loblolly pine plantation. Carbon sequestration occurs in four components of the forest: trees, understory vegetation, forest floor, and soil (Birdsey 1993).[7] When the plantation is managed as a permanent stand, cumulative sequestration increases monotonically, with the magnitude of annual increments declining so that an equilibrium quantity of sequestration is essentially reached within a hundred years, as material decay comes into balance with natural growth.

The figure also shows the cumulative carbon sequestration path for a similar stand that is periodically harvested (with 45-year rotations). In this case, carbon accrues at the same rate as in a permanent stand until the first harvest, when a substantial amount of carbon is released as a result of harvesting, processing, and manufacturing of derivative products. Much of the carbon sequestered in wood products is also released to the atmosphere, although this occurs with considerable delay

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[6] A central assumption underlying the use of an econometric approach to simulating carbon sequestration costs is that estimated parameters remain valid with variable values employed in the counterfactual simulations; in particular, that land owners can be expected to react to carbon taxes or subsidies the same as they have reacted to *equivalent* changes in the relative revenues and costs associated with timber and agricultural crop production. A referee notes that — depending upon the forces behind the partial adjustment coefficients — those coefficients may be sensitive to the change.

[7] Although the shares vary greatly among forest types, reference points are: tree carbon contains about 80 percent of ecosystem carbon, soil carbon about 15 percent, forest litter 3 percent, and the understory 2 percent. Soil carbon is defined as all organic matter to a depth of one meter, excluding coarse tree roots larger than 2 millimeters in diameter (which are classified as part of "tree carbon"). The variation in these shares is significant; for some species, soil carbon accounts for nearly 50% of total forest carbon. Our calculations of releases from the understory, forest floor, soil, and non-merchantable timber are based upon Moulton and Richards (1990) and Richards, Moulton, and Birdsey (1993).

as wood products gradually decay.[8] As can be seen in the figure, in this scenario the forest is replanted, and the same process takes place again.

Although the carbon yield curve with harvesting in Figure 1 eventually moves above the yield curve for a "permanent" stand, this need not be case. It depends upon the share of carbon that is initially sequestered in wood products and upon those products' decay rates (plus the decay rate of soil carbon). With zero decay rates, the peaks in the harvesting yield curve would increase monotonically, but with positive decay rates, the locus of the peaks approaches a steady-state quantity of sequestration, and that quantity can, in theory, lie above or below the level associated with the equilibrium level of the "permanent" yield curve.[9]

The intertemporal nature of net carbon sequestration raises a question: how can we associate a number -- the marginal cost of carbon sequestration -- with units of carbon that are sequestered in different years? This is important if we wish to compare the costs of carbon sequestration with the costs of conventional carbon abatement measures, such as fuel switching and energy-efficiency enhancements. Previous sequestration studies have used a variety of methods to calculate costs in terms of dollars per ton, the desired units for a cost-effectiveness comparison (Richards and Carrie Stokes 1995). Our approach is to divide the discounted present value of costs by the discounted present value of tons sequestered. This may be thought of as assuming that the marginal damages associated with additional units of atmospheric carbon are constant and that benefits (avoided damages) and costs are to be discounted at the same rate. Note that such an assumption of constant marginal benefits is approximately correct if marginal damages are essentially proportional to the rate of climate change, which many studies have asserted. We initially use a 5 percent real rate, supplemented by sensitivity analysis.

By developing the constituent intertemporal yield curves (and net revenue streams) for different species, location, and management conditions, we can calculate a set of present-value equivalent carbon-sequestration measures. By way of example, we focus on periodically harvested

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[8] The share of forest carbon that goes into merchantable wood varies considerably. A reference point is about 40%. Much of the remaining 60% is released at the time of harvest and in the process of manufacturing wood products (in both cases through combustion), the major exception being soil carbon, which exhibits a much slower decay rate (reasonably assumed to be zero in some cases). As Sedjo et. al. (1995) point out, examinations of the long-term effects of timber growth on carbon sequestration are "highly dependent upon the assumptions of the life-cycle of the wood products" (p. 23). M. E. Harmon, W. K. Farrell, and J. F. Franklin (1990) found this to be the case in their scientific review. The two critical parameters are the assumed length of the life-cycle of wood products, and the assumed share of timber biomass that goes into long-lived wood products. Drawing upon the work of Clark Row (1992), Row and Robert B. Phelps (1990), and D. P. Turner et. al. (1993), we develop a time path of gradual decay of wood products over time, based upon an appropriately weighted average of pulpwood, sawlog, hardwood, and softwood estimates from Plantinga and Birdsey (1993). The final profile is such that one year following harvest, 83 percent of the carbon in wood products remains sequestered; this percentage falls to 76 percent after 10 years, and 25 percent after 100 years (and is assumed to be constant thereafter). At an interest rate of 5 percent, the present value equivalent sequestration is approximately 75 percent, identical to that assumed by William D. Nordhaus (1991).

[9] A potential scenario that we do not consider is that harvested wood is used for fuel. If this were used to produce electricity or liquid fuels such as methanol, thereby substituting for fossil-fuel use, then the *net* impact on atmospheric CO_2 emissions of each unit of forestation would be significantly enhanced.

pine, and assume that when and if deforestation occurs, on-site merchantable timber is sold.[10] In this case, the present value of net carbon sequestration associated with forestation is 41.05 tons per acre, and the present value of carbon emissions associated with deforestation is 51.83 tons (Table 1).

Finally, we define the present values (in year t) of the time-paths of carbon sequestration and carbon emissions associated with forestation or deforestation occurring in year t as Ω_t^S and Ω_t^E, respectively. Thus, the total, present-value equivalent net carbon changes associated with a baseline or policy simulation are calculated as:

$$(15) \qquad PV(SEQ) = \sum_{i=1}^{36} \left[\sum_{t=0}^{90} \left(FORCH_{it}^{a} \cdot D_{it}^{a} \cdot \Omega_t^S - FORCH_{it}^{c} \cdot D_{it}^{c} \cdot \Omega_t^E \right) \cdot (1 + r)^{-t} \right]$$

$$(16) \qquad \Omega_t^S = \sum_{h=t}^{90} CS_h \cdot (1 + r)^{t-h}$$

$$(17) \qquad \Omega_t^E = \sum_{h=t}^{90} CE_h \cdot (1 + r)^{t-h}$$

where CS_h and CE_h are, respectively, annual incremental carbon sequestration and carbon emissions per acre, and $FORCH_{it}$, is simulated with equations (7), (8), (9), (10), (13), and (14), above.[11]

III. The Costs of Carbon Sequestration

It might be argued that since the policy intervention we model is a tax/subsidy on land use, not on carbon emissions and sequestration, it does not lead to the true (minimum) carbon sequestration marginal cost function. This criticism is not valid in a realistic policy context. It would be virtually impossible to levy a tax on carbon emissions or a subsidy on sequestration, because the costs of administering such policy interventions would be prohibitive. Looked at this

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[10] For a comparison of sequestration costs under different management regimes and other conditions, see: Stavins 1995. The growth curves that underlie respective yield curves are themselves a function, partly, of precipitation and temperature, both of which are presumably affected in the long run by atmospheric concentrations of CO_2 and induced climate change (Dixon et. al. 1994). We ignore this endogeneity to climate change in estimating sequestration costs, as have all previous studies. Likewise, all studies have ignored potential economic endogeneity of relevant variables to climate change (Brent Sohngen and Robert Mendelsohn 1995).

[11] A 90-year period was used to allow at least one rotation of each forest species. Given the consequences of discounting, the results are not fundamentally affected by the length of the period of analysis, once that period exceeds 50 years or so.

way, it becomes clear that such an instrument would likely be *more* costly per unit of carbon sequestered than would the deforestation tax/forestation subsidy policy instrument.

A simulation of equations (15), (16), and (17) with the subsidy/tax, Z, set equal to zero (in equations (13) and (14)) generates a baseline quantity of carbon sequestration/emissions. By subtracting this quantity from the results of simulations employing positive values of Z, we trace out a supply curve of net carbon sequestration, in which the marginal costs of carbon sequestration, measured in dollars per ton, can be arrayed in a schedule with net annual[12] carbon sequestration.

Table 2 provides the results for a periodically harvested pine plantation, with the sale of merchantable timber when/if deforestation occurs. Such a scenario is most directly comparable with those examined in other studies. The relatively attractive forest revenues associated with this management regime result in a small amount of net forestation taking place in the baseline simulation, a gain of about 52 thousand acres (over the 90-year study period). Baseline net carbon sequestration is approximately 4.6 million tons annually. Marginal costs of carbon sequestration increase gradually, until these costs are about $66 per ton, where annual sequestration relative to the baseline has reached about 7 million tons. This level of sequestration is associated with a land-use tax/subsidy of $100 per acre and net forestation, relative to baseline, of 4.7 million acres.

Beyond this point, marginal costs depart more rapidly from a linear trend. Beyond about $200 per ton, they turn steeply upward. Indeed, the marginal cost function is nearly asymptotic to a sequestration level of about 15 to 16 million tons annually. This is not surprising, since such an implicit limit would be associated with net forestation of about 10.5 million acres, for a total forested area of 13 million acres, just shy of the total area of the study region.[13]

IV. Placing the Sequestration Cost Estimates in Context

In this section, we first seek to compare our estimated sequestration marginal cost function with estimates of sequestration costs from previous studies using different methods. Then, we compare our sequestration cost estimates with estimates of the costs of abating carbon emissions through fuel switching and energy-efficiency enhancements.

First, to compare our results with those of other sequestration studies, we need to normalize the results to some common set of standards (Table 3). Since the other studies of carbon sequestration costs (and carbon abatement costs) are for the U.S. as a whole, one thing we need to do is normalize our results for the U.S. In doing so, it is important to recognize that the marginal

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[12] Recall that both dollars of costs and tons of sequestration (and emission) are discounted. Hence, annual sequestration refers to an annuity that is equivalent to a respective present value (employing a discount rate of 5 percent).

[13] Because of the long time horizon employed, it is natural to ask how sensitive are the results to the assumed interest rate. As the discount rate decreases, marginal sequestration costs decrease monotonically because the present-value equivalent sequestration increases with decreased interest rates. Later in the paper, when we compare our marginal cost results with those from other sequestration and abatement studies, we always normalize the results so that all, in effect, employ the same discount rate.

costs of sequestration in the Delta states are not necessarily representative of nationwide sequestration costs.[14] In effect, we re-scale the horizontal dimension of the estimated supply function to represent the change from the study area to the relevant U.S. land base,[15] and we normalize the results from other studies by converting those results to appropriately discounted units.

The results of this process are provided in Figure 2, where our results are compared with those of Richards, Moulton, and Birdsey (1993), Adams et.al. (1993), and Callaway and McCarl (1996). All of these marginal cost functions lie within our 95 percent confidence interval,[16] at least up to 300 million tons/year in the case of Adams et.al. (1993), but all are less steep than our central tendency and lie well below it for most of their ranges. Other studies have not reported, indeed not calculated, confidence intervals around their results, and so it is especially difficult to make comparisons. Overall, the general impression is that our marginal cost estimates are at least as great and may well be greater than others previously reported. Such differences may arise because several of the factors previously identified as affecting land-use decisions — including non-pecuniary returns to land and decision-making inertia — would tend to lead "engineering" or "least cost" analyses to under-estimate sequestration costs.

Next, we turn to estimates of the costs of carbon emissions abatement. We use results from Working Group 12 of the Energy Modeling Forum (EMF) (1995), which examined carbon abatement costs for the United States. The EMF results are presented as time paths of predicted carbon emissions under baseline and policy scenarios over hundred-year time frames, and include estimates of the time paths of carbon taxes necessary under each of the policy scenarios.[17]

To construct comparable marginal cost estimates, we first calculate the present discounted value of carbon abatement and the present discounted values of carbon taxes for each time-path of taxes and emission reductions from baseline; from this set of numbers, we calculate an equivalent annuity (at the 5 percent discount rate). Each of the time-paths for alternative policy scenarios then constitutes a single point on a marginal cost function associated with a given model. These results are plotted along with of our estimated carbon sequestration marginal cost function in Figure 3.

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[14] It is likely that the difference is not very great. During the relevant time period, farm real estate prices in Arkansas, Louisiana, and Mississippi have tended to be within about 15 to 20 percent of the U.S. average.

[15] The scaling factor is equal to the ratio of total farm acreage in the continental U.S. (551 million acres in Richards, Moulton, and Birdsey 1993) to total farm acreage in our 36 study counties (10.6 million acres). It is agricultural acreage alone that is relevant for the normalization because in the scenario considered there is no deforestation in the baseline (and hence all carbon sequestration is coming from planting trees on formerly agricultural land).

[16] An advantage of the econometric approach is that we can provide a richer description of the marginal cost function through the use of stochastic (Monte Carlo) simulations, drawing upon the relevant variance-covariance matrix from the econometric estimation, but because there is also uncertainty associated with several variables employed in the analysis, the confidence bounds in the figure may underestimate the true error bounds.

[17] The policy scenarios are: 20 percent reduction from 1990 emission levels by 2010; a 50 percent reduction in annual emissions by 2050; emission stabilization by 2000; 2 percent per year emissions reductions; and a phased-in carbon tax.

The central tendency of marginal sequestration costs lies everywhere above the estimated marginal abatement costs, although the difference is small at low levels of carbon reduction.[18] As we move beyond 400 million tons per year (30 percent of current U.S. emissions, and 12 percent of estimated emissions in 2050), the two central tendencies depart more dramatically, as the marginal cost function for sequestration begins to approach an implicit vertical asymptote, due to limited availability of land.[19] Still, most of the abatement cost estimates lie within the confidence interval for sequestration costs. Hence, we cannot conclude rigorously that sequestration costs are systematically greater than abatement costs, particularly given the fact that the EMF abatement cost estimates do not have associated confidence intervals.

On the other hand, there are two reasons why it is likely that the figure under-estimates the difference between the sequestration and abatement cost functions. First, since the EMF scenarios do not represent cost-effective time paths of achieving a given present-value of abatement at minimum cost, the true carbon abatement marginal cost function is better thought of as constituting the lower envelope of these points. Second, the partial equilibrium nature of our underlying econometric estimates means that the true marginal cost function for sequestration likely lies above the estimated function, because endogenous agricultural prices and endogenous forest product prices would both lead to greater sequestration cost estimates.[20]

In the long term, carbon sequestration costs are likely to increase further, relative to carbon abatement costs, because of three factors: (1) there is a limited land base on which sequestration can operate, in contrast with a much less limited emissions base -- due to economic growth -- on which abatement operates; (2) the available land base for forestry may decrease due to population pressures, driving up the opportunity cost of land; and (3) the magnitude of improvements in the silvicultural domain (growing more biomass more quickly per acre) and the forest product domain (less decay of wood products, for example) will probably be less than the magnitude of technological improvements in the case of abatement, including increased efficiency of energy generation and use, and decreased reliance on fossil fuels.

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[18] Forestation and retarded deforestation provide a set of secondary environmental benefits, and it has been argued that these should be taken into account in a cost-effectiveness comparison with energy-efficiency enhancements (Sedjo et. al. 1994). However, the same would need to be done for calculating the costs of energy efficiency (which may, for example, bring about reduced emissions of sulfur dioxide).

[19] These U.S. comparisons cannot simply be extrapolated to other nations. We can note, however, that at the global level, Nordhaus (1991) has combined results from a number of studies, and provided a schedule of marginal costs associated with percentage reductions in worldwide greenhouse gas emissions. As in our analysis for the United States, Nordhaus finds an increasing departure between the global marginal cost functions for carbon abatement and carbon sequestration. The sequestration marginal cost function rapidly becomes nearly vertical, while marginal abatement costs increase more gradually.

[20] In a general equilibrium context, a given conversion tax/forestation subsidy decreases agricultural production, thereby increases agricultural product prices, and thus increases carbon sequestration costs (since the opportunity cost of the land is increased). Likewise, a conversion tax/forestation subsidy increases forest production, thereby decreases timber prices, and thus increases carbon sequestration costs (since the private benefits of forestry relative to agriculture decrease). Thus, taking account of the potential endogeneity of agricultural and forest product prices may lead to greater sequestration cost estimates.

Subject to the various caveats expressed above, this comparison between carbon sequestration and abatement costs suggests that sequestration ought to be *part* of our overall portfolio of greenhouse strategies in the short term, providing a significant fraction of overall carbon reductions, although less than from conventional abatement activities (such as through carbon taxes on fossil fuels or tradeable carbon rights). In the long term, however, the relative cost of carbon sequestration in the United States is likely to be such that it should provide a smaller and smaller share of overall reductions.

V. Conclusions

Our purpose was to develop and demonstrate a method by which the marginal costs of carbon sequestration can be estimated for various regions of the world by drawing upon (existing) regional econometric analyses of the factors affecting land use. Since our empirical application was intended mainly to be illustrative, what conclusions -- if any -- can be drawn from the quantitative results?

First, focusing exclusively on our regional analysis, we found that the marginal costs of carbon sequestration are by no means trivial, and that the heterogeneity of land brings sharply increasing marginal costs of sequestration as higher quality agricultural lands are converted to forested use. Therefore, studies that provide only single point estimates of average costs or even linear estimates of marginal costs may be very misleading.

Moving beyond the regional cost estimates, what can we make of our illustrative comparison with national cost estimates of sequestration and abatement costs from other studies? First, subject to the necessary caveats regarding the results of any extrapolation, our sequestration cost function is significantly less linear than ones previously estimated with engineering/optimization methods. This becomes potentially important if one is interested in relatively high levels of annual sequestration, i.e. greater than 300 or 400 million tons. Second, subject to the same caveats, our implied sequestration costs for the United States as a whole are not very different from carbon abatement costs for relatively low levels of carbon reduction, but marginal sequestration costs appear to turn upward more rapidly than abatement costs. Further, we identified a set of reasons why our estimate of the difference between sequestration and abatement cost is probably a lower bound, and we identified another set of factors that suggest that this difference will likely increase over time.

Finally, we can reflect briefly on the analytical method we have employed. The model can be improved along a number of dimensions. Primary among these is endogenizing some variables currently treated as exogenous: agricultural and forestry product prices; the mix of cultivated crops and forest species; and management regimes.[21] A general equilibrium approach should be possible, both at the econometric stage and in simulations. This would not simply be desirable, but necessary,

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[21] For example, it would be desirable to allow for the economic endogeneity of the forest rotation length. In this regard, a very different approach to thinking about the carbon supply function is found in a paper by G. Cornelis Van Kooten, Clark S. Binkley, and Gregg Delecourt (1995). They examine the sensitivity of the socially optimal rotation length to alternative values of carbon (dollars per ton), and thus develop a supply curve of carbon *per acre*. As timber prices increase, the optimal rotation length decreases; and as carbon value increases, the (socially) optimal rotation length increases.

if the general approach developed here were to be applied directly to estimate the carbon sequestration marginal cost function for the United States as a whole.

Opportunities abound for the application of land-use econometrics to estimating sequestration costs.[22] The major advantage of this approach is that simulations of marginal costs build directly upon revealed-preference patterns of how landowners have actually responded to the economic incentives they continually face regarding the alternative uses of their lands. Linking such regional econometric models of land use with dynamic simulation models of carbon sequestration can provide better estimates of the true costs of carbon sequestration, and thereby add significantly to our understanding of the costs of addressing the threat of global climate change.

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[22] There is a growing literature of econometric analyses of forestation and deforestation (Theodore Panayotou and Somahawin Sungsuwan 1989; Parks and Randall A. Kramer 1995; Alexander S. Pfaff 1997; Eustáquio J. Reis and Rolando M. Guzmán 1992; and Douglas Southgate, Rodrigo Sierra, and Lawrence Brown 1991). The increasing availability of digital land-use data derived from satellite images means that econometric analysis of the type described in this paper can now be carried out at relatively moderate cost for large geographic areas.

TABLE 1: DESCRIPTIVE STATISTICS[a]

Variable	Mean	Standard Deviation
Gross Agricultural Revenue ($/acre/year)	259.04	44.58
Agricultural Production Cost ($/acre/year)	220.39	52.03
Forest Revenue[b] ($/acre/year)		
Mixed Stand (prior to deforestation)	19.29	7.45
Pine Stand (subsequent to forestation)	58.96	23.38
Tree-Farm Establishment Cost ($/acre)	92.00	0.00
Conversion Cost ($/acre)	27.71	6.73
Fraction of County Naturally Protected from Periodic Flooding	0.614	0.264
Index of Artificial Flood Protection	0.371	0.371
Palmer Hydrological Drought Index	0.74	0.84
Carbon Sequestration due to Forestation[c] (tons/acre) Pine Plantation Periodically Harvested	41.05	0.00
Carbon Emissions due to Deforestation, with Sale of Merchantable Timber[d] (tons/acre)	51.83	0.00
Interest Rate[e]	5%	0.00

[a] The sample is of 36 counties in Arkansas, Louisiana, and Mississippi, located within the Lower Mississippi Alluvial Plain. All monetary amounts are in 1990 dollars; means are unweighted county averages.

[b] Gross forest revenue minus harvesting costs; an annuity of stumpage values.

[c] Present value equivalent of net life-cycle sequestration.

[d] Present value equivalent of net life-cycle emissions.

[e] The historical analysis uses actual, real interest rates; simulations of future scenarios use the 5 percent real rate.

TABLE 2:
SIMULATED LAND CHANGES AND CARBON SEQUESTRATION

Periodically Harvested Pine Plantation, Sale of Merchantable Timber at Deforestation

Baseline Deforestation = + 51,654 acres

Baseline Carbon Sequestration = 4,578,202 tons

Marginal Cost per Acre ($/acre/yr)	Forestation Relative to Baseline (1,000s acres)	Average Cost per Acre ($/acre/yr)	Annual Carbon Sequestration Relative to Baseline (1,000s tons/yr)	Marginal Cost of Carbon Sequestration ($/ton)	Average Cost of Carbon Sequestration ($/ton)
0	0	0.00	0	0.00	0.00
100	4,653	57.32	7,045	66.05	37.86
200	6,579	105.63	9,961	135.97	69.77
300	7,484	129.15	11,332	202.03	85.31
400	7,897	142.25	11,957	268.05	93.96
500	8,212	155.98	12,434	334.11	103.03
600	8,470	169.22	12,825	400.18	111.77
700	8,689	182.74	13,156	466.22	120.71
800	8,874	195.72	13,437	532.20	129.28
900	9,038	208.21	13,685	598.31	137.53
1000	9,178	219.53	13,897	664.35	145.01

TABLE 3:

COMPARISON WITH RESULTS FROM OTHER STUDIES

Study	Total Quantity		Average Cost		Marginal Cost	
	Land (mil. acres)	Carbon (mil. tons/yr)	Land ($/acre/yr)	Carbon ($/ton)	Land ($/acre/yr)	Carbon ($/ton)
This Study[a]						
United States normalization	342	518	106	70	≤200	≤136
Delta States	5	7	58	38	≤100	≤66
Moulton and Richards (1990)						
United States[b]	269	690	--	27	≤81	≤37
Delta States Cropland	25	67	50	22	--	--
Richards, Moulton, and Birdsey (1993)						
United States[c]	244	416	--	--	--	≤41
Delta States Cropland[d]	11	29	42	18	≤52	≤22
Adams et.al. (1993)[e]	274	700	--	--	--	≤27
Nordhaus (1991)[f]	248	44	81	64	--	--
Parks and Hardie (1995)[g]	9	22	49	21	--	≤24
Rubin et al. (1992)[h]	71	73	--	23	--	--
Dudek and LeBlanc (1990)[i]	14	--	--	38	--	--
Plantinga (1995)[j]	0.65	1.5	--	--	--	6-13
Callaway and McCarl (1996)[k]	187	280	--	--	--	≤25

[a] From Scenario #3, pine plantation, periodically harvested, at a 5% discount rate.

[b] Permanent stands on cropland and pastureland only, i.e., not forest land.

[c] Figure for total U.S. carbon sequestration is an annuity calculated at 5% over 160 years.

[d] These figures were used, but not reported, in Richards, Moulton, and Birdsey (1993). Reference is to a permanent pine stand, based on data provided in a personal communication from Richards (1994). Carbon costs and tonnages were annualized over 160 years at a 5% discount rate.

[e] Nationwide results for a scenario with harvesting and sale of timber (Table 1, p. 79 and Table 4, p. 83), recalculated at a 5% discount rate.

[f] Permanent forestation of "marginal U.S. land" (Table 8, p. 60). For this and other studies, we have converted to acres at a rate of one hectare = 2.477 acres and to short tons at a rate of one metric ton = 1.102 short tons.

[g] Figures are for U.S. cropland-only scenario (Table 1, p. 127). Marginal costs were computed from marginal cost formula for Figure 4 (p. 131) using 22 million tons per year and annualized using a 4 percent discount rate over 10 years.

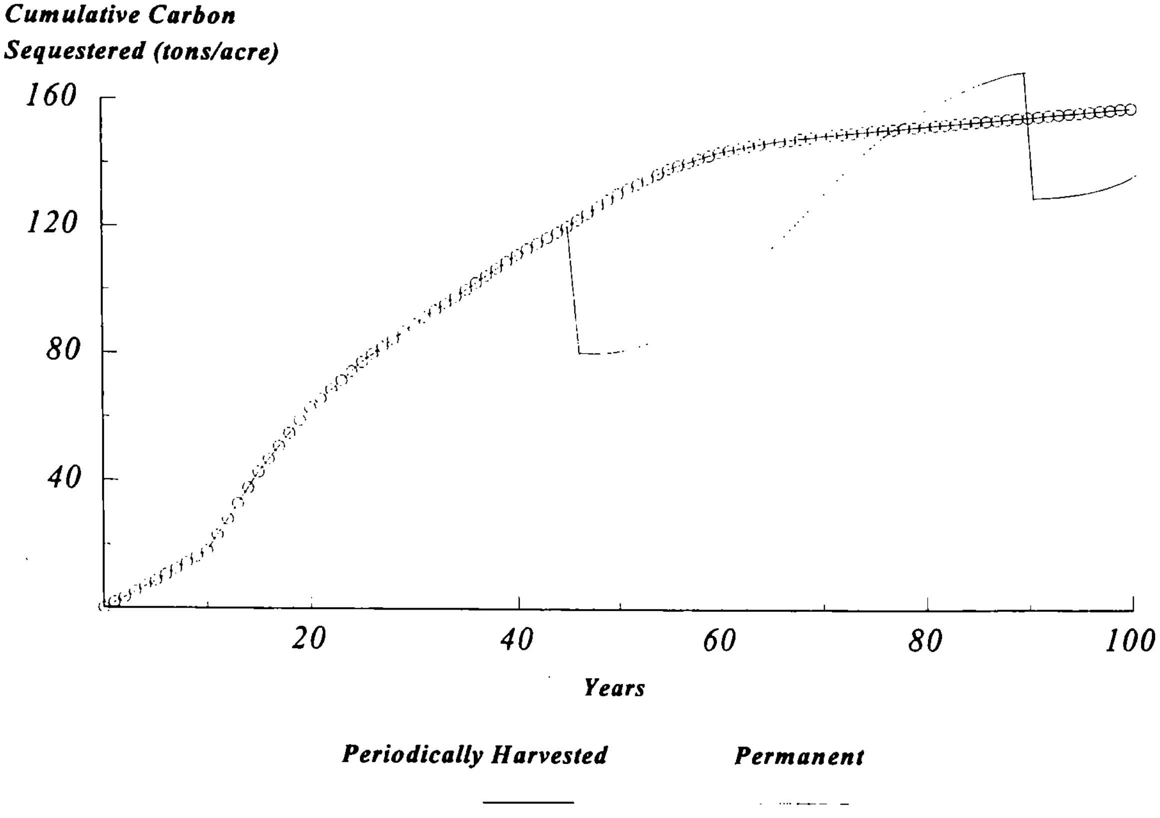
[h] Nationwide results converted from original study (Table 3, p 261) at a rate of 3.67 tons of carbon dioxide (CO_2) equals one ton of carbon, and into short tons from metric tons.

[i] An average permanent stand of U.S. tree species, from Table 3, p. 36; CO_2 converted to carbon.

[j] Figures are for a 14-county region of Wisconsin for the scenario assuming a least-cost program at a 4% discount rate and a constant annual sequestration rate of 2.25 tons of carbon per acre (Table II). Hectares converted to acres.

[k] Calculations use a 5% discount rate, employ carbon yield functions from Birdsey (1992), and do not allow for farm programs.

FIGURE 1:
TIME PROFILE OF CARBON SEQUESTRATION
(Loblolly Pine in Delta States Region)



Source: Based on data from Moulton and Richards (1990) and Richards (1994).

FIGURE 2:
ALTERNATIVE ESTIMATES OF MARGINAL COST OF U.S. CARBON SEQUESTRATION

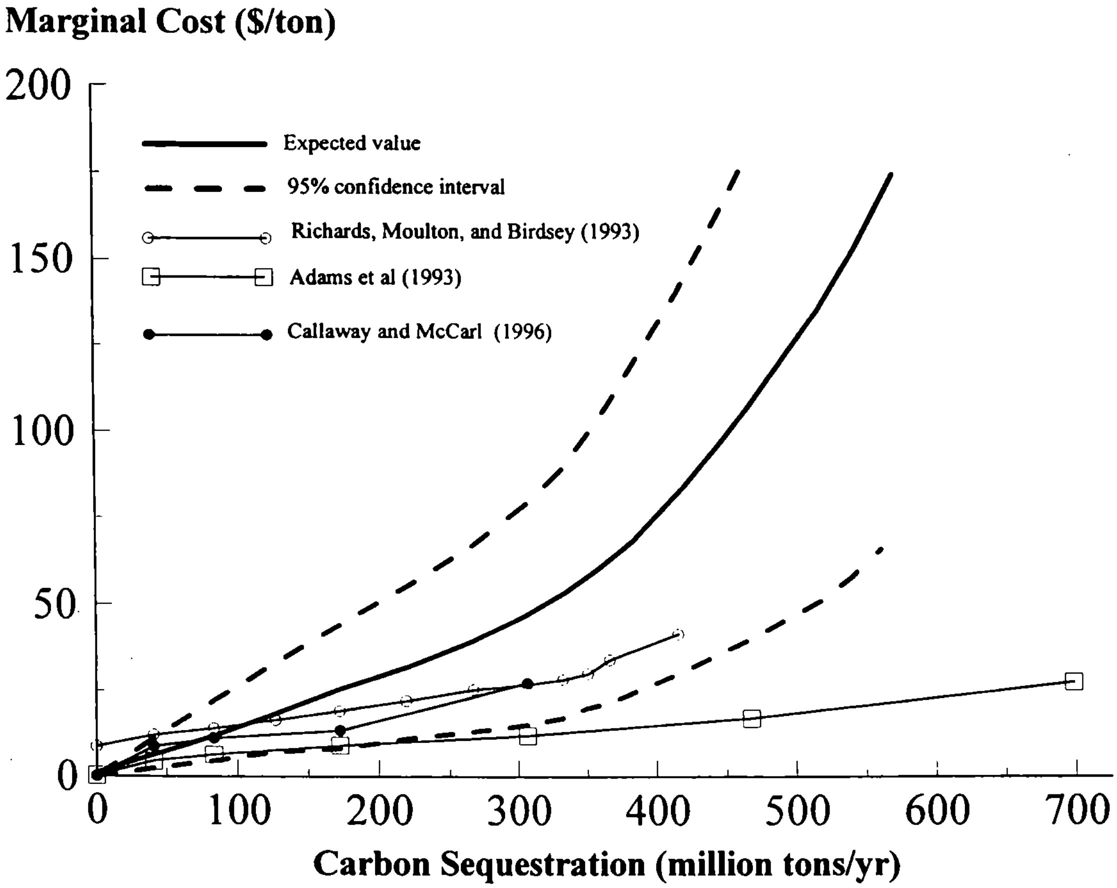
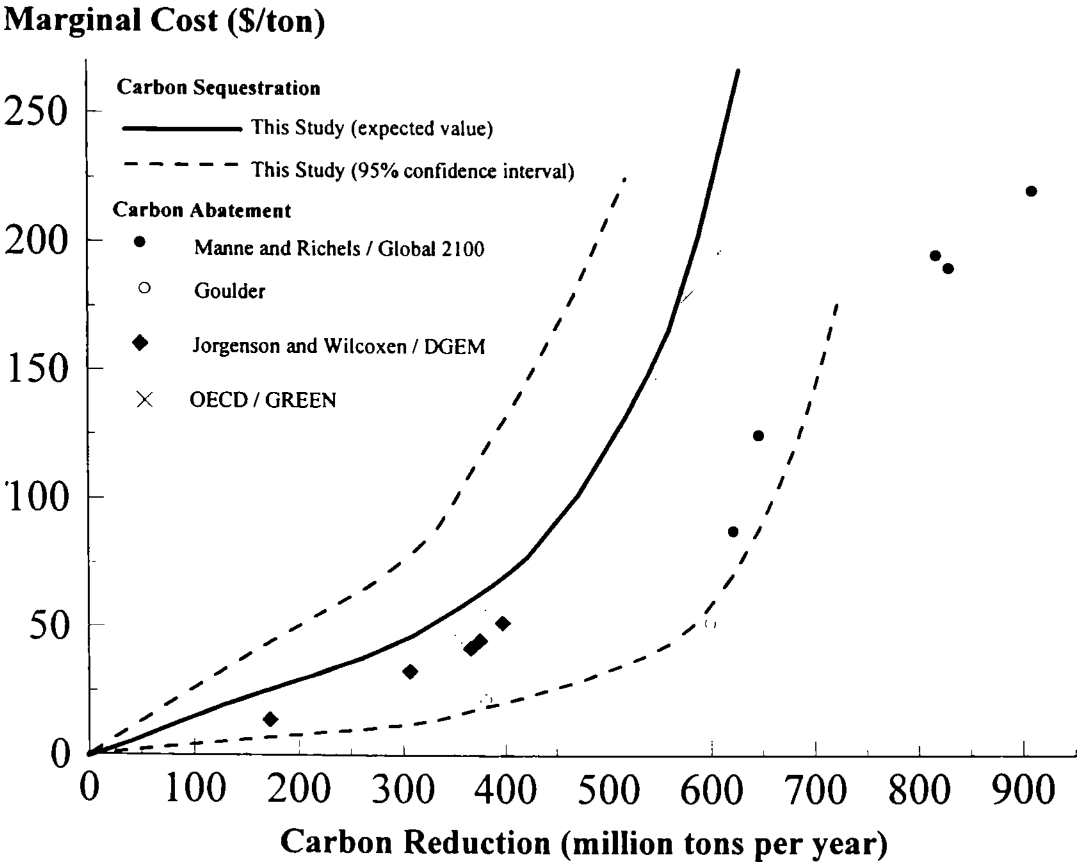


FIGURE 3:
ESTIMATES OF MARGINAL COSTS
OF U.S. CARBON ABATEMENT AND SEQUESTRATION



Source: Carbon abatement marginal cost estimates are annuities calculated from time-paths of 100-year predicted baseline carbon emissions and predicted carbon emissions under alternative policy scenarios presented in: Energy Modeling Forum (1995). See text of present study for detailed explanation.

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Buyer Liability for Greenhouse Gas Trading is Good for the Environment and Good for Emissions Trading

by

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What is emissions trading? What is the liability issue?

Under Article 17, the Kyoto Protocol on limiting greenhouse gases allows for the transfer of "assigned amounts" of greenhouse gases (GHG) among Annex I Parties. "Assigned amounts" are internationally agreed upon levels of emissions for a five year budget period beginning in 2008 and ending in 2012. Annex I countries are primarily the developed countries and the transitional economies, including the United States, Russia and Ukraine, Europe, Australia, Canada, New Zealand, and Japan.

Under the rules of the Protocol, these countries will limit their emissions of greenhouse gases by a certain percentage of 1990 levels of GHG emissions during the 2008-2012 interval.

If Parties emit less than their assigned amount during this time, they will be able to sell some or all of these surplus "assigned amounts" to other countries or "bank" their surplus GHG emissions for use during the next time period. Buyer companies or countries will be able to use these surplus GHG emission allocations to meet their own GHG caps. Analysts predict that the trading of emission allocations (usually called emissions trading or ET) will reduce the cost of compliance with GHG reduction targets by billions of dollars.

While Annex I countries include the developed and transitional economies, non-Annex I countries are synonymous with the notion of "developing countries," still GHG trades can be conducted between Annex I and non-Annex I countries. Trades between Annex I countries differ from trades between Annex I and non-Annex I countries. While emissions trading among Annex I countries is described in Article 17, trading between Annex I and non-Annex I is described under Article 12 of the Kyoto Protocol -- the Clean Development Mechanism (CDM). The CDM allows developing countries to trade GHG reductions that result from specific projects. Trades of so-called "certified emissions reductions" (CERs) will be based on the difference between a project's GHG emissions and a baseline determined to be those emissions that would have happened anyway. CERs that result from CDM actions can be traded only after they are created and certified.

Besides trading CERs and emissions trading of assigned amounts, there is a third trading initiative is called joint implementation, or JI. JI is described under Article 6 of the Kyoto Protocol. JI is similar to the CDM in that the focus of the trade is a surplus emission reduction that flows from a specific project. Any emissions credit that flows from a JI project is created after the fact -- it is certified after the emission reduction has been qualified, quantified, and certified.

JI and CDM-based reductions are first certified, then they are traded or banked for future use. Many people envision a system where surplus assigned amounts are traded first and demonstrated to be surplus latter. The question, therefore, arises as to who is liable if the traded "assigned amount" is not demonstrated to be surplus.

This paper addresses the mechanics of emissions trading of assigned amounts between Annex I Parties. The concern is that total emissions from Annex I Parties will not be subject to verification tests until the end of the initial period between 2008 and 2012, and may not be known until 2014. To preserve the integrity of the global greenhouse gas trading system, emissions trades of assigned amounts must only be for surplus GHG emissions. Therefore, GHG sellers must only be allowed to sell, and buyers must only buy, those allocations which are left over after the seller's own emissions control obligations have been met.

Purchasing countries or companies will want to buy GHG emissions allocations to help them meet their own commitments during the initial period between 2008 and 2012. Since country-specific inventories of GHG emissions will not be reported until as late as 2014, buyers will be purchasing GHG allowances before the seller's actual emissions are known. Since there is a potential for noncompliance, there is a need to specify which party is liable if a country determines that sold (so-called) surplus allocations are not, in fact, surplus. Therefore, GHG trading rules must clarify which party in a emissions trade is liable for a failure to perform -- the buyer or the seller or both.

Is the buyer or seller responsible for ensuring the surplus nature of traded GHGs?

Responsibility for validating the surplus nature of purchased assigned amount could rest with sellers of emissions allocations, with buyers, or with some combination of the two. If sellers are liable, they will held responsible for making sure they have sufficient parts of assigned amount to cover their emissions after any sales are conducted, and would be subject to domestic and international penalties for selling their assigned amounts that are not surplus. On the other hand, since buyers would be using any purchased allocations to meet a domestic GHG emission limit, domestic regulators can only sanction GHG buyers who attempt to apply non-surplus reductions against a domestic emission control obligation. Responsibility could also be imposed upon both the buyer and seller, as is done under certain US environmental regulations. The Conference of the Parties to the Framework Convention on Climate Change will consider this issue when they meet in Buenos Aires in November. And, while this is a complex Issue, Tables 1 and 2 provide some insight into how this problem might be approached.

Making sellers liable is simple in concept, but difficult in practice. An allocation, once sold, would retain its value as a portion of an assigned amount in the market no matter what the seller finally emitted. At the end of the trading period, compliance would be confirmed and sanctions invoked on those countries and companies that claimed to sell surplus GHG emission reductions but failed to establish "surplusness."

Table 1
Upon whom do we impose liability?

On the buyer
When the buyer can best influence the integrity of the outcome or when the regulator or public can only recover from the buyer. Consider the case of the person who has acquired, or bought, counterfeit money. The buyer must beware and the buyer assumes complete liability since any future "buyer" of the money cannot get relief from the original seller.

On the seller
When the seller's behavior best influences the integrity of the outcome or when the regulator can only recover from the seller; examples relate to property law where the seller has more knowledge about the property than does the buyer; thus, full disclosure is required and indemnification provisions are commonplace.

On both buyers and sellers
When there is an over-riding public policy reason for insuring fulfillment of a regulatory obligation (i.e., Superfund).

While, in theory, seller liability provides punishment once noncompliance is discovered in 2013, it does nothing to promote compliance along the way. In addition, seller liability works only when sellers are accountable and punishable. But this is a highly unlikely outcome under any anticipated climate change negotiation.

Table 2
Whose behavior can we affect and what does that mean?
On whom does liability for the integrity of the surplus reduction rest?

Who is the enforcer of liability ↓	The "creator" (Seller company)	The "user" (Buyer company)
regulator in "seller" country	Regulator can affect seller's behavior	Regulators cannot affect behavior
regulator in "buyer" country	Cannot affect behavior	Regulator <u>can</u> affect buyer's behavior

It is unlikely that countries can be punished if they sell GHG emission reductions that are implied to be surplus and are subsequently found to be defective. It is virtually impossible for a domestic regulator say, in Canada, to enforce sanctions against a GHG seller in Russia. Therefore seller liability for yet-to-be-proven surplus allocations is a functional impossibility.

The need for environmental and commercial integrity of traded "surplus" reductions dictates rules that make Parties meet their emissions reduction obligations and attain the Protocol's environmental goals. For the reasons discussed below, the best commercial and environmental outcomes are achieved when it is the responsibility of buyers to ensure the surplus nature of the GHG emissions they are purchasing.

Why doesn't seller liability create the right economic and environmental incentives?
The scale of emissions trading will be global; domestic sanctions may not provide a sufficient deterrent for non-compliant behavior, and they may not be sufficiently enforced in all countries. The United States has proposed two international methods of dealing with Parties that sell non-surplus parts of assigned amount: sellers could be excluded from future emissions trades or they would have to deduct the excess, with a penalty, from the next period's assignment. The second option sounds very much like emissions borrowing, a concept already rejected by the Conference of Parties.

While proposed "sticks" create penalties for non-compliance, they may not be sufficient deterrents for Parties with a short-term outlook, and they do not provide "carrots" for compliant behavior. In the two proposed methods for correcting illegal trades, damage to the environment is irreparable because buyers have used non-surplus emissions to cover their own. Damage is also imposed on the system of emissions trading by getting "counterfeit" trades into the system. And even if the concept of emissions borrowing is accepted, there is no guarantee that borrowing behavior exhibited during the first commitment period will not be repeated in future budget periods, thus emission control repayment is never achieved.

In addition, international trade sanctions are notoriously difficult to impose, even for issues (like weapons proliferation) that enjoy broad popular consensus. Because trades of GHGs will cross international boundaries, legal and financial penalties for sale of emissions that are not surplus will be problematic. With weak enforcement or insufficient penalties, sellers will have a financial incentive to sell an assigned amount that exceeds the penalties of non-compliance. These sales could undercut prices from countries and firms that legitimately sell surplus assigned amounts. A system that builds incentives for compliance into the trading program is preferable.

What is buyer liability and why is it better?
With buyer liability, the buyer would be responsible for ensuring the purchased "assigned amount" is <u>truly surplus</u>. If the seller is found to have sold non-surplus assigned amounts, these assigned amounts will be invalidated and buyers will not be able use them to meet their emissions control obligations.

If buyers are liable for a seller's failure to perform, the market for "assigned amounts" will be differentiated by seller. Countries that act in ways to insure the surplus nature of the sold assigned amounts will have more valuable assigned amounts since the likelihood of default will be less than for low integrity assigned amounts. Since buyers will be responsible for ensuring the surplus nature of the assigned amount they purchase, they will be vigilant about who they buy from, and buyers will pay more for credits that have a high probability of being surplus after the first budget period. Buyers will be willing to pay more for high-integrity assigned amount and will pay less for low-integrity assigned amounts. With buyer liability, the international GHG market will give value to the assigned amount that is likely to be surplus, and devalue an assigned amount that is of low integrity. It will therefore provide incentives to the seller to maintain the integrity of the parts of assigned amount they sell and to stay within their cap.

The initial buyers of GHG emissions could also have the option of purchasing insurance from the private sector or governments that allows for the replacement of a non-surplus assigned amount. The insurance premium charged would be based on the risk associated with the seller. If the seller runs a high risk of not having enough surplus emissions to cover its sales, the premium will be high. Conversely, if the seller is likely to meet its emissions commitments, the premium will be low.

Because the price of insurance will be incorporated into the market price for GHG allocations, sellers will have an incentive to keep their default risk low and sell only those allowances they know to be surplus. To minimize this risk, sellers might also have an incentive to control emissions below the required levels, thus maintaining a reserve to protect against default. This is an environmental benefit of buyer liability that seller liability does not provide.

There are a variety of remedies if, at the end of the budget period, a seller is found not to hold a surplus allocations equal to the amount that they have sold. For example:

1. sales could be disallowed in reverse order (last in-first out), until the seller has enough assigned amount to cover its needs, or
2. all traded allocations could be pro-rated downward to adjust for the amount oversold, or
3. all traded allocations could be viewed as defective since it is impossible to determine which ones were non-surplus.

Each remedy will have a different effect on the market for potentially non-surplus allocations.

Disallowing transactions in reverse order might create an incentive to begin trading early in the commitment period, and to register these trades as soon as possible but this option puts little pressure on sellers of assigned amounts to maintain quality reductions. Pro-rating all reductions downward provides some security for GHG allocation buyers and reduces the any insurance premium. However, pro-rating may not provide a strong incentive for assigned- amount-selling countries to be rigorous in maintaining GHG surpluses. Option 3 puts the

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~~only~~ depends on which credit you have.

most market pressure on sellers of GHG because buyers will demand higher guarantees of surplusness. Option 3 provide the most environmental integrity and promotes the development of the most rigorous GHG monitoring and reporting systems. Impounding all traded allocations may be too strict of a system for some parties, but this system guarantees the integrity of the GHG trading system while creating a complementary market for ancillary insurance products.

All three systems could encourage the development of insurance services, information services to provide information on buyer risks, and better GHG monitoring systems in seller-countries. Any insurance product would likely follow the assigned amount even if the assigned amount is resold. The insurance information would be only two or three data items in an emissions trading data-base, hardly a big task. Because the insurance would be country- and date-specific, the insurance premium and pay-out would be very specific, much the same as is political risk insurance. If purchases are disallowed, insurers will provide valid assigned amounts (or cash equivalents) as compensation.

Buyer liability promotes the market-based objectives by encouraging market-based risk-management solutions. Buyer liability also promotes environmental objectives by incentivizing countries to create high-integrity emission reductions via the avoidance of GHG emissions shortfalls by over-controlling.

Is buyer liability tenable?

Organizations like the United Nations could provide information that tracks the probability of sellers being in compliance. Annual reporting of progress towards Kyoto Protocol goals is likely to be written into the rules for either liability scenario, and potential assigned amount deficits will become obvious over time. Emissions will be tracked by country, sector, company, and facility. With buyer liability, sellers with potential deficits will not be able to find buyers for their assigned amounts, and insurance and information products will be developed to help companies and countries manage their risk. The GHG emissions market, like the bond and stock markets, will discriminate by quality.

In addition, because U.S. companies will be responsible for validating the surplus emissions they purchase, and would likely be subject to domestic sanctions if they do not, citizens, regulators and environmental organizations will gain faith in the international GHG trading program.

What is at stake?

The stakes are huge. A well designed international trading program will help participants achieve the environmental objective of GHG emissions reductions while cutting the cost of compliance billions of dollars over the coming decades. A successful trading program will broaden and sustain international participation. A poorly designed program will encourage non-participation and non-compliance, raise costs, and exacerbate environmental problems. Once a trading program is designed, it will be difficult to change. Buyer liability is one critical piece of this complicated puzzle; it's important to put it in place the first time around.

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7 pages

Natural gas. Electricity. Endless possibilities.™

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September 1998

ANALYSIS OF POST-KYOTO CO_2 EMISSIONS TRADING USING MARGINAL ABATEMENT CURVES

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ANALYSIS OF POST-KYOTO CO$_2$ EMISSIONS TRADING USING MARGINAL ABATEMENT CURVES

I. BACKGROUND, PURPOSE OF THE STUDY

At the Third Conference of the Parties (COP-3) to the United Nations Framework Convention on Climate Change (UNFCCC), held in Kyoto in December, 1997, Annex B parties[1] agreed to CO_2 emissions ceilings for the years centered on 2010, but left many details to be decided through further negotiations and subsequent COPs. In particular, the extent to which parties could resort to emissions trading to meet their commitments is to be addressed at COP-4 in Buenos Aires in November, 1998.

This paper provides an analysis of the importance of emissions trading by using marginal abatement curves (MACs) generated by MIT's Emissions Prediction and Policy Analysis (EPPA) model. These cost curves can be used to determine marginal, average and total cost, but more importantly they can indicate the potential gains from emissions trading for various parties and the extent to which those parties would wish to resort to emissions trading. The effect of constraints on the selling or buying of tradable carbon permits can also be illustrated. Thus, this paper attempts to clarify what is at stake at in Buenos Aires and in subsequent negotiations to determine the role of emissions trading in a global carbon regime.

EPPA is a multi-regional, multi-sectoral Computable General Equilibrium (CGE) model of economic activity, energy use and carbon emissions.[2] The acronyms for the twelve regions are indicated below. The six regions listed on the left are Annex B regions; the other six are non-Annex B regions. The study takes the year 2010 as representative of the first commitment period, which includes the years 2008 through 2012. The model keeps tract of five vintages of capital. Version 2.6 of the model, which is used here, incorporates two backstop technologies; however, because these energy sources will not play a substantial role in 2010, they are omitted from the calculations presented here.

ANNEX B REGIONS:		NON-ANNEX B REGIONS:	
USA:	USA	EEX:	Energy Exporting Countries
JPN:	Japan	CHN:	China
EEC:	European Union (EC-12 as of 1992)	IND:	India
OOE:	Other OECD Countries	DAE:	Dynamic Asian Economies
EET:	Eastern Europe	BRA:	Brazil
FSU:	Former Soviet Union	ROW:	Rest Of World

Notation of Regions in the EPPA Model

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[1] OECD countries, plus countries of Eastern Europe and the former Soviet Union, as listed in the Kyoto Protocol.

[2] See Yang et. al. *The MIT Emissions Prediction and Policy Analysis (EPPA) Model, Report #6*, MIT Joint Program on the Science and Policy of Global Change, Cambridge, MA, 1996.

The carbon emission reduction constraints used for this study are based on the commitments made by the various Annex B parties to the Kyoto Protocol. Table 1 states these commitments for the regional aggregates used in EPPA, indicates the reference (or business-as-usual) emissions for the year 2010 as predicted by EPPA version 2.6, and calculates the absolute and percentage reductions required to meet the Kyoto Protocol commitments.[3]

		USA	JPN	EEC	OOE	EET	FSU	Non An. B
Ref emissions 1990 (Mton)		1362	298	822	318	266	*891*	2022
Ref emissions 2010 (Mton)		1838	424	1064	472	395	*763*	4142
Kyoto commitments / 1990		93%	94%	92%	94.5%	104%	*98%*	NA
Hence Emissions Target in 2010 (Mton)		1267	280	756	301	273	873	4142
i.e. Reduction / ref	Mton	571	144	308	171	118	0	NA
	%	31%	34%	29%	36%	30%	0	NA
'hot air' (Mton)		0	0	0	0	0	*111*	NA

Table 1: Emissions Levels Corresponding to Kyoto Commitments

The next section of this paper concerns methodology; it explains marginal abatement curves and how they are generated by Computable General Equilibrium (CGE) models, such as EPPA. In particular, we explore the robustness of these MACs, that is, whether the abatement costs for a given region are invariant with respect to abatement in other regions.

Section III presents three illustrative cases in which the scope of the market is progressively widened from no trading to full global trading. Perfectly competitive markets are assumed both to simplify the presentation and to illustrate the maximum gains from emissions trading. We also discuss 'hot air' and 'leakage' in this section.

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[3] The correspondence between regional aggregates in EPPA and Annex B parties is not exact. For instance, Turkey is included in OOE (Other OECD), but it is not an Annex B party. Similarly EET includes all of the former Yugoslavia, but only Slovenia and Croatia are Annex B parties. Likewise, the Central Asian Republics are included in the FSU, but they also are not Annex B parties. Furthermore, the Kyoto commitments indicated for these EPPA regions depend upon our weighting of various constituent Annex B countries. Finally, the Annex B countries constituting the EET committed to targets at Kyoto that were from 5% to 8% below baseline emissions; however, these countries were allowed to choose an alternative to 1990 as the baseline year. Based on the national communications to date, the change of baseline year appears to translate into a limitation that is 4% above 1990 emissions for this region as a whole. The term 'hot air' refers to the amount by which any country's emissions are expected to be below the Kyoto Commitment, which is widely expected to be the case for the FSU.

In Section IV, we examine several departures from the simplifying assumptions of perfect competition to impart a more realistic light on the potential gains from emissions trading. In particular, three departures are examined: import limits, non-competitive behavior, and inefficiencies in supply.

The final section gathers the main findings of the study, in terms of both methodology and policy analysis, and suggests future extensions of this research.

II. METHODOLOGY: USING THE MACS GENERATED BY THE EPPA MODEL FOR TRADE STUDIES

a) What are Marginal Abatement Curves and What Do They Represent? (Fig. 1)

A CGE model will produce a shadow price for any constraint on carbon emissions for a given region R at time T. An example would be a 10% reduction below the reference case for the USA in 2010. This price indicates the marginal cost for reducing or abating the last ton of carbon required to meet the constraint. As might be expected in a proper CGE model, the shadow prices corresponding to constraints of increasing severity rise as an increasing function of emissions reduction.

A Marginal Abatement Curve plots the shadow prices corresponding to constraints of increasing severity at time T against the quantity abated. One point (q, p) on the curve thus represents the marginal cost for region R of abating an additional unit of carbon emissions at quantity q in time T. Fig. 1 shows such a Marginal Abatement Curve.

The integral under the curve (hatched area) represents the total abatement cost for region R of carbon emission reduction q at time T.

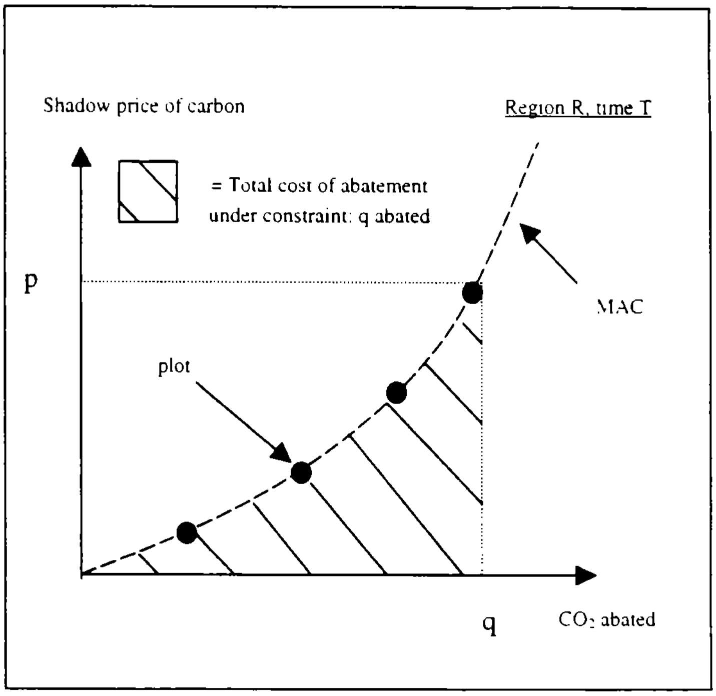

Fig. 1: Marginal Abatement Curves

b) How Can MACs Be Used for Trade Studies? (Fig. 2)

Any emission reduction for a region can be represented as a point on its marginal abatement curve. If several regions commit to achieve emission reductions at the same time, and if the marginal costs associated with those reductions are different, the aggregate cost of meeting the commitments will be less to the extent that a region with higher marginal costs can induce a region with lower marginal costs to abate more on its behalf.[4] By abating more, the lower cost region creates 'rights to emit,' or emission permits, which it can sell to the higher cost region. The difference in the marginal costs associated with each region's commitment in the absence of trade creates a potential gain to be shared in some manner between the two regions. The aggregate emission reduction will be achieved at least cost when the regions trade until their marginal abatement costs are equal at what will then be the market clearing price for the 'right to emit' carbon.

Fig. 2 illustrates the gains from trading for two regions, R_1 and R_2, subject to the constraints: CO_2 abated = q_1 for R_1 and q_2 for R_2, and Table 2 below displays the cost calculations in the no trading and trading cases.

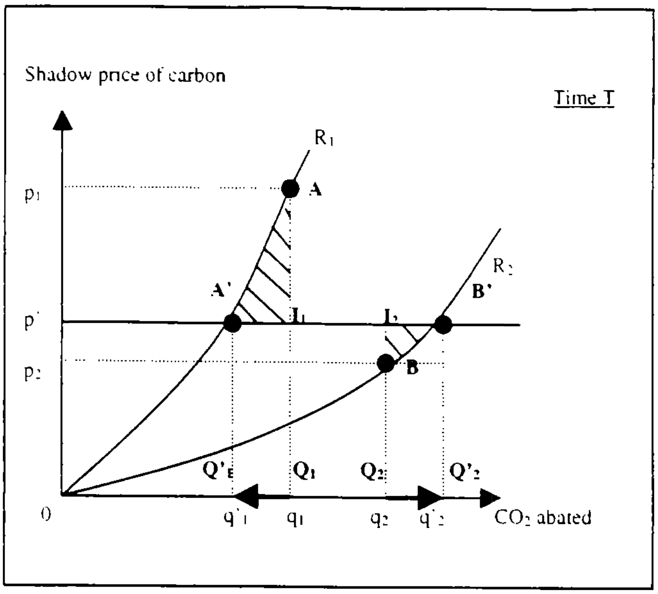

Fig. 2: MACs Used for Trade Studies

	No Trade	Trade between R_1 and R_2
Constraints	R_1: q_1 abated R_2: q_2 abated	R_1 and R_2: $q_1 + q_2$ abated
Marginal Cost / Market Price	R_1: p_1 R_2: p_2	R_1 and R_2: p' such that $p'_1(q'_1) = p'_2(q'_2) = p'$ and $q'_1 + q'_2 = q_1 + q_2$
Abatement Cost	R_1: area AOQ_1 R_2: area BOQ_2	R_1: area $(A'OQ'_1)$ R_2: area $(B'OQ'_2)$
Emission Permits Trading	NA	R_1: buys right to emit $q_1-q'_1$ R_2: sells right to emit $q'_2-q_2 = q_1-q'_1$
Imports (+) / Exports (-) Flows	NA	R_1: pays $p' * (q_1-q'_1)$ = area $(A'I_1Q_1Q'_1)$ to R_2 R_2: receives $p' * (q'_2-q_2)$ = area $(B'I_2Q_2Q'_2)$ from R_1
Total Cost	R_1: area AOQ_1 R_2: area BOQ_2	R_1: area $(A'OQ'_1)$ + area $(A'I_1Q_1Q'_1)$ < area (AOQ_1) R_2: area $(B'OQ'_2)$ – area $(B'I_2Q_2Q'_2)$ < area (BOQ_2)
Savings from Trading	NA	R_1: area (AI_1A') (hatched) R_2: area (BI_2B') (hatched)

Table 2: Basics of Trade Studies

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[4] As is typically assumed in such analyses, and as is the case here, the environmental goal pursued – reducing atmospheric concentration of a long-lived greenhouse gas like CO_2, which is well-mixed globally – is not affected by the location of the emission reduction.

These cost calculations can easily be generalized to N regions, and they constitute the basis of this study: we will calculate, under various trading assumptions, the volume of trade and the resulting savings for the regions.

c) How Can MACs Be Generated by the EPPA Model? (Fig. 3 and 4)

To build the MACs, we run the EPPA model under different constraints corresponding to different levels of carbon abatement, such as 10%, 20%, or 30% below reference emissions. For each set of constraints, the corresponding, regional shadow prices of carbon are an output of the model. Then we plot the shadow prices as a function of the level of abatement, for time T and region R. A line can then be fitted between the plots to get the MAC of a region R at time T (for example, in the Kyoto case, we are interested in time T = 2010).

As an example, Fig. 3 shows the results obtained for the four OECD regions in 2010 when the policies applied are proportional reductions by all OECD regions (1, 5, 10, 15, 20, 30 and 40% of reference 2010 emissions) in 2010, and no reduction by other regions. Here, the shadow prices have been plotted as a function of the percentages of carbon emission reductions (and not the absolute quantities), in order to show the variations across regions without taking into account the size of the economy. We can see that, for any equal percentage reduction, the abatement of the corresponding quantities would cost most in Japan and least in USA and OOE among the OECD regions.

Similar curves can be obtained for all regions. For example, we can apply the same proportional reductions, but to all of EPPA's twelve regions at the same time.[5] Fig. 4 displays the marginal abatement curves thus obtained. It shows where it is the cheapest to abate carbon emissions (India and China) and where it is the most expensive (Japan). Now, to allow trade studies like in Fig. 2, we need to re-scale the x-axis of these curves to actual absolute quantities instead of percentages, and it is the way MACs will be represented from now on.

d) Assessing the 'Robustness' of MACs with Regard to the Policy Applied (Fig. 5)

One question that arises immediately from our use of equal proportional reduction across regions to generate the MACs is whether the location of these curves, or more generally, the cost associated with any given level of carbon abatement, is affected by differing levels of abatement in other regions. For instance, as can be seen in table 1, the levels of implied abatement corresponding to the Kyoto commitment are not strictly proportional, and with emissions trading, we would not expect the percentage reductions among regions to remain the same. Will region R_1's MAC look different depending on whether region R_2 reduces by 10% or 40%? In a model with international trade in all goods, such as EPPA, there is the possibility that a 40% reduction by region R_2 would alter trade flows such that abatement of, say, 100 Mton by R_1 would cost more (or less) than if R_2 reduced emissions by

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[5] In doing so, we do not imply that non-Annex B countries assume quantitative national constraints, but only that when faced with the corresponding price for carbon emission reductions, they choose to abate emissions in the proportions indicated. The result is similar, but the motivation is different.

only 10%. This fundamental question is that of the robustness of the MACs. And indeed, a drawing like Fig. 2 and the simple method we have deduced from it assume this robustness (one curve for each region, whatever the reductions in other regions). The answer: they are robust.

For example, Fig. 5 shows simultaneously the two sets of MACs corresponding to varying levels of OECD abatement assuming no emissions trading and fully efficient emissions trading.[6] The curves in both sets are similar (less than 10% variation in price for any given level of abatement), thus showing that the MACs are robust with regard to this change of policy. We have made similar comparisons for Annex B trading and global trading, and we have examined one region's MAC (the USA) when all other regions vary from reference to as much as a 60% reduction. In all cases, we have found the same fundamental result: whatever the trading scheme, whatever the extent of the market, the marginal abatement curves are almost identical. These model results indicate that abatement cost in a region is largely independent of abatement efforts in other regions.

Our conclusion is that MACs, and more generally, the costs associated with a given level of domestic abatement, are robust to different levels of abatement among regions and the scope of emissions trading. Whatever the reductions of other regions, a MAC for a region R at time T looks the same.

e) Analytical Approximations: a Simple Tool for Trade Studies (Fig. 6)

Robustness implies that each region at time T has a unique marginal abatement curve. This fundamental result validates the use of marginal abatement curves, and makes actual trade analysis straightforward and simple. Analysis can be simplified even further if each curve could be described by a single mathematical expression because, once we have the equations of the MACs, the cost calculations (i.e. integration under the curves) are extremely simple and rapid.

Fig. 6 shows, for the OECD regions, that we can fit simple analytical curves to the sets of plots resulting from the EPPA runs, and that those fits are very good (for each curve, R^2 is very close to 1). This result is true for all the other regions as well. The curves that best fit the EPPA-generated plots are of the form: $P = aQ^2 + bQ$, where Q is the amount of abatement in million metric tons of carbon (Mton) and P is the marginal cost, or shadow price, of carbon in 1985 US$.[7] By integration, the total cost of abatement is: $C = 1/3*aQ^3 + 1/2*bQ^2$). The table below displays the coefficients a and b for each region in 2010, as well as the coefficient of determination, R^2.

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[6] Note that, compared to figs. 3 and 4, the x-axis has been re-scaled to quantities.

[7] Multiplication by 1.5 converts all price and cost data in this paper into current (1998) USdollars.

Region	a	B	R^2	Region	a	b	R^2
USA	**0.0005**	**0.0398**	0.9923	**EEX**	**0.0032**	**0.3029**	0.9983
JPN	**0.0155**	**1.816**	0.9938	**CHN**	**0.00007**	**0.0239**	0.9992
EEC	**0.0024**	**0.1503**	0.9951	**IND**	**0.0015**	**0.0787**	0.9970
OOE	**0.0085**	**- 0.0986**	0.9981	**DAE**	**0.0047**	**0.3774**	0.9996
EET	**0.0079**	**0.0486**	0.9973	**BRA**	**0.5612**	**8.4974**	0.9997
FSU	**0.0023**	**0.0042**	0.9938	**ROW**	**0.0021**	**0.0805**	0.9967

Table 3: Coefficients of the Approximations of the MACs of the Form: $P = aQ^2 + bQ$

In using these approximations, analysts should keep in mind that the price of this simplicity is some loss of the details of the general equilibrium features of the underlying model. The robustness of the curves assures us that the relation between price and quantity of abatement is relatively fixed, but the curves do not capture all the effects of emissions trading. Since the EPPA model remains our primary analysis tool, we have run the model in every policy case we studied not only to ensure that the approximations are not misleading, but also to check for any significant side effects. The prices and quantities for abatement were all very close to the approximations, but there is a side effect that the MACs do not show: "leakage." As will be discussed more extensively later, when only some regions' carbon emissions are constrained, carbon emissions tend to leak to non-constrained regions. Nevertheless, these effects are not essential to the analysis, and the analytical approximations are a powerful computational shortcut to particular results. They provide a convenient way to graphically represent the results of the analysis of trading, and we use them extensively for that purpose in the remaining sections.

f) Aggregate Supply and Demand Curves (Fig. 7)

Marginal abatement curves are the basis for determining the demand and supply for emission permits in any given market. Emission permits represent 'rights to emit' and these rights can be produced by some party abating more than it is required to do, or undertaking some abatement when not required to do so. The willingness of any party to purchase or to sell these permits is illustrated by Fig. 7. The vertical dotted line represents the amount of abatement required for a region to meet its Kyoto commitment. In the absence of any emissions trading it would

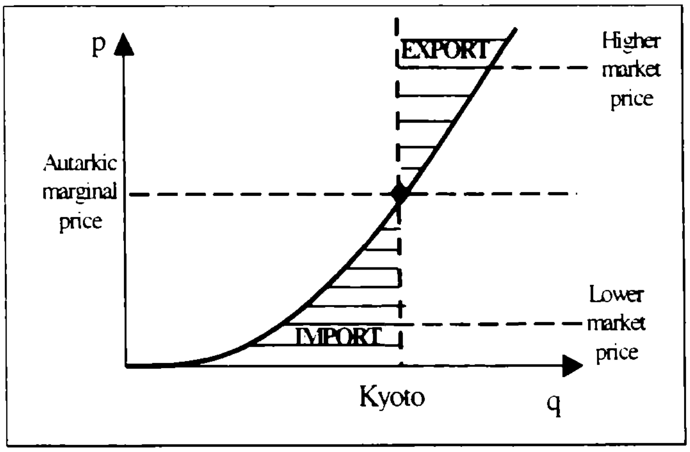

Fig. 7: Willingness to Import / Export with Regard to Market Price of Permits

abate the amount indicated by the intersection of this line with the MAC, and the corresponding price would be its autarkic marginal cost. If emissions trading were a possibility, the region would purchase or sell permits according to the relation of the market price to its autarkic marginal cost.

- If the market price is lower than its autarkic marginal abatement cost, this region would be willing to buy emission permits corresponding to the quantity difference between the autarkic emission reduction and the domestic abatement it would undertake at the market price.
- Conversely, if the market price is higher than its autarkic marginal abatement cost, it would be willing to undertake more abatement and supply the market with the 'right to emit' the corresponding quantity.
- Unconstrained regions, such as the non-Annex B regions or the FSU, are a special case. Their autarkic marginal cost is zero, and they would be only suppliers to the market at any positive price.

For whatever market one is considering, we simply add up the quantities (x-axis) potentially supplied and those potentially demanded at each price (y-axis) across the constituent regions. As we vary the price, we describe the demand and the supply curves for this market, and their intersection indicates the market clearing price on the y-axis and the total quantity traded in that market on the x-axis. Examples of aggregate demand and supply curves for the Annex B and global markets will be introduced subsequently.

III. CASE STUDIES OF PERFECTLY COMPETITIVE TRADING

As a first step in illustrating how the cost of meeting Kyoto commitments for different regions is affected by emissions trading, we consider a simple case consisting of only the four OECD regions (USA, JPN, EEC, OOE). We then expand the scope of the market to include all Annex B regions, *i.e.*, OECD + FSU + EET. Finally, to illustrate full global trading, we broaden the market to include the potential supply from the non-Annex B regions. All the numerical results corresponding to different cases are displayed in the tables at the end of the paper.

a) A First Case Study: OECD Only

The No-Trading Case (Fig. 8, Table A)

The MACs for the four OECD regions are all presented on Fig. 8. The black diamonds on the MACs correspond to the quantity of abatement required to meet the Kyoto commitment for each region, on the horizontal axis, and, on the vertical axis, the no-trading, or autarkic, marginal cost for that region. The autarkic marginal cost of abatement for Japan (**$584/ton**) is much higher than the marginal costs of abatement for the EEC (**$273**), the OOE (**$233**), or the USA (**$186**). The areas under the curves represent the total costs of abatement for each region. The total cost for the OECD is **$115 billion**.

The Trading Case (Fig. 9, Table B)

Fig. 9 depicts what happens when there is emissions trading. Regional marginal costs equalize in such a way that the total amount of carbon abated is the same as in the no-trading case (the arrows on the x-axis, which represent the changes in quantities of carbon abated when trade occurs, sum to zero). The resulting price is the market price of emissions permits (**$240/ton**). It is below the autarkic marginal costs for JPN and the EEC, but above those for the OOE and USA. Consequently, JPN and EEC are importers of permits equivalent to **86 Mton** of higher-cost domestic abatement avoided, while the OOE and USA undertake additional abatement in this amount to export the permits. Every region achieves some gains through trading, and the total savings for the OECD are **$13 billion**. The areas representing the regional savings from trade are displayed as the hatched areas on the graph for JPN and USA. Japan imports the most, **65 Mton** i.e. **45%** of the reduction required by its Kyoto commitment, and benefits the most from emissions trading (**$10 billion**). The USA is the principal exporter (**83 Mton**) and it draws the second largest benefit from emissions trading in this market (**$2 billion**). The EEC imports and the OOE exports smaller amounts of emission reductions, respectively, and each benefits by less than **$1 billion**. These relationships point out an important feature of emissions trading: regions whose autarkic marginal cost is farther from the trading equilibrium will import (or export) more and benefit more than those regions whose autarkic marginal cost is closer to the trading equilibrium.

b) Trading with All Annex B Regions

No Trade / Trade within Annex B Regions (Fig. 10 and 11, Tables C and D)

Here we conduct the same analysis as above, except that the FSU and EET are included. In the no-trading case, the marginal cost of meeting the Kyoto commitment for the EET is **$116/ton** and its total cost of abatement is **$5 billion**. As for FSU, the commitment made at Kyoto would not result in a constraint on its carbon emissions, according to our model and nearly all predictions, because its Kyoto commitment corresponds to an emission level higher than the one predicted for 2010 (see Table 1). Therefore, compliance with Kyoto would result in no cost whatsoever for the FSU. The cost of compliance for all of Annex B would be **$120 billion**, i.e. the $115 billion for OECD regions, + $5 billion for EET.

In the emissions trading case with the FSU and EET included, the equilibrium market price is much lower than in the OECD only case, **$127/ton.** The OECD regions are all importers of permits, since the market price is lower than autarkic marginal cost for all of these regions; and the EET and FSU are exporters. The FSU accounts for virtually all of the exports (**98%**). As shown in Fig. 10, about a third of these consist of 'hot air,' with a cost of zero; but the remaining exports are generated by abatement undertaken to earn additional export profits up to the point that marginal abatement cost equals the market price. It costs the FSU **$10 billion** to abate the **234 megatons** (Mton), but the permits can be sold for **$30 billion** for a net gain of **$20 billion**. When added to the **$14 billion** earned for exporting **111 Mton** of the unused Kyoto entitlement, the FSU's total gain from emissions trading is **$34 billion**.

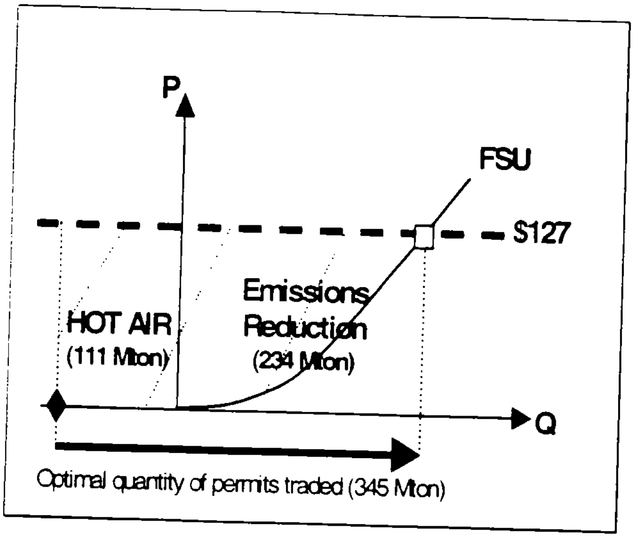

Fig. 10: Trade with FSU: the 'Hot Air' Effect

For the five Kyoto-constrained regions, the cost of meeting the Kyoto commitment is reduced by **$32 billion**, as illustrated in Fig. 11.[8] The four OECD regions avoid more costly domestic abatement by importing permits, and the EET is able to reduce its costs by a small profit on its exported permits. The reductions in cost, that is, the gains from emissions trading for the five Kyoto-constrained regions, are distributed roughly in proportion to autarkic marginal cost. The two regions with the highest autarkic marginal costs, Japan and the EEC, benefit the most from emissions trading in this market. Japan imports **66%** of its reduction requirement and reduces its cost by **$19 billion**. The EEC imports **35%** of its reduction requirement and reduces its cost by **$7 billion**. These two regions account for about one-third of the total emission reduction requirement for the five Kyoto-constrained regions, and about five-sixths of the gains from emissions trading for these regions accrue to them. The other three regions are characterized by autarkic marginal costs much closer to the Annex B market price; consequently, they trade much less. The USA and OOE are importers for **19%** and **25%** of their respective requirements, and the EET abates emissions by **5%** more than required in order to export permits. The gains for these regions, which account for two-thirds of the total reduction requirement, total **$5 billion**, about a sixth of the gains from trading for the Kyoto-constrained regions. From the standpoint of world resource use, the aggregate cost of meeting the Kyoto commitments is much lower with Annex B trade (**$54 billion**) than without (**$120 billion**). The total gains from emissions trading are **$66 billion**, split about evenly between the FSU (**$34 billion**) and the OECD + EET (**$32 billion**).

How Much Difference Does the 'Hot Air' Make? (Table E)

Part of the gains from Annex B trading results from a controversial feature that has come to be called 'hot air:' the difference between the FSU commitment at Kyoto and its predicted emissions level in 2010. Since no abatement is undertaken to produce these permits, their export relaxes the aggregate constraint faced by the five Kyoto-constrained regions by about 8%. As a result, many observers argue that such exports should not be permitted, although admittedly, were the FSU's economy to grow faster than predicted here, global emissions would rise equivalently. From this point of view, the FSU's commitment represents a permissible level of emissions, which if unused is available for banking or export, as would be the case for any other Annex B party.

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[8] In Figure 11, the OOE and EET MACs are virtually identical and thus superimposed.

It is possible, of course, to model Annex B trading without the 'hot air', i.e. without allowing the FSU to sell permits that do not correspond to actual emission reductions.[9] With less supply, the Annex B market clearing price is higher, **$150**, so that the OECD regions + EET abate **90 Mton** more domestically, import correspondingly fewer permits, and pay more for those imports. At this higher price, the FSU also abates more (**20 Mton**) and it sells 90 Mton less, hence **254 Mton**. It is interesting to note that the reduction in the gains from trade are shared about equally: **$9 billion** less for the FSU (**-25%**) and **$7 billion** less for the OECD + EET (**-21%**).

Nevertheless, the reduction in OECD compliance cost and the corresponding gains from emissions trading, **$51 billion**, are still substantial and much greater than if trading were restricted to OECD regions only. This result occurs because, so long as the FSU is not as severely constrained by a Kyoto commitment as its potential trading partners are, it remains a very cheap source of emission reductions.

c) Full Global Trading

Adding the Non-Annex B Regions (Fig. 12, Table F)

To illustrate full global trading, we rely on aggregate supply and demand curves for emissions permits, as explained earlier and now illustrated in Fig. 12. These curves indicate the total quantities of permits that would be supplied or demanded at various price levels in a given market. In the figure, there is only one demand curve because the Kyoto-constrained regions are the same in both the Annex B and the global markets. This single demand curve intersects the horizontal axis at the quantity equal to the sum of the emission reductions required to meet the Kyoto commitments, **1.31 Gton**. This is the 'Kyoto cap' represented by a vertical dotted line on the figure; it is also the quantity of emission permits that would be demanded if the price were $0/ton. At this price, the aggregate supply is the quantity of permits available at no cost: the FSU's 'hot air', **111 Mton**.

As the price increases, the demand for permits diminishes, as more and more domestic abatement is undertaken, and the supply of permits increases as more abatement is justified in the exporting regions. As long as the market price is less than $116, the lowest autarkic marginal cost for the Kyoto-constrained regions,[10] these regions are always on the demand side; and the unconstrained regions are on the supply side. When the price reaches the marginal cost for EET, $116, this region becomes an exporter, supply grows faster, and the demand decreases more slowly, resulting in a 'kink' on all curves, which is almost indiscernible because of the EET's small economic size. Such a kink is, however, readily seen on both supply and demand curves when the price reaches $186, the autarkic marginal cost for USA. There will be similar kinks at $233 when OOE becomes a supplier and at $273 when the EEC does. At $584, the autarkic marginal cost for Japan meeting the commitment, the demand for permits will be zero.

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[9] In making this assumption for modeling purposes, we do not address the practical difficulties of distinguishing 'real' reductions from 'hot air,' nor whether such disallowance would upset diplomatic understandings that may underlie the adherence of Russia, the Ukraine, and other potential beneficiaries of 'hot air' to the Kyoto Protocol.

[10] Note that most of the equilibrium prices we have been considering are below this price.

The ample supply of permits from non-Annex B regions causes a marked shift in the supply curve and results in a market price that is much lower (**$24/ton**) than in the Annex B trading case. The total cost of reducing global CO_2 emissions to achieve the Kyoto goals is astonishingly low: **$11 billion** vs. **$54 billion** with Annex B trading or **$120 billion** with no emissions trading!

At this price, the Kyoto-constrained regions depend far more on imports than when trading was restricted to Annex B regions only. In the aggregate, **71%** of OECD + EET commitments are met through importing emission reductions from non-constrained regions; and the largest importers (proportionately) are those regions facing the highest autarkic marginal cost: Japan, **92%**; EEC, **76%**; USA, **68%**; OOE, **66%** and EET, **56%**. On the suppliers' side, three countries account for the bulk of exports: China (**47%**), the FSU (**23%**) and India (**11%**), hence **81%** altogether. Whether because of relatively small size or high relative abatement costs, the remaining four non-Annex B regions are small suppliers of emission permits to the Annex B regions.

With full global trading, the gains from emissions trading are much greater for the Kyoto-constrained regions (**$94 billion** vs. **$32 billion** with Annex B trading). The non-Annex B regions gain **$10 billion** by exporting permits, but their gains are much less than those of the Kyoto-constrained regions. The FSU is the only party that is worse off by this widening of the market. At $24/ton, the FSU abates about half as much as before, (**101 Mton**), and the 'hot air' is worth much less. As a result, the FSU's net gain (**$4 billion**) in the global market is much less than when it does not compete with the non-Annex B regions (**$34 billion**). The distribution of the gains from emissions trading in the global market illustrates again the feature of emissions trading we just noted: regions whose autarkic marginal cost is further from the equilibrium price benefit more than regions whose marginal cost is closer to that price: in this global trading case, the clearing price is much closer to the shadow price of the exporting regions when they are not involved (**$0/ton**) than it is to the autarkic marginal cost of any of the importers.

Hot Air and Leakage (Fig. 13, Table G)

One of the arguments surrounding the use of emissions trading has been that it would increase global emissions, unless the 'hot air' from the FSU (or elsewhere) could be kept out of the system. This argument ignores an interesting feature of the general equilibrium solution of CGE models, to which we alluded earlier: leakage. When only a sub-set of the regions of the world are constrained and there is no emissions trading, emissions 'leak' to unconstrained regions; however, with emissions trading, there is no leakage, since all regions face the same carbon price.

The compensating effects of leakage and hot air are shown in Fig. 13. If there were no leakage and no hot air, the **1,312 Mton** reduction of emissions required of the five Kyoto-constrained regions could be expected to reduce 2010 global emissions from **9,098 Mton** to **7,786 Mton**. In the no trading case, a total **62 Mton** of leakage (10 Mton to the FSU and 52 Mton to the non-Annex B regions) offsets a portion of the Annex B emission reduction, so that global emissions are actually **7,848 Mton**. When the FSU is included in the trading regime, there is no leakage to the FSU since the carbon price is the same as in the Kyoto-constrained regions, but there is still some leakage to the non-Annex B regions. This amount is less, **35 Mton**, because the price attached to carbon, and thus the incentive to leak, is less for all the

Kyoto-constrained regions.[11] Global emissions increase not by 111 Mton, the amount of hot air, but by 84 Mton (111 Mton less the reduction in leakage, 27 Mton). With full global trading, there is no leakage whatsoever, as all regions face the same carbon price, and the net increase in global emissions associated with emissions trading is only **48 Mton**.

The particular numbers obtained in this model simulation are not what should be stressed. The important point is that, when evaluating emissions trading, the effect of 'hot air' on the global reduction of emissions cannot be considered in isolation from leakage. Emissions trading would allow 'hot air' into the system to the extent any party's Kyoto commitment is not binding, but it also reduces leakage to countries with non-binding commitments or no commitment at all. The net balance depends upon the amount of leakage and hot air, and both are sensitive to the model's emission prediction for countries with non-binding Kyoto commitments and its specification of the trade sector. For instance, higher 2010 emissions for the FSU will reduce hot air without much effect on leakage, and more substitutability in trade will lead to more leakage. Other assumptions than those presented here could easily yield results that would indicate that emissions trading would lead to a net reduction of global emissions. In sum, the interaction of leakage and emissions trading calls for a more nuanced treatment of 'hot air.'

d) Summary of the Three Competitive Trading Cases (Fig. 14 and 15)

Figs. 14 and 15 summarize the three competitive cases we have studied: no trade; trade within Annex B; and world trade, with respect to both the quantity and cost aspects of meeting the Kyoto commitments.

In Fig. 14, the five constrained Annex B regions are represented by bars extending to the right representing the combination of domestic abatement and imported permits that would be chosen by each of these regions to meet the Kyoto commitment. For the two trading cases, the darker portions indicate the amount of the commitment met by importing emissions permits, and the percentage of imports is indicated. The quantities imported are progressively larger as the scope of the market is expanded (from bottom to top for each region) to include more low cost sources of emission reduction. The exporting regions - FSU and non-Annex B, and EET in the Annex B trading case - have bars both to the right and to the left. The amount of emissions reduction they undertake is indicated to the right; and to the left, the amount of emissions permits they export.[12] Those amounts are equal, except that the FSU disposes of a quantity of permits it can sell without undertaking any reductions, namely, the 'hot air,' represented by the striped segment of the bar. This 'hot air' shows up on the right-hand side in the smaller quantities of reduction associated with the two trading cases for Annex B and the World.

Fig. 15 compares the effects of the Kyoto commitment, across cases, in terms of costs, that is, the quantities of fig. 14 multiplied by prices. While trading benefits every region to some extent, two points

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[11] There is also some leakage from the FSU to the non-Annex B regions because the FSU faces a positive carbon price while the non-Annex B regions do not. The general equilibrium solution provided by EPPA shows that whatever that amount is, it is more than compensated by the reduced leakage from the Kyoto-constrained Annex B regions.

[12] Note that the results presented in this figure do not show the leakage effects discussed in the previous section.

become quite clear from this graph. First, the Kyoto-constrained regions facing relatively higher marginal costs derive relatively greater benefit from emissions trading. In both trading cases, Japan and the EEC import more and benefit more than does the USA, because the latter faces lower marginal costs of meeting the Kyoto commitment than the other regions. Second, the FSU exports more and benefits more when it does not compete with the non-Annex B regions to satisfy the demand from the importing regions. Notably, it is the only region that fails to gain from the expansion of the market to embrace global trading, and its loss is striking.

IV. DEPARTURES FROM PERFECT TRADING

All of the cases studied so far assume that potential participants in emissions trading are not impeded by restrictions on trading, that competitive conditions apply, and that trading is conducted efficiently with low or non-existent transactions cost. Such assumptions simplify the analysis and exposition of emissions trading, but they are not necessarily realistic. In this section, we use the aggregate demand and supply curves to evaluate the effects of departures from these simplifying assumptions.

a) The Effect of Quantitative Limits on Demand (Tables H and I, Fig. 16)

The Kyoto Protocol itself contains provisions relating to 'supplementarity' that suggest that a party's ability to rely on emissions trading for meeting its Kyoto commitment may be limited in some manner. This provision has been given further impetus by the call for a "concrete ceiling" by the EU environmental ministers. The imposition of a limit on imports would affect the gains from trade; and in this section, we illustrate the effects by assuming a limit of 33% on any Annex B party's ability to meet its emission reduction requirement through imported permits.[13]

In the case of Annex B trading without restrictions, Japan would optimally realize 66% of its Kyoto commitment through imports, well above the 33% limitation, and EEC 35%, slightly above the limit, while none of the other importing regions would be constrained. As a result, Japan would import commensurately fewer permits and have to abate more domestically, up to a marginal cost of **$322/ton.** However, this is not all that happens.

As illustrated in Fig. 16, less demand shifts the aggregate demand curve downwards, so the market clearing price is slightly lower than it otherwise would be: **$114/ton.** As an interesting result, all the regions that are not affected by this limit import more in response to the cheaper price, and they reduce domestic abatement by a corresponding amount. The USA would thus increase permit imports from 19% to 23% of its emissions reduction requirement, OOE from 25% to 29%. Those regions are unambiguously better off because the supplementarity condition removes the potential demand by higher cost abaters from the emissions trading market. Japan accrues some benefit from the cheaper permit

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[13] The Kyoto Protocol specifies only that "trading shall be supplemental to domestic actions." We define this potential limitation as a percentage relative to the emission reduction implied by the Kyoto commitment, given EPPA's prediction of reference emissions.

imports, but the savings are swamped by the higher costs for significantly more domestic abatement.[14] EEC imports also are affected by the limit, but it benefits slightly from the lower price for the permits it does import. Overall, on the importers' side, the aggregate savings is practically the same, (**99%** of that of the non constrained case), but the gains are redistributed, mostly from Japan that loses **$4 billion** of potential gains, to USA, EEC, OOE. The two exporters, the FSU and EET, are hurt as well. The FSU sells slightly fewer permits at a lower price, thus losing **$4 billion** of potential gains. EET's gains as an exporter disappear, as it becomes a small importer. Overall, the aggregate gains from emissions trading are only reduced from **$66 billion** to **$61 billion**.

The exact numbers and effects will vary of course depending on the supplementarity limit and on the reduction required of various parties to meet the Kyoto commitment. The essential feature is that while the global costs might be a little higher with the supplementarity constraint, such a restriction on imports affects countries very differently. As a result, there is a significant redistribution of gains within importing regions, from regions with relatively high abatement cost, who would otherwise depend more heavily on imports, to regions with relatively low abatement cost.

The same 33% limit on imported permits would have a much greater effect with full global trading. Now, all the importing regions are constrained by the limitation. The price of imports is much lower than in the unconstrained case, **$6** vs. **$24**, but for the constrained regions, the cheaper imports do not make up for the higher domestic abatement cost required: all importing regions, except EET, are worse off. Thus, for the OECD + EET, the aggregate cost for meeting the Kyoto commitments rises from $26 billion to **$43 billion**. The exporting regions gain virtually nothing in this situation (**$1.7 billion** compared to the $14 billion possible gains in the unconstrained situation), because of the restricted demand and the very low market price.

b) Non-Competitive Behavior in Supply

It is premature to worry about non-competitive behavior in a market that is not yet created, but there are dominant suppliers in each of the markets we have reviewed and we have examined the gains from emissions trading only under the assumption that maximizes those gains: perfect competition. The FSU is a particularly dominant supplier in the Annex B market and we turn to that case first.

The FSU in the Annex B Market (Table J)

As an unconstrained Annex B region with hot air, the FSU is the source of the significant gains associated with Annex B trading and the almost exclusive supplier of permits in this market. The FSU is no longer a single political entity, but for the sake of illustration we show what would be the effect if the

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[14] Of course, consumers will not receive the benefit of cheaper imports since the discrepancy between the internal marginal abatement cost of $322 and the world market price of $114 creates a rent for the allowed imports that will be collected somehow, perhaps through a government auction of the rights to import permits. Since this sum is a internal transfer, we do not count it as a resource cost. We are indebted to Ken Chomitz of the World Bank for pointing out this feature of our analysis.

constituent nations were to take advantage of their dominant position by colluding to limit supply in order to maximize their profit.[15] The effect is not great: the price of permits is raised slightly, to **$142/ton** vs. $127 in the competitive case. The reason is that, as the price rises, the importing regions abate more and import less. It makes sense for the FSU (or any monopolist) to restrict supply only so long as the increase in price more than compensates for the decrease in quantity exported. In this case, the elasticity of the aggregate demand curve is such that there is not much to gain for the FSU by restricting supply. As a result, the gains from emissions trading are only slightly less than in the competitive case (**$64 billion**). What is changed is the distribution of the gains from emissions trading. The FSU increases its gains by **$2.4 billion**, while the gains for the importing regions is diminished by **$4.7 billion**. The benefits from emissions trading for the importing regions are still significantly greater than when there is no trading.

A Non-Annex B Cartel? (Tables K and L)

In full global trading, there is no dominant supplier of permits; however, the Kyoto Protocol does specify that non-Annex B emission reductions are to be provided to Annex B parties through a Clean Development Mechanism (CDM). The role of the CDM is not yet established; however, part of the rationale for it appears to be ensuring that non-Annex B countries receive acceptable prices (however determined) for their permit exports.[16] And indeed, as shown earlier, the prices under full global trading would be very low, compared to other alternatives. Furthermore, at a price of $24 and a volume of trade of 935 Mton of emissions reductions, elasticity conditions are more favorable to collusive behavior than in the Annex B case. Nevertheless, assuming successful combination through the CDM or other means, the non-Annex B nations do not enjoy as dominant a position as the FSU in the Annex B market. As a group, the non-Annex B regions supply 77% of the permits in full global trading, whereas FSU supplies 98% in the Annex B market. Consequently, any attempt by the non-Annex B regions to restrict supply would have to take into account the response of the FSU. We study below two cases: FSU competing with the non-Annex B regions and FSU cooperating.

In the first case, only the non-Annex B regions are acting as a monopoly.[17] The Annex B regions are all price takers, OECD + EET as importers, and the FSU as an exporter. The market price is significantly increased (to **$63**), so that the importers abate more and import **279 Mton** less. Their gains from global emissions trading are reduced from $94 billion to **$59 billion**. Non-Annex B regions more than double their gains (now **$22 billion**) despite the reduction in exports by **342 Mton**. As a competitive supplier, the FSU benefits doubly, from the higher price and greater exports (**+63 Mton**). Its gains from trading more than triple, to **$14 billion**. Overall, the global cost of meeting the commitment is still very low, **$20 billion**, but the gains from trade have shifted somewhat more in favor of the exporting regions (**38%** vs. **13%**).

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[15] The results for non-competitive behavior have been derived using the Cournot model: one region/group of regions is the price maker, the other regions are price takers.

[16] For example, in reviewing possible roles for the CDM, Aslam, 1998, cites "offering an 'umbrella' security against possible exploitation in an unequal bilateral negotiation scenario."

When the FSU cooperates with the non-Annex B regions, the resulting price, **$108/ton**, is considerably higher. What happens in the first case is here enhanced: the gains from emissions trading to the importing regions are reduced another $24 billion, to **$34 billion**, while those to the suppliers are increased, by **$4 billion** for the FSU and by **$8 billion** for the non-Annex B regions. Both the non-Annex B regions and the FSU cut back exports drastically compared to the fully competitive case, **-24%** for FSU, to **161 Mton**, and **-61%** for non-Annex B regions, to **285 Mton**.[18] The overall gains from trade are reduced to **$82 billion**, which is still considerable, and shifted even more in favor of the exporters (**58%** of the total gains). This case, the best possible one for the suppliers, provides the theoretical limit of the suppliers' gains from trading emissions permits in a world market: **$47 billion**.

These two cases illustrate that, if it could be organized, there is ample room for non-competitive behavior in the global emissions trading market, in contrast to the Annex B market. Such behavior leads to significant redistribution of the gains from importing regions to exporting regions, whether the FSU competes or cooperates with the non-Annex B regions. Furthermore, the gains to importing regions from emissions trading would still be very large, and greater than would be the case if trading were restricted to the Annex B regions only. For the FSU however, the gains would remain always lower than in the Annex B trading case.

c) Transactions Cost and Other Inefficiencies in Supply (Tables M to O, Fig. 17 and 18)

A far more likely outcome in the global market, or the Annex B market for that matter, is that supply would be limited by transaction costs or a more general failure to take advantage of the economic opportunities provided by emissions trading. For instance, concerns about 'additionality' and the inherent difficulty of identifying a counterfactual baseline for joint implementation projects may impose high transaction costs and thereby limit the supply from non-Annex B regions.[19] Alternatively, potential suppliers may not pursue available export opportunities with the complete economic rationality assumed by EPPA. Such departures from the model's assumptions can be easily simulated by assuming that only a certain share of what is potentially available at any given price would be supplied. If such were the case, the aggregate supply curves would be shifted upward and the market clearing prices would be higher, as shown in Figures 17 and 18.

Fig. 17 illustrates the effect of a 50% reduction in available supply from the FSU due to such imperfections, in the Annex B trading case, assuming unfettered demand.[20] The price is raised to **$167/ton**, compared to $127 when completely efficient supply is assumed. As a result, the role of EET as

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[17] In fact, a perfectly coordinated oligopoly acting as a monopoly.

[18] The FSU reduces much less because of the implicit assumption in our analysis that the monopoly incurs the least cost possible in producing the exported permits. Because of its hot air, the FSU has a proportionately much larger share of low cost permits available.

[19] These costs will be greatly reduced to the extent that non-Annex B regions accept emission caps that remove the concern about additionality and more generally the necessity to establish a counterfactual baseline.

[20] Note that the quantity of available hot air is also reduced to 50% of the theoretical quantity.

a supplier in increased (to **11%** total), as well as its benefits. Importing countries whose autarkic marginal cost is low, such as the USA, almost do not resort to trade, hence their gains decrease, while emissions trading still conveys considerable benefits to the relatively high cost abaters, Japan and the EEC. The FSU exports fewer permits than otherwise (now **190 Mton** compared to 345 Mton), but at a higher price, so it still benefits from this new export opportunity, although its gains are reduced, to **$30 billion** from $34 billion.[21] The gains from emissions trading are less for all parties, but at **$51 billion** in the aggregate, those gains are still important.

Fig. 18 depicts the market equilibrium when only 50% and 25% of the quantities available from the FSU and non-Annex B regions are available. As was the case with Annex B trading, the price increases with the reduced supply, from $24 to **$52** and **$94** respectively. As before, the gains from trade for the importers are less than otherwise, especially for the low cost abaters, but still appreciable. The interesting feature is what happens on the supply side. Unlike the case with Annex B trading with such imperfections, the gains to the supplying regions are enhanced. The increase in the price more than compensates for their limited ability to supply, and their gains are significantly increased (**+85%** and **+137%** respectively for non-Annex B regions, **+30%** and **+35%** respectively for FSU).[22]

V. CONCLUSIONS

A Readily Available Technique for Analyzing Trading Issues

Emissions trading raises many issues concerning magnitude and distribution of the benefits from trade. The primary purpose of this paper has been to explain a readily available technique for analyzing and explaining these issues. Marginal abatement curves are often drawn illustratively, but for all their heuristic value, good empirical estimates of these curves are hard to find. The MACs used here are not empirically estimated, but they are derived from the complex economic models that are commonly used to predict emissions and to evaluate the costs of various policies. As such, they are a compromise: better than purely heuristic curves, but not as good as an empirically estimated relationship. They are in fact only as good as the underlying models, which, for all their faults, are still commonly relied upon to provide insight and estimates of costs and other effects. Analysts who lack such a model and who have a slight aptitude for algebra can take the parameter estimates provided in Table 3 and conduct their own analyses.

It can also be hoped that other modeling groups will make explicit the MACs that are generated by their models, so that policy analysts will have the benefit of knowing how alternative representations of the

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[21] Note that in the efficient monopolistic case (Table J), the best case for FSU, the equilibrium price was only $142. At a price of $167, the FSU is above the price that maximizes its gains.

[22] These two cases can be compared with the case of a perfect supply monopoly (Table L). In that case, which maximizes the gains for the supply side, the market price is $108. Thus, as long as the market price is below $108, which is the case with the two constraints considered here, transaction costs and other imperfections in supply, besides increasing global resource costs, increase the revenues received by suppliers.

underlying economic reality will affect the magnitude and distribution of the gains from emissions trading.

Emission Permit Trading: Implications for Policy

The object of any analytic exercise is to gain insight into policy issues; and many arise from this exercise.

The most fundamental is almost trivial: *any emissions trading, no matter how constrained or imperfect, is better than none at all.* The effect of trading is always to require less resources to achieve the same environmental goal, and thereby to preserve resources for other useful social goals. There is no emissions trading scheme in which all participating parties do not derive at least some benefit.

Second, *the potential for gains from trading is huge*, because of the considerable differences in abatement costs across regions. This potential should certainly provide incentives to both Kyoto-constrained and unconstrained regions to support emissions trading.

Third, from the standpoint of husbanding the world's limited resources, *the fewer the constraints on trading the better*. Even though non-competitive behavior and other departures from perfect trading do not eliminate the gains from emissions trading, they do inevitably increase costs.

Fourth, *the gains from emissions trading will not be evenly distributed.* As a general rule, regions whose autarkic marginal cost of abatement is relatively far from the market price of permits for a given market will derive the greatest benefit from emissions trading.

Fifth, unlike all other regions, *the FSU is adversely affected by opening the market to non-Annex B supply*. The potential conflict of interest between the FSU and non-Annex B regions may influence future negotiations over accession to Annex B or expanding trading to non-Annex B nations.

Finally, *limitations and imperfections* not only reduce the overall gains from trading, they also *redistribute the remaining gains, often in unsuspected ways*. For instance, a quantitative limitation on imports reduces the gains from emissions trading for exporters and for countries whose imports are restricted; but it benefits importing countries that are not affected by the limitation. Also, transaction costs and other forms of inefficiency might be expected to reduce the gains from trading for suppliers; but when supply is ample and prices low, any increase of price increases export revenues and gains from trading, whether due to strategic behavior or plain inefficiency.

Suggestions for Future Research

Our analysis has been limited to CO_2, yet another important dimension of the flexibility accepted at Kyoto is inclusion of the enhancement of sinks and the reduction of other greenhouse gases in meeting Kyoto commitments. Thus, another dimension for further research is broadening of the potential market by the inclusion of sinks and other greenhouse gases. Given appropriate CO_2-equivalence, analogous marginal cost curves could be constructed for the enhancement of sinks and the reduction of other greenhouse gases, and any region's resort to CO_2 emission reduction, sink enhancement and other GHG emission reduction could be explored using these curves. While aggregate costs would undoubtedly be reduced, it is quite unlikely that the distribution of the gains from trading would be the same as when only carbon is included.

Little has been said about uncertainty, and the analysis presented here is based upon one view of the future, that represented by the reference run in EPPA version 2.6. Other futures are quite possible, and it is evident that the marginal costs faced by Annex B parties in 2010 depend as much upon such predictions of economic and emissions growth as they do upon the relative positions of the MACs or the commitments undertaken at Kyoto. Higher or lower emissions growth may not shift the MACs (as opposed to moving along them), but such variations in growth will certainly affect regional supply and demand for permits, and thus the market clearing prices and trade flows detailed above. An important further research direction is the extent to which the conclusions drawn from this single forecast would be modified by a richer treatment of uncertainty.

The relative position of the MACs constitutes the backbone of this analysis. The MACs generated from EPPA are robust with respect to emissions trading policies and to variations in emissions growth, but we doubt that this result would hold for variations in more fundamental assumptions such as technology and substitution elasticities. The relative positioning of the MACs in EPPA – e.g. Japan as the highest cost abater, EEC next then USA and OOE – seems plausible, but what makes costs in Japan twice as high as in the EEC? And what makes China such a low cost supplier of emission reductions? We have tried to make our conclusions general, and thus not overly dependent on the particular MACs generated by EPPA 2.6; but the practical interest of most policy-makers will remain the application of the general principles to specific countries and regions. This calls for a better appreciation of what underlying characteristics make certain countries relatively high or low cost sources of abatement.

VI. TABLES AND FIGURES

Fig. 3: EPPA-Generated Marginal Abatement Curves - 2010
OECD Regions, Proportional Reductions, No Trading

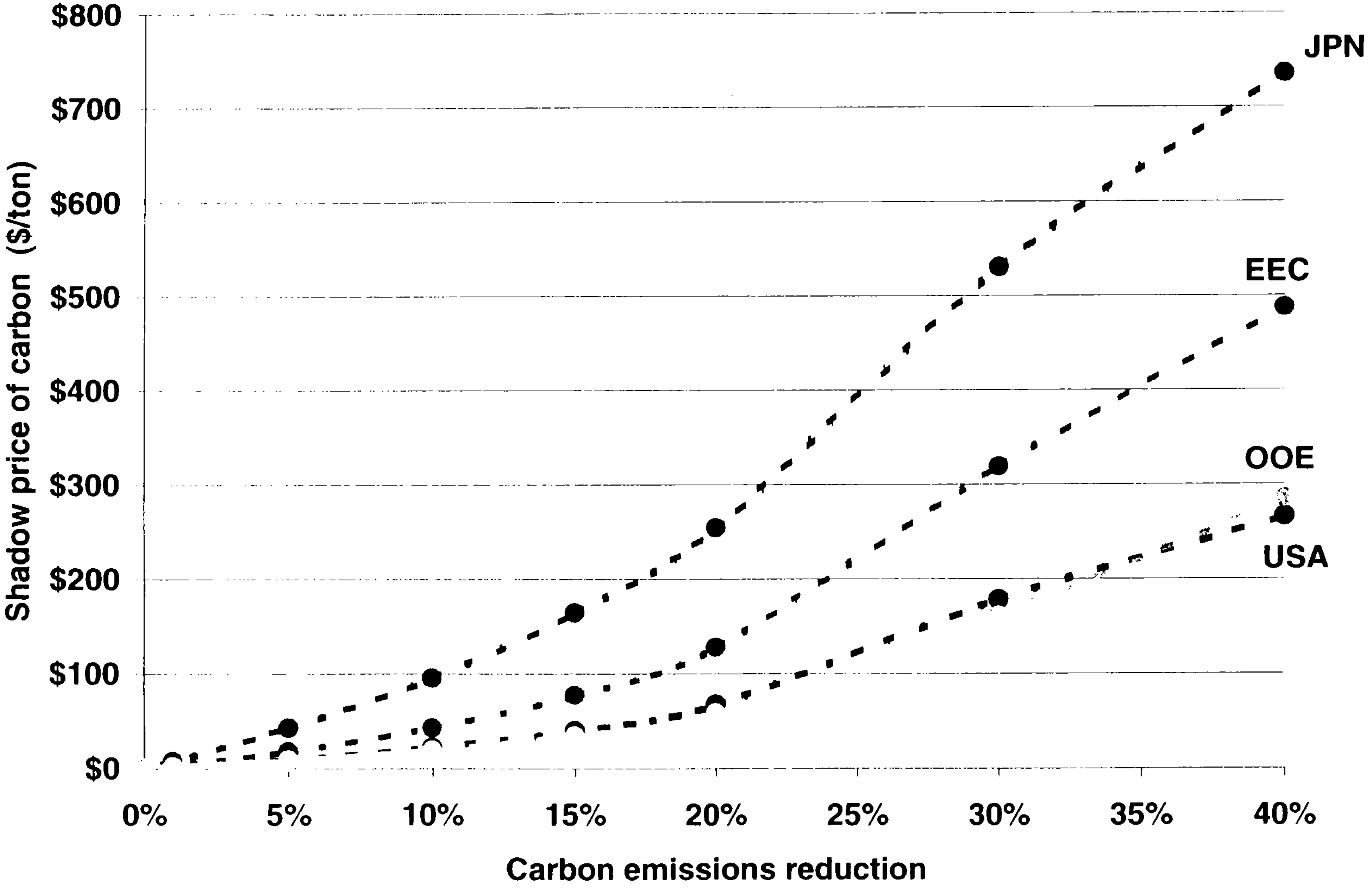


Fig. 4: EPPA-Generated Marginal Abatement Curves - 2010
All Regions, Proportional Reductions, No Trading

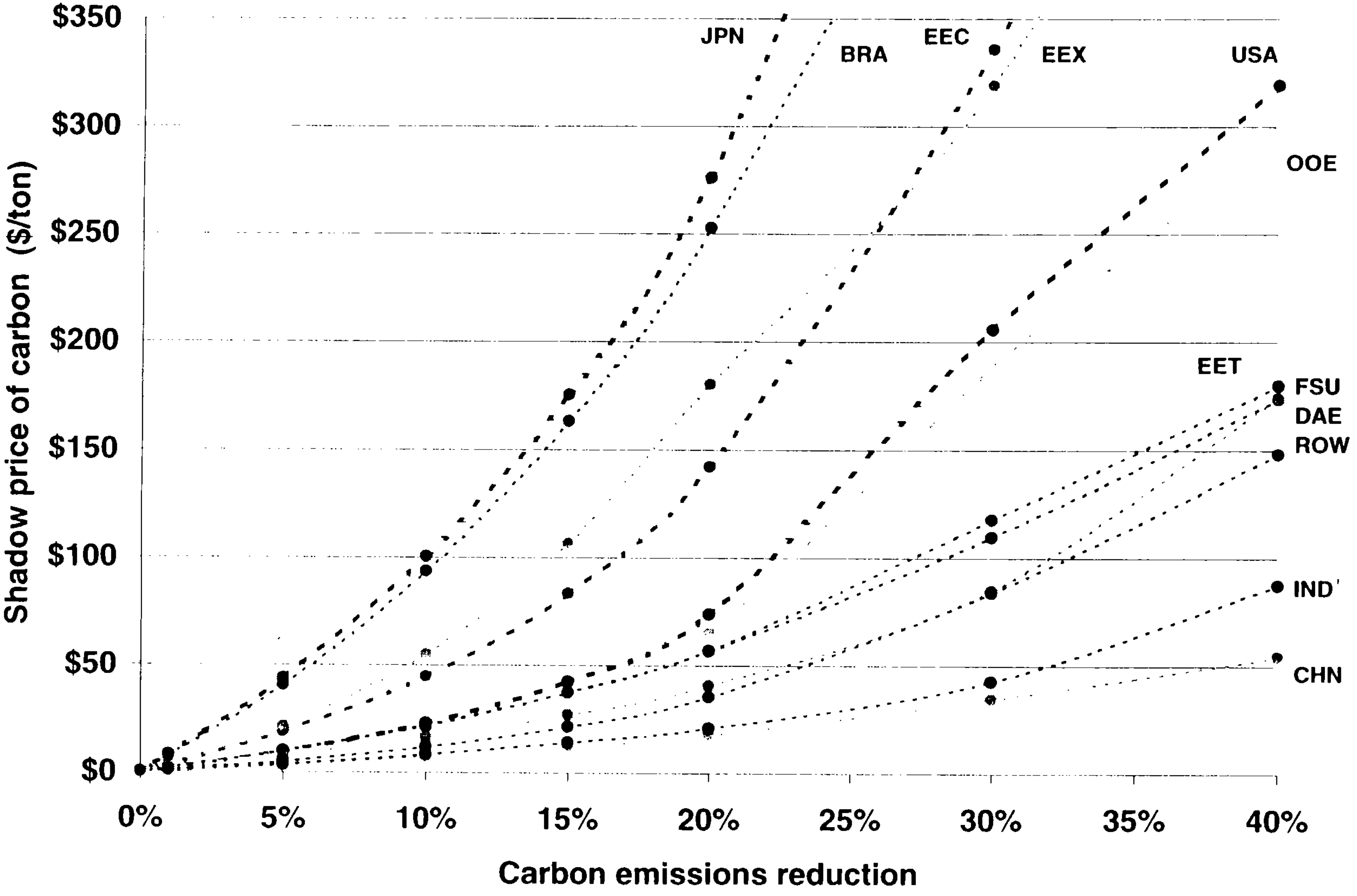


Fig. 5: EPPA-Generated Marginal Abatement Curves - 2010
OECD Proportional Reductions - No Trading / OECD Trading

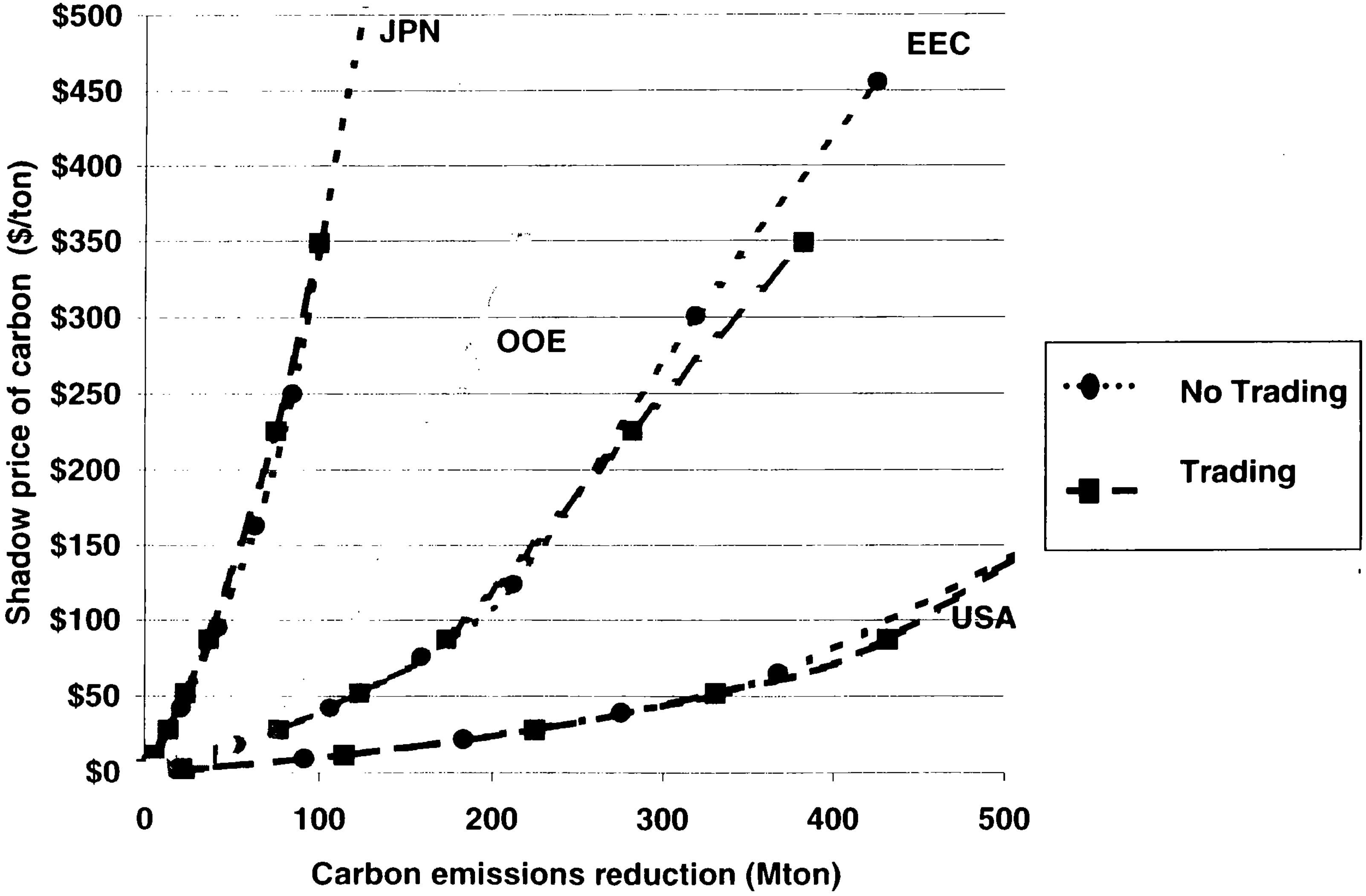


Fig. 6: Marginal Abatement Curves - 2010
OECD Regions - Polynomial Approximations

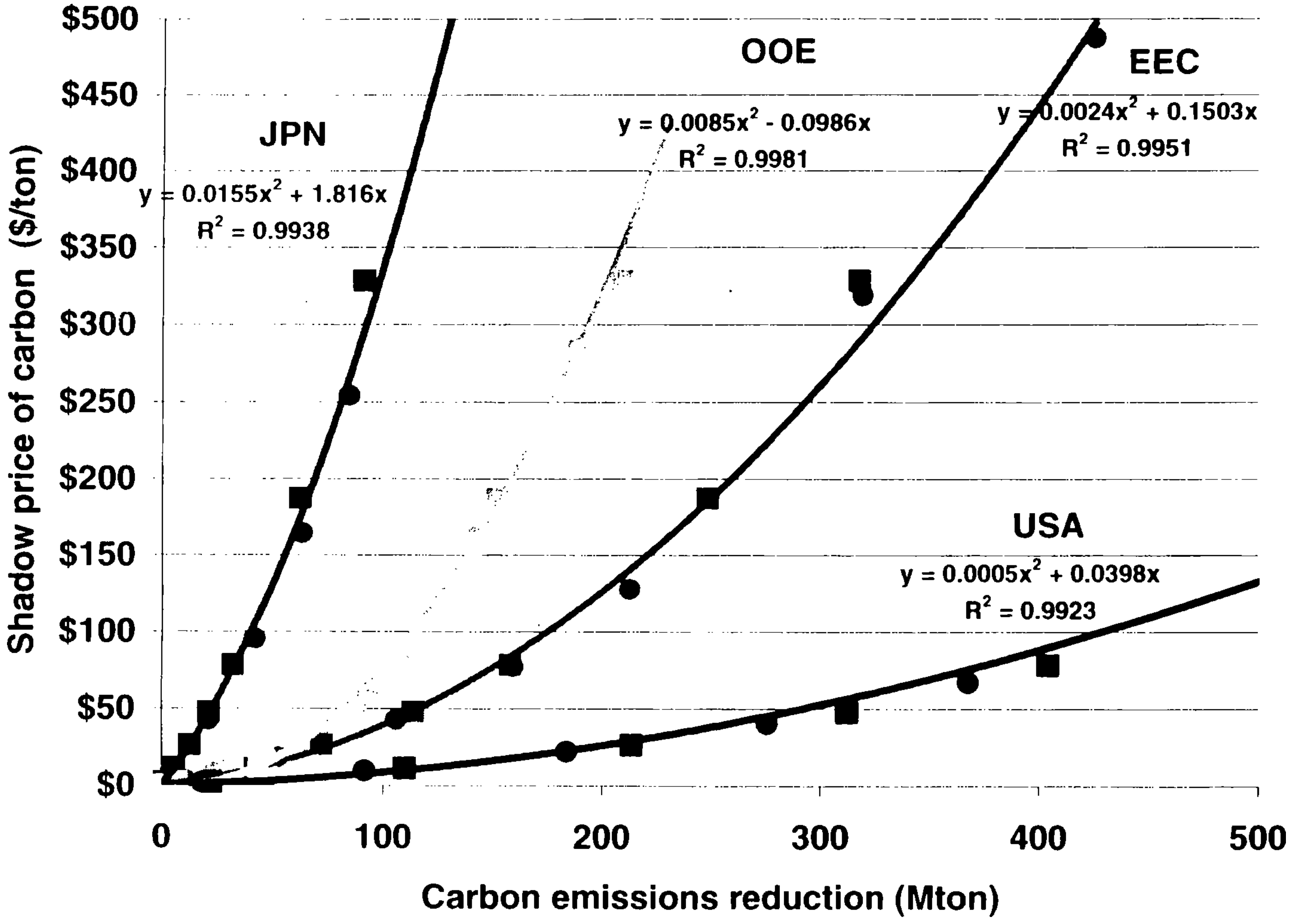


Fig. 8: OECD Regions Meeting their Kyoto Commitment, No Trading

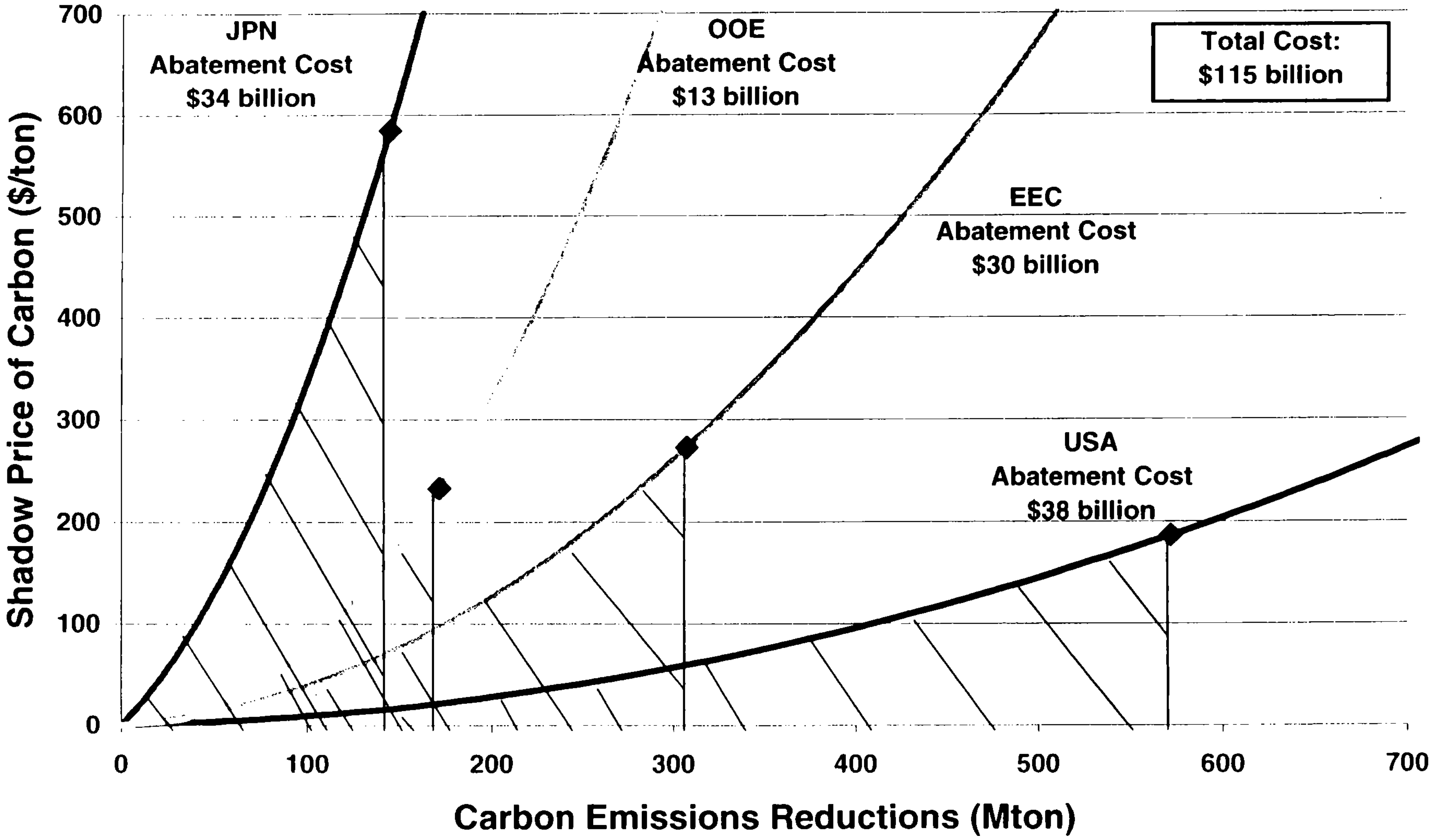


Fig. 9: OECD Regions Meeting their Kyoto Commitment, No Trading / Trading

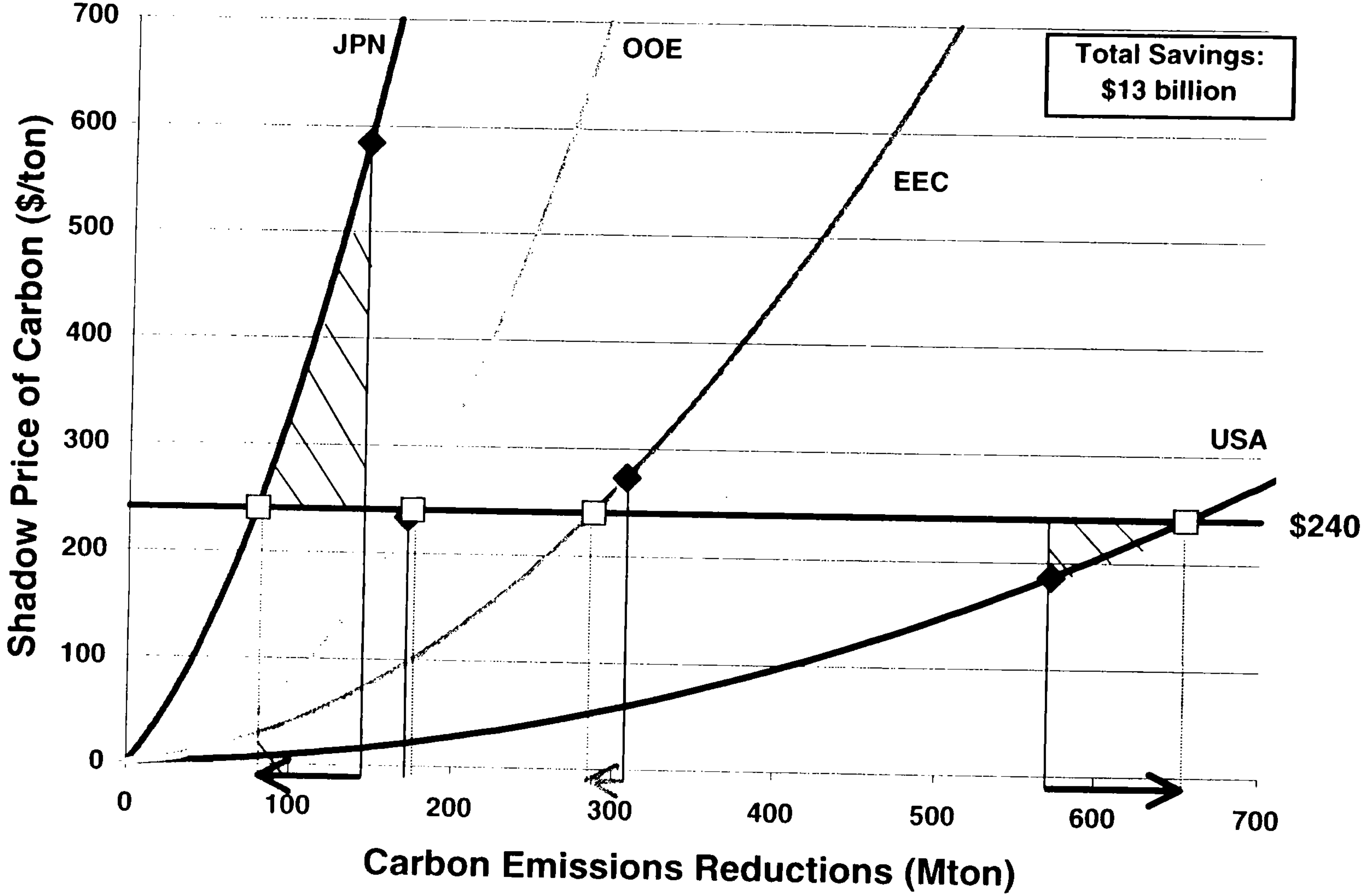


Fig. 11: Annex B Meeting their Kyoto Commitment, No Trading / Trading

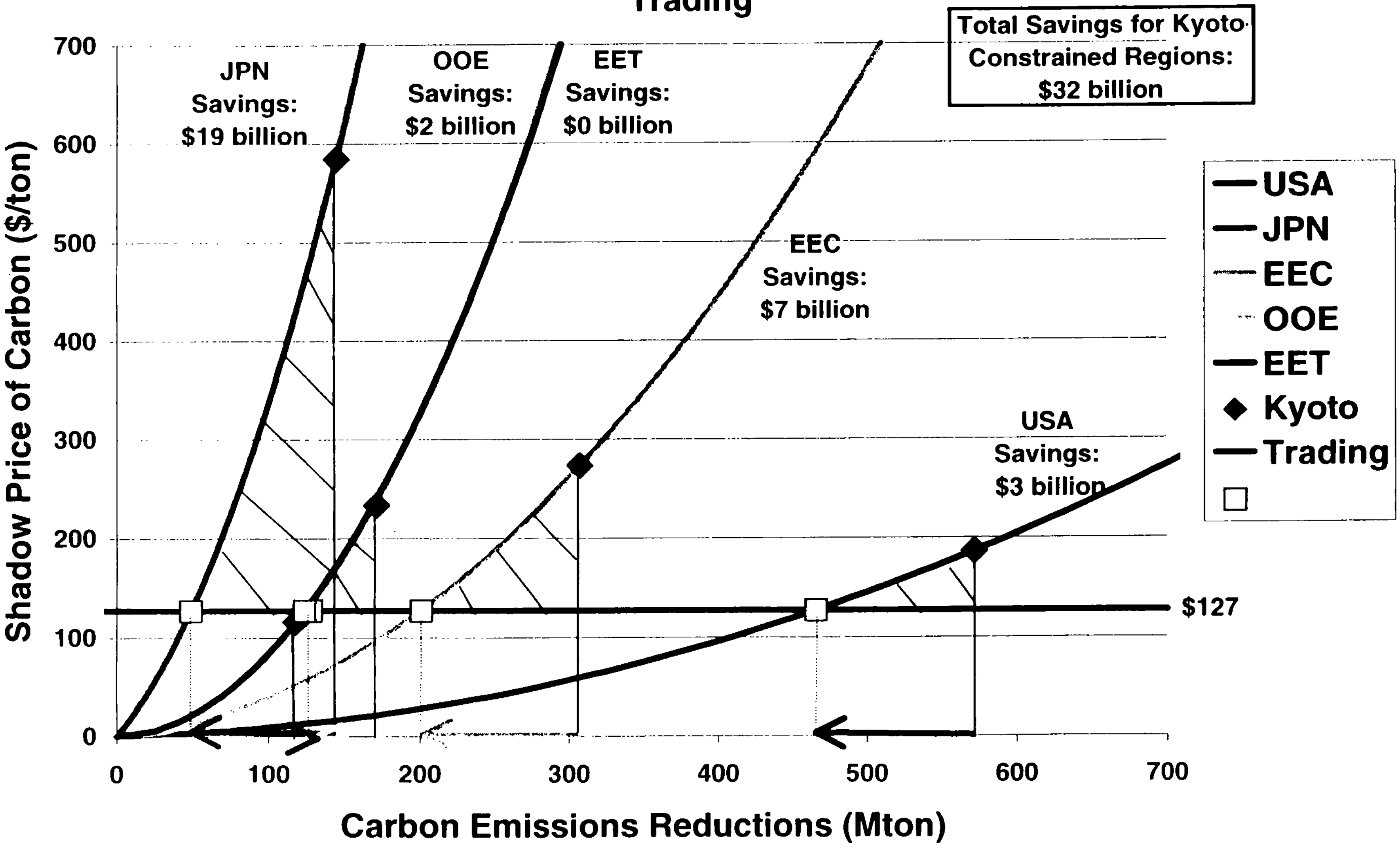


Fig. 12: Aggregated Supply and Demand Curves - Kyoto - 2010
Annex B Trading / World Trading

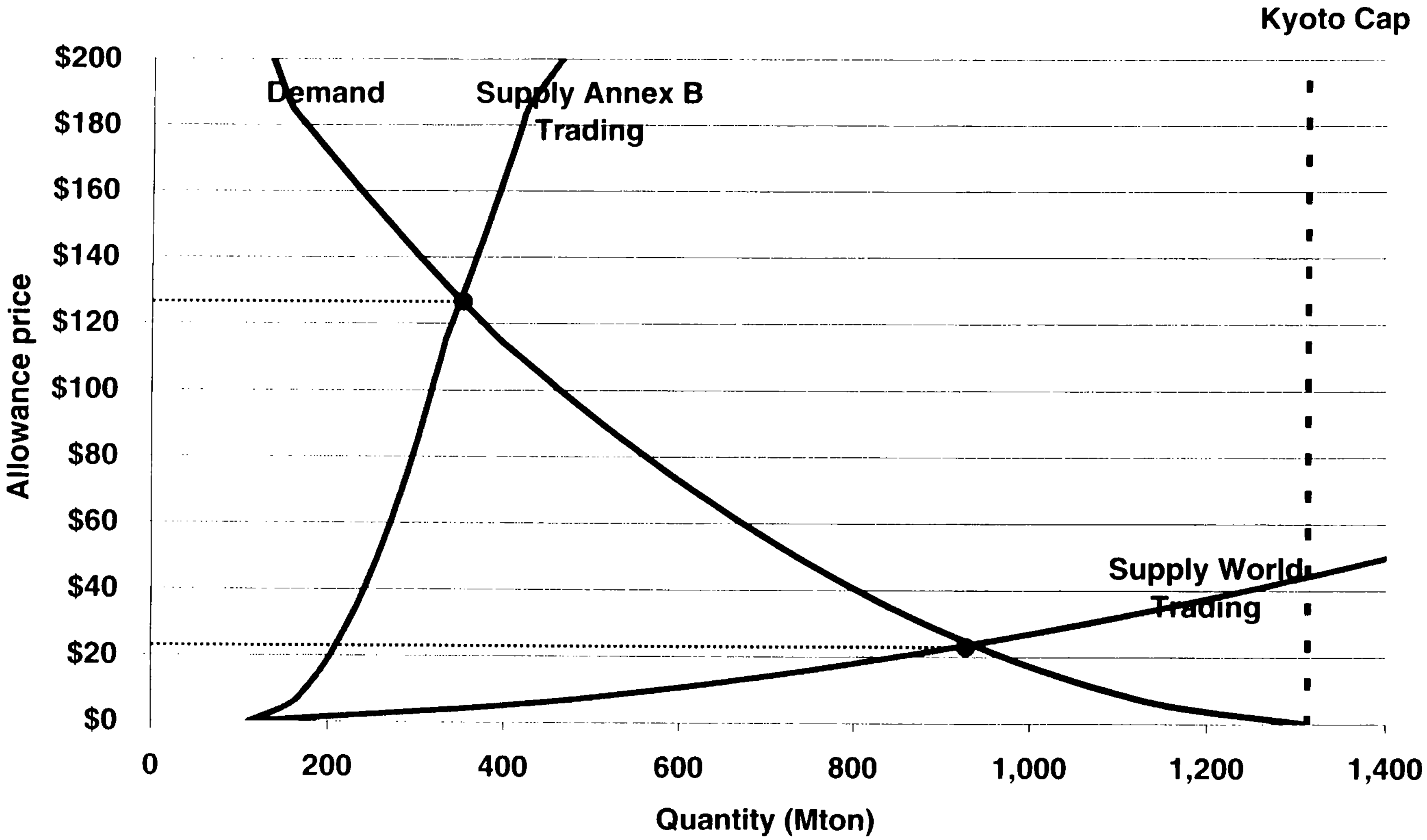


Fig. 13: Actual Levels of Emissions in the Different Trading Cases: Effects of Leakage and the FSU 'Hot Air'

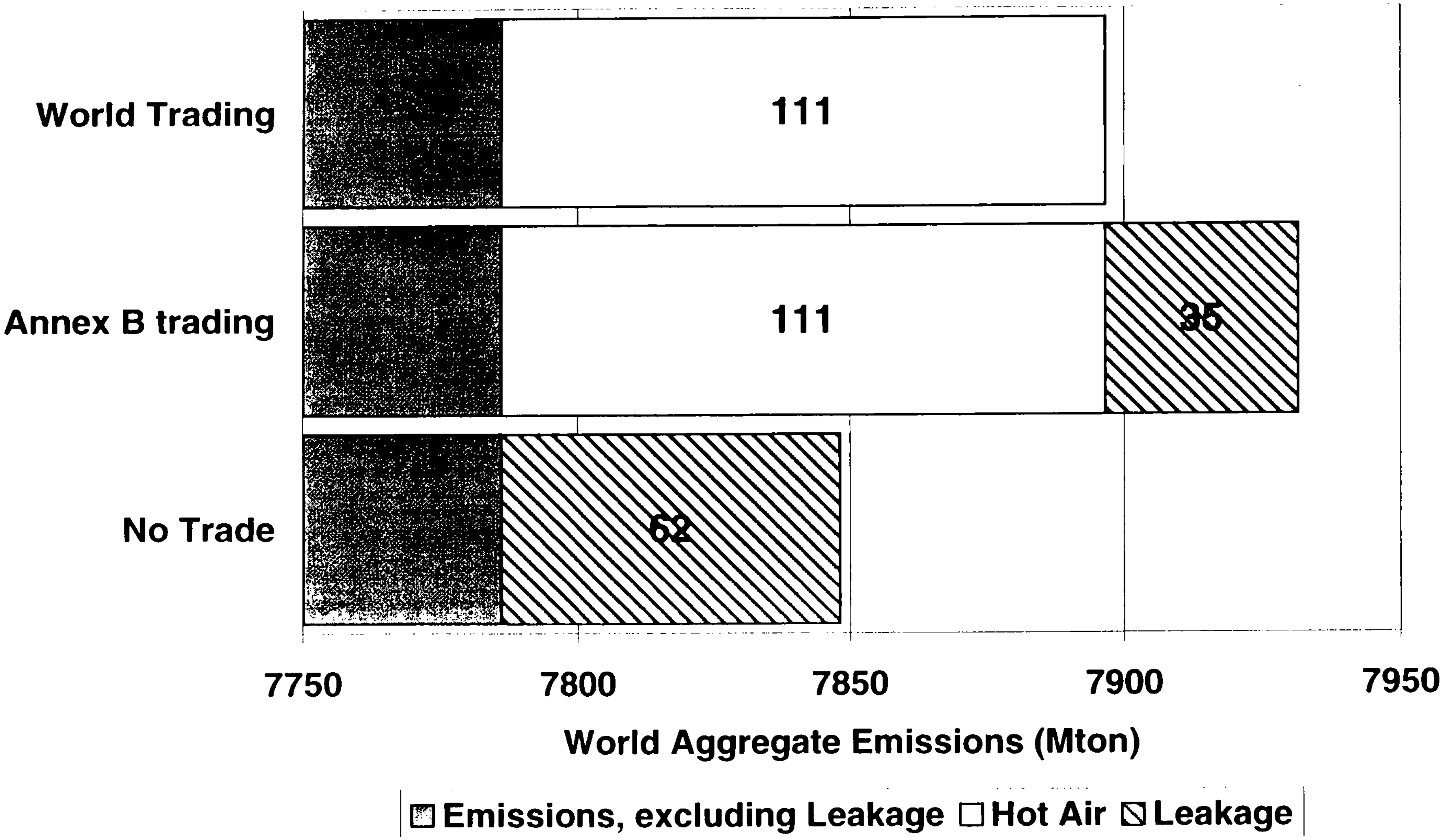


Fig. 14: The effects of Trading: Emissions Reductions, Trade Quantities, Hot Air

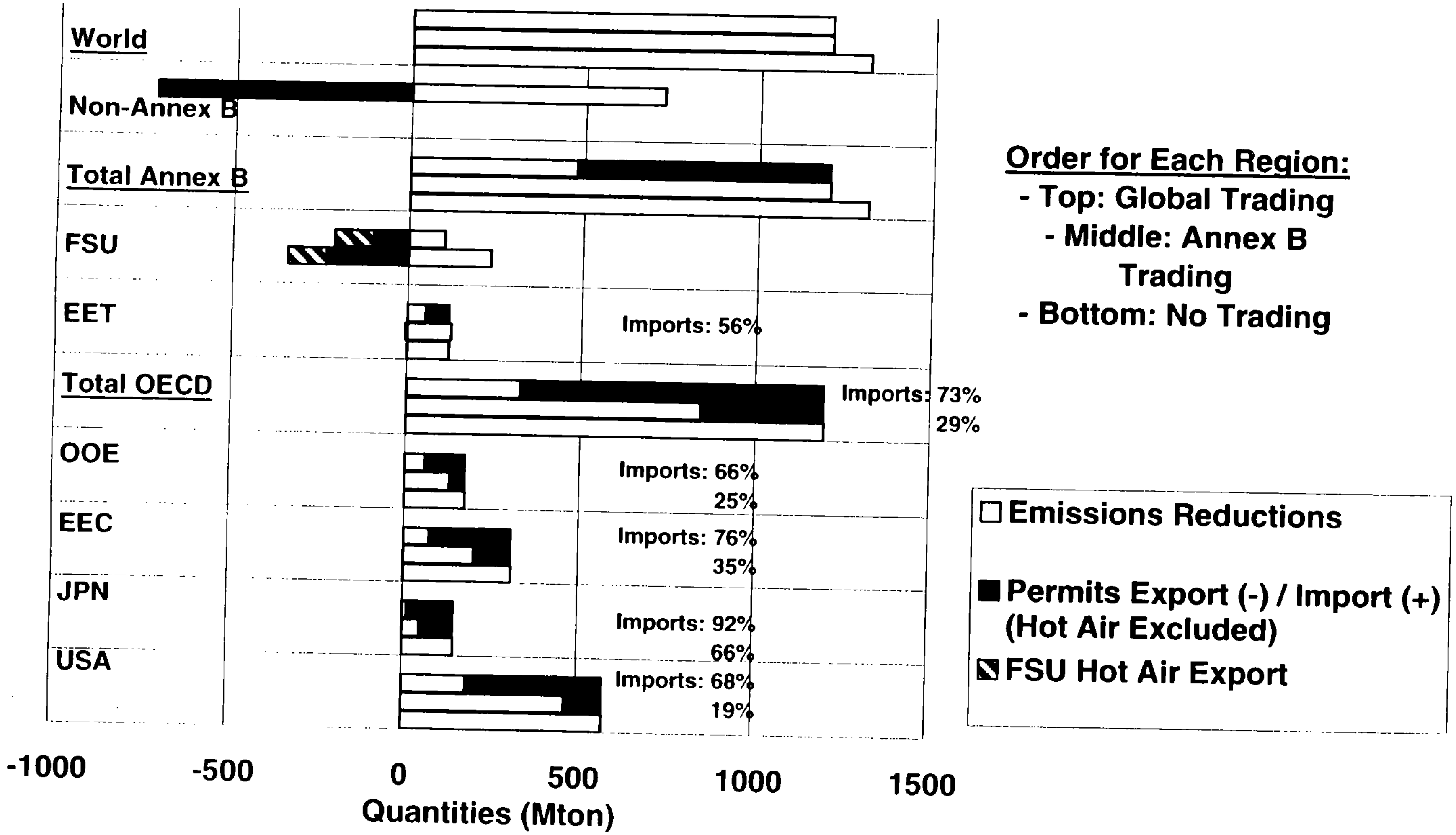


Fig. 15: The Effects of Trading: Regional Abatement Costs and Trade Flows

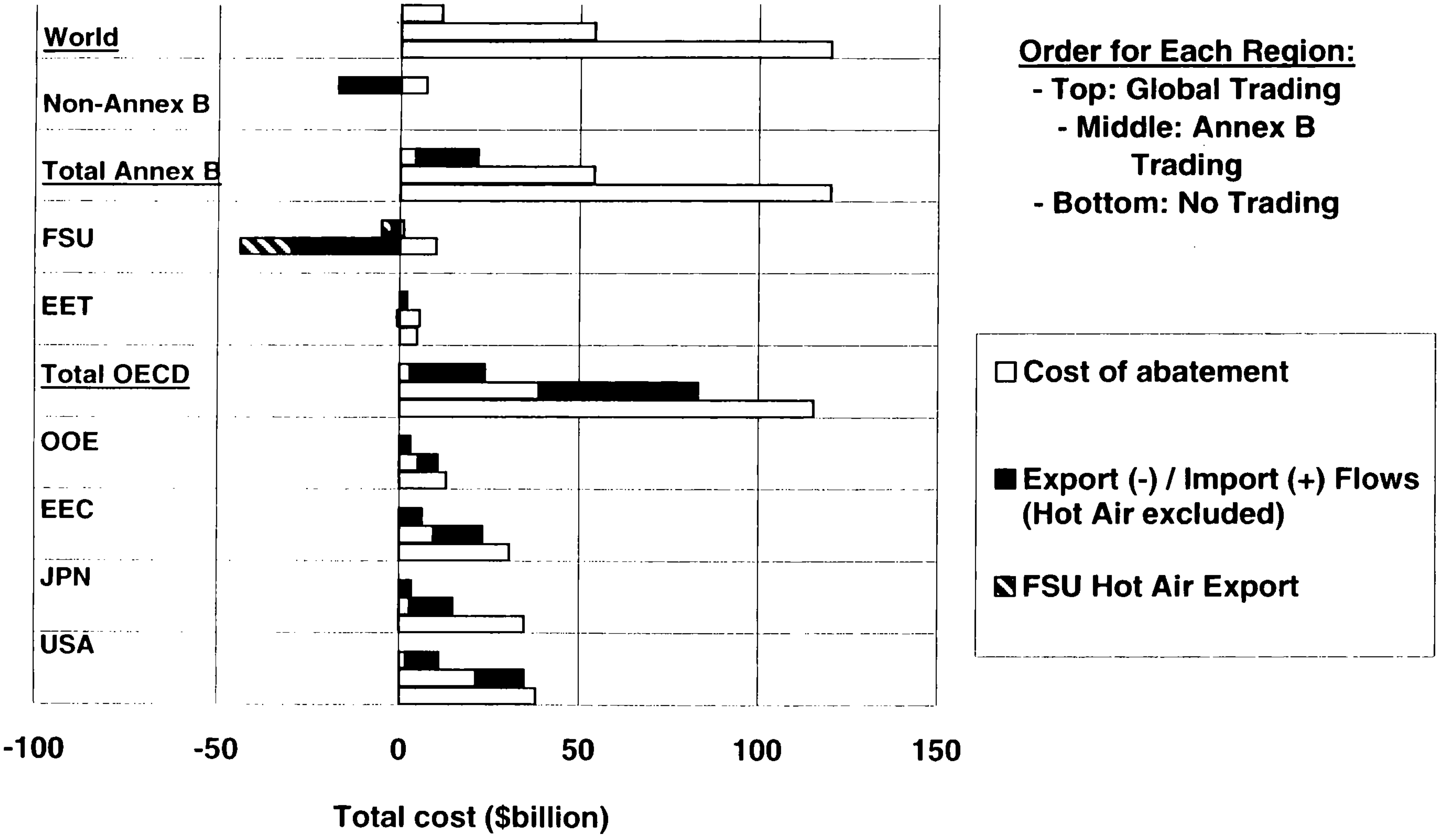


Fig. 16: Annex B / World Supply and Demand - Kyoto - 2010
Demand from Each Importing Region Limited to 33% of Commitment

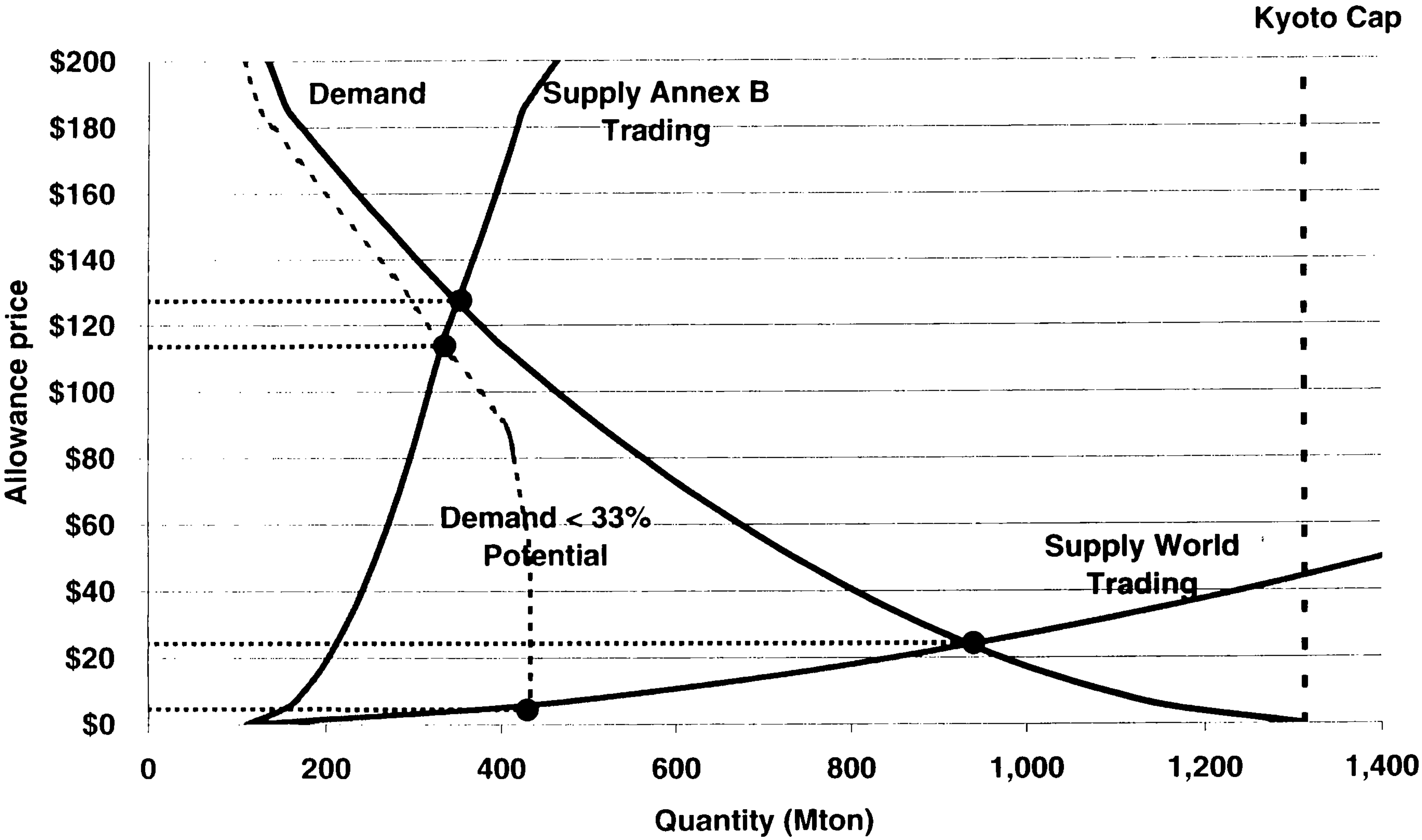


Fig. 17: Annex B Permit Supply and Demand - Kyoto - 2010
Inefficient Supply: Supply = 50% Total

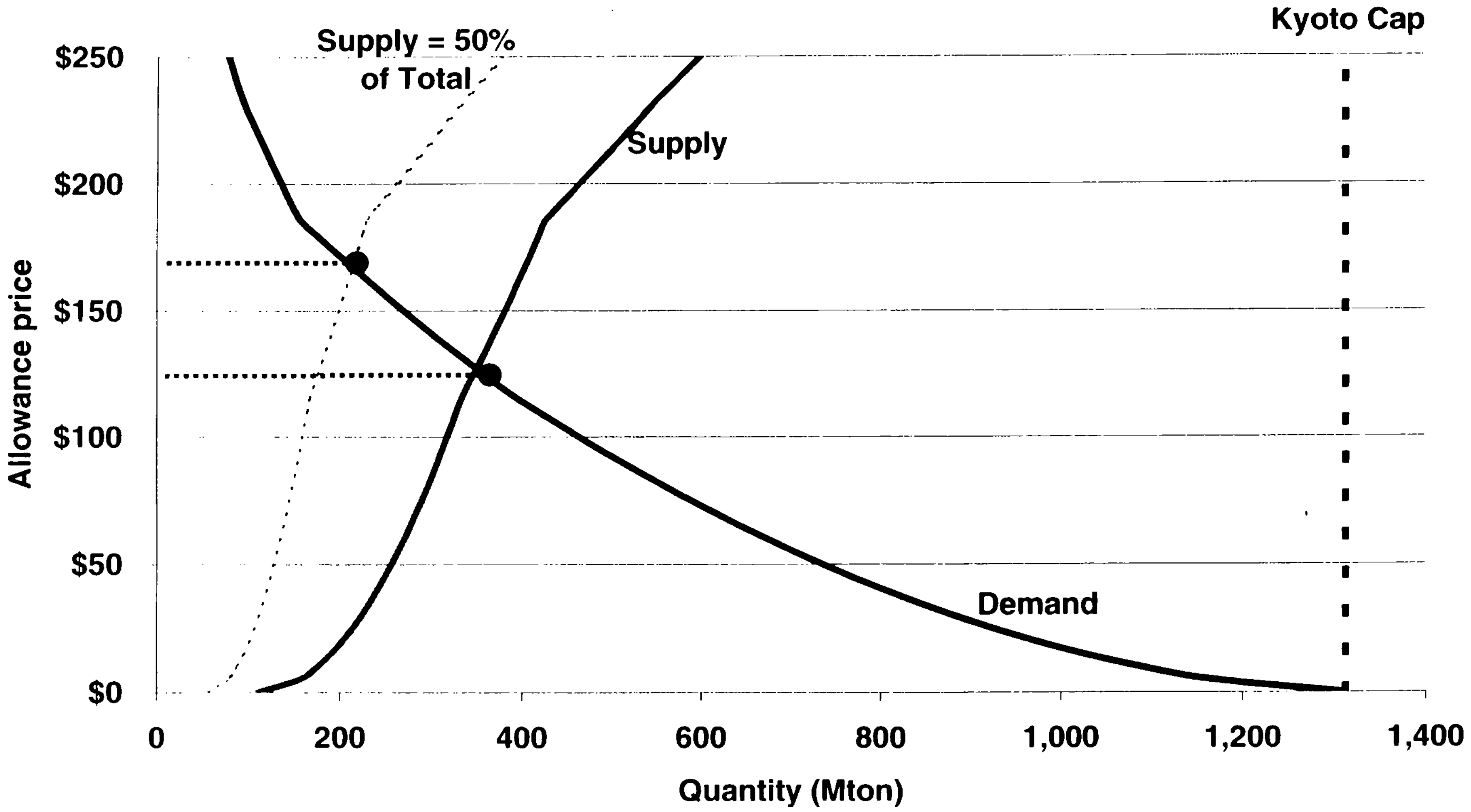
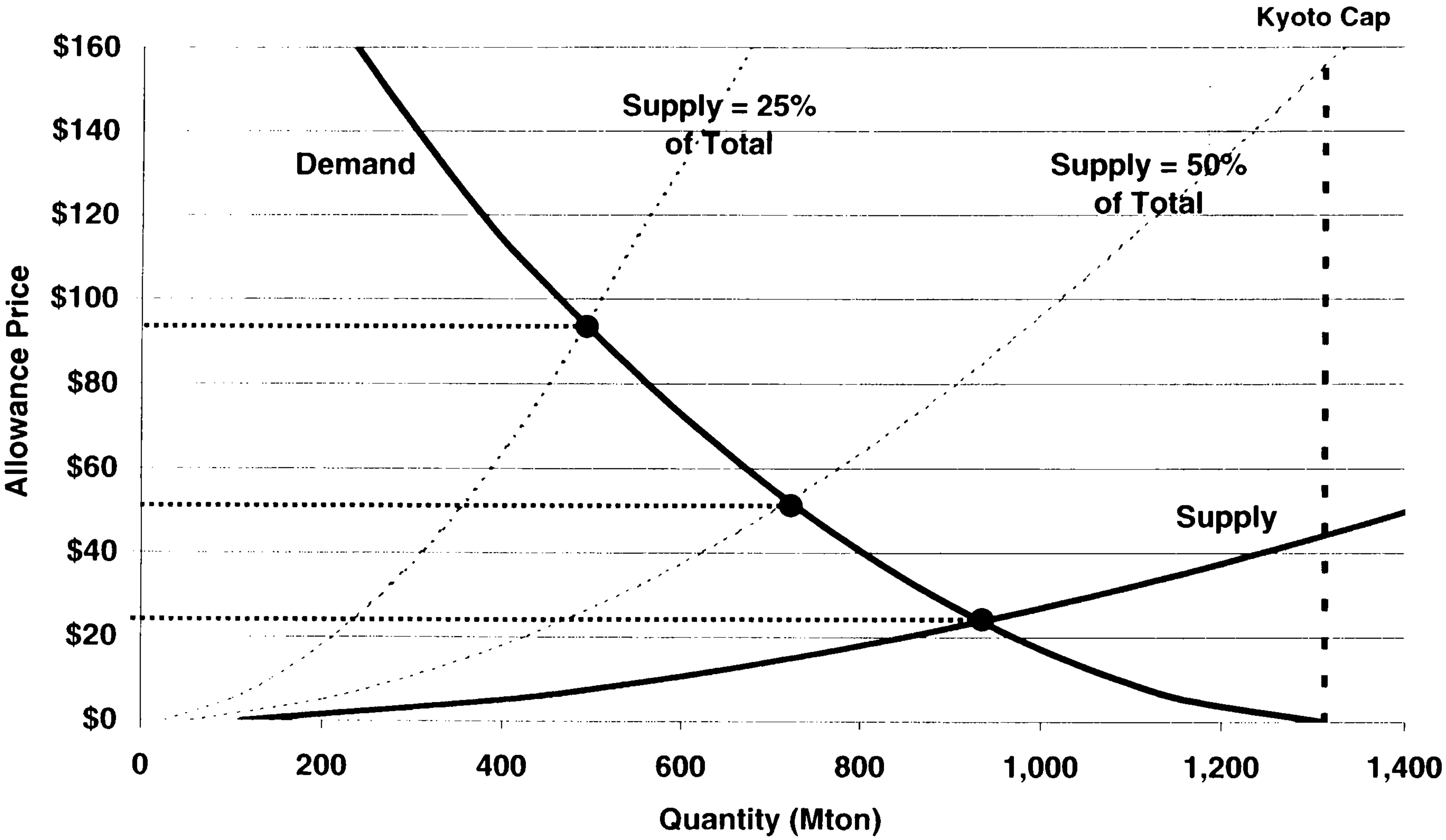


Fig. 18: World Permit Supply and Demand - Kyoto - 2010
Inefficient Supply: Supply = 50% - 25% Total



NB: all the prices in the following tables are in 1985$.   NAB = Non-Annex B regions

I and II. BACKGROUND, METHODOLOGY

TABLE 1 - bis: Reference emissions and Kyoto commitments

Reference emissions	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Ref 1990 (Mton)	1362	298	822	318	266	3066	891	2022	2022	508	833	183	115	63	320
Ref 2010 (Mton)	1838	424	1064	472	395	4193	763	4142	4142	927	1792	486	308	97	532
Kyoto	0.93	0.94	0.92	0.95	1.04		0.98								
Emissions in 2010 (Mton)	1267	280	757	301	277	2881	873	4142	7896	927	1792	486	308	97	532
Reductions / ref 2010 (Mton)	572	144	307	171	118	1312	-111	0	1202	0	0	0	0	0	0
Marginal Costs ($/ton)	**$186**	**$584**	**$273**	**$233**	**$116**										

TABLE 3 - bis: MACs approximations coefficients (P = aR^2+bR)

	USA	JPN	EEC	OOE	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW
a	5.0E-04	1.6E-02	2.4E-03	8 5E-03	7.9E-03	2 3E-03	3.2E-03	7.0E-05	1.5E-03	4.7E-03	5.6E-01	2 1E-03
b	0.0398	1.816	0.1503	-0.0986	0.0486	0.0042	0.3029	0.0239	0.0787	0.3774	8.4974	0.0805

III. BASIC CASES

TABLE A: Kyoto OECD only no trading

	USA	JPN	EEC	OOE	Oecd
Reductions / ref 2010 (Mton)	572	144	307	171	1194
Marginal Costs ($/ton)	**$186**	**$584**	**$273**	**$233**	
Cost of Abatement ($billion)	37.62	34.37	30.29	12.81	**115.09**

TABLE B: Kyoto OECD only OECD trading

	USA	JPN	EEC	OOE	Oecd
Reductions / ref 2010 (Mton)	655	79	287	174	1194
Market Price of Permits ($/ton)	**$240**	**$240**	**$240**	**$240**	**$240**
Cost of Abatement ($billion)	55.28	8.22	25.02	13.44	101.96
Permits exp(-)/imp(+) (Mton)	-83	65	21	-3	0
i.e % of commitment (import)		*45%*	*7%*		
Flows exp(-)/imp(+) ($billion)	-19.95	15.66	4.94	-0.64	0.01
Total Cost ($billion)	35.33	23.88	29.96	12.80	**101.97**
Gains from trade ($billion)	2.30	10.49	0.33	0.01	**13.12**

TABLE C: Kyoto no trading

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	World
Reductions / ref 2010 (Mton)	572	144	307	171	118	1312	0	1312
Marginal Costs ($/ton)	**$186**	**$584**	**$273**	**$233**	**$116**			
Cost of Abatement ($billion)	37.62	34.37	30.29	12.81	4.67	119.76	0.00	**119.76**

TABLE D: Annex B trading

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	World
Reductions / ref 2010 (Mton)	466	49	201	128	124	968	234	1202
'Hot air' (Mton)						0	111	111
Market Price of Permits ($/ton)	**$127**	**$127**	**$127**	**$127**	**$127**	**$127**	**$127**	**$127**
Cost of Abatement ($billion)	21.16	2.82	9.51	5 16	5.36	44 01	9.95	53.96
Permits exp(-)/imp(+) (Mton)	106	95	106	43	-6	345	-345	0
i.e % of commitment (import)	*19%*	*66%*	*35%*	*25%*		*26%*		
Flows exp(-)/imp(+) ($billion)	13.44	12.06	13.51	5 49	-0.73	43.77	-43 77	0.00
Total Cost ($billion)	34.60	14.88	23.02	10.64	4.64	87.78	-33.82	**53.96**
Gains from trade ($billion)	3.03	19.49	7.27	2.17	0.03	31.99	33.82	**65.81**

TABLE E: Annex B trading, No hot air

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	World
Reductions / ref 2010 (Mton)	509	56	220	139	135	1058	254	1312
'Hot air' (Mton)						0	0	0
Market Price of Permits ($/ton)	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**	**$150**
Cost of Abatement ($billion)	27.10	3 73	12.21	6.60	6.86	56 51	12.73	69.23
Permits exp(-)/imp(+) (Mton)	63	88	87	33	-17	254	-254	0
i.e % of commitment (import)	*11%*	*61%*	*28%*	*19%*		*19%*		
Flows exp(-)/imp(+) ($billion)	9.40	13.23	13.00	4.90	-2 48	38.05	-38.05	0.00
Total Cost ($billion)	36.50	16.96	25.21	11.50	4.38	94.55	-25 32	**69.23**
Gains from trade ($billion)	1 12	17.41	5.08	1.31	0.29	25.21	25 32	**50.53**

TABLE F: World trading

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	182	12	73	59	52	378	101	723	1202	51	437	102	42	2	89
'Hot air' (Mton)						0	111	0	111						
Market Price of Permits ($/ton)	**$24**	**$24**	**$24**	**$24**	**$24**	**$24**	**$24**	**$24**	**$24**	**$24**	**$24**	**$24**	**$24**	**$24**	**$24**
Cost of Abatement ($billion)	1.66	0 14	0 71	0 41	0.43	3.36	0.81	6 99	11 15	0 54	4 22	0 95	0 44	0 03	0.81
Permits exp(-)/imp(+) (Mton)	390	132	234	112	66	935	-211	-723	0	-51	-437	-102	-42	-2	-89
i.e % of commitment (import)	*68%*	*92%*	*76%*	*66%*	*56%*	*71%*									
Flows exp(-)/imp(+) ($billion)	9.27	3 15	5.57	2 67	1.57	22.24	-5.03	-17.21	0.00	-1.21	-10.40	-2.44	-0.99	-0 06	-2.12
Total Cost ($billion)	10.94	3.29	6.29	3.09	2.01	25.60	-4.22	-10.22	**11.15**	-0.68	-6 17	-1.49	-0.55	-0.03	-1.31
Gains from trade ($billion)	26.69	31.08	24.00	9.73	2.66	94 16	4.22	10.22	**108.61**	0.68	6.17	1.49	0.55	0.03	1.31

THE EFFECTS ON DEVELOPING COUNTRIES OF THE KYOTO PROTOCOL AND CO_2 EMISSIONS TRADING

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TABLE OF CONTENTS

1. INTRODUCTION

The Kyoto Protocol recognizes a strong linkage between CO_2 emission reduction goals, emissions trading, and the role of developing economies. Annex B parties, generally the industrialized nations, have set targets that, for most, imply a significant reduction of CO_2-equivalent emissions by 2010. The ability and even willingness of Annex B parties to achieve these targets will depend on the cost of abatement. The cheapest sources of CO_2 emission reductions are found, not in the Annex B countries, but in the developing economies or non-Annex B parties, which for historic and equity reasons are not presently expected to contribute to the global reduction in greenhouse gas emissions. Since the location of CO_2 emissions does not matter from a global warming perspective, the achievement of the Kyoto targets will depend in large part upon the ability of Annex B countries to substitute cheaper emission reductions in non-Annex B parties for equivalent abatement at home. In providing a mechanism for this exchange, emissions trading not only reduces the cost of meeting the Kyoto goals for Annex B parties, but also provides a new source of export earnings for non-Annex B parties.

Developing country interest in emissions trading is not limited to the potential for new export earnings. Achieving the goals set at Kyoto will change patterns of consumption and production within the Annex B nations; and these changes will have inevitable effects on the flows of internationally traded goods. As a result, developing countries will be affected through conventional trade linkages with the Annex B countries; however, these effects, both favorable and unfavorable, will be diminished to the extent that emissions trading reduces the cost of achieving the Kyoto targets.

In examining the effects of the Kyoto Protocol upon non-Annex B parties, we assume that the Annex B goals are met, and we focus in particular on how emissions trading would affect the developing countries. We refer to emissions trading generically, to include bubbles, joint implementation, allowance or credit systems, and perhaps other forms yet to be devised. The chief practical distinction among these forms concerns the transaction cost involved in effecting an individual trade.

The paper relies heavily upon the use of marginal abatement curves (MACs). These curves represent the marginal cost of reducing carbon emissions by different amounts within an economy. The details of their construction, and the elaboration of the aggregate demand and supply curves for carbon permits which are drawn from them, are explained in Appendix A. The MACs used here are generated using MIT's Emissions Prediction and Policy Assessment (EPPA) model (Yang et al. 1996). This is a multi-sectoral, multi-regional, computable general equilibrium (CGE) model of global economic activity, energy use and carbon emissions. The underlying model simulates real emission reductions, so that our analysis implicitly assumes that the "additionality" criterion established in the Kyoto Protocol [Arts. 6.1(b) and 12.5(c)] is satisfied. We do not attempt to address the considerable political and practical problems of measurement and verification that are associated with this criterion, but we will account for the effect of these problems in a subsequent section.[2]

The main body of the paper consists of five sections. Section 2 uses the MACs to analyze three basic cases: no emissions trading, emissions trading limited to Annex B parties (including the FSU), and full global trading. Results are presented in graphical form in the text, and the regional

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[2] UNCTAD 1998 contains an excellent discussion of these issues.

detail--in terms of abatement, costs, emission permit trade and prices for all the cases discussed--is presented in tabular form in Appendix B.

The next three sections address the effects of various departures from the three basic cases. The first departure, in Section 3, is the effect of limitations on imports of emission permits, as might correspond to the "supplementarity" criterion included in the Kyoto Protocol [Arts. 6.1(d) and 17] or to the recent call by the EU environmental ministers for a "concrete ceiling" on emissions trading. Section 4 evaluates the effect of surcharges on emission permits generated under the Clean Development Mechanism (CDM), as also provided in the Kyoto Protocol [Art. 12.8], and of monopolistic pricing. The third departure, discussed in Section 5 is the effect of a smaller supply of permits from the non-Annex B regions than is indicated by EPPA's assumptions of complete economic rationality and zero transaction costs, which we term "inefficient supply."

In Sections 2 through 5, the measure of welfare used is the total direct resource cost required to meet the emissions constraint. As explained in Appendix A, for any country this cost is the area under its marginal abatement curve up to any point of constraint, corrected for any purchase or sale of emissions permits. This is the conventional measure which is generated using the MAC approach. However, because the MACs are generated at the country level, they are not able to take account of effects that are mediated through international trade in energy or other goods. As shown in Appendix A, the MAC results themselves are not sensitive to these effects. They may influence other types of welfare measures, however, and they will effect sub-national details, such as patterns of trade in particular goods and activity at the sectoral level. To explore these effects, we depart from the MAC analysis in Section 6, and present results taken directly from the EPPA model.

In Section 7 we offer some concluding observations.

In conducting our analysis, we will make frequent reference to the twelve regions represented in EPPA, which are listed below with the model's acronyms.

ANNEX B REGIONS:		NON-ANNEX B REGIONS:	
USA:	USA	EEX:	Energy Exporting Countries
JPN:	Japan	CHN:	China
EEC:	European Union (12 countries)	IND:	India
OOE:	Other OECD Countries	DAE:	Dynamic Asian Economies
EET:	Eastern Economies in Transition	BRA:	Brazil
FSU:	Former Soviet Union	ROW:	Rest Of World

Definition of Regions in the EPPA Model

The CO_2 emission reductions required of Annex B regions are calculated as the differences between EPPA's predicted emissions for these regions in 2010 and the goals established at Kyoto for the constituent parties, which are generally stated as a percentage of 1990 emissions, as indicated in Table 1 below.[3]

	USA	JPN	EEC	OOE	EET	FSU	Non An. B
Ref emissions 1990 (Mton)	**1362**	**298**	**822**	**318**	**266**	***891***	**2022**
Ref emissions 2010 (Mton)	**1838**	**424**	**1064**	**472**	**395**	***763***	**4142**
Kyoto commitments / 1990	**93%**	**94%**	**92%**	**94.5%**	**104%**[4]	***98%***	**NA**
Hence Emissions Target in 2010 (Mton)	**1267**	**280**	**756**	**301**	**273**	**873**	**NA**
i.e. Reduction / ref (Mton)	**571**	**144**	**308**	**171**	**118**	**0**	**NA**
i.e. Reduction / ref (in %)	**31%**	**34%**	**29%**	**36%**	**30%**	**0**	**NA**
'hot air'	**0**	**0**	**0**	**0**	**0**	***110***	**0**

Table 1: Emissions Levels corresponding to Kyoto Commitments

Only five of the six EPPA regions encompassing Annex B countries are constrained by the commitment made at Kyoto,[5] and these five will subsequently be termed the Kyoto-constrained regions. For the sixth Annex B region, the FSU, emissions are predicted to be below the aggregate level to which the principal nations constituting the FSU—Russia, the Ukraine, and the Baltics— committed at Kyoto. The difference between the FSU commitment and predicted emissions is controversially called 'hot air,' but in our analysis we assume that it constitutes a "right to emit" that can be exported. For the non-Annex B regions, as well as for the FSU, any reduction from 2010 reference emissions also generates a permit for export to the Kyoto-constrained regions.

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[3] Under Kyoto Protocol accounting, as best it is understood, this procedure involves the implicit assumption that all other GHGs are also reduced by the same percentage below the appropriate baseline value. No costs are included for these controls in our study, nor is any account taken of possible carbon sinks.

[4] The countries constituting the EET committed to targets at Kyoto that were from 5% to 8% below baseline emissions, however, these countries were allowed to choose an alternative year to 1990. Based on the national communications of these countries to date, the change of baseline year appears to translate to a limitation that is 4% above 1990 emissions for the region as a whole.

[5] The Kyoto Protocol refers to the targets established for Annex B parties as "legally binding commitments," although neither the legal structure nor the sanctioning mechanism are evident. In this paper, we use the terms "goals," "targets," and "commitments" more or less interchangeably.

2. THREE BASIC CASES: NO TRADING, ANNEX B TRADING AND FULL GLOBAL TRADING

Three basic cases are used to illustrate the effects of the Kyoto Protocol and the role of emissions trading. The first case is an autarkic one in which Annex B parties meet their Kyoto commitments without any emissions trading. As a result, the FSU and non-Annex B regions are affected only through the prices and quantities of goods traded with the Kyoto-constrained regions. In the second case, Annex B parties (notably including the former Soviet Union) trade emission permits among themselves. Emissions trading within Annex B reduces the costs of the Kyoto commitment for the constrained regions, and the former Soviet Union finds a new source of export revenue; but non-Annex B countries will continue to be affected only through conventional trade linkages. The third basic case examines emissions trading on a global scale in which non-Annex B countries join the former Soviet Union in earning export revenue from supplying permits to Annex B countries. Further variations on these basic cases will be developed in subsequent sections, but these three frame the salient alternatives.

a) The Autarkic, No-Trading Case (Fig. 1, Table A)

Fig. 1 presents the MACs and the costs associated with the carbon emission reductions required of each of the Kyoto-constrained regions (excluding the FSU) when there is no emissions trading.[6] The black diamonds on the MACs indicate, on the horizontal axis, the quantity of abatement required of each region (cf. Table 1), and, on the vertical axis, the shadow price of carbon for the region. The shadow price is the marginal cost for the last ton abated. The autarkic marginal cost of abatement for Japan (**$584/ton**) is much higher than the marginal costs for the EEC (**$273**), the OOE (**$233**), the USA (**$186**), or the EET (**$116**). The areas under the curves represent the total costs of abatement for each region, which sum to **$120 billion**.

With no emissions trading, there are no export earnings for the FSU or the non-Annex B regions. None of these regions would have any incentive to abate in order to generate 'rights to emit' for export; and, of course, the FSU would not be able to export its "hot air." Nevertheless, these regions would be affected through trade in conventional goods (excluding emissions permits), as will be subsequently discussed. The details of these results are presented in Appendix B, Table A.

b) Annex B Trading (Figs. 2 and 3, Table A)

Fig. 2 shows the effect of Annex B trading on the Kyoto-constrained regions. At the market clearing price of **$127/ton**, the OECD regions (USA, EEC, JPN, OOE) are importers of permits and the EET and FSU are exporters. As an unconstrained Annex B party, the FSU accounts for virtually all of the exports (**98%**). As shown in Fig. 3, about a third of these consist of 'hot air,' with a cost of zero; but the remaining exports are generated by abatement undertaken to earn additional export profits up to the point where marginal abatement cost equals the market price. It costs the FSU **$10 billion** to abate the **234 megatons** (Mton), but the permits can be sold for **$30 billion** for a net gain of **$20 billion**. When added to the **$14 billion** earned for exporting **111 Mton** of the unused Kyoto entitlement, the FSU's total gain from emissions trading is **$34 billion**.

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[6] The MACs for the OOE and EET are virtually identical and are therefore superimposed in Fig. 1.

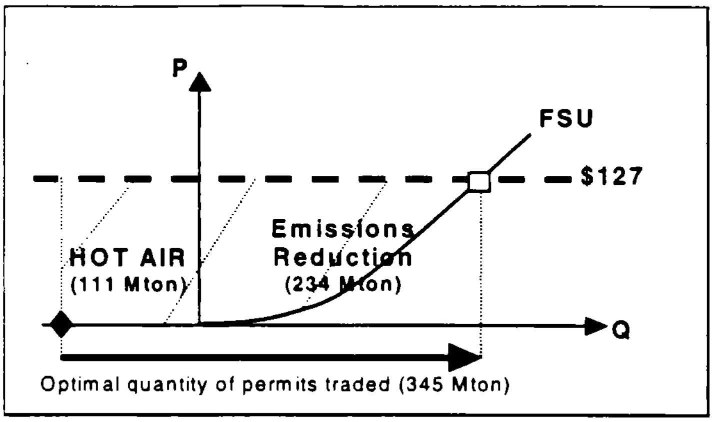

Fig. 3: Trade with FSU: the 'hot air' effect

For the five Kyoto-constrained regions depicted on Fig 2, the cost of meeting the Kyoto commitment is reduced by **$32 billion**. This is the area of the hatched triangles, which represent costly domestic abatement avoided by importing permits for the four OECD regions and the export earnings for the EET. From the standpoint of world resource use, the aggregate cost of meeting the Kyoto commitments is much lower with Annex B trade (**$54 billion**) than without (**$120 billion**). The total gains from emissions trading are **$66 billion**, split about evenly between the FSU (**$34 billion**) and the OECD + EET (**$32 billion**).

The distribution of the reduction in cost, that is, the gains from emissions trading for the Kyoto-constrained regions, is distributed roughly in proportion to autarkic marginal cost. The two regions with the highest autarkic marginal costs, Japan and the EEC, benefit the most from traded permits. Japan imports **66%** of its reduction requirement and reduces its cost by **$19 billion**. The EEC imports **35%** of its reduction requirement and reduces its cost by **$7 billion**. These two regions account for about one-third of the total emission reduction requirement for the five Kyoto-constrained regions, and about five-sixths of the gains from emissions trading for these regions accrue to them. The other three regions are characterized by autarkic marginal costs much closer to the Annex B market price; consequently, they trade much less. The USA and OOE are importers for **19%** and **25%** of their respective requirements, and the EET reduces emissions by **5%** more than required in order to export permits. The gains for these regions, which account for two-thirds of the total reduction requirement, total **$5 billion**, about a sixth of the gains from trading for the Kyoto-constrained regions.

This distribution of the gains from trade reflects an important feature of emissions trading. Regions with autarkic marginal cost farther from the trading equilibrium will import or export more (and benefit more) than those regions with autarkic marginal cost closer to the trading equilibrium. Thus, Japan and the EEC benefit most from emissions trading among the importers, as does the FSU, not just because of the 'hot air,' but also because its autarkic marginal cost (**$0/ton**) is far from the market price.

c) Full Global Trading (Figure 4, Table C)

To illustrate full global trading, we rely on aggregate supply and demand curves for emissions permits (not abatement), as explained in the Appendix A and illustrated in Fig. 4. These curves indicate the total quantities of permits that would be supplied or demanded at various price levels in a given market. In Figure 4, there is only one demand curve because the Kyoto-constrained regions are the same in both the Annex B and the global markets. Only the supply changes, reflecting the huge amounts of potentially cheap carbon abatement that becomes available as non-Annex B regions take full advantage of new export earnings opportunities. The ample supply of permits from non-Annex B regions results in a market price that is much lower (**$24/ton**) than in the Annex B trading case. The total cost of reducing global CO_2 emissions to achieve the Kyoto goals is astonishingly low: **$11 billion** vs. **$54 billion** or **$120 billion** in the other two cases!

At this price, the Kyoto-constrained regions depend far more on imports than when trading was restricted to Annex B regions only. In the aggregate, **71%** of OECD + EET commitments are met by importing emission permits from non-constrained regions; and the percentage reliance upon imports reflects autarkic marginal cost: Japan, **92%**; EEC, **76%**; USA, **68%**; OOE, **66%** and EET, **56%**. On the suppliers' side, three countries account for the bulk of exports: China (**47%**), the FSU (**23%**) and India (**11%**), hence **81%** altogether. Whether because of relatively small size or high relative abatement costs, the remaining four non-Annex B regions are small suppliers of emission permits to the Annex B regions.

With full global trading, the gains from emissions trading are much greater for the Kyoto-constrained regions (**$94 billion** vs. **$32 billion** with Annex B trading). The non-Annex B regions gain **$10 billion** by exporting permits, but their gains are markedly less than those of the Kyoto-constrained regions. The FSU is the only party that is worse off by this widening of the market. At $24/ton, the FSU abates about half as much as before, (**101 Mton**), and the 'hot air' is worth much less. As a result, the FSU's net gain (**$4 billion**) in the global market is much less than its **$34 billion** gain when it does not compete with the non-Annex B regions.

The distribution of the gains from emissions trading in the global market illustrates again the feature of emissions trading we just noted: regions whose autarkic marginal cost is further from the equilibrium price benefit more than regions whose marginal cost is closer to that price. In this global trading case, the clearing price is much closer to the suppliers' autarkic marginal cost (**$0/ton**) than it is to the autarkic marginal cost of any of the importers.

3. THE EFFECT OF IMPORT LIMITATIONS (Figure 5, Tables D-F)

The three basic cases presented earlier are based on several assumptions:

- Potential participants in emissions trading are not impeded by restrictions on trading,
- All parties participate to the extent warranted by the economics,
- Trading is conducted efficiently with low or non-existent transactions costs, and
- There is no monopolistic behavior.

Such assumptions simplify exposition and the analysis of emissions trading, but they are not necessarily realistic. One of the possible departures from this theoretical ideal is a limit on the extent to which an Annex B party can rely on emission permits to reduce what otherwise would be its domestic abatement requirement. The 'supplementarity' provisions of the Kyoto Protocol suggest such a limit, although no specific number has been agreed upon. More recently, the EU environmental ministers have called for a 'concrete ceiling' that would establish a firm limit on permit imports.

To illustrate this effect, we consider limits of 75%, 50% and 25% on any Annex B party's ability to meet its emission reduction requirement through imported permits.[7] From the full global trading case without restrictions, we know that Japan would optimally realize **92%** of its Kyoto commitment through imports, so that with a 75% limit, it would have to abate more domestically. The EEC would also be affected, but to a very slight extent since it would otherwise import **76%** of its emission reduction requirement; but none of the other importing regions would be affected. With a 50% limit, all regions would be limited and forced to abate more domestically at higher cost; and at a 25% limit, the reliance on higher cost domestic abatement would be even greater.

Fig. 5 shows how the demand curve is shifted inward by such limitations, and Table 2 summarizes the effects on prices, quantities and costs. The "No Limit" case is the same as full global trading, and it is provided for comparison.

TABLE 2: Effects of Import Limits on Global Emissions Trading

	No Limit	**75% Limit**	**50% Limit**	**25% Limit**
Market Price (85US$/tonC)	$24	$23	$13	$3
Quantity Traded (Mton C)	935	913	656	328
FSU (Mton)	211	209	183	148
Non Annex B (Mton)	723	704	473	180
World Cost (Billion US85$)	$11.2	$11.9	$21.7	$55.3
OECD+EET Cost	**$25.6**	**$25.4**	$27.1	$56.1
FSU Gain	$4.2	$4.0	$2.0	$0.5
Non Annex B Gain	$10.2	$9.5	$3.4	$0.3

The 75% limit significantly restricts only Japan and the overall effect is relatively slight: world cost increases slightly (**6.5%**), the quantity traded is **2%** less, and the price falls by **4.1%**. The effect of input limits upon the exporting regions is predictable. With less demand, the market price falls, fewer 'rights to emit' are produced and exported, and there is a drop in the gains to exporters. The effects on importers are twofold. Importers that are not affected by the limitation import more, and at a cheaper price; thus they realize more savings. They are better off because the limitation removes some of the demand by higher cost abaters from the market. Importers who are affected by the limitation also benefit from this lower market price on their imports, but they incur more domestic abatement cost. For the EEC the net balance between these two opposing effects is positive (**+1.14%** gains) but for Japan it is negative (**-1.94%**). Overall, the cost to importers is slightly less with the 75% limit on imports than without it.

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[7] The Kyoto Protocol specifies only that "trading shall be supplemental to domestic actions." We define this potential limitation as a percentage relative to the emission reduction implied by the Kyoto commitment, given EPPA's prediction of reference emissions.

With a 50% or 25% limit on imported permits, all the importing regions are restricted, and the price of imports is much lower, **$12.54** and **$3.39**, respectively. Among the importing regions, the effects of this tighter limit depend upon the balance between higher domestic abatement costs and cheaper import costs. At 50%, this balance is now negative for both EEC and Japan, but the benefit of the much cheaper imports continues to outweigh the higher domestic abatement costs for the other three importing regions. With a 25% limit, all the importing regions are worse off than they would be without any limit on imports, and the percentage increases in cost are greatest for the higher cost producers of abatement among the importing regions (JPN, **+425%**; EEC, **+123%**; OOE, **+73%**; USA, **+58%**; EET, +5%).

From the standpoint of the suppliers, the effect of a limitation on imports is to skew the distribution of gains from trading even more heavily in favor of the importing regions. It can be seen in Table 2 that, as the limit becomes more stringent, greater domestic abatement by the importing regions causes world costs to rise, but at least up to the 50% limit, the total cost for the importing regions remains relatively constant, at **$25-27 billion**. In contrast, for the exporting regions, the gains from emissions trading diminish. The global efficiency losses due to the import limit are effectively shifted to the exporting regions through the lower price of imported permits. Only when the limit becomes very tight and the price of permits is very low, for instance within 25% limit, do the increases in domestic abatement costs outweigh the benefits of cheaper imports, and the importing regions start to absorb the efficiency losses.

The effect of a quantitative limit on imports can be summarized quickly. To the extent that it is binding, it redistributes the gains from trading among the importing regions from those facing the highest abatement costs to those facing the lowest costs. Furthermore, and at least initially, it shifts the increase in global cost caused by a binding import limit onto the suppliers.

4. EFFECT OF CDM “SURCHARGES” AND CARTELIZATION OF SUPPLY

Departures from the theoretical ideal can also arise on the supply side. The Kyoto Protocol provides for a Clean Development Mechanism (CDM) by which non-Annex B emissions reductions would be certified and made available as emission permits for Annex B countries. The exact role of the CDM has yet to be defined, but the Protocol does provide that the CDM would apply a surcharge to cover its administrative expense and to collect funds to assist countries "to meet the cost of adaptation" (Article 12.8). Also, because of the inelasticity of demand at low market prices, there is a possibility that suppliers could increase their gains significantly by colluding to limit supply, instead of competing among themselves.

a) CDM surcharges

CDM surcharges would create a wedge between the price paid by consumers of emission permits and that received by producers, as illustrated in Fig. 6 for surcharges of 25%, 50% and 100%. Table 3 provides details concerning prices, quantities and gains. Surcharges of 50% or 100% are beyond any level being discussed currently, but they do illustrate the effects of inelastic demand. Since FSU exports would not be surcharged, we treat the FSU as a competitive supplier in all these cases.

TABLE 3. PRICES, FLOWS AND GAINS WITH A CDM SURCHARGE

LEVEL OF CDM SURCHARGE	**None**	**25%**	**50%**	**100%**
Market Price (85$)	$23.80	$27.44	$30.55	$35.88
Producers Marginal Cost (85$)	$23.80	$21.95	$20.37	$17.94
CDM Net profit (billion $)	$10.2	$12.6	$14.4	$17.0
Profit to producers	$10.2	$8.9	$7.9	$6.3
Surcharge Proceeds	$0	$3.7	$6.6	$10.7
CDM Exports (MtonC)	723	687	654	602
FSU Exports (MtonC)	211	219	225	235
FSU Gains (billion $)	$4.2	$5.0	$5.7	$6.9
OECD+EET Cost (")	$25.6	$28.9	$31.7	$36.3
World Cost (")	$11.2	$15.0	$18.2	$23.0

The most notable feature of Table 3 is that CDM net profit, defined as revenue minus abatement cost, increases as the surcharge is raised even though importers reduced demands in response to the higher prices. This phenomenon reflects the price inelasticity of demand over this portion of the aggregate demand curve. As would be true of any tax, there is a welfare loss, equal to the increase in world cost as a result of the more expensive abatement undertaken by importers.

The second notable feature of Table 3 is that producer profit decreases. Of course, the distribution of the proceeds raised by the surcharge would be a matter for the producers to decide. With inelastic demand, it would be theoretically possible to devise distributions that would keep producers whole and still make funds available for other purposes such as adaptation. Nevertheless, any redistribution of funds for such purposes will reduce what the non-Annex B producers might otherwise receive.

The implicit conflict between producer interests and re-distributive goals has larger implications for the evolution of the global climate regime. It will be readily evident to all non-Annex B producers that the producer that benefits the most from CDM surcharges is the FSU. As a competitive supplier, the FSU benefits directly from the increase of the market price and the increase of its exports. It is able to benefit doubly because, having accepted an Annex B limit on emissions, its exports are not surcharged. The example will be compelling for many non-Annex B producers, who will come to see Annex B accession as a way to by-pass the CDM. Proponents of the CDM will not be pleased, but such action is essential both to the creation of a more efficient global trading system and to achieving the stabilization of atmospheric concentrations of GHGs.[8]

Accession logically implies a transitional role for the CDM. So long as the CDM provides an essential service—certification and verification—for converting non-Annex B emission reductions into tradable emission permits, a reasonable fee can be charged. But that service, and the

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[8] See Yang and Jacoby (1997) for a discussion of the relation between accession and stabilization.

attendant role for the CDM, would no longer be needed as non-Annex B parties accept limits and arrange for their own certification and verification as part of the global emissions trading regime.

b) Cartelization of supply

The ability to raise surcharges without diminishing net profit to non-Annex B producers may inspire thoughts of a cartel, not so much because of the CDM which might serve as a coordinating mechanism, but because of the inelasticity of demand that characterizes the global emissions market.[9] This potential is explored in Table 4 which compares the trade effects for a fully competitive market and two alternative assumptions about non-competitive behavior:

1) A CDM cartel in which the FSU is a competitive supplier, and
2) A full supplier monopoly in which the FSU and the non-Annex B countries cooperate through the CDM or an alternative mechanism.

In calculating the gains for the FSU and the non-Annex B regions, we assume that the monopoly rent, the difference between market price and marginal cost, is shared in proportion to the quantity of abatement provided at marginal cost. In effect, we assume a highly efficient monopoly in which in which only the lowest cost sources of permits are produced (including the FSU's hot air).

TABLE 4. EFFECT OF MONOPOLY ON GAINS FROM TRADE, COSTS AND PRICES

	Competitive case	Non-Annex B cartel	Non-Annex B + FSU cartel
Market Price ($/metric ton C)	$23.8	$62.7	$108.2
World Cost (Billion 85US$)	$11.2	$20.0	$32.2
Non-Annex B Gains (")	$10.2	$22.4	$30.1
FSU Gains (")	$4.2	$13.8	$17.4
OECD+EET Savings (")	$94.2	$63.6	$39.2

Successful monopolization has the expected effects: the market price is higher, as is world resource cost, and the gains from trade are shifted substantially to the suppliers. In the case of the CDM cartel for example, the importing regions lose **$32 billion**: the **$9 billion** increase in global costs plus a **$23 billion** transfer of income to the suppliers. With the full supply monopoly, the importing regions lose another **$25 billion, $12 billion** in increased resource cost and another **$13 billion** transfer to the suppliers. Even though this is a dramatic change in the distribution of the gains from permit trade, the Kyoto-constrained regions are still better off (by **$7 billion**) than if there were no supply from the non-Annex B regions. The FSU is, however, always worse off, even when the suppliers successfully create an efficient monopoly.

The incentive to collude would be even greater if limits were placed on import demands, since the effect of such limits is to make demand more inelastic. Table 5 makes the point. It shows the effect of the full monopoly on price, world cost and gains when there is no limit on permit imports and when a 50% limit is set.

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[9] In contrast, there is little potential for cartelization in the Annex B case because of the higher price and more price elastic demand, as discussed in Ellerman and Decaux.

TABLE 5. EFFECT OF MONOPOLY ON GAINS FOR SUPPLIERS WHEN LIMIT ON PERMIT IMPORTS	Limit on imports	Competitive case	Non-Annex B + FSU cartel
Market Price ($/metric ton C)	*No limit*	$23.8	$108.2
	50% limit	$12.5	$103.4
World Cost (Billion 85US$)	*No limit*	$11.2	$32.2
	50% limit	$21.7	$37.6
Non-Annex B Gains (")	*No limit*	$10.2	$30.1
	50% limit	$3.4	$26.2
FSU Gains (")	*No limit*	$4.2	$17.4
	50% limit	$2.0	$16.3
OECD + EET Savings (")	*No limit*	$94.2	$39.2
	50% limit	$92.6	$39.8

The effect of successful monopoly is much the same whether or not there are import limits. The market price rises to about the same level, **$103** vs. **$108**, world cost increases, and the exporting regions gain significantly at the expense of the importing regions. The 50% import limit reduces the price, increases world cost and diminishes producer gains in both the competitive and monopoly cases, but by much less in the latter.

5. INEFFICIENT SUPPLY

Full global trading is an appealing case, to importers for the great reductions in cost and to exporters for the possibilities of non-competitive pricing, but both should remember that CGE models indicate a potential given complete economic rationality and negligible transactions cost.[10] The more likely contour of global emissions trading is that this potential will not spring forth full blown once trading is allowed and appropriate modalities devised, but that it develop only slowly as experience is gained. Fig 7 depicts several possibilities for less than fully efficient supply in which it is assumed that 5%, 10%, 15%, 25%, and 50% of the supplies from the FSU and non-Annex B regions are available at every price. The lowest line is fully efficient global trading, as previously discussed.

Inefficient supply could result from several causes. The most serious and most likely is transaction cost, particularly that involved in meeting the 'additionality' criterion. Past experience with credit-based emissions trading systems applied to other environmental problems and with Joint Implementation pilot projects has shown these costs to be large and the quantities traded to be small.[11] Alternatively, a general failure to take full advantage of economic opportunities presented

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[10] EPPA 2.6 is not alone in making such forecasts. The recent analysis provided by the U.S. Council of Economic Advisors to support Chairman Janet Yellen's earlier testimony obtains a similar permit price for a comparable market, albeit in 1996 dollars.

[11] See UNCTAD 1978 for a discussion of the relative efficiency of allowance and credit based trading systems. These costs will be greatly reduced to the extent that non-Annex B regions accept emission caps that remove the concern

by emissions trading would also limit the amount of credits available from the non-Annex B regions and the FSU. Finally, some non-Annex B countries have expressed considerable antipathy to emissions trading as a concept; and they may decide not to participate in an emissions trading regime, whether through the CDM or otherwise, for political or other reasons. It would be impossible to assess beforehand to what extent these causes might operate in a global market, but they will certainly be present.

If the supplies from the global market are very small initially, say 5% of the full global potential, then the market price for permits would be relatively high (**$181**) and the quantities traded small (**170 Mton**). As experience is gained and supplies become more ample, the quantities traded would increase and prices fall. The gains from emissions trading increase with improved efficiency of supply and they become quite large well before attaining 100% efficiency. As shown in Fig 8, total gains increase steadily, but those for exporters increase only up to a point a little above15%. Thereafter, the relatively inelastic demand causes the gains to exporters to decline, while those to the importers increase dramatically.

When supply is very inefficient, the market distortions considered earlier have little effect. For example, as severe a limitation on demand as a 25% ceiling would affect only Japan if supplies from the FSU and non-Annex B regions were only 5% of the full potential. And at the prices reflecting very inefficient supply, there would be no gain to monopoly. Nevertheless, as supply becomes more efficient and prices decrease, a limitation on imports would become more binding; and as the market clearing price moved into the inelastic range (below about $110), monopoly could become more of a concern.

The effect of CDM surcharges will also depend on the elasticity of demand. In the inelastic range, corresponding to greater supply from the non-Annex B regions, the surcharge can result in greater gains, so that it is at least possible to keep producers whole (compared to no surcharge) and generate funds for other purposes. However, when supply is very inefficient and the price for permits falls in the elastic range, any surcharge will reduce the total gain to be shared between producers and other claimants.

As would be expected, inefficient supply implies a higher market price, greater world cost and fewer gains from trade, but the gains will still be substantial and decidedly worth pursuing. The effects of distortions, such as import limitations and non-competitive pricing, are the same as with fully efficient supply, but the magnitude of the effect is less because there is less to lose. Perhaps the most notable feature of inefficient supply is that the gains to early entrants in the global emissions market will be very large. Thereafter, as is true for any innovator, the large initial reward will dissipate as imitators follow.

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about additionality and the necessity to establish a counterfactual baseline. Curiously, the Kyoto Protocol also asserts 'additionality' as a criterion for joint implementation projects within Annex B countries (cf. Art. 6).

6. EFFECTS OF KYOTO AND EMISSIONS TRADING THROUGH TRADE IN GOODS

MACs provide a simple and direct way to study emissions trading, but they do not indicate the effect of abatement actions on the prices and quantities of goods in international trade. The effects of emissions reductions may not be restricted to the countries undertaking the abatement actions. Through trade they may be transmitted to countries that made no commitment. In this section, we abandon the use of MACs and examine these other effects using the EPPA results directly.

The central feature driving these trade-in-goods effects is the shadow price for carbon that is faced by the Kyoto-constrained regions and the effect of that shadow price on the world price for oil and natural gas. Table 6 provides a quick summary of those prices for the 2010 reference case and our three basic emissions trading scenarios. Carbon prices are shown in 1985 dollars; oil and gas prices are shown as an index with the 2010 price in the reference case set to 1.0.

TABLE 6. CARBON AND ENERGY PRICES IN 2010 for Kyoto-constrained regions

	Reference	No Trading	Annex B	Global
Carbon Price	$0	$116-584	$127	$24
Oil Price	1.0	0.90	0.95	0.99
Natural Gas Price	1.0	0.83	0.86	0.96

Oil and natural gas are treated as Hecksher-Ohlin goods in EPPA, which means that there is complete freedom of trade among regions and a single world price. As a result, restrictions on carbon emissions in Annex B countries lead to (equally) lower oil and natural gas prices for producers and consumers throughout the world. In contrast, coal is an Armington good, which means that there is no single world price but a series of regional prices that can be affected by changes in trade flows. Consequently, actions by the Annex B regions will affect coal prices in these regions, but generally not elsewhere, or only through the quantities traded which are not great.

As the scope of emissions trading expands and the price of carbon declines, and the effect on energy prices diminishes. This effect occurs because one of the cheapest forms of carbon abatement is the reduction of and substitution away from the use of coal. Emissions trading makes it possible to substitute cheaper carbon abatement by reducing coal use in non-Annex B regions for more expensive abatement by reducing oil and natural gas use in Annex B regions.

The effects on trade patterns of the Kyoto commitments and emissions trading are most usefully observed by comparing the no trading case with full global trading. The former can be viewed as a relatively inefficient way of achieving the goals set at Kyoto, while the latter represents the absolutely most efficient way. Emissions trade limited to Annex B is an intermediate case, which we omit because its effects are midway between what occurs with no emission trading and with full global trading.[12]

a) Effects of Kyoto through trade in goods in the no emissions trading case

The starting point for the no emissions trading case is the effect of the carbon price on domestic demand in the Kyoto-constrained regions. Table 7 provides the percentage change from the reference prediction for domestic use of sectoral output (production less exports plus imports) by Kyoto-constrained region. The sectoral breakdown in EPPA includes five energy sectors (oil, gas, coal, electricity and refined oil) and three non-energy sectors (agriculture, energy intensive industries, and other industries).

TABLE 7. % CHANGE IN DOMESTIC USE BY SECTOR AND REGION DUE TO KYOTO COMMITMENT WITHOUT EMISSIONS TRADING

	USA	JPN	EEC	OOE	EET
OIL	-3.5%	-19.6%	-4.0%	-7.6%	-3.4%
GAS	-11.1%	-24.8%	-10.3%	-14.1%	-12.1%
COAL	**-54.5%**	**-48.8%**	**-52.1%**	**-63.2%**	**-49.4%**
ELEC	-11.1%	-11.3%	-12.2%	-13.1%	-19.7%
REFOIL	-6.5%	-20.3%	-7.7%	-10.6%	-7.7%
AGR	-0.7%	-2.2%	-0.2%	-0.9%	-0.4%
ENINTSV	-0.5%	-5.1%	-2.6%	-1.7%	-2.2%
OTHIND	+0.1%	-1.1%	-0.2%	-0.4%	-0.6%

With one insignificant exception, all the signs are negative, and they are greatest in magnitude for the energy sectors. Coal is hit hardest with domestic use declining by about half in all regions; however, coal, like electricity and refined oil, is mostly a domestic good so that the international trade effect of this reduction in demand is not particularly great. Oil and gas are more traded internationally, and the effect of the reduction in Annex B demand is a world-wide fall in the price of oil and gas: by **10%** and **17%**, respectively, as was shown above in table 6.[13] This reduction in price reduces the income of oil and gas producers throughout the world; and the effect will be particularly large on the two oil and gas exporting regions, the EEX and the FSU. Interestingly, oil and gas quantities exported and traded internationally do not change much, but there is a shift in the destination of energy exports away from the Kyoto-constrained regions towards the non-constrained regions, as illustrated below through trade in energy-intensive goods.

The domestic use of energy-intensive goods declines in all Kyoto-constrained regions; however, the most significant effects show up in the trade balances and domestic output for these goods, as shown in Table 8.

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[12] The FSU is the one exception. With Annex B trading, its demand for energy declines in the same manner as the Kyoto-constrained Annex B regions, as does its production and export of energy-intensive goods.

[13] The greater effect upon natural gas results from the greater responsiveness to price changes in the industrial and residential sectors, where natural gas is mostly used, than in the transportation sector, where petroleum products dominate. Both oil and natural gas gain share in electricity generation at the expense of coal, but electricity demand also shrinks. In the end, the balance between the losses in non-electricity sectors and the gains in electricity generation are less favorable for natural gas than for oil.

TABLE 8. CHANGES IN EXPORT, IMPORT AND OUTPUT OF ENERGY INTENSIVE GOODS: NO EMISSIONS TRADING

Absolute Change in:	USA	JPN	EEC	OOE	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW
Net trade	-2.57	-30.96	-26.20	-6.29	-1.61	+7.93	+22.8	+6.78	+1.13	+6.07	+1.86	+21.1
Output	-6.90	-61.68	-42.25	-9.31	-4.99	+9.81	+21.1	+15.3	+2.74	+15.8	+3.46	+22.9

The patterns are very clear. The Kyoto-constrained regions reduce production and net exports of energy-intensive goods, while the non-constrained regions increase output and net exports of them. The Kyoto-constrained regions increase imports of these goods, and of the non-taxed carbon that is embodied in them.

b) Comparing no-trading case effects with full global trading case effects

Meeting the Kyoto commitments with full global trading has much less effect on Annex B demand for oil and gas and on the trade in energy-intensive goods than was the case with no emissions trading, as shown in Table 9 and Table 10.

TABLE 9. % CHANGE IN DOMESTIC USE BY SECTOR AND REGION DUE TO KYOTO COMMITMENT WITH FULL GLOBAL TRADING

	USA	JPN	EEC	OOE	EET
OIL	-0.2%	-0.2%	-0.2%	-0.3%	-0.5%
GAS	-0.5%	-0.5%	-0.7%	-0.04%	-0.9%
COAL	-21.5%	-5.0%	-13.2%	-25.0%	-15.4%
ELEC	-2.5%	-0.3%	-1.6%	-2.3%	-5.0%
REFOIL	-1.0%	-0.8%	-0.6%	-1.2%	-1.5%
AGR	-0.1%	-0.1%	-0.03%	-0.1%	+0.2%
ENINTSV	-0.1%	-0.1%	-0.1%	-0.1%	+0.02%
OTHIND	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%

The effects of the Kyoto Protocol remain negative, but the magnitudes are much attenuated. Coal use is reduced by at most a quarter; and the effect on other goods is generally less than **1%**. The world prices for oil and natural gas are reduced by only **1.3%** and **3.5%**, respectively, instead of 10% and 17% in the no trading case.

TABLE 10. CHANGES IN EXPORT, IMPORT AND OUTPUT OF ENERGY INTENSIVE GOODS: FULL GLOBAL TRADING

Absolute Change in:	USA	JPN	EEC	OOE	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW
Net trade	+0.37	+0.30	-0.09	+0.16	+0.19	**-0.71**	+1.61	**-2.60**	**-0.94**	+0.53	-0.02	+1.22
Output	-0.59	-0.18	-0.93	-0.02	+0.21	**-1.81**	+0.45	**-8.90**	**-2.25**	+0.10	-0.01	+1.24

The changes in trade and output of energy-intensive goods are all relatively small; and there is no consistent pattern as in Table 8, because the price of carbon is the same in all countries. Output and the net trade position is most adversely affected in China, India and FSU because their production of energy intensive goods is more dependent on coal, which is the fuel most adversely affected by any positive price on carbon emissions.

c) Summary

The effects of the Kyoto Protocol and of emissions trading on non-Annex B regions consist of three analytically separate elements, which can be summarized by the following simple matrix.

TABLE 11: EFFECT OF KYOTO AND EMISSIONS TRADING

KYOTO EFFECT	No Emissions Trading	Global Emissions Trading
Permit Revenues	0	+
Oil & Gas Export Revenue	- -	-
Energy Intensive Goods Trade	+	0

Whether there is emissions trading or not, the effect of the Kyoto commitments on non-Annex B countries is mixed. Without emissions trading, there will be no permit exports, but an increase in the production and export of energy intensive goods can be expected, assuming no protective trade measures are enacted by the Kyoto-constrained regions. With global emissions trading, there will be permit export revenues, but no significant increase in production and exports of energy intensive goods. The revenues of Non-Annex B regions that export oil and gas will be adversely affected in either case, but much less so with the lower carbon price associated with a broadened market for emissions permits. In effect, oil and gas exporters benefit as emissions trading makes it possible for Kyoto-constrained regions to substitute reduced coal use in non-Annex B regions for reduced oil and natural gas use at home.

The temptation is almost overwhelming to produce a single aggregate number to indicate the extent to which particular countries and regions are better or worse off as a result of some policy intervention. Although EPPA produces such a number, as does any CGE model, we have chosen not to cite it here for several reasons.[14] Some of the abstractions used in EPPA, such as a single representative consumer and full employment of resources, seem particularly inappropriate in the context of an economically developing country. Then, such numbers lend themselves to inappropriate cardinal comparisons and they detract from the fundamental story at the sectoral level. The effects of meeting the Kyoto commitments will not be evenly felt across all sectors, either in the constrained or the non-constrained regions. To take an obvious example, coal producers in non-Annex B regions will lose some market to cheaper oil and gas even with no

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[14] See Jacoby *et al.* 1997 does present such a number but it is a discounted sum over many periods for a somewhat more stringent Annex B reduction. This estimate is slightly negative for all non-Annex B regions.

emissions trading, but they will lose much more with emissions trading. Oil and gas producers will be in exactly the opposite position, as will coal producers in Kyoto-constrained regions.

In any case, the amounts involved are not large when viewed in the context of the entire economy. The earnings from the export of permits or the increased export of energy intensive goods is always less than 2% of GDP for the non-Annex B regions, and typically less than 1%.

7. CONCLUDING OBSERVATIONS

The effect on developing countries of Annex B actions to comply with the Kyoto Protocol will depend on the particular country and on the success of emissions trading. All developing economies will have an interest in emissions trading as a source of new export earnings, but their interest will extend beyond this new commercial possibility. In particular, oil and gas exporters will have a strong interest in emissions trading as a means to reduce the cost for Annex B parties generally, and specifically to allow Annex B parties to substitute reduced coal emissions abroad for reduced oil and gas emissions at home. It is possible that some countries and sectors would be adversely affected by emissions trading. For instance, the advantage enjoyed by producers of energy-intensive goods will be greater with no emissions trading, assuming that the embodied carbon imports would be permitted by the Annex B regions. The net balance will be different for various countries, but in general it seems likely that developing countries will benefit from emissions trading.

The gains from emissions trading are potentially very large, fully sufficient to give potential buyers and sellers an economic incentive to support such a system. Most studies of permit trade suggest ample supplies would be offered by non-Annex B regions, at commensurately low prices, yielding large cost reductions for the Kyoto-constrained regions and substantial benefits to non-Annex I regions. The actual supply is likely to be somewhat less, at least initially, due to transactions cost and less than complete participation in the market by all non-Annex B regions. Nevertheless, whatever the initial extent of the market and its subsequent development, both importing and exporting parties will gain.

As in any market, the potential for welfare damaging distortions is always present. Given the undefined meaning of “supplemental” in the Kyoto Protocol, a particularly alarming distortion from the developing country standpoint is a limitation on Annex B imports of emission permits. Not only will such limits depress permit prices and the export earnings of non-Annex B parties, but they will have perverse effects on importing countries. Annex B parties with relatively high domestic abatement costs, and thus higher imports, would be penalized, while those with relatively low domestic abatement costs, and fewer imports, would find the cost of meeting their Kyoto commitments reduced.

The ability of the CDM to impose surcharges to help countries meet the costs of adaptation will depend upon the elasticity of demand, which depends in turn on the supply available from non-Annex B regions. Ironically, the greater the supply and the lower the price, the greater the ability to impose surcharges without fear of losing revenue. Still, there is an unavoidable conflict between the interests of the producers of the permits and redistributive goals. The same price inelasticity of demand that makes it possible to impose the surcharge while keeping producers whole will likely also inspire attempts at cartelizing the global market for emission permits.

The FSU and the non-Annex B countries appear as clear rivals to each other in the stylized cases we have presented, but casting this rivalry in geopolitical terms obscures its more practical aspect. The stylized Annex B or global emissions markets typically posited in modeling exercises will not spring into life as soon as appropriate institutional arrangements are made. Rather these markets will develop, probably slowly, over time. As is true of any new market, the first to enter, whether from the FSU or from the developing countries, will enjoy large gains that will be dissipated as others follow.

The FSU does however have one large advantage: its acceptance of an Annex B emission limitation, which removes the high costs associated with the certification and verification of emission reductions that will be required in non-Annex B countries. This example will encourage the most enterprising non-Annex B countries to accede to Annex B to capture more of the large gains of early emissions trading. In doing so, these parties will foster more efficient emissions trading and promote the ultimate goals of the Kyoto Protocol, but they will also necessarily reduce the ability of the CDM to act as a re-distributive mechanism.

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APPENDIX A: MARGINAL ABATEMENT CURVES[15]

a) What are Marginal Abatement Curves and what do they represent? (Fig. A1)

A CGE model will produce a shadow price for any constraint on carbon emissions for a given region R at time T. An example would be a 10% reduction below the reference case for USA in 2010. This price indicates the marginal cost of reducing the last ton of carbon required to meet the constraint; and, as might be expected in a proper CGE model, the shadow prices corresponding to constraints of increasing severity rise as an increasing function of emissions reduction.

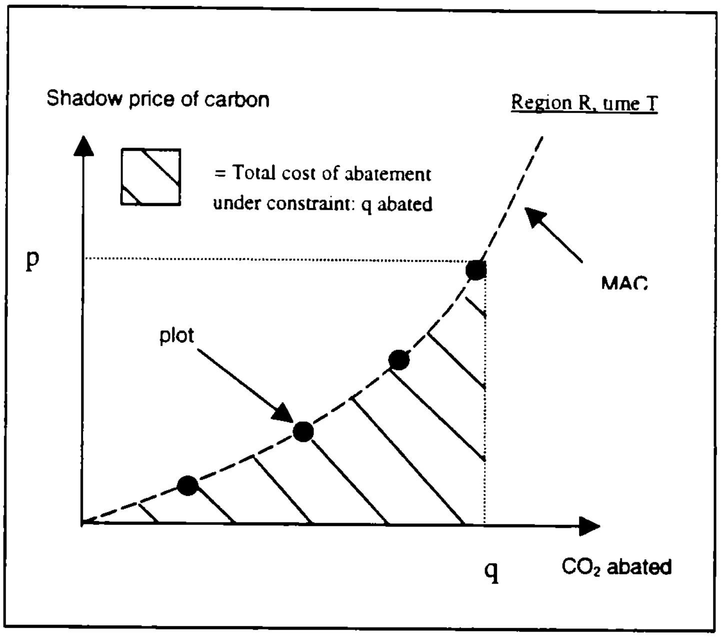

Fig. A1: Marginal Abatement Curves

A Marginal Abatement Curve is described by generating the plots of the shadow prices corresponding to constraints of increasing severity at time T, then drawing a line joining the plots, as in Fig. A1. Each plot on the curve for region R at time T represents the marginal cost (p) of abating an additional unit of carbon emissions at quantity q. The integral under the curve (hatched area) represents the total abatement cost associated with each level of abatement, that is, the resources re-allocated to abatement because of the constraint.[16] This area is not the same as the welfare loss that is calculated by most CGE models, although it is closely related.

b) How can MACs be used for Trade Studies? (Fig. A2)

If several regions commit to achieve emission reductions at the same time and there is some prediction of what emissions would be without the commitment, the abatement required can be represented as a point on each region's marginal abatement curve. Moreover, if the marginal costs associated with those reductions are different across regions, the aggregate cost of meeting the commitments will be less to the extent that a region with higher marginal costs can induce a region with lower marginal costs to abate more on its behalf.[17] By abating more, the lower cost region produces 'rights to emit,' or emission permits, which it can sell to the higher cost region which

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[15] This section of the paper draws heavily on Ellerman and Decaux, 1998.

[16] As is true of any CGE model, full employment of resources is always assumed.

[17] As typically assumed in such analyses, and as is the case here, the environmental goal pursued – reducing atmospheric concentrations of greenhouse gases – is not affected by the location of the emission reduction.

would thereby avoid a like amount of higher cost domestic abatement. Thus, the difference in the marginal costs associated with each region's commitment in the absence of trade creates a potential gain to be shared in some manner between the two regions. The aggregate emission reduction will be achieved at least cost when the regions trade until their marginal abatement costs are equal at what will then be the market clearing price for the 'right to emit' carbon.

Fig. A2 illustrates the gains from trading for 2 regions R_1 and R_2, subject to the constraints: CO_2 abated = q_1 for R_1 and q_2 for R_2, and Table A1 below displays the cost calculations in the no trading and trading cases.

These cost calculations can easily be generalized to N regions, and they constitute the basis of this study: we will calculate, under various trading assumptions, the volume of trade and the resulting savings for the regions.

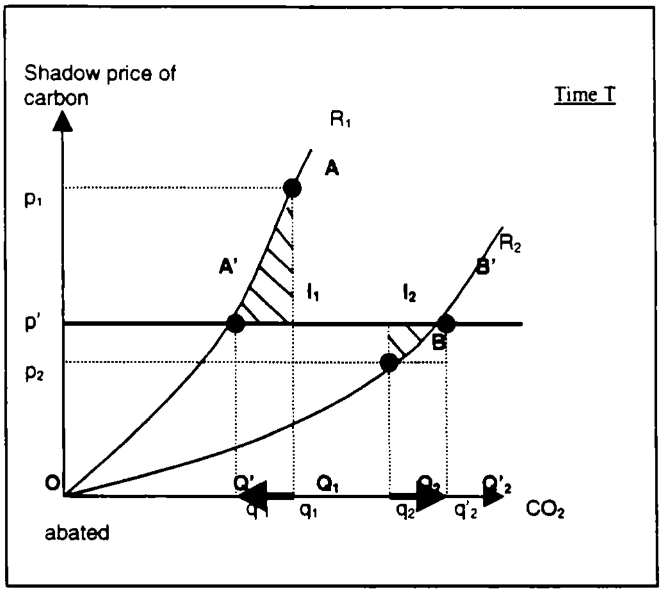

Fig. A2: MACs used for Trade Studies

	No Trade	**Trade between R_1 and R_2**
Constraints	R_1: q_1 abated R_2: q_2 abated	R_1 and R_2: $q_1 + q_2$ abated
Marginal Cost / Market Price	R_1: p_1 R_2: p_2	R_1 and R_2: p' such that $p'_1(q'_1) = p'_2(q'_2) = p'$ and $q'_1 + q'_2 = q_1 + q_2$
Abatement Cost	R_1: area AOQ_1 R_2: area BOQ_2	R_1: area $A'OQ'_1$ R_2: area $B'OQ'_2$
Emission Permits Trading	NA	R_1: buys right to emit $q_1-q'_1$ R_2: sells right to emit $q'_2-q_2 = q_1-q'_1$
Imports (+) / Exports (-) Flows	NA	R_1: pays $p' * (q_1-q'_1)$ = area $A'I_1Q_1Q'_1$ to R_2 R_2: receives $p' * (q'_2-q_2)$ = area $B'I_2Q_2Q'_2$ from R_1
Total Cost	R_1: area AOQ_1 R_2: area BOQ_2	R_1: area $A'OQ'_1$ + area $A'I_1Q_1Q'_1$ < area AOQ_1 R_2: area $B'OQ'_2$ – area $B'I_2Q_2Q'_2$ < area BOQ_2
Savings from Trading	NA	R_1: area AI_1A' (hatched) R_2: area BI_2B' (hatched)

Table A1: Basics of Trade Studies

c) How are MACs generated from CGE Models? (Fig. A3, A4 and A5)

The CGE model we use to generate MACs is the MIT Emissions Prediction and Policy Assessment (EEPA) model. It is a multi-sectoral, multi-regional global model of economic activity, energy use and greenhouse gas (GHG) emissions that is part of MIT's larger Integrated Global Systems Model.[18] As such, EPPA is frequently used to predict emissions and to assess the costs associated with constraints on carbon emissions. Although EPPA predicts emissions and assesses costs through the year 2100, this study takes the year 2010 as representative of the first commitment period, which includes the years 2008 through 2012. The model keeps track of five vintages of capital. Version 2.6 of the model incorporates two backstop technologies; however, because these energy sources will not play a substantial role in 2010, they are omitted from the calculations presented here.

To build the MACs, we run the EPPA model under different constraints corresponding to different levels of carbon abatement, such as 10%, 20%, or 30% of reference emissions in the year 2010. For each set of constraints, the corresponding, regional shadow prices of carbon are an output of the model (in 1985 US$).[19] The shadow prices for each region can then be plotted as a function of the level of abatement, and a line can be fitted to the plots to get the MAC for that region and time.

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[18] See Yang et. al, 1996, for a description of EPPA and Prinn et. al., 1998, for a description of the IGSM.

[19] Although we often refer to CO_2 emissions, all prices and quantities are in terms of carbon. Each ton of carbon corresponds to 3.67 tons of carbon dioxide.

As an example, Fig. A3 shows the results obtained for the four OECD regions in 2010 when the policies applied are: proportional reductions by all OECD regions (1, 5, 10, 15, 20, 30 and 40% of reference 2010 emissions), and no reduction by other regions. Here, the shadow prices have been plotted in function of the percentage of carbon emission reduction (and not the absolute quantities), in order to show the variations across regions without taking into account the size of the economy. We can see that, for any equal percentage reduction among the OECD regions, the abatement of the corresponding quantities would cost most in Japan, then in EEC, and least in USA and OOE.

Similar curves can be obtained for all regions. For example, we can apply the same proportional reductions, but to all of EPPA's twelve regions at the same time.[20] Fig. A4 displays the marginal abatement curves thus obtained. It shows where it is the cheapest to abate carbon emissions (India and China) and where it is the most expensive (Japan and Brazil).

Now, to allow trade studies like in Fig. A2, we need to re-scale the x-axis of these curves to actual absolute quantities instead of percentages, and it is the way MACs will be represented from now on. Stating marginal cost in terms of the proportional reduction, as above, reveals the relative cost of carbon abatement among the twelve EPPA regions, but it does not indicate the importance of various regions in an emissions trading market. For example, as shown in figure A4, both China and India are relatively low cost suppliers of abatement. However, China is a significantly greater potential supplier of abatement than India by the simple fact that its reference emissions are 3.5 times as large (1,792 vs. 486 Mton). China is about 70% more carbon intensive than India, its economy is predicted to be about twice the size of India's in 2010. Thus, as can be seen on Fig. A5, which represents on the quantitative scale the marginal curves of the six non-Annex B regions and the USA (for comparison), the MAC for China is much lower than the other non-Annex B MACs. China is the largest potential source of emissions permits from the non-Annex B regions. To illustrate, if the market price for emissions permits were $50, China would provide about 700 Mton of emissions reduction, while the five other regions combined would provide only 400 Mton.

d) Assessing the 'Robustness' of MACs with regard to the Policy applied (Fig. A6)

One question that arises immediately is how the location of a MAC is influenced by events in other regions. More specifically, how is the cost associated with any given level of carbon abatement for one region affected by differing levels of abatement in other regions? For instance, one can notice in Table 1 (see body of the text) that the levels of implied abatement corresponding to the Kyoto commitment are not strictly proportional, e.g. 29% for EEC, 36% for OOE.[21] Also, with emissions trading, we would not expect the reductions among regions to be proportional. Will MACs generated by assumptions other than proportional reductions in all regions look the same?

This fundamental question is that of the robustness of the MACs. And indeed, a drawing like Fig. A2, and the simple method we have deduced from it assume this robustness (one curve for each region, whatever the reductions in other regions). The answer is: they are robust. In all the runs we have done, whatever the reduction schemes assumed (we went as far as one region reducing its

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[20] In doing so, we do not imply that non-Annex B countries assume constraints, but only that they choose to abate emissions in the proportions indicated, as they might to pursue the export earnings implicit with trading when a positive price for carbon emissions is being paid by Annex B regions.

[21] In addition, different assumptions about economic and emissions growth between 1990 and 2010 from those used in this model prediction can yield even greater variation.

emissions by 60% while the others keep reference emissions), the plots obtained are all located on or very close to the curves we have generated using proportional abatement scenarios.

For example, Fig. A6 shows simultaneously the two sets of MACs corresponding to varying levels of OECD abatement assuming no emissions trading and fully efficient emissions trading. The curves in both sets are similar, thus showing that the MACs are robust with regard to this change of policy. We have made similar comparisons for other assumptions—no trading, Annex B trading and world trading—and each time we have found the same fundamental result: whatever the trading scheme, whatever the extent of the market, the marginal abatement curves are almost identical.

Our conclusion is that MACs, and more generally, the costs associated with a given level of domestic abatement, are sufficiently insensitive to different levels of abatement among regions and the scope of emissions trading to justify the analytic method applied here.

e) Analytical Approximations: a Simple Tool for Trade Studies (Fig. A7)

Robustness implies that each region at time T has a unique marginal abatement curve. This result allows independent use of marginal abatement curves, once generated from CGE model, and makes trade analysis straightforward and simple. Now, such an analysis can be even more simplified if each curve could be described by a single mathematical expression because, once we have the equations of the MACs, the cost calculations (i.e. integration under the curves) are extremely simple and rapid.

Fig. A7 shows, for the OECD regions, that we can fit very simple analytical curves to the sets of plots resulting from the EPPA runs, and that those fits are very good (for each curve, R^2 very close to 1). This result holds for all the other regions as well. The curves that best fit the EPPA-generated plots are of the form: $P = aQ^2 + bQ$, where Q is the amount of carbon abatement in Mton and P is the marginal cost, or shadow price, of carbon in 1985 US$. By integration, the total cost of abatement is $C = 1/3*aQ^3 + 1/2*bQ^2$. The table below displays the coefficients a and b for each region in 2010, as well as the coefficient of determination R^2.

Region	*a*	*b*	*R^2*	*Region*	*a*	*b*	*R^2*
USA	**0.0005**	**0.0398**	0.9923	**EEX**	**0.0032**	**0.3029**	0.9983
JPN	**0.0155**	**1.816**	0.9938	**CHN**	**0.00007**	**0.0239**	0.9992
EEC	**0.0024**	**0.1503**	0.9951	**IND**	**0.0015**	**0.0787**	0.9970
OOE	**0.0085**	**- 0.0986**	0.9981	**DAE**	**0.0047**	**0.3774**	0.9996
EET	**0.0079**	**0.0486**	0.9973	**BRA**	**0.5612**	**8.4974**	0.9997
FSU	**0.0023**	**0.0042**	0.9938	**ROW**	**0.0021**	**0.0805**	0.9967

Table A2: Coefficients of the Approximations of the MACs of the Form: $P = aQ^2 + bQ$

In using these approximations, analysts should keep in mind that the price of this simplicity is abandonment of the general equilibrium features of the underlying model. The robustness of the

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[22] Note that, compared to figs. 3 and 4, the x-axis has been re-scaled to quantities.

curves assures us that the relation between price and quantity of abatement is relatively fixed, but the curves do not capture all the effects of emissions trading. Since the EPPA model remains our primary analysis tool, we have run the model in every policy case we studied in order both to ensure that the approximations are not misleading and to capture any possible side effects. The prices and quantities for abatement were all very close to the approximations, but there is a side effect that the MAC approach does not capture: "leakage." When carbon emissions are constrained for only a sub-set of regions, carbon emissions tend to "leak" to non-constrained regions. These effects are not an essential feature of the present analysis; however, the analytical approximations are a powerful computational shortcut. They also provide a convenient way to represent graphically the results of the trading analysis, and we use them extensively for that purpose in the remaining sections.

f) Construction of Aggregate Supply and Demand Curves (Fig. A8)

Marginal abatement curves are the basis for determining the demand and supply for emission permits in any given market. Emission permits represent 'rights to emit' and these rights can be produced by some party abating more than it is required to do, or undertaking some abatement when not required to do so. The willingness of any party to produce these permits is a function of the underlying cost relationships represented by the MAC, of the amount the party is otherwise required to abate, and of the price of permits. The demand for 'rights to emit' is a function of the same three factors. Given the MACs and a set of reduction requirements,[23] aggregate supply and demand can be calculated by adding the (positive) quantities supplied or demanded at every price across regions.

If a region is unconstrained (non-Annex B regions, or FSU in this case), then it is always a seller of permits. At any market price, it will be willing to sell a quantity of permits equal to the amount of abatement it would undertake when the marginal cost on its MAC equals the market price. And, for the FSU, the quantity of 'hot air' (111 Mton here) can be added, on the assumption that trade in such "hot air" will be allowed under the Kyoto Protocol.

If a region is constrained by its Kyoto commitment, then its position in the market, as seller or buyer, depends on the market price.

- If the market price is lower than its autarkic marginal abatement cost, this region would be willing to buy emission permits corresponding to the quantity difference between the reduction implied by its Kyoto commitment and the domestic abatement it would provide at the market price.
- Conversely, if the market price is higher than its autarkic marginal abatement cost, it would be willing to undertake more abatement and supply the market with the 'right to emit' for the corresponding quantity.

Now, for each price (y-axis) and each market we are considering (Annex B, or the world, for instance), we simply add up the quantities (x-axis) potentially supplied and those potentially demanded. As we vary the price, we describe the demand and the supply curves for this market,

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[23] A reduction requirement depends both on the Kyoto commitment and an estimate of what emissions would otherwise be (e.g., reference or business-as-usual emissions).

and their intersection indicates the market clearing price on the y-axis and the total quantity traded on the x-axis.

Fig. A8 shows the aggregate demand and supply curves obtained in the Annex B and world trading cases. The aggregate demand curve is the same in both the Annex B and the global market because both include all Kyoto-constrained, i.e. potentially importing, regions. This single demand curve intersects the horizontal axis at the quantity equal to the sum of the emission reductions required to meet the Kyoto commitments, which is 1.31 Gton. This is the 'Kyoto cap' represented by a vertical dotted line on the figure; it is also the quantity of emission permits that would be demanded if the price were $0/ton. At this price, the aggregate supply is the quantity of permits available at no cost. This is the FSU's 111 Mton of "hot air".

As the price increases, the demand for permits diminishes, as more and more domestic abatement is undertaken, and the supply of permits increases as more abatement is justified in the unconstrained, exporting regions. As long as the market price is less than the lowest autarkic marginal cost for the Kyoto-constrained regions, these regions are always on the demand side; and the unconstrained regions are on the supply side. When the price reaches $116, the marginal cost for EET, this region switches from the demand side to the supply side, resulting in a 'kink' on the demand and supply curves (which happens to be almost indiscernible because of the small economic size of this region). Such a kink can readily be seen on both supply and demand curves when the price reaches $186, the autarkic marginal cost for USA. There would be similar kinks at $233 when OOE becomes a supplier and at $273 when the EEC does. At $584, the autarkic marginal cost for Japan meeting the commitment, the demand for permits would be zero.

APPENDIX B: DATA TABLES

NB: all the prices in the following tables are in 1985$

BASIC CASES

TABLE A: Kyoto no trading

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World
Reductions / ref 2010 (Mton)	571.58	144.19	307.21	171.38	118.04	1312.41	0.00	0.00	1312.41
Marginal Costs ($/ton)	**$186.10**	**$584.12**	**$272.68**	**$232.76**	**$115.82**	\	\	\	\
Cost of Abatement ($billion)	37.62	34.37	30.29	12.81	4.67	119.76	0.00	0.00	119.76

TABLE B: Annex B trading

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	World
Reductions / ref 2010 (Mton)	465.77	49.24	200.85	128.18	123.76	967.80	234.08	1201.88
'Hot air' (Mton)	\	\	\	\	\	0.00	110.53	110.53
Marginal Costs ($/ton)	**$127.01**	**$127.01**	**$127.01**	**$127.01**	**$127.01**	**$127.01**	**$127.01**	**$127.01**
Cost of Abatement ($billion)	21.16	2.82	9.51	5.16	5.36	44.01	9.95	53.96
Permits exp(-)/imp(+) (Mton)	105.81	94.95	106.36	43.21	-5.71	344.61	-344.61	0.00
i.e % of commitment (import)	*18.51%*	*65.85%*	*34.62%*	*25.21%*	\	*26.26%*	\	\
Flows exp(-)/imp(+) ($billion)	13.44	12.06	13.51	5.49	-0.73	43.77	-43.77	0.00
Total Cost ($billion)	34.60	14.88	23.02	10.64	4.64	87.78	-33.82	**53.96**
Gains from trade ($billion)	3.03	19.49	7.27	2.17	0.03	31.99	33.82	**65.81**

TABLE C: World trading

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	181.96	11.90	73.07	59.03	51.89	377.84	100.81	723.23	1201.88	51.04	436.81	102.42	41.55	2.42	88.99
'Hot air' (Mton)	\	\	\	\	\	0.00	110.53	0.00	110.53	\	\	\	\	\	\
Marginal Costs ($/ton)	**$23.80**	**$23.80**	**$23.80**	**$23.80**	**$23.80**	**$23.80**	**$23.80**	**$23.80**	**$23.80**	**$23.80**	**$23.80**	**$23.80**	**$23.80**	**$23.80**	**$23.80**
Cost of Abatement ($billion)	1.66	0.14	0.71	0.41	0.43	3.36	0.81	6.99	11.15	0.54	4.22	0.95	0.44	0.03	0.81
Permits exp(-)/imp(+) (Mton)	389.63	132.30	234.14	112.36	66.15	934.57	-211.34	-723.23	0.00	-51.04	-436.81	-102.42	-41.55	-2.42	-88.99
i.e % of commitment (import)	*68.17%*	*91.75%*	*76.22%*	*65.56%*	*56.04%*	*71.21%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	9.27	3.15	5.57	2.67	1.57	22.24	-5.03	-17.21	0.00	-1.21	-10.40	-2.44	-0.99	-0.06	-2.12
Total Cost ($billion)	10.94	3.29	6.29	3.09	2.01	25.60	-4.22	-10.22	**11.15**	-0.68	-6.17	-1.49	-0.55	-0.03	-1.31
Gains from trade ($billion)	26.69	31.08	24.00	9.73	2.66	94.16	4.22	10.22	**108.61**	0.68	6.17	1.49	0.55	0.03	1.31

IMPORT LIMITATIONS

TABLE D: 75%

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	177.53	36.05	76.80	57.94	50.76	399.09	98.71	704.08	1201.88	49.48	425.28	99.88	40.28	2.33	86.83
'Hot air' (Mton)	\	\	\	\	\	0.00	110.53	0.00	110.53	\	\	\	\	\	\
Marginal Costs ($/ton)	**$22.82**	**$22.82**	**$22.82**	**$22.82**	**$22.82**	**$22.82**	**$22.82**	**$22.82**	**$22.82**	**$22.82**	**$22.82**	**$22.82**	**$22.82**	**$22.82**	**$22.82**
Cost of Abatement ($billion)	1.56	1.42	0.81	0.39	0.41	4.58	0.76	6.54	11.88	0.50	3.96	0.89	0.41	0.03	0.76
Permits exp(-)/imp(+) (Mton)	394.05	108.14	230.41	113.44	67.28	913.32	-209.24	-704.08	0.00	-49.48	-425.28	-99.88	40.28	-2.33	-86.83
i.e % of commitment (import)	*68.94%*	*75.00%*	*75.00%*	*66.19%*	*57.00%*	*68.07%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	8.99	2.47	5.26	2.59	1.54	20.84	-4.77	-16.07	0.00	-1.13	-9.70	-2.28	-0.92	-0.05	-1.98
Total Cost ($billion)	10.55	3.89	6.06	2.97	1.94	25.42	-4.02	-9.52	**11.88**	-0.63	-5.75	-1.39	-0.51	-0.03	-1.22
Gains from trade ($billion)	27.07	30.48	24.22	9.84	2.73	94.34	4.02	9.52	**107.88**	0.63	5.75	1.39	0.51	0.03	1.22
delta gain in % / no limit (table C)	**1.44%**	**-1.94%**	**0.93%**	**1.14%**	**2.46%**	**0.19%**	**-4.88%**	**-6.84%**	**-0.67%**	**-7.26%**	**-6.85%**	**-6.66%**	**-7.28%**	**-7.73%**	**-6.60%**

TABLE E: 50%

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	285.79	72.10	153.60	85.69	59.02	656.20	72.93	472.75	1201.88	31.15	285.65	68.88	25.27	1.35	60.45
'Hot air' (Mton)	\	\	\	\	\	0.00	110.53	0.00	110.53	\	\	\	\	\	\
Marginal Costs ($/ton)	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**
Cost of Abatement ($billion)	5.52	6.66	4.67	1.42	0.63	18.89	0.31	2.50	21.70	0.18	1.52	0.35	0.15	0.01	0.30
Permits exp(-)/imp(+) (Mton)	285.79	72.10	153.60	85.69	59.02	656.20	-183.46	-472.75	0.00	-31.15	-285.65	-68.88	-25.27	-1.35	60.45
i.e % of commitment (import)	*50.00%*	*50.00%*	*50.00%*	*50.00%*	*50.00%*	*48.91%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	3.58	0.90	1.93	1.07	0.74	8.23	-2.30	-5.93	0.00	-0.39	-3.58	-0.86	-0.32	-0.02	-0.76
Total Cost ($billion)	9.10	7.56	6.60	2.50	1.37	27.12	-1.99	-3.42	**21.70**	-0.21	2.06	-0.51	-0.17	-0.01	-0.46
Gains from trade ($billion)	28.53	26.81	23.69	10.32	3.30	92.64	1.99	3.42	**98.06**	0.21	2.06	0.51	0.17	0.01	0.46
delta gain in % / no limit (table C)	**6.88%**	**-13.75%**	**-1.30%**	**6.06%**	**24.10%**	**-1.61%**	**-52.83%**	**-66.51%**	**-9.71%**	**-68.83%**	**-66.57%**	**-65.47%**	**-68.93%**	**-70.98%**	**-65.06%**

TABLE F: 25%

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	428.69	108.14	230.41	128.54	88.53	984.31	37.51	180.06	1201.88	10.12	107.92	28.09	8.16	0.39	25.37
'Hot air' (Mton)	\	\	\	\	\	0.00	110.53	0.00	110.53	\	\	\	\	\	\
Marginal Costs ($/ton)	**$3.39**	**$3.39**	**$3.39**	**$3.39**	**$3.39**	**$3.39**	**$3.39**	**$3.39**	**$3.39**	**$3.39**	**$3.39**	**$3.39**	**$3.39**	**$3.39**	**$3.39**
Cost of Abatement ($billion)	16.79	17.15	13.77	5.20	2.02	54.94	0.04	0.28	55.26	0.02	0.17	0.04	0.01	0.00	0.04
Permits exp(-)/imp(+) (Mton)	142.90	36.05	76.80	42.85	29.51	328.10	-148.04	-180.06	0.00	-10.12	-107.92	-28.09	-8.16	-0.39	-25.37
i.e % of commitment (import)	*25.00%*	*25.00%*	*25.00%*	*25.00%*	*25.00%*	*24.45%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	0.48	0.12	0.26	0.15	0.10	1.11	-0.50	-0.61	0.00	-0.03	-0.37	-0.10	-0.03	0.00	-0.09
Total Cost ($billion)	17.27	17.28	14.04	5.35	2.12	56.05	-0.46	-0.33	**55.26**	-0.02	-0.20	-0.05	-0.01	0.00	-0.05
Gains from trade ($billion)	20.35	17.09	16.25	7.47	2.55	63.72	0.46	0.33	**64.51**	0.02	0.20	0.05	0.01	0.00	0.05
delta gain in % / no limit (table C)	**-23.74%**	**-45.01%**	**-32.29%**	**-23.26%**	**-4.13%**	**-32.33%**	**-89.14%**	**-96.76%**	**-40.61%**	**-97.39%**	**-96.80%**	**-96.43%**	**-97.41%**	**-97.79%**	**-96.27%**

CDM SURCHARGES

TABLE G: 25% CDM Surcharge

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	197.82	13.54	80.10	62.91	55.94	410.32	108.32	686.52	1205.17	48.06	414.70	97.55	39.11	2.25	84.85
'Hot air' (Mton)	\	\	\	\	\	0.00	110.53	0.00	110.53	\	\	\	\	\	\
Marginal Costs ($/ton)	**$27.44**	**$27.44**	**$27.44**	**$27.44**	**$27.44**	**$27.44**	**$27.44**	**$21.95**	\	**$21.95**	**$21.95**	**$21.95**	**$21.95**	**$21.95**	**$21.95**
Cost of Abatement ($billion)	2.07	0.18	0.89	0.51	0.54	4.19	1.00	6.15	11.34	0.47	3.72	0.81	0.38	0.02	0.72
Permits exp(-)/imp(+) (Mton)	373.76	130.65	227.10	108.47	62.10	902.09	-218.85	686.52	-3.29	-48.06	-414.70	97.55	39.11	-2.25	-84.85
i.e % of commitment (import)	*65.39%*	*90.61%*	*73.92%*	*63.29%*	*52.61%*	*67.24%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	10.26	3.58	6.23	2.98	1.70	24.75	-6.01	-15.07	**3.68**	-1.05	-9.10	2.14	-0.86	0.05	-1.86
Total Cost ($billion)	12.32	3.76	7.13	3.49	2.24	28.94	5.01	-8.92	15.02	-0.59	5.38	1.30	0.48	0.03	-1.15
Gains from trade ($billion)	25.30	30.60	23.16	9.33	2.43	90.82	5.01	8.92	104.75	0.59	5.38	1.30	0.48	0.03	1.15
delta gain in % / no limit (table C)	**-5.20%**	**-1.54%**	**-3.50%**	**-4.13%**	**-8.76%**	**-3.55%**	**18.54%**	**-12.76%**	**-3.56%**	**-13.52%**	**-12.77%**	**-12.44%**	**-13.55%**	**-14.35%**	**-12.32%**

TABLE H: 50% CDM Surcharge

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	210.57	14.92	85.78	66.03	59.19	436.48	114.34	653.99	1204.81	45.44	395.10	93.22	36.96	2.10	81.17
'Hot air' (Mton)	\	\	\	\	\	0.00	110.53	0.00	110.53	\	\	\	\	\	\
Marginal Costs ($/ton)	**$30.55**	**$30.55**	**$30.55**	**$30.55**	**$30.55**	**$30.55**	**$30.55**	**$20.37**	\	**$20.37**	**$20.37**	**$20.37**	**$20.37**	**$20.37**	**$20.37**
Cost of Abatement ($billion)	2.44	0.22	1.06	0.60	0.63	4.95	1.17	5.46	11.58	0.41	3.30	0.75	0.31	0.02	0.64
Permits exp(-)/imp(+) (Mton)	361.01	129.27	221.43	105.35	58.86	875.93	-224.87	-653.99	-2.93	-45.44	-395.10	-93.22	-36.96	2.10	-81.17
i.e % of commitment (import)	*63.16%*	*89.65%*	*72.08%*	*61.47%*	*49.86%*	*65.29%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	11.03	3.95	6.76	3.22	1.80	26.76	-6.87	-13.32	**6.57**	-0.93	-8.05	-1.90	-0.75	-0.04	-1.65
Total Cost ($billion)	13.47	4.17	7.82	3.82	2.43	31.71	-5.70	-7.86	18.15	-0.51	-4.74	-1.15	-0.42	0.02	-1.01
Gains from trade ($billion)	24.16	30.20	22.46	9.00	2.24	88.06	5.70	7.86	101.61	0.51	4.74	1.15	0.42	0.02	1.01
delta gain in % / no limit (table C)	**-9.48%**	**-2.84%**	**-6.40%**	**-7.55%**	**-15.83%**	**-6.48%**	**34.88%**	**-23.12%**	**-6.44%**	**-24.41%**	**-23.13%**	**-22.57%**	**-24.46%**	**-25.80%**	**-22.36%**

TABLE I: 100% CDM Surcharge

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	231.02	17.23	94.90	71.03	64.39	478.57	123.99	601.66	1204.22	41.25	363.54	86.23	33.53	1.88	75.23
'Hot air' (Mton)	\	\	\	\	\	0.00	110.53	0.00	110.53	\	\	\	\	\	\
Marginal Costs ($/ton)	**$35.88**	**$35.88**	**$35.88**	**$35.88**	**$35.88**	**$35.88**	**$35.88**	**$17.94**	\	**$17.94**	**$17.94**	**$17.94**	**$17.94**	**$17.94**	**$17.94**
Cost of Abatement ($billion)	3.12	0.30	1.36	0.77	0.80	6.34	1.49	4.46	**12.30**	0.33	2.70	0.61	0.27	0.02	0.53
Permits exp(-)/imp(+) (Mton)	340.56	126.97	212.31	100.35	53.66	833.84	-234.52	-601.66	-2.34	-41.25	-363.54	86.23	-33.53	-1.88	75.23
i.e % of commitment (import)	*59.58%*	*88.05%*	*69.11%*	*58.56%*	*45.45%*	*62.15%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	12.22	4.56	7.62	3.60	1.93	29.92	-8.41	-10.79	10.71	-0.74	-6.52	-1.55	-0.60	-0.03	-1.35
Total Cost ($billion)	15.34	4.85	8.98	4.37	2.73	36.26	-6.92	-6.33	23.01	-0.41	-3.82	-0.93	0.33	-0.02	-0.82
Gains from trade ($billion)	22.29	29.52	21.31	8.45	1.94	83.50	6.92	6.33	96.76	0.41	3.82	0.93	0.33	0.02	0.82
delta gain in % / no limit (table C)	**-16.49%**	**-5.04%**	**-11.22%**	**-13.18%**	**-27.08%**	**-11.32%**	**63.88%**	**-38.04%**	**-10.91%**	**-39.94%**	**-38.08%**	**-37.23%**	**-40.02%**	**-41.90%**	**-36.92%**

MONOPOLISTIC BEHAVIOR

TABLE J: CDM cartel with FSU as competitive supplier

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	316.67	27.90	133.38	91.91	86.10	655.97	164 26	381.65	1201.88	24.25	230.46	56 46	19.64	1.02	49.83
'Hot air' (Mton)	\	\	\	\	\	0.00	110.53	0.00	110 53	\	\	\	\	\	\
Marginal Costs ($/ton)	**$62.74**	**$62.74**	**$62.74**	**$62.74**	**$62.74**	**$62.74**	**$62.74**	**$62.74**	**$62.74**	**$62.74**	**$62.74**	**$62.74**	**$62.74**	**$62.74**	**$62.74**
Cost of Abatement ($billion)	7.29	0.82	3.24	1.78	1.86	14 99	3.45	1.52	19 96	0.10	0 92	0.22	0 08	0 00	0 19
Permits exp(-)/imp(+) (Mton)	254.91	116.29	173.83	79.47	31 95	656 44	274.79	381 65	0 00	24 25	230 46	-56 46	19.64	-1 02	-49 83
i.e % of commitment (import)	*44.60%*	*80.65%*	*56.58%*	*46.37%*	*27.06%*	*50.02%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	15.99	7.30	10 91	4.99	2 00	41.19	-17 24	-23 94	0.00	-1.52	-14.46	-3.51	-1.23	-0 06	-3 13
Total Cost ($billion)	23.28	8.12	14.14	6.77	3 86	56 17	-13.79	-22.43	19.96	-1.42	-13 54	-3.33	1 15	-0.06	-2.94
Gains from trade ($billion)	14.34	26.25	16.15	6 05	0.80	63.59	13.79	22 43	99.81	1 42	13.54	3 33	1 15	0.06	2 94

TABLE K: CDM+FSU monopoly

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	417.36	42.03	178.91	116.41	111.54	866.25	50.86	284.77	1201.88	17.22	171.62	43.03	13 92	0.69	38.30
'Hot air' (Mton)	\	\	\	\	\	0.00	110.53	0.00	110.53	\	\	\	\	\	\
Marginal Costs ($/ton)	**$108.24**	**$108.24**	**$108.24**	**$108.24**	**$108.24**	**$108.24**	**$108.24**	**$108.24**	**$108.24**	**$108.24**	**$108.24**	**$108.24**	**$108.24**	**$108.24**	**$108.24**
Cost of Abatement ($billion)	15.58	1.99	6.99	3.80	3.96	32.31	0 11	0.77	33 20	0.05	0 47	0 11	0 04	0.00	0.10
Permits exp(-)/imp(+) (Mton)	154.22	102.16	128.30	54.97	6.50	446.16	-161 39	-284.77	0.00	-17.22	-171 62	13 03	13 92	-0 69	-38 30
i.e % of commitment (import)	*26.98%*	*70.85%*	*41.76%*	*32.08%*	*5.51%*	*34.00%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	16.69	11.06	13.89	5.95	0.70	48.29	-17 47	-30.82	0 00	-1 86	-18 58	-4 66	-1 51	-0 08	-4 15
Total Cost ($billion)	32.28	13.05	20.87	9.75	4.66	80.61	-17.36	-30 05	**33.20**	-1 81	-18 11	-4 54	-1 47	-0 07	-4 05
Gains from trade ($billion)	5.35	21.32	9.41	3.06	0.01	39.16	17.36	30.05	**86.57**	1 81	18 11	4 54	1 47	0 07	4 05

TABLE L: CDM+FSU monopoly and 50% import Limitation

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	416.71	72.10	178.61	116.25	111.38	895.04	47.70	259.14	1201.88	15 42	156.03	39.42	12 46	0 61	35 19
'Hot air' (Mton)	\	\	\	\	\	0.00	110.53	0.00	110.53	\	\	\	\	\	\
Marginal Costs ($/ton)	**$103.41**	**$103.41**	**$103.41**	**$103.41**	**$103.41**	**$103.41**	**$103.41**	**$103.41**	**$103.41**	**$103.41**	**$103.41**	**$103.41**	**$103.41**	**$103.41**	**$103.41**
Cost of Abatement ($billion)	15.52	6.66	6.96	3.78	3.94	36.85	0.09	0.63	37.56	0.04	0 38	0.09	0.03	0.00	0.08
Permits exp(-)/imp(+) (Mton)	154.87	72.10	128.60	55.13	6.67	417.37	-158.23	-259.14	0 00	-15 42	-156.03	-39.42	-12.46	-0.61	-35.19
i.e % of commitment (import)	*27.10%*	*50 00%*	*41.86%*	*32.17%*	*5.65%*	*31.11%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	16.02	7.46	13.30	5.70	0.69	43.16	-16.36	-26 80	0.00	-1.60	-16.14	-4.08	-1 29	-0.06	-3.64
Total Cost ($billion)	31.53	14.11	20.25	9.49	4.63	80 01	-16.27	-26 17	**37.56**	-1.56	-15.76	-3.98	-1 26	-0.06	-3.56
Gains from trade ($billion)	6.09	20.26	10.03	3.33	0.04	39.75	16.27	26 17	**82.20**	1.56	15.76	3 98	1 26	0.06	3.56
delta gain in % / no limit (table C)	**-77.17%**	**-34.83%**	**-58.20%**	**-65.79%**	**-98.46%**	**-57.78%**	**285.37%**	**155.99%**	**-24.32%**	**129.23%**	**155.30%**	**167.85%**	**128.13%**	**105.89%**	**172.51%**

INEFFICIENT SUPPLY

TABLE M: 50% of Potential FSU and non-Annex B Supply

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	286 14	23 93	119 63	84 48	78 37	592 54	74 96	589 64	1257 14	44 51	355 29	81 19	36 37	2 35	69 92
'Hot air' (Mton)	\	\	\	\	\	0 00	55 27	0 00	55 27	\	\	\	\	\	\
Marginal Costs ($/ton)	**$52.33**	**$52.33**	**$52.33**	**$52.33**	**$52 33**	**$52.33**	**$52.33**	**$52.33**	**$52.33**	**$52.33**	**$52.33**	**$52.33**	**$52 33**	**$52.33**	**$52.33**
Cost of Abatement ($billion)	5 53	0 59	2 45	1 36	1 42	11 34	1 32	11 98	24 63	0 98	7 20	1 59	0 80	0 06	1 35
Permits exp(-)/imp(+) (Mton)	285 44	120 26	187 58	86 91	39 67	719 86	130 23	589 64	-0 01	44 51	355 29	81 19	36 37	2 35	69 92
i.e % of commitment (import)	*49 94%*	*83 41%*	*61 06%*	*50 71%*	*33 61%*	*54 85%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	14 94	6 29	9 82	4 55	2 08	37 67	6 82	30 86	0 00	2 33	18 59	4 25	1 90	0 12	3 66
Total Cost ($billion)	20 47	6.88	12.26	5 90	3 49	49 01	5 50	18 88	**24.63**	-1.35	-11 39	-2 66	-1 10	0 07	-2 31
Gains from trade ($billion)	17 15	27.48	18.03	6 91	1.18	70 75	5 50	18 88	**95.13**	1 35	11 39	2 66	1 10	0 07	2 31
delta gain in % / no limit (table C)	**-35.73%**	**-11.58%**	**-24.90%**	**-28.97%**	**-55.78%**	**-24.86%**	**30.23%**	**84.65%**	**-12.41%**	**99.43%**	**84.56%**	**78.77%**	**100.19%**	**120 66%**	**76 76%**

TABLE N: 25% of Potential FSU and non-Annex B Supply

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	394 93	38 77	168 75	110 95	105 88	819 27	50 23	415 27	1284 78	32 55	249 70	56 27	26 66	1 85	48 23
'Hot air' (Mton)	\	\	\	\	\	0 00	27 63	0 00	27 63	\	\	\	\	\	\
Marginal Costs ($/ton)	**$93 70**	**$93.70**	**$93.70**	**$93.70**	**$93 70**	**$93.70**	**$93 70**	**$93.70**	**$93.70**	**$93 70**	**$93.70**	**$93.70**	**$93 70**	**$93.70**	**$93 70**
Cost of Abatement ($billion)	13 37	1 67	5.98	3 26	3 40	27.68	1 58	14 67	43 92	1 23	8.79	1 92	1 01	0 08	1 63
Permits exp(-)/imp(+) (Mton)	176.65	105 42	138 46	60.43	12.17	493.13	-77 86	-415 27	0 00	-32 55	-249.70	56 27	-26 66	-1 85	-48 23
i e % of commitment (import)	*30 91%*	*73.11%*	*45 07%*	*35 26%*	*10 31%*	*37.57%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	16 55	9.88	12.97	5.66	1.14	46.21	-7 30	-38 91	0 00	-3 05	-23 40	5 27	-2 50	-0 17	4 52
Total Cost ($billion)	29 92	11.54	18 96	8 93	4 54	73 89	-5 72	-24 24	**43.92**	-1 82	-14 60	-3 35	-1 49	0 10	2 89
Gains from trade ($billion)	7.70	22.82	11.33	3 89	0 13	45 88	5.72	24 24	**75 84**	1 82	14 60	3 35	1 49	0 10	2 89
delta gain in % / no limit (table C)	**-71.14%**	**-26.57%**	**-52.80%**	**-60.03%**	**-95.04%**	**-51.28%**	**35.44%**	**137.12%**	**-30.17%**	**168.21%**	**136.65%**	**125.11%**	**169.93%**	**220.09%**	**121 16%**

TABLE O: 15% of Potential FSU and non-Annex B Supply

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	464 53	49 05	200 29	127.87	123 44	965 19	35 03	295 61	1295 83	23 54	177 56	39.78	19 30	1 39	34 04
'Hot air' (Mton)	\	\	\	\	\	0 00	16 58	0 00	16 58	\	\	\	\	\	\
Marginal Costs ($/ton)	**$126 38**	**$126.38**	**$126.38**	**$126.38**	**$126.38**	**$126.38**	**$126.38**	**$126 38**	**$126.38**	**$126.38**	**$126.38**	**$126.38**	**$126.38**	**$126.38**	**$126.38**
Cost of Abatement ($billion)	21 00	2 79	9.44	5.12	5 32	43 68	0 54	6.04	50 26	0 56	3 60	0 75	0 46	0 04	0 63
Permits exp(-)/imp(+) (Mton)	107 05	95 14	106 92	43 51	-5 40	347 22	-51 60	-295 61	0 00	-23 54	-177 56	39 78	-19 30	-1 39	34 04
i.e % of commitment (import)	*18 73%*	*65 98%*	*34 80%*	*25 39%*	*-4 58%*	*26.46%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	13 53	12.02	13.51	5.50	-0 68	43 88	-6 52	-37 36	0 00	-2 98	-22 44	5 03	-2 44	0 18	-4 30
Total Cost ($billion)	34 53	14 82	22.96	10.62	4.64	87 56	-5 98	-31 32	**50.26**	2 42	-18 84	4 27	-1 98	0 13	3 67
Gains from trade ($billion)	3 09	19.55	7.33	2 20	0.03	32 20	5 98	31 32	**69.51**	2 42	18 84	4 27	1 98	0 13	3 67
delta gain in % / no limit (table C)	**-88.40%**	**-37.10%**	**-69.45%**	**-77.41%**	**-98.92%**	**-65.80%**	**41.71%**	**206.35%**	**-36.00%**	**256 28%**	**205.34%**	**187.36%**	**259.13%**	**347 47%**	**181.28%**

TABLE P: 10% of Potential FSU and non-Annex B Supply

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	509.14	55.88	220.54	138 71	134.70	1058.96	25 44	216.96	1301.36	17 42	130 24	29 09	14 29	1 04	24 87
'Hot air' (Mton)	\	\	\	\	\	0 00	11 05	0.00	11 05	\	\	\	\	\	\
Marginal Costs ($/ton)	**$149 87**	**$149.87**	**$149.87**	**$149.87**	**$149.87**	**$149.87**	**$149.87**	**$149.87**	**$149.87**	**$149.87**	**$149.87**	**$149.87**	**$149.87**	**$149 87**	**$149 87**
Cost of Abatement ($billion)	27.16	3 74	12 24	6.61	6 88	56.62	0 21	2.76	59 59	0.27	1 64	0 33	0 23	0 02	0 27
Permits exp(-)/imp(+) (Mton)	62 44	88 31	86 67	32.67	-16 65	253 45	-36 49	-216.96	0 00	-17 42	-130 24	-29 09	-14 29	-1 04	-24 87
i e % of commitment (import)	*10 92%*	*61 25%*	*28 21%*	*19 06%*	*-14.11%*	*19 31%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	9 36	13 24	12 99	4.90	2 50	37 98	-5 47	-32 52	0 00	2 61	-19 52	-4 36	2 14	0 16	3 73
Total Cost ($billion)	36 51	16 97	25.23	11.51	4 38	94 60	-5.26	-29.75	**59.59**	-2.34	-17 88	-4 03	1 91	0 13	3 46
Gains from trade ($billion)	1.11	17 40	5 06	1.30	0 29	25.16	5 26	29 75	**60.18**	2 34	17 88	4 03	1 91	0 13	3 46
delta gain in % / no limit (table C)	**-95.84%**	**-44.03%**	**-78.91%**	**-86.59%**	**-89.12%**	**-73.28%**	**24.58%**	**191.03%**	**-44.59%**	**244.45%**	**189.80%**	**170.91%**	**247.56%**	**347 50%**	**164.57%**

TABLE Q: 5% of Potential FSU and non-Annex B Supply

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	563 01	64 31	245 01	151 80	148 28	1172 41	13 98	120 50	1306 88	9 75	72 29	16 10	8 01	0 60	13 75
'Hot air' (Mton)	\	\	\	\	\	0 00	5 53	0 00	5.53	\	\	\	\	\	\
Marginal Costs ($/ton)	**$180.90**	**$180.90**	**$180 90**	**$180.90**	**$180.90**	**$180.90**	**$180.90**	**$180 90**	**$180.90**	**$180.90**	**$180.90**	**$180 90**	**$180 90**	**$180 90**	**$180 90**
Cost of Abatement ($billion)	36.05	5 13	16 28	8.77	9 12	75 35	0.04	0 67	76.05	0 07	0 39	0 07	0 06	0 01	0 06
Permits exp(-)/imp(+) (Mton)	8 57	79 88	62 20	19 58	-30 24	140 00	-19 50	-120 50	0 00	-9 75	-72 29	16 10	-8 01	-0 60	13 75
i e % of commitment (import)	*1.50%*	*55.40%*	*20.25%*	*11.43%*	*-25 61%*	*10.67%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	1 55	14.45	11 25	3 54	-5 47	25 33	3 53	-21 80	0 00	-1 76	-13 08	-2 91	-1 45	-0 11	2 49
Total Cost ($billion)	37 60	19 58	27 53	12 32	3 65	100 68	3 49	-21 13	**76.05**	-1 69	-12 69	2 84	1 39	0 10	2 43
Gains from trade ($billion)	0 02	14 79	2 76	0 50	1 02	19 09	3 49	21 13	**43.71**	1 69	12.69	2 84	1 39	0 10	2 43
delta gain in % / no limit (table C)	**-99.92%**	**-52.42%**	**-88.51%**	**-94 89%**	**-61.67%**	**-79.73%**	**-17 29%**	**106.69%**	**-59.75%**	**149.29%**	**105.58%**	**90.81%**	**151.83%**	**236.29%**	**85 88%**

COMBINED CASES with 50% Efficient Supply

TABLE R: CDM cartel, No Import Limitation

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	385.25	37.38	164.36	108.60	103.43	799.03	98.20	359.92	1257.14	25.38	217.38	50.99	20.66	1.20	44.31
'Hot air' (Mton)	\	\	\	\	\	0.00	55.27	0.00	55.27	\	\	\	\	\	\
Marginal Costs ($/ton)	**$89.54**	**$89.54**	**$89.54**	**$89.54**	**$89.54**	**$89.54**	**$89.54**	**$89.54**	**$89.54**	**$89.54**	**$89.54**	**$89.54**	**$89.54**	**$89.54**	**$89.54**
Cost of Abatement ($billion)	12.48	1.54	5.58	3.05	3.17	25.83	2.84	3.45	32.22	0.26	2.09	0.47	0.22	0.01	0.40
Permits exp(-)/imp(+) (Mton)	186.33	106.81	142.84	62.78	14.61	513.38	-153.47	-359.92	-0.01	-25.38	-217.38	-50.99	-20.66	1.20	-44.31
i.e % of commitment (import)	*32.60%*	*74.08%*	*46.50%*	*36.63%*	*12.38%*	*39.12%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	16.68	9.56	12.79	5.62	1.31	45.97	-13.74	-32.23	0.00	-2.27	-19.46	-4.57	-1.85	-0.11	-3.97
Total Cost ($billion)	29.17	11.10	18.37	8.67	4.48	71.79	-10.80	-28.77	**32.22**	-2.01	-17.38	-4.10	-1.63	-0.09	3.57
Gains from trade ($billion)	8.46	23.27	11.91	4.15	0.19	47.97	10.80	28.77	**87.54**	2.01	17.38	4.10	1.63	0.09	3.57
delta gain in % / no limit (table C)	**-68.31%**	**-25.15%**	**-50.36%**	**-57.39%**	**-92.94%**	**-49.06%**	**155.67%**	**181.42%**	**-19.40%**	**195.96%**	**181.57%**	**175.31%**	**196.64%**	**212.37%**	**173.04%**

TABLE S: CDM+FSU monopoly, No Import Limitation

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	434.50	44.56	186.67	120.58	115.87	902.17	44.75	310.23	1257.15	21.38	187.44	44.37	17.38	0.98	38.68
'Hot air' (Mton)	\	\	\	\	\	0.00	55.27	0.00	55.27	\	\	\	\	\	\
Marginal Costs ($/ton)	**$111.69**	**$111.69**	**$111.69**	**$111.69**	**$111.69**	**$111.69**	**$111.69**	**$111.69**	**$111.69**	**$111.69**	**$111.69**	**$111.69**	**$111.69**	**$111.69**	**$111.69**
Cost of Abatement ($billion)	17.43	2.26	7.82	4.25	4.42	36.18	0.28	2.40	38.87	0.18	1.45	0.33	0.15	0.01	0.28
Permits exp(-)/imp(+) (Mton)	137.08	99.64	120.54	50.81	2.18	410.24	-100.02	-310.23	-0.01	-21.38	-187.44	-44.37	-17.38	-0.98	38.68
i.e % of commitment (import)	*23.98%*	*69.10%*	*39.24%*	*29.65%*	*1.84%*	*31.26%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	15.31	11.13	13.46	5.67	0.24	45.82	-11.17	-34.65	0.00	-2.39	-20.94	-4.96	-1.94	-0.11	-4.32
Total Cost ($billion)	32.74	13.39	21.29	9.92	4.67	82.00	-10.89	-32.25	**38.87**	-2.21	-19.48	-4.63	-1.79	-0.10	-4.04
Gains from trade ($billion)	4.89	20.98	9.00	2.89	0.00	37.76	10.89	32.25	**80.90**	2.21	19.48	4.63	1.79	0.10	4.04
delta gain in % / no limit (table C)	**-81.69%**	**-32.50%**	**-62.49%**	**-70.30%**	**-99.83%**	**-59.90%**	**157.81%**	**215.41%**	**-25.52%**	**225.38%**	**215.68%**	**210.98%**	**225.80%**	**234.41%**	**209.21%**

TABLE T: No cartel or monopoly, 50% Import Limitation

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	285.79	72.10	153.60	85.69	70.55	667.73	67.71	521.71	1257.14	38.78	314.58	72.30	31.66	1.99	62.39
'Hot air' (Mton)	\	\	\	\	\	0.00	55.27	0.00	55.27	\	\	\	\	\	\
Marginal Costs ($/ton)	**$42.75**	**$42.75**	**$42.75**	**$42.75**	**$42.75**	**$42.75**	**$42.75**	**$42.75**	**$42.75**	**$42.75**	**$42.75**	**$42.75**	**$42.75**	**$42.75**	**$42.75**
Cost of Abatement ($billion)	5.52	6.66	4.67	1.42	1.05	19.31	0.97	8.75	29.03	0.70	5.27	1.17	0.58	0.04	0.99
Permits exp(-)/imp(+) (Mton)	285.79	72.10	153.60	85.69	47.50	644.68	-122.98	-521.71	-0.01	-38.78	-314.58	-72.30	-31.66	-1.99	-62.39
i.e % of commitment (import)	*50.00%*	*50.00%*	*50.00%*	*50.00%*	*40.24%*	*49.12%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	12.22	3.08	6.57	3.66	2.03	27.56	-5.26	-22.30	0.00	-1.66	-13.45	-3.09	-1.35	-0.09	-2.67
Total Cost ($billion)	17.73	9.74	11.24	5.08	3.08	46.87	-4.29	-13.55	**29.03**	-0.95	-8.18	-1.92	-0.78	-0.05	-1.67
Gains from trade ($billion)	19.89	24.63	19.05	7.73	1.59	72.89	4.29	13.55	**90.73**	0.95	8.18	1.92	0.78	0.05	1.67
delta gain in % / no limit (table C)	**-25.47%**	**-20.76%**	**-20.64%**	**-20.55%**	**-40.12%**	**-22.59%**	**1.49%**	**32.53%**	**-16.46%**	**40.55%**	**32.51%**	**29.30%**	**40.96%**	**51.43%**	**28.17%**

TABLE U: CDM cartel, 50% Import Limitation

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	378.74	72.10	161.42	107.02	101.79	821.06	96.68	339.41	1257.14	23.72	205.03	48.26	19.30	1.11	41.99
'Hot air' (Mton)	\	\	\	\	\	0.00	55.27	0.00	55.27	\	\	\	\	\	\
Marginal Costs ($/ton)	**$86.80**	**$86.80**	**$86.80**	**$86.80**	**$86.80**	**$86.80**	**$86.80**	**$86.80**	**$86.80**	**$86.80**	**$86.80**	**$86.80**	**$86.80**	**$86.80**	**$86.80**
Cost of Abatement ($billion)	11.91	6.66	5.32	2.91	3.03	29.82	2.81	2.99	35.63	0.23	1.81	0.41	0.19	0.01	0.35
Permits exp(-)/imp(+) (Mton)	192.84	72.10	145.79	64.37	16.25	491.35	-151.95	-339.41	-0.01	-23.72	-205.03	-48.26	-19.30	-1.11	-41.99
i.e % of commitment (import)	*33.74%*	*50.00%*	*47.46%*	*37.56%*	*13.77%*	*37.44%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	16.74	6.26	12.65	5.59	1.41	42.65	-13.19	-29.46	0.00	-2.06	-17.80	-4.19	-1.68	-0.10	3.64
Total Cost ($billion)	28.65	12.91	17.98	8.49	4.44	72.47	-10.38	-26.47	**35.63**	-1.83	-15.99	-3.78	-1.49	-0.08	-3.30
Gains from trade ($billion)	8.98	21.45	12.31	4.32	0.23	47.29	10.38	26.47	**84.14**	1.83	15.99	3.78	1.49	0.08	3.30
delta gain in % / no limit (table C)	**-66.36%**	**-30.98%**	**-48.71%**	**-55.60%**	**-91.36%**	**-49.78%**	**145.76%**	**158.90%**	**-22.53%**	**169.98%**	**159.06%**	**154.16%**	**170.48%**	**181.67%**	**152.35%**

TABLE V: CDM+FSU monopoly, 50% Import Limitation

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	432.45	72.10	185.74	120.08	115.35	925.72	42.39	289.04	1257.14	19.69	174.65	41.54	16.00	0.89	36.27
'Hot air' (Mton)	\	\	\	\	\	0.00	55.27	0.00	55.27	\	\	\	\	\	\
Marginal Costs ($/ton)	**$110.72**	**$110.72**	**$110.72**	**$110.72**	**$110.72**	**$110.72**	**$110.72**	**$110.72**	**$110.72**	**$110.72**	**$110.72**	**$110.72**	**$110.72**	**$110.72**	**$110.72**
Cost of Abatement ($billion)	17.20	6.66	7.72	4.19	4.36	40.14	0.24	2.02	42.40	0.15	1.23	0.28	0.12	0.01	0.24
Permits exp(-)/imp(+) (Mton)	139.13	72.10	121.47	51.31	2.69	386.69	-97.66	-289.04	-0.01	-19.69	-174.65	-41.54	-16.00	0.89	-36.27
i.e % of commitment (import)	*24.34%*	*50.00%*	*39.54%*	*29.94%*	*2.28%*	*29.46%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	15.40	7.98	13.45	5.68	0.30	42.81	-10.81	-32.00	0.00	-2.18	-19.34	-4.60	-1.77	-0.10	-4.02
Total Cost ($billion)	32.61	14.64	21.17	9.88	4.66	82.95	-10.57	-29.98	**42.40**	-2.03	-18.11	-4.32	-1.65	-0.09	-3.78
Gains from trade ($billion)	5.02	19.73	9.12	2.94	0.01	36.81	10.57	29.98	**77.36**	2.03	18.11	4.32	1.65	0.09	3.78
delta gain in % / no limit (table C)	**-81.19%**	**-36.52%**	**-62.01%**	**-69.79%**	**-99.74%**	**-60.90%**	**150.34%**	**193.21%**	**-28.77%**	**199.23%**	**193.48%**	**190.38%**	**199.46%**	**203.43%**	**189.17%**

TABLE W: No cartel or monopoly, 25% Import Limitation

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	428.69	108.14	230.41	128.54	88.53	984.31	36.46	236.37	1257.14	15.57	142.82	34.44	12.64	0.68	30.22
'Hot air' (Mton)	\	\	\	\	\	0.00	55.27	0.00	55.27	\	\	\	\	\	\
Marginal Costs ($/ton)	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**	**$12.54**
Cost of Abatement ($billion)	16.79	17.15	13.77	5.20	2.02	54.94	0.15	1.25	56.34	0.09	0.76	0.18	0.07	0.00	0.15
Permits exp(-)/imp(+) (Mton)	142.90	36.05	76.80	42.85	29.51	328.10	-91.73	-236.37	-0.01	-15.57	-142.82	-34.44	-12.64	-0.68	-30.22
i.e % of commitment (import)	*25.00%*	*25.00%*	*25.00%*	*25.00%*	*25.00%*	*25.00%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	1.79	0.45	0.96	0.54	0.37	4.11	-1.15	-2.96	0.00	-0.20	-1.79	-0.43	-0.16	-0.01	-0.38
Total Cost ($billion)	18.58	17.61	14.74	5.74	2.39	59.05	-1.00	-1.71	**56.34**	-0.11	-1.03	-0.26	-0.09	0.00	-0.23
Gains from trade ($billion)	19.05	16.76	15.55	7.07	2.28	60.71	1.00	1.71	**63.42**	0.11	1.03	0.26	0.09	0.00	0.23
delta gain in % / no limit (table C)	**-28.64%**	**-46.07%**	**-35.21%**	**-27.29%**	**-14.27%**	**-35.52%**	**-76.41%**	**-83.25%**	**-41.61%**	**-84.42%**	**-83.28%**	**-82.74%**	**-84.47%**	**-85.49%**	**-82.53%**

TABLE X: CDM cartel, 25% Import Limitation

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	428.69	108.14	230.41	128.54	114.40	1010.17	108.37	138.60	1257.14	8.34	83.51	20.98	6.74	0.33	18.69
'Hot air' (Mton)	\	\	\	\	\	0.00	55.27	0.00	55.27	\	\	\	\	\	\
Marginal Costs ($/ton)	**$108.95**	**$108.95**	**$108.95**	**$108.95**	**$108.95**	**$108.95**	**$108.95**	**$108.95**	**$108.95**	**$108.95**	**$108.95**	**$108.95**	**$108.95**	**$108.95**	**$108.95**
Cost of Abatement ($billion)	16.79	17.15	13.77	5.20	4.26	57.18	3.95	0.36	61.49	0.02	0.22	0.05	0.02	0.00	0.05
Permits exp(-)/imp(+) (Mton)	142.90	36.05	76.80	42.85	3.64	302.23	-163.64	-138.60	0.00	-8.34	-83.51	-20.98	-6.74	-0.33	-18.69
i.e % of commitment (import)	*25.00%*	*25.00%*	*25.00%*	*25.00%*	*3.09%*	*23.03%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	15.57	3.93	8.37	4.67	0.40	32.93	-17.83	-15.10	0.00	-0.91	-9.10	-2.29	-0.73	-0.04	-2.04
Total Cost ($billion)	32.36	21.08	22.14	9.87	4.66	90.11	-13.88	-14.74	61.49	-0.89	-8.88	-2.23	-0.72	-0.04	-1.99
Gains from trade ($billion)	5.27	13.29	8.14	2.94	0.01	29.66	13.88	14.74	58.27	0.89	8.88	2.23	0.72	0.04	1.99
delta gain in % / no limit (table C)	**-80.26%**	**-57.25%**	**-66.07%**	**-69.74%**	**-99.53%**	**-68.50%**	**228.58%**	**44.14%**	**-46.35%**	**30.50%**	**43.85%**	**50.10%**	**29.93%**	**18.13%**	**52.39%**

TABLE Y: CDM+FSU monopoly, 25% Import Limitation

	USA	JPN	EEC	OOE	EET	oecd+eet	FSU	NAB	World	EEX	CHN	IND	DAE	BRA	ROW
Reductions / ref 2010 (Mton)	447.47	108.14	230.41	128.54	119.14	1033.70	31.36	192.08	1257.14	12.22	115.99	28.40	9.90	0.51	25.06
'Hot air' (Mton)	\	\	\	\	\	0.00	55.27	0.00	55.27	\	\	\	\	\	\
Marginal Costs ($/ton)	**$117.93**	**$117.93**	**$117.93**	**$117.93**	**$117.93**	**$117.93**	**$117.93**	**$117.93**	**$117.93**	**$117.93**	**$117.93**	**$117.93**	**$117.93**	**$117.93**	**$117.93**
Cost of Abatement ($billion)	18.92	17.15	13.77	5.20	4.80	59.85	0.10	0.77	60.72	0.05	0.47	0.11	0.04	0.00	0.09
Permits exp(-)/imp(+) (Mton)	124.11	36.05	76.80	42.85	-1.10	278.70	-86.63	-192.08	-0.01	-12.22	-115.99	-28.40	-9.90	-0.51	-25.06
i.e % of commitment (import)	*21.71%*	*25.00%*	*25.00%*	*25.00%*	\	*21.24%*	\	\	\	\	\	\	\	\	\
Flows exp(-)/imp(+) ($billion)	14.64	4.25	9.06	5.05	-0.13	32.87	-10.22	-22.65	0.00	-1.44	-13.68	-3.35	-1.17	-0.06	-2.96
Total Cost ($billion)	33.55	21.41	22.83	10.26	4.67	92.71	-10.12	-21.88	**60.71**	-1.39	-13.21	-3.24	-1.12	-0.06	-2.86
Gains from trade ($billion)	4.07	12.96	7.46	2.56	0.00	27.05	10.12	21.88	**59.05**	1.39	13.21	3.24	1.12	0.06	2.86
delta gain in % / no limit (table C)	**-84.75%**	**-58.29%**	**-68.94%**	**-73.70%**	**-99.95%**	**-71.27%**	**139.58%**	**114.03%**	**-45.63%**	**104.56%**	**114.08%**	**117.82%**	**104.10%**	**93.50%**	**119.08%**

Fig. 1: Annex B meeting their Kyoto commitment, no trading

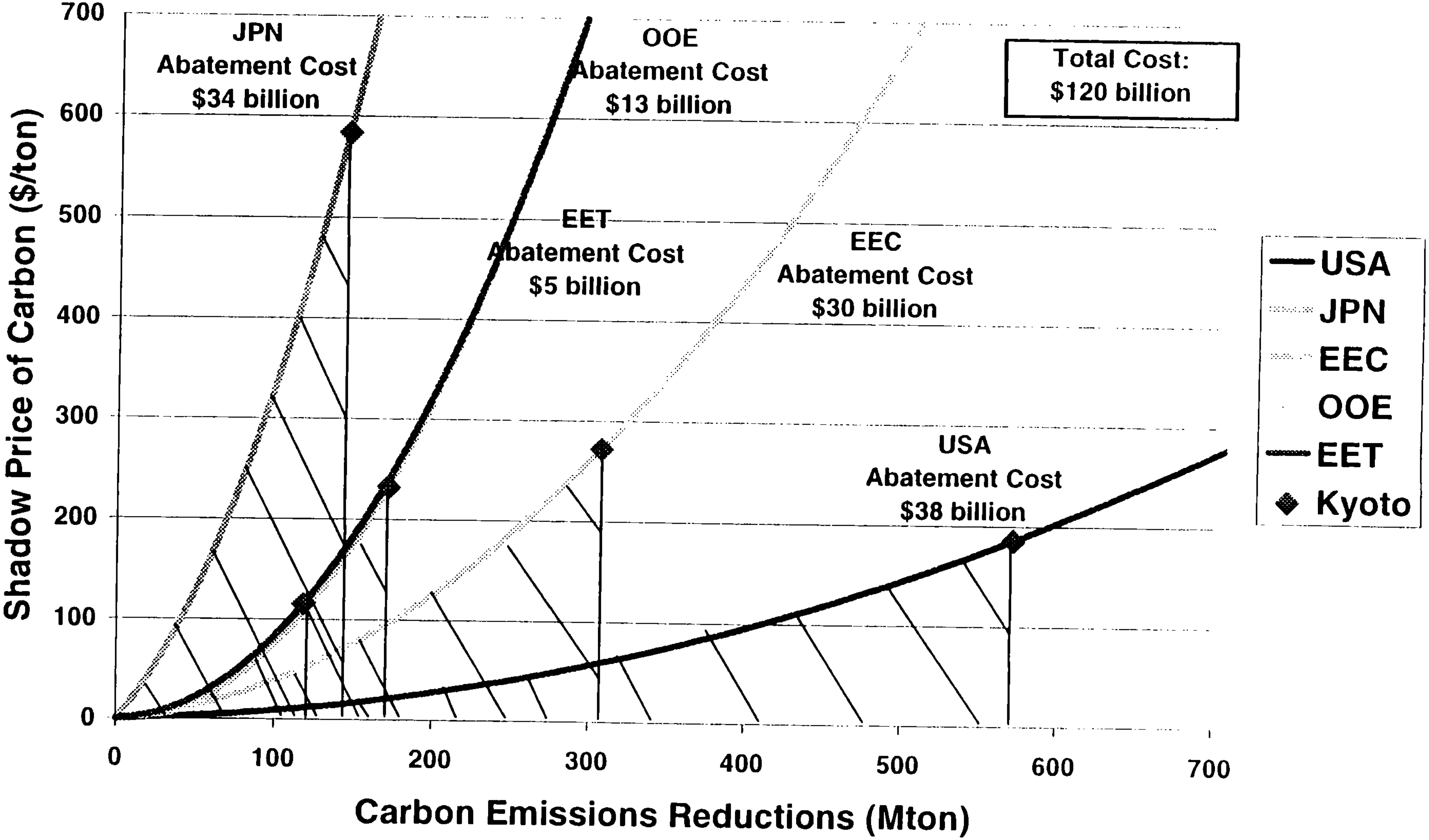


Fig. 2: Annex B meeting their Kyoto commitment, no trading / trading

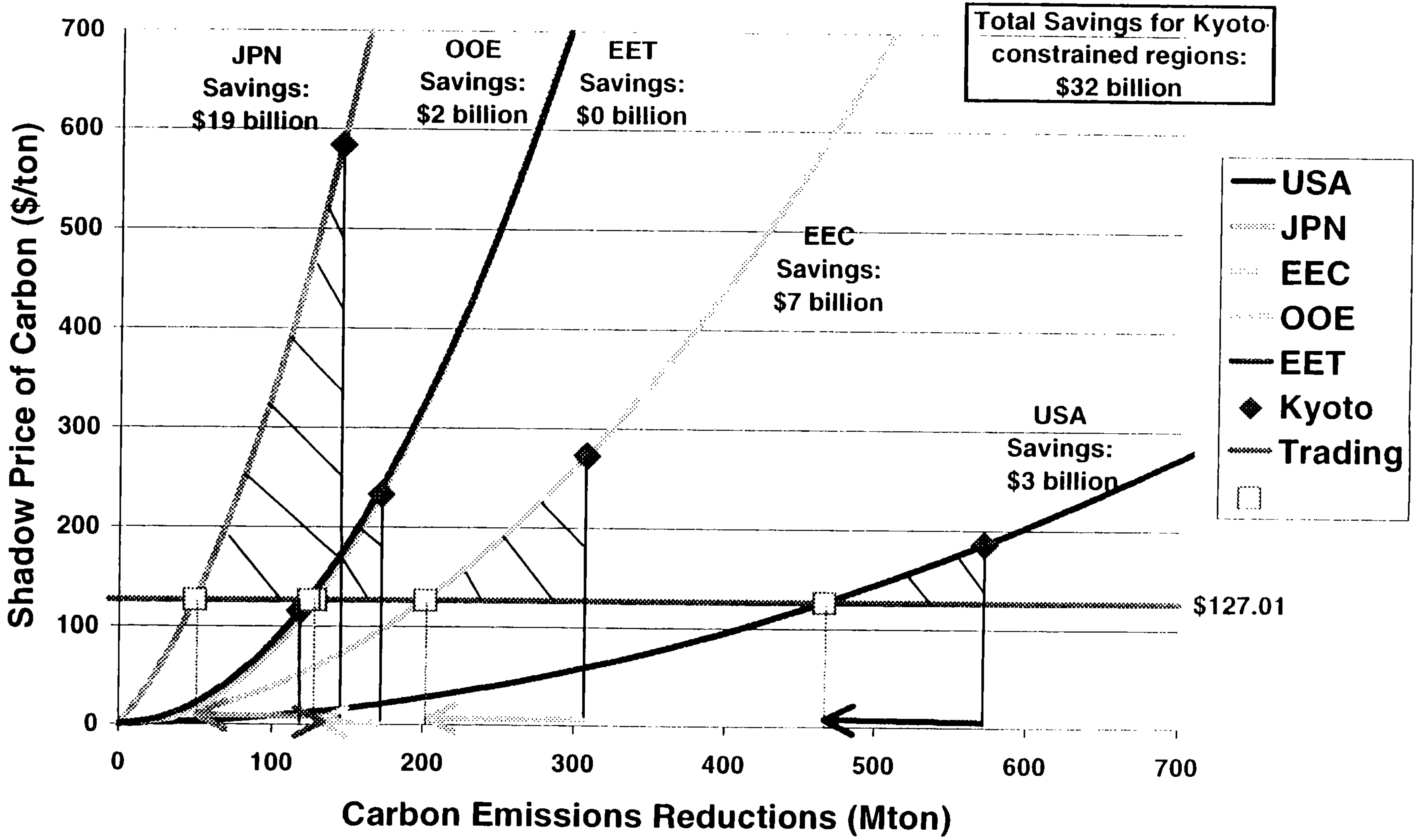


Fig. 4: Aggregated Supply and Demand Curves - Kyoto - 2010 Annex B Trading / World Trading

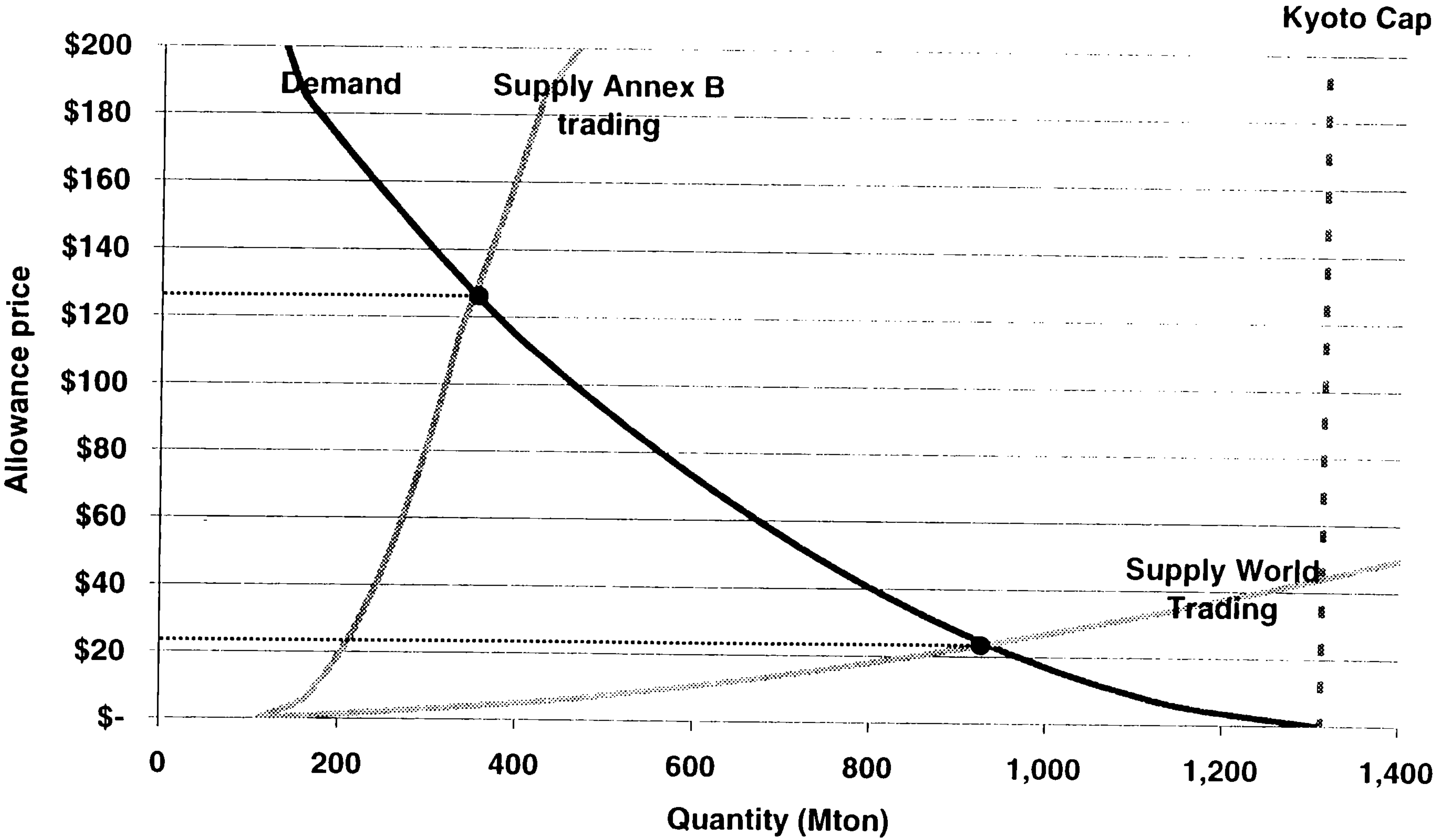


Figure 5: World Supply and Demand - Kyoto - 2010
Limitations on demand: 75%, 50%, 25%

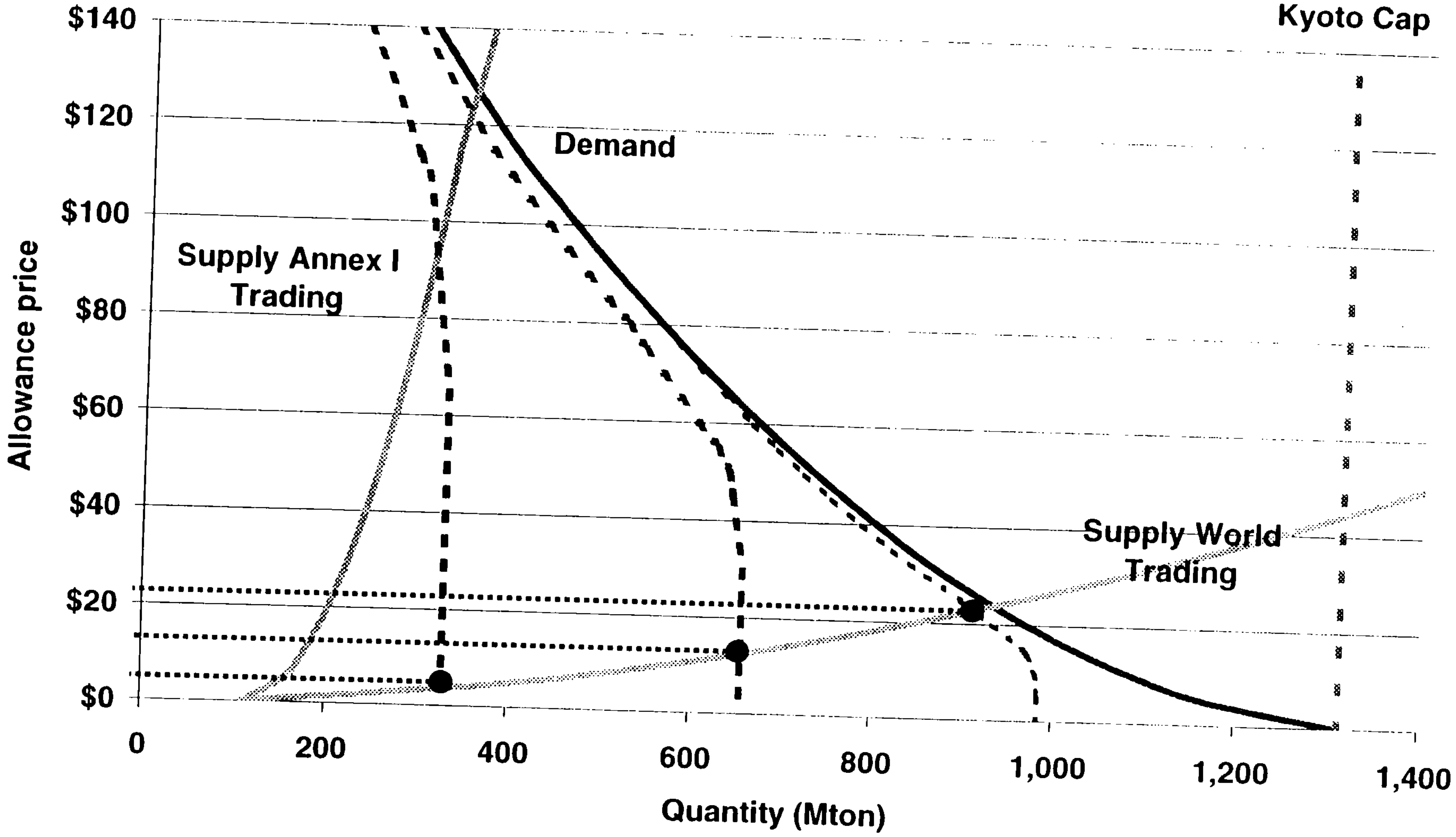


Figure 6: CDM surcharges: 25%, 50%, 100%

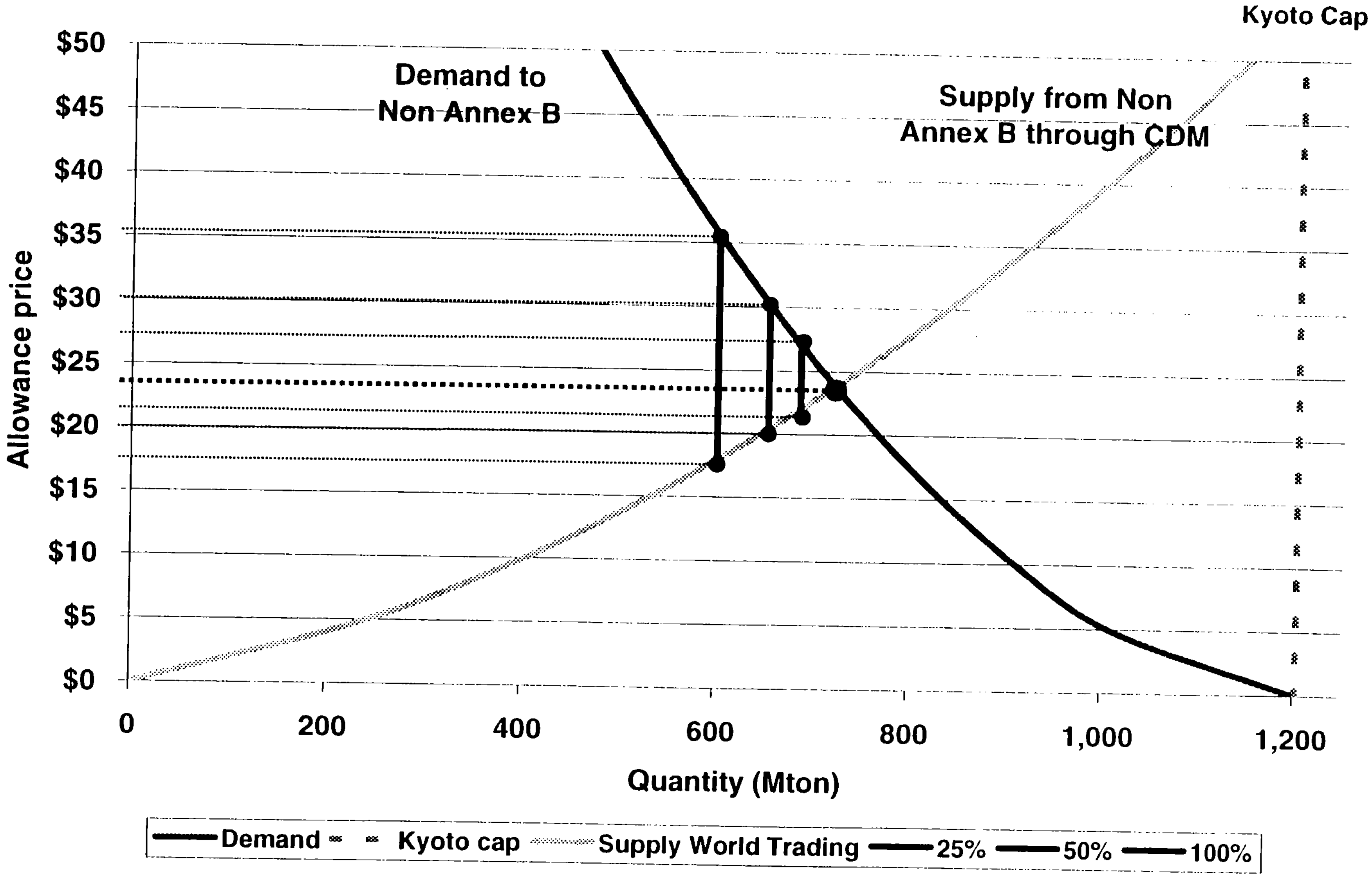


Fig. 7: World Permit Supply and Demand - Kyoto - 2010
Limitation on Supply: Supply = 50% - 25% - 15% - 10% - 5% Total

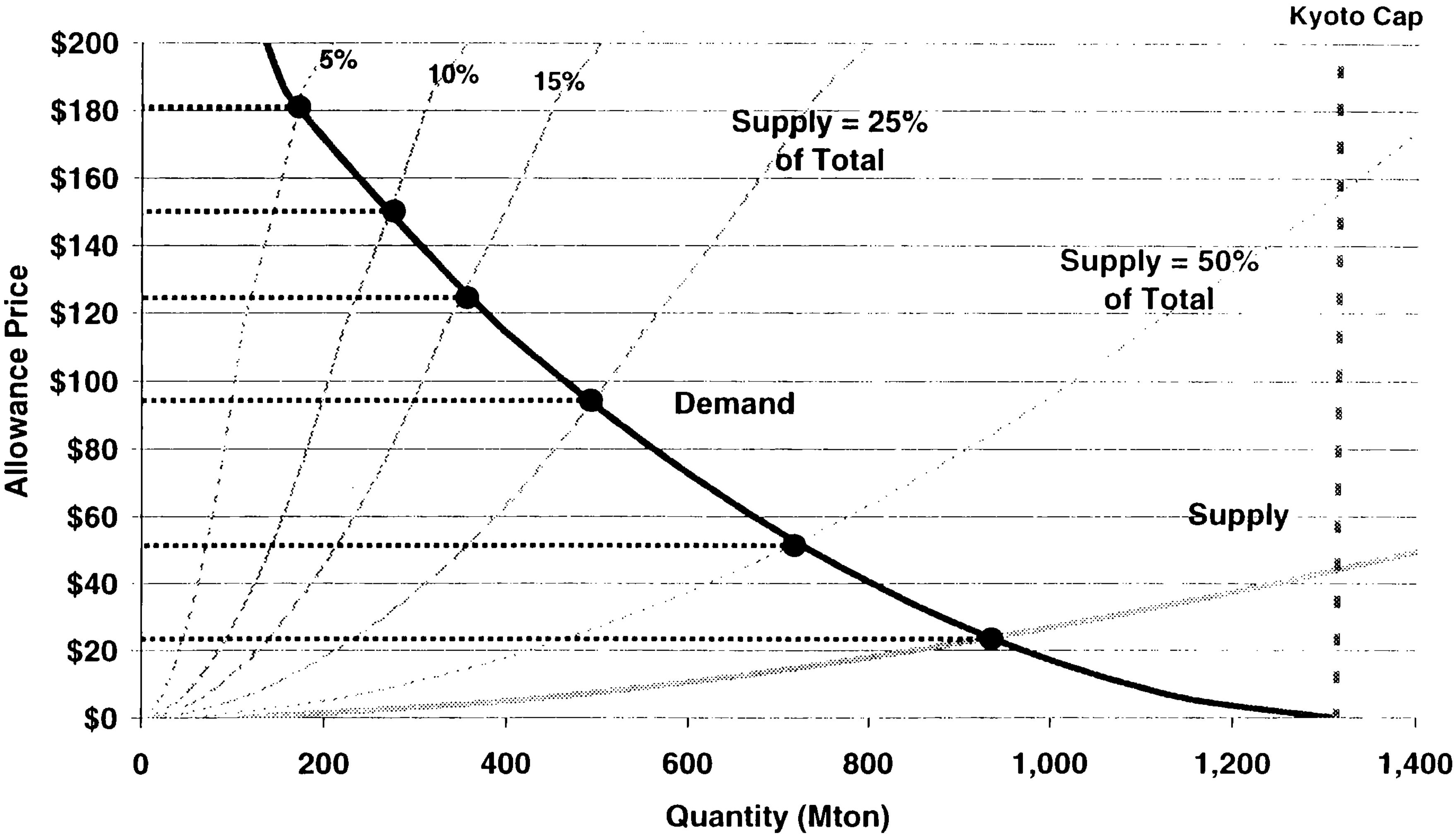


Fig. 8: Gains from More Efficient Global Trading

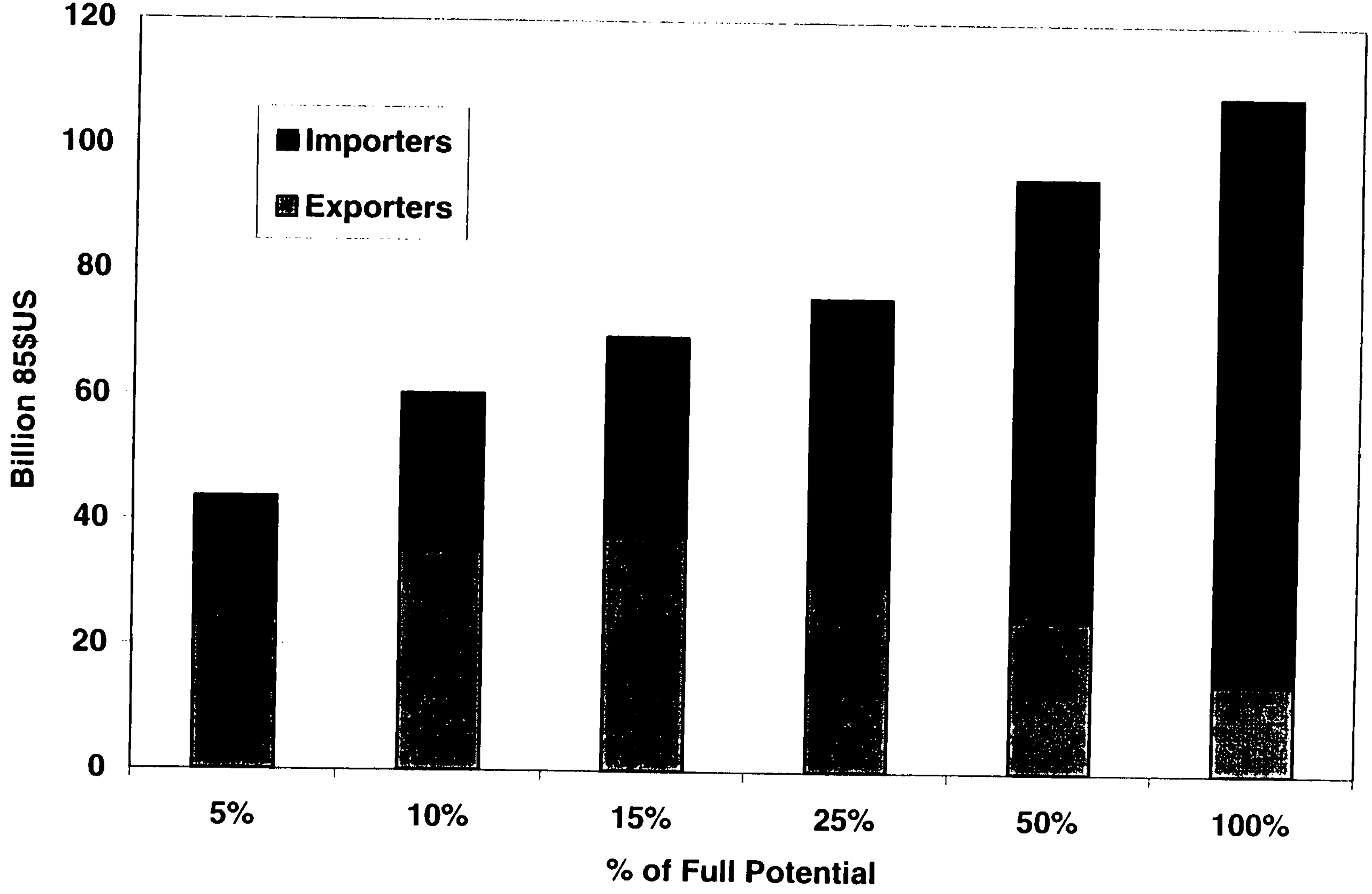


Fig. A3: EPPA-generated Marginal Abatement Curves - 2010
OECD Regions, Proportional Reductions, No Trading

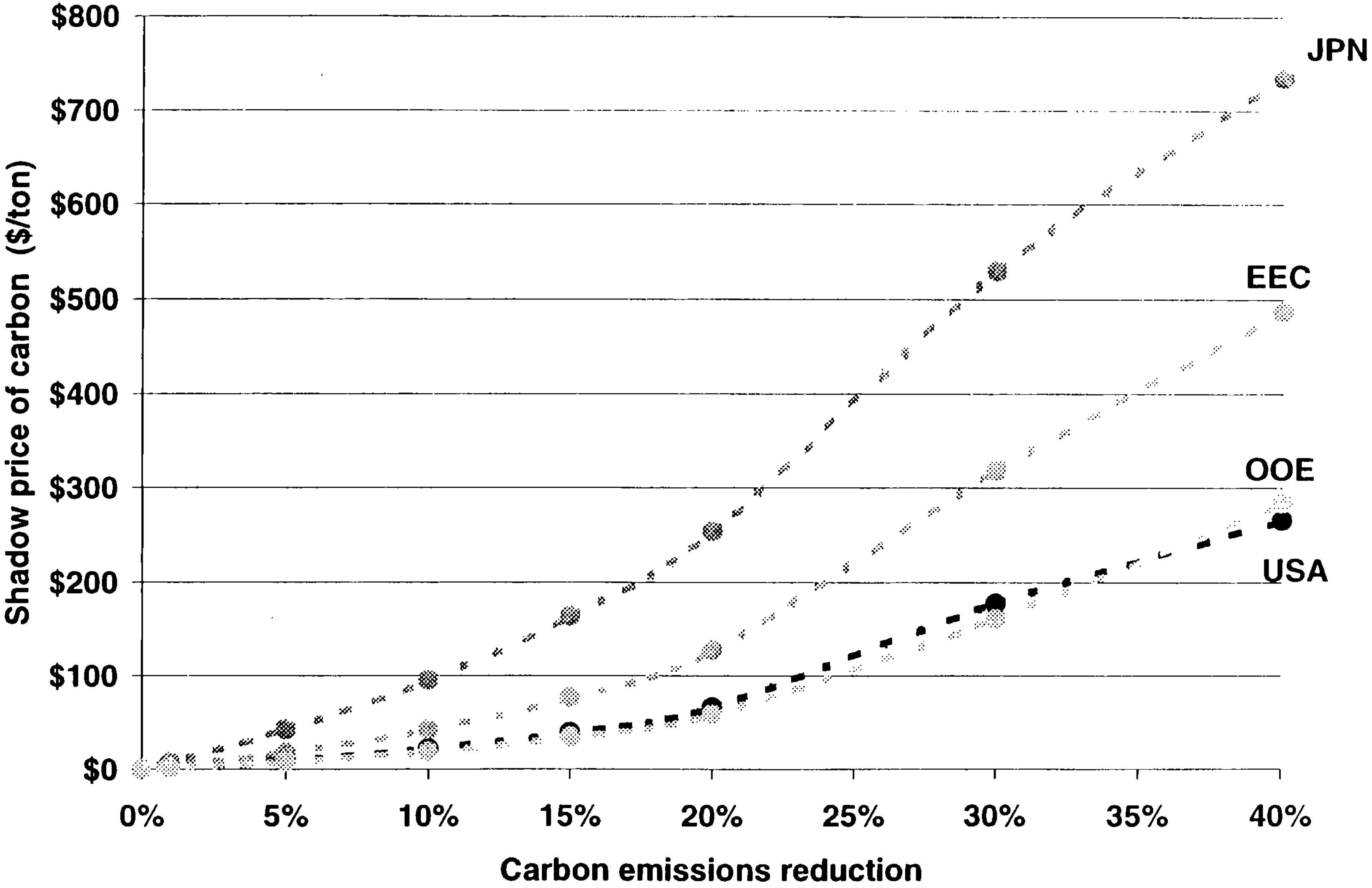
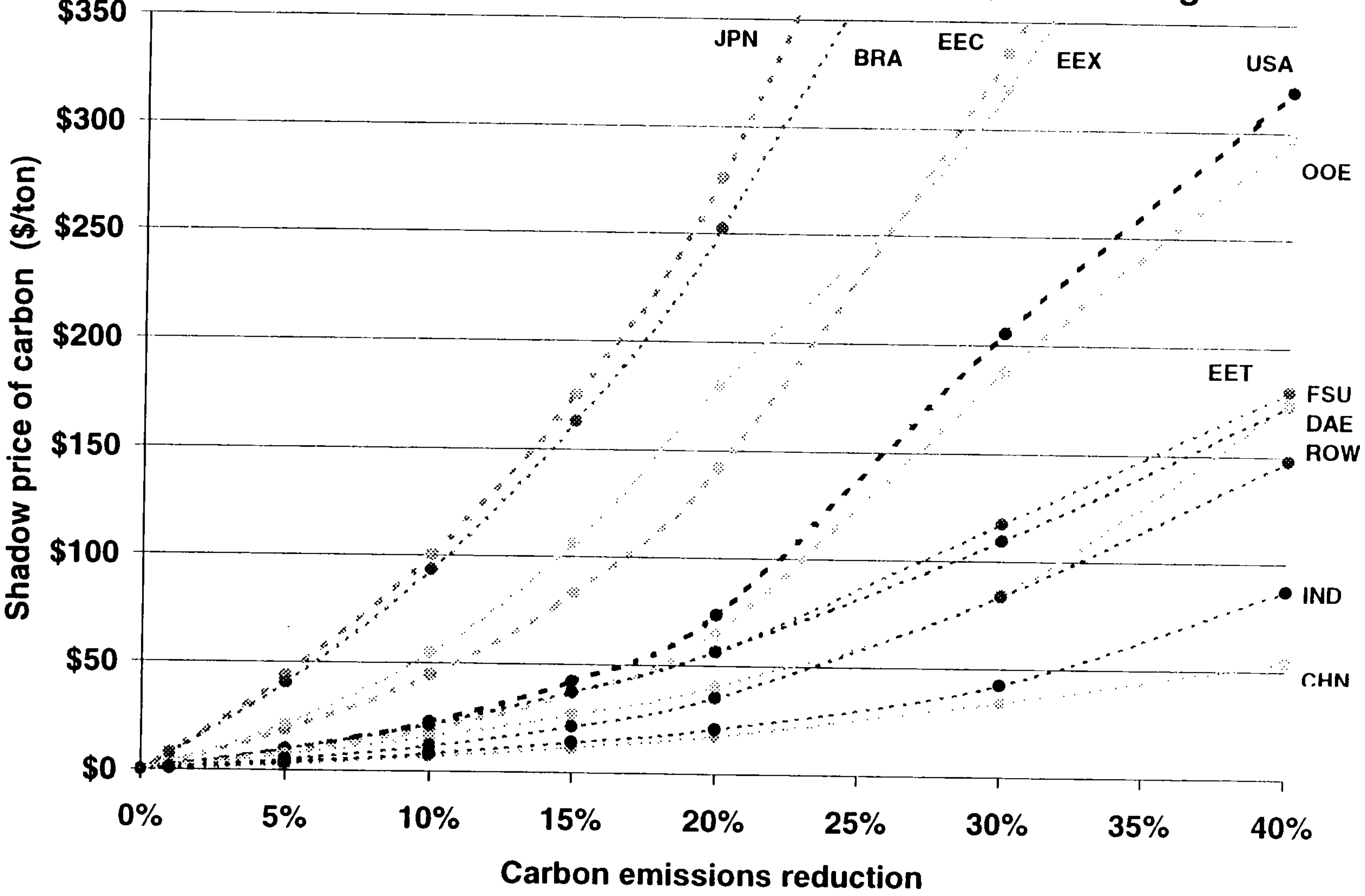


Fig. A4: EPPA-generated Marginal Abatement Curves - 2010
All Regions, Proportional Reductions, No Trading



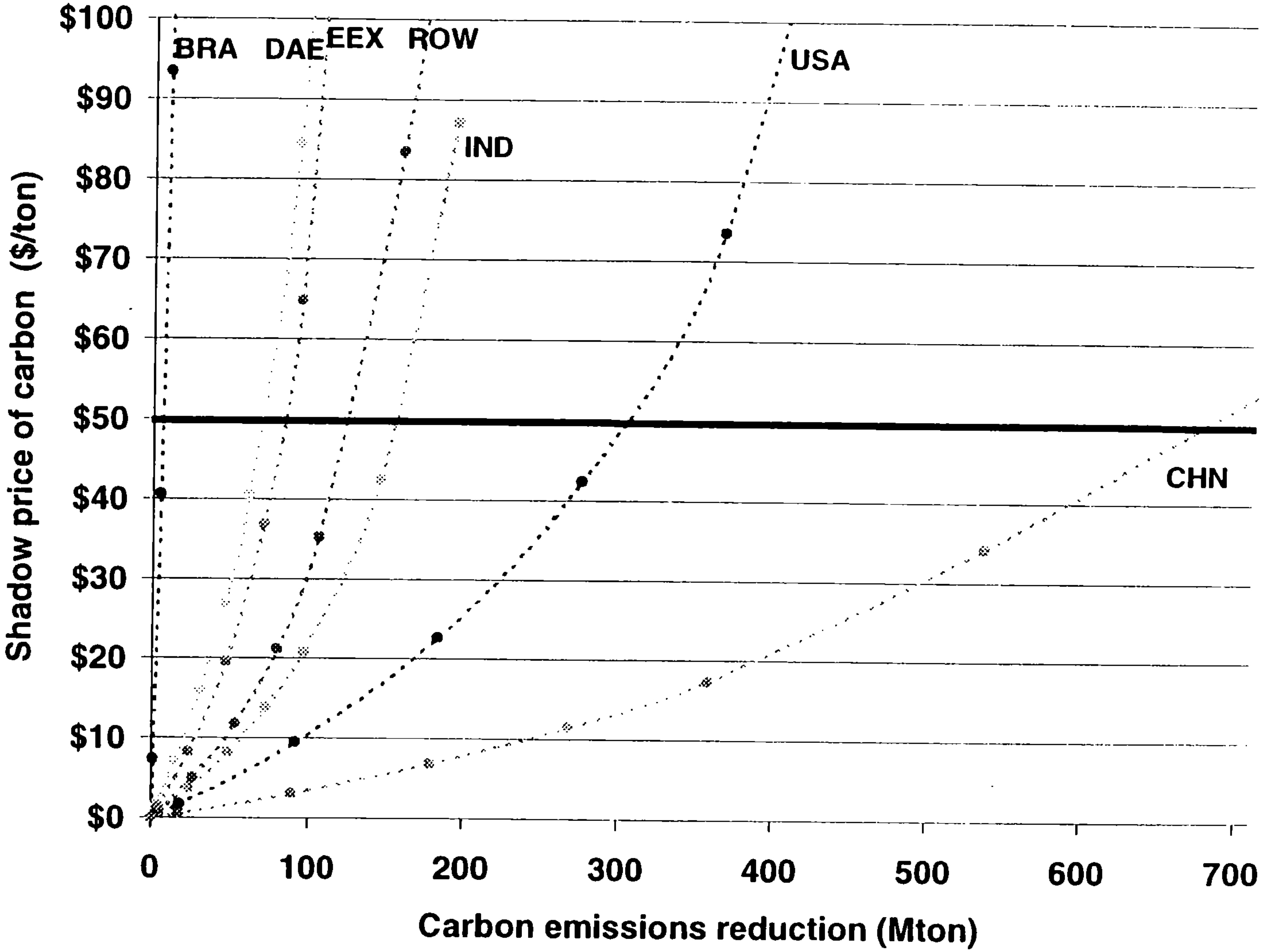


Fig. A5: EPPA-generated Marginal Abatement Curves - 2010
Non-Annex B regions, Proportional Reductions, No Trading

Fig. A6: EPPA-generated Marginal Abatement Curves - 2010
OECD Proportional Reductions - No Trading / OECD Trading

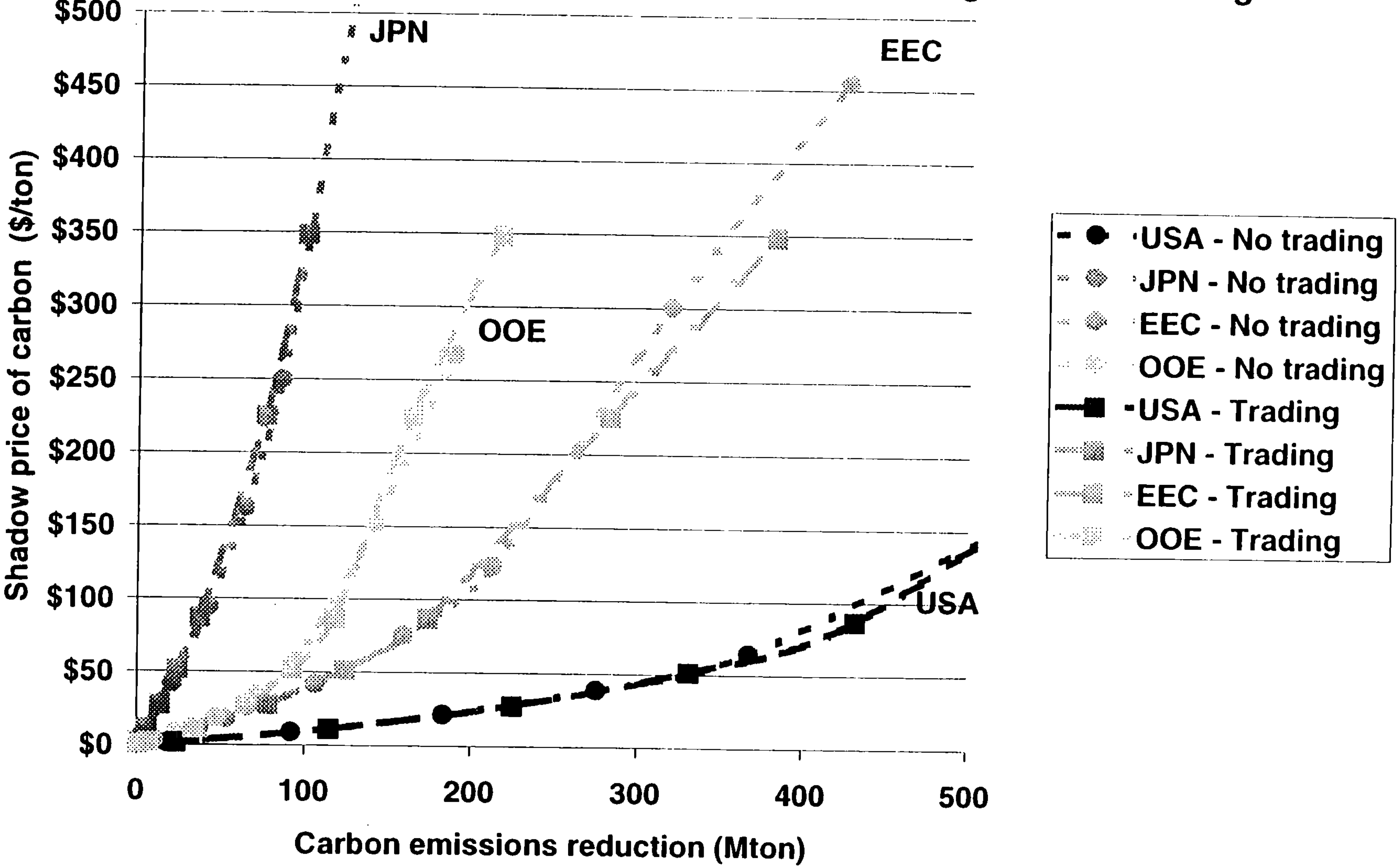


Fig. A7: Marginal Abatement Curves - 2010
OECD Regions - Polynomial Approximations

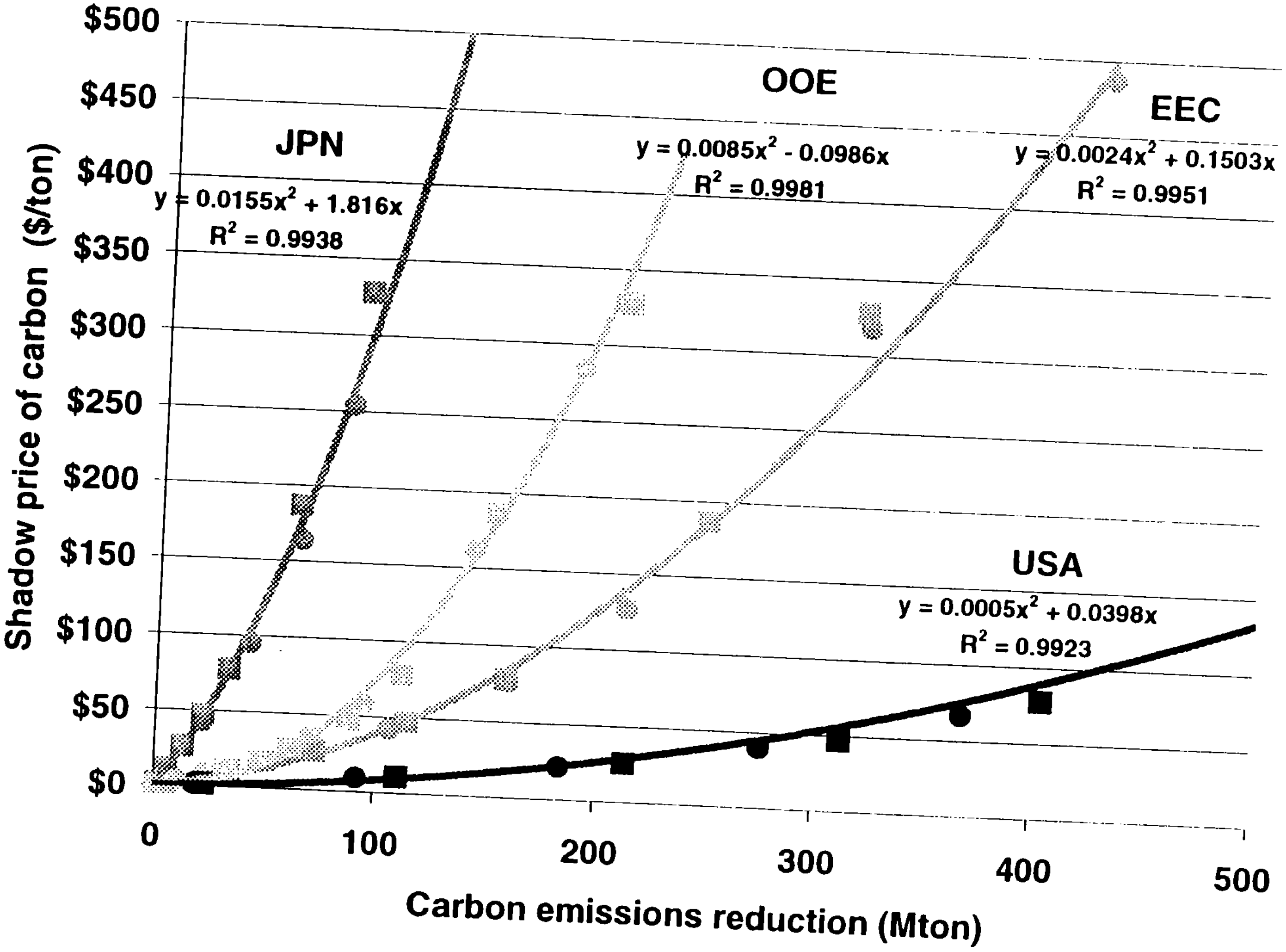
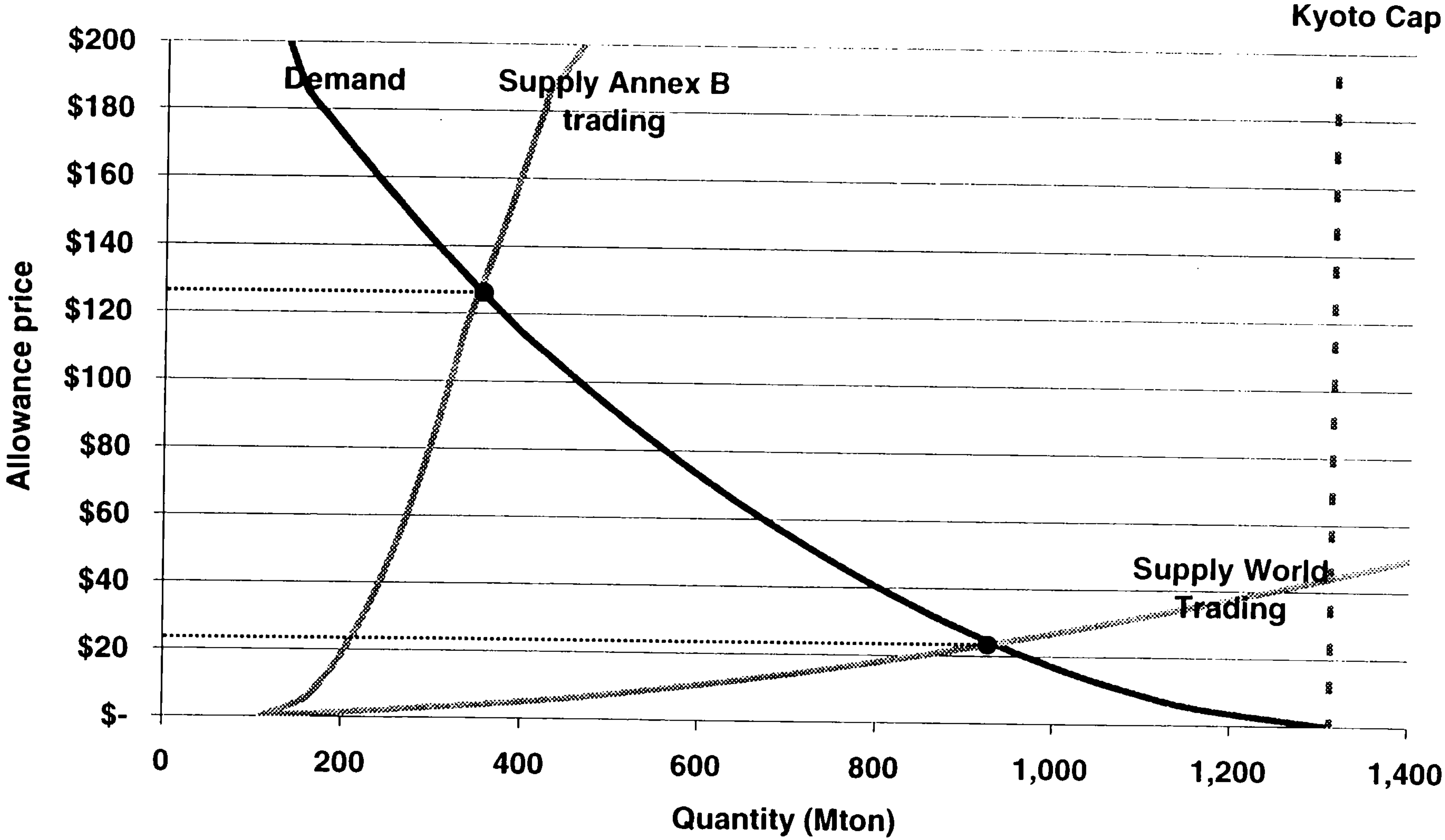


Fig. A8: Aggregated Supply and Demand Curves - Kyoto - 2010
Annex B Trading / World Trading



Curbing Carbon Emisions and the Kyoto Protocol: Perspective from the Administration

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Washington Policy Seminar
Macroeconomic Advisers, LLC
Georgetown Conference Center, Thursday, Sept. 10, 1998

I will make some general comments about the Administration position on the Kyoto Agreement, before responding to the two panelists who have gone before me.

The key bottom line of the economic analysis that we released in July was as follows, in qualitative terms: *Given key elements of the Agreement and of Administration policy (including tradeable permits and other flexibility features), the U.S. economic impacts are likely to be modest.*

Those key features are of several sorts. The Administration insisted that the design of the agreement be market-based, flexible, and global. The flexibility comes in three categories:

“When” flexibility	• 1st-period reductions less drastic than some countries wanted
	• targets phrased as multi-year averages
	• banking
“What” flexibility	• 6 gases included, not just carbon dioxide
	• sinks
“Where” flexibility	• international trading in emission permits
	• CDM

Finally, we require a global solution, to address a global problem.

- Without meaningful LDC participation, the President will not submit the Treaty for Senate ratification

Economic analysis of climate change policy is difficult for many reasons, which again fall into three categories.

- It is impossible to put a single monetary number on the benefits of averting Global Climate Change. Putting numbers on the economic costs of a 2-to-6 degree F increase in temperature or a 6-inch to 3-foot rise in sea level, which is what the IPCC scientists are forecasting for the next 100 years, is difficult enough. But that difficulty pales next to the uncertainties surrounding the appropriate discount rate, danger of catastrophic climate events, and appropriate risk aversion.
- Some terms of the international agreement are still uncertain.

Labs say Pacific Northwest, Laboratories'

- Econometric models are subject to inevitable ~~limitations. Some are good at some things,~~ other at others. No one model does it all.

Despite these difficulties, we used some estimates based on Battelle Labs' SGM, which is well-designed to handle international trading. The most important quantitative findings, supporting the qualitative finding that I led with, were as follows.

- Full and successful implementation of Annex I trading would reduce costs by one-half, relative to a situation where each country had to satisfy its commitment domestically.

- Full and successful implementation of global trading (including developing countries) would reduce costs by 80-87%.

- Global trading would reduce resource costs by an estimated \$7-\$12 b/yr in 2010, which is 0.1 % GDP in 2010. This is a cost that I would describe as, if anything, less than modest.

- The effect on the price of carbon is estimated at \$14-\$23/ton.

  - Δ price of natural gas = 3-5 %
  - Δ price of fuel oil = 5-9 %
  - Δ price of gasoline = 4-6¢ / gal.
  - Δ price of electricity = 3-4 %

In one respect, these estimates are optimistic: we cannot be sure of getting full developing-country participation in the near future. But in other respects they are conservative. They omit some factors that would reduce the net costs of the agreement:

- The Administration proposal for Federal electricity restructuring, which we consider part of our energy-and-environment policy, would save approximately \$20 billion in costs

- Allowance for sinks, such as land forestation, would potentially reduce the need for emission reductions substantially. ~~[illegible] [illegible]. sinks~~. The Kyoto Prot. explicitly recognizes sinks...

- The President's proposal to allocate \$6.3 billion over the next five years in Research and Development and tax breaks to develop and disseminate carbon-saving technologies could further reduce costs if it were enacted and if some of the technological payoff were to come in the next ten years. To be conservative, we assumed that it did not.

- Ancillary non-climate benefits, such as the health benefits of reduced air pollution could reduce net costs by an estimated one-quarter.

- Of course, the most important factor that has been left out of the above assessment is the benefit of mitigating climate change itself. (A full cost-benefit analysis would include mitigation in the benefits column. The only reason we have not done so, explained repeatedly above, is the difficulty in coming up with a number to capture the monetary benefits.) But nobody should lose sight of our ultimate objective -- keeping our planet the hospitable home that we enjoy today.

General comments on the other two panelists

We, as economic modelers, all have one important goal in common (among others). That is to avoid giving non-economists grounds to confirm their prejudices that models are of little use -- that they all say different things, depending on the inclinations of the modeler. It is true that if you listen to one-sentence summaries of the conclusions of different studies, the predicted effects of the Kyoto Protocol will appear to vary over a wide range. But for the most part the numbers pertain to different experiments. The questions vary, and so the answers vary -- as they should. It is important to be clear and explicit about the question that is being asked. We at the CEA have tried to do this in our public reports (the congressional testimony that Janet Yellen presented last last spring and the recent Administration Economic Analysis). Fortunately I think that the two papers that have been presented are also very clear and explicit.

Unfortunately, the experiments to which which the central Jones and Montgomery conclusions pertain are not the experiments that correspond to real aspects of the Kyoto Protocol and essential elements of the President's Climate Change policy:

1) Their main conclusions do not allow for Annex I trading;
2) They do not allow for LDC participation (no CDM or "growth targets"); and
3) They do not include the role of other gases and sinks.

When these studies are interpreted so as to take into account these factors, they reinforce and underscore our own analysis and negotiating position that flexible mechanisms are essential to responding to climate change. I am particularly pleased that David Montgomery has approximately replicated the results of the Administration Economic Analysis when allowing for full trading of emission rights. These results in part underly our judgment that the economic costs of complying with the Kyoto Agreement are likely to be modest.

Russell Jones Analysis

Jones and Dougher use the "Kaya Identity" (emissions = carbon intensity of energy * energy intensity of output * per capita output * population) to look at historical changes in the factors contributing to our emissions to show that the changes necessary to meet Kyoto commitments are "unprecedented". This approach offers a useful perspective. Attaining Kyoto-sized reductions in domestic emissions will not be completely effortless for the United States, or for other industrialized countries. Anyone who thinks otherwise -- e.g., that "technology will save us," even without price signals or any other government actions -- ought to think seriously about the Kaya identity.

But it does not follow that complying with Kyoto is impossible or even that it will impose large economic costs on us. There are two very crucial steps separating the analysis in this paper from a negative verdict on Kyoto.

- **The analysis assumes commitment is met entirely at home.** The Kyoto Protocol includes various flexibility mechanisms that enable us to reduce emissions elsewhere at lower cost. Our estimate is that international trading can reduce the costs by as much as 80-87 percent. After taking into account trading, the required domestic reductions are within the range of historical efforts as viewed in the Kaya framework.

- **The United States has never tried to reduce carbon intensity of energy.** Looking at historical changes in the carbon intensity of energy is misleading. The oil shocks of the 1970s raised the prices of oil (moderately high carbon content) and natural gas (low carbon content), far more than it raised the price of coal (highest carbon content). While we have tried to improve our economy's energy intensity in the past, we have never tried to improve our carbon intensity of energy. Therefore, looking at our historical experience in this field will not be indicative of what we may expect in the future.

Charles River Associates (Montgomery) Analysis

The model used by Charles River Associates' (CRA) is capable of analyzing the effects of changes in the price of carbon that go outside our historical experience. Their capsule assessment of the Administration's economic analysis of Kyoto says that the costs would be higher than the Administration's estimates. Again, this verdict leaves out central elements of the Kyoto Protocol and of the Administration's policy.

- **"Realistic" Trading Assumptions**. CRA argues that without trading, the costs of complying with our Kyoto target would be higher. We have no disagreement here. This is precisely why the Administration advocated and won international trading and other flexibility mechanisms in the Kyoto Protocol and is insisting on meaningful participation by developing countries. Assessments purportedly of the Kyoto Protocol that exclude trading, or assume trading constraints, are neither analyses of the Protocol nor of the Administration's position on implementing the Protocol. As I already mentioned, we are pleased to see that the CRA model, given the relevant assumptions, does generally replicate the low price effects estimated with Pacific Northwest Laboratories SGM Model and in the Administration's economic analysis.[1]

- **"Rapid" replacement of coal plants with natural gas plants**. CRA claims that the Administration assumes extremely rapid replacement of coal-fired plants with natural gas plants by 2008. I don't believe this is right. The Administration's estimates of natural gas consumption and coal consumption, relative to what they would be without any efforts to reduce greenhouse gas emissions, rebut this claim. With permit prices of $14 to $23/ton, natural gas consumption is roughly equal to what it is projected to be otherwise, while coal consumption, though somewhat lower than it would otherwise be, is still higher than present consumption. Thus there is no rapid reduction of coal-fired capacity.

- **Measurement of Economic Costs**. CRA claims that the Administration's assessment of economic costs underestimates the true costs to the whole economy (by a factor of 2-4).

    - First, it should be noted that this claim only concerns the definition and calculation of total resource costs given a specific permit price -- the argument does not address the estimated effects on prices. Prices seem to be the area of greatest interest to many in Congress, business, and the political process more broadly, as opposed to theoretical economists. [On price there is much less disagreement, once the experiment is specified carefully.]

    - Second, I have checked the references given, and can't find there anything like this proposition regarding indirect costs.

    - Third, CRA does not provide any specific demonstration or intuition as to what the indirect costs are, or why the total (direct and indirect costs) would be several times higher than what is evident in the measurement of direct costs. I am aware of several arguments, incorporated in some models, as to why the indirect effects might operate to reduce total resource costs, but not to add to them.

        - The first is that, if tradeable permits were auctioned off to generate revenue, which was then recycled as pro-investment reductions in distortionary taxes, then the real resouce cost would be reduced. We have never included this effect; the Administration has not yet decided whether even to distribute permits by auction.

        - But the second argument is potentially more relevant: raising the price of energy has auxiliary benefits, such as reducing SO2 pollution and thus reducing health costs. (Our estimates are that these benefits offset roughly 1/4 of the economic costs of meeting the Kyoto targets.)

        - Third, because the US is large in the world, we have some monopsony power. Policies to reduce the domestic demand for oil will thus work to reduce the price on world oil markets, improving our national terms of trade.

We have not included this effect either. But these are the indirect effects I can think of. I would like to hear from David Montgomery what are the indirect effects in his model that go the other way.

In the absence of more information, I can only think of two possibilities.

- The first possibility is that he is looking at indirect effects on industries that are more energy-intensive than the average, neglecting the indirect effects on industries that are less energy-intensive than the average.

  - The second possibility is that he is generalizing from historical studies of command-and-control policies, which do indeed tend to have costs that go beyond the increase in price of the commodity directly effected. This would be inappropriate, however, because the Administration's oft-stated plan is to implement its reductions through efficient market-oriented policies, not inefficient command-and-control policies. I offer these two possible hypotheses only as questions.

- **Technology Assumption**. Finally, I would like to highlight that in the Administration Economic Analysis we did not give in to the temptation of assuming that technology would bail us out, without help from price signals or other government policies.2 Rather, we adopted the default assumption about energy efficiency improvement used by the modelers who developed the Second Generation Model (AEEI =.96 % a year).3

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Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity

— DRAFT REPORT—
September 8, 1998

NOT FOR QUOTATION OR CITATION

Energy Information Administration
Office of Integrated Analysis and Forecasting
U.S. Department of Energy
Washington, DC 20585

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Preface

From December 1 through 11, 1997, more than 160 nations met in Kyoto, Japan, to negotiate binding limitations on greenhouse gases for the developed nations, pursuant to the objectives of the Framework Convention on Climate Change signed on May 4, 1992. The outcome of the meeting was the Kyoto Protocol, in which the developed nations agreed to limit their greenhouse gas emissions, relative to the levels emitted in 1990. The United States agreed to reduce emissions from 1990 levels by 7 percent during the period 2008 to 2012.

The analysis in this report was undertaken at the request of the Committee on Science of the U.S. House of Representatives. In its request, the Committee asked the Energy Information Administration (EIA) to analyze the Kyoto Protocol, "focusing on U.S. energy use and prices and the economy in the 2008-2012 time frame," as noted in the first letter in Appendix D. The Committee specified that EIA consider several cases for energy-related carbon reductions in its analysis, with sensitivities evaluating some key uncertainties: U.S. economic growth, the cost and performance of energy-using technologies, and the possible construction of new nuclear power plants.

The energy projections and analysis in this report were conducted using the National Energy Modeling System (NEMS), an energy-economy model of U.S. energy markets designed, developed, and maintained by EIA. NEMS is used each year to provide the projections in the *Annual Energy Outlook* (*AEO*). In its second letter, in Appendix D, the Committee requested that the analysis use the same general methodologies and assumptions underlying the *Annual Energy Outlook 1998* (*AEO98*), published in December 1997; however, some minor modifications were made to allow greater flexibility in NEMS in response to higher energy prices and to incorporate some methodologies that were formerly represented offline. These differences are outlined in Appendix A. The macroeconomic analysis used the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy, which is also used for the economic analysis in the *AEO*.

Chapter 1 of this report provides background discussion of the Kyoto Protocol and the framework and methodology of the analysis. Chapter 2 summarizes the energy market results from the various carbon reduction cases. Chapters 3, 4, and 5 analyze in more detail the issues and results for the end-use demand sectors, the electricity generation sector, and the fossil fuel supply markets, respectively. Chapter 6 provides the results of EIA's analysis of the macroeconomic impacts of carbon reduction under different monetary and fiscal policy assumptions. Chapter 7 compares the results of this study with those from other studies of the costs of carbon reduction, with accompanying tables in Appendix C. Appendix B includes the detailed energy market results from the carbon reduction cases.

Within its Independent Expert Review Program, EIA arranged for leading experts in the fields of energy and economic analysis to review earlier versions of this analysis and provide comment. The assistance of the following reviewers in preparing the report is gratefully acknowledged:

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The legislation that established EIA in 1977 vested the organization with an element of statutory independence. EIA does not take positions on policy questions. It is the responsibility of EIA to provide timely, high-quality information and to perform objective, credible analyses in support of the deliberations of both public and private decisionmakers. This report does not purport to represent the official position of the U.S. Department of Energy or the Administration.

Other EIA reports on the topic of greenhouse gases include the following annual reports:

- *Annual Energy Outlook 1998*, published in December 1997, with projections of domestic energy carbon emissions through 2020
- *International Energy Outlook 1998*, published in April 1998, with projections of international energy carbon emissions through 2020
- *Emissions of Greenhouse Gases in the United States 1996*, published in October 1997, with an inventory of all domestic greenhouse gas emissions
- *Mitigating Greenhouse Gas Emissions: Voluntary Reporting*, published in October 1997, reporting voluntary actions in 1995 to reduce greenhouse gases in the United States
- *Greenhouse Gases, Global Climate Change, and Energy*, an information brochure on greenhouse gases.

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Executive Summary

Greenhouse Gases and the Kyoto Protocol

Over the past several decades, rising concentrations of greenhouse gases have been detected in the Earth's atmosphere. It has been hypothesized that the continued accumulation of greenhouse gases could lead to an increase in the average temperature of the Earth's surface and cause a variety of changes in the global climate, sea level, agricultural patterns, and ecosystems that could be, on net, detrimental.

The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization and the United Nations Environment Programme in 1988 to assess the available scientific, technical, and socioeconomic information in the field of climate change. The most recent report of the IPCC concluded that: "Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitudes and patterns of long-term variability and the time-evolving pattern of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of evidence suggests that there is a discernable human influence on global climate."[1]

The Framework Convention on Climate Change was signed by more than 160 countries in Rio de Janeiro, Brazil, on May 4, 1992. The objective of the Framework Convention was to ". . . achieve . . . stabilization of the greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." The signatories agreed to formulate programs to mitigate climate change, and the developed country signatories agreed to adopt national policies to return anthropogenic emissions of greenhouse gases to their 1990 levels.

The first and second Conference of the Parties in 1995 and 1996 agreed to address the issue of greenhouse gas emissions for the period beyond 2000, and to negotiate quantified emission limitations and reductions for the third Conference of the Parties. On December 1 through 11, 1997, representatives from more than 160 countries met in Kyoto, Japan, to negotiate binding limits on greenhouse gas emissions for developed nations. The resulting Kyoto Protocol established emissions targets for each of the participating developed countries—the Annex I countries[2]—relative to their 1990 emissions levels. The targets range from an 8-percent reduction for the European Union to a 10-percent increase allowed for Iceland. The target for the United States is 7 percent below 1990 levels.

Although atmospheric *concentrations* of greenhouse gases are thought to have the potential to affect the global climate, the Protocol establishes targets in terms of *annual emissions*. Non-Annex I countries have no targets under the Protocol, but the Protocol reaffirms the commitments of the Framework Convention by all parties to formulate and implement climate change mitigation and adaptation programs.

Should the Protocol enter into force, the emissions targets for the developed countries would have to be achieved on average over the commitment period 2008 to 2012. The greenhouse gases covered by the Protocol are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The aggregate target is based on the carbon dioxide equivalent of each of the greenhouse gases. For the three synthetic greenhouse gases, countries have the option of using 1995 as the base year.

Several provisions of the Protocol allow for some flexibility in meeting the emissions targets. Net changes in emissions by direct anthropogenic land-use changes and forestry activities may be used in meeting the commitment, but they are limited to afforestation, reforestation, and deforestation since 1990. Emissions trading

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[1] Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change* (Cambridge, UK: Cambridge University Press, 1996).

[2] Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom of Great Britain and Northern Ireland, and United States of America. Turkey is an Annex I nation but did not commit to a quantifiable emissions target.

among the Annex I countries is also allowed. According to estimates presented by the Energy Information Administration (EIA) in its *International Energy Outlook 1998*,[3] there may be 165 million metric tons of carbon permits available from the Annex I countries of the former Soviet Union in 2010. Greenhouse gas emissions for those countries as a group are expected to be 165 million metric tons below 1990 levels in 2010 as a result of the economic decline that has occurred in the region during the 1990s. Additional carbon permits may also be available, depending on the "carbon price" that is established in international trading.

Joint implementation projects are permitted among the Annex I countries, allowing a nation to take emissions credits for projects that reduce emissions or enhance emissions-absorbing sinks, such as forests and other vegetation, in other Annex I countries. The Protocol also establishes a Clean Development Mechanism (CDM), under which Annex I countries can take credits for projects that reduce emissions in non-Annex I countries. In addition, any group of Annex I countries may create a bubble or umbrella to meet the total commitment of all the member nations. In a bubble, countries would agree to meet their total commitment jointly by allocating a share to each member. In an umbrella arrangement, the total reduction of all member nations would be met collectively through the trading of emissions rights. There is potential interest in the United States in entering into an umbrella trading arrangement with Annex I countries outside the European Union.

In 1990, total greenhouse gas emissions in the United States were 1,618 million metric tons carbon equivalent.[4] Of this total, 1,346 million metric tons, or 83 percent, consisted of carbon emissions from the combustion of energy fuels. By 1996, total U.S. greenhouse gas emissions had risen to 1,753 million metric tons carbon equivalent, including 1,463 million metric tons of carbon emissions from energy combustion. EIA's *Annual Energy Outlook 1998* (*AEO98*)[5] projects that energy-related carbon emissions will reach 1,803 million metric tons in 2010, 34 percent above the 1990 level. Because energy-related carbon emissions constitute such a large percentage of the Nation's total greenhouse gas emissions, any action or policy to reduce emissions will have significant implications for U.S. energy markets.

At the request of the U.S. House of Representatives Committee on Science, EIA performed an analysis of the Kyoto Protocol, focusing on the potential impacts of the Protocol on U.S. energy prices, energy use, and the economy in the 2008 to 2012 time frame. The request specified that the analysis use the same methodologies and assumptions employed in the *AEO98*, with no changes in assumptions about policy, regulatory actions, or funding for energy and environmental programs.

Methodology

The international provisions of the Kyoto Protocol, including international emissions trading between Annex I countries, joint implementation projects, and the CDM, may reduce the cost of compliance in the United States. Guidelines for those provisions, however, remain to be resolved at future negotiating meetings, and rules and guidelines for the accounting of emissions and sinks from activities related to agriculture, land use, and forestry activities must be developed. The specific guidelines may have a significant impact on the level of reductions from other sources that a country must undertake. Reductions in the other greenhouse gases may also offset the reductions required from carbon dioxide. A fact sheet issued by the U.S. Department of State on January 15, 1998, estimated that the method of accounting for sinks and the flexibility to use 1995 as the base year for the synthetic greenhouse gases may reduce the target to 3 percent below 1990 levels.[6] A similar estimate was cited by Dr. Janet Yellen, Chair, Council of Economic Advisers, in her testimony before the House Committee on Commerce, Energy and Power Subcommittee, on March 4, 1998.[7]

Because the exact rules that would govern the final implementation of the Protocol are not known with certainty, the specific reduction in energy-related emissions cannot be established. This analysis includes cases that assume a range of reductions in energy-related carbon emissions in the United States. Each case was analyzed to estimate the energy and economic impacts of achieving an assumed level of reductions.

A reference case and six carbon emissions reduction cases were examined in this report. The cases are defined as follows:

- **Reference Case (33 Percent Above 1990 Levels).** This case represents the reference projections of energy markets and carbon emissions without any enforced reductions and is presented as a baseline for comparisons of the energy market impacts in the reduction cases. Although this reference case is

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[3] Energy Information Administration, *International Energy Outlook 1998*, DOE/EIA-0484(98) (Washington, DC, April 1998).

[4] Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1996*, DOE/EIA-0573(96) (Washington, DC, October 1997).

[5] Energy Information Administration, *Annual Energy Outlook 1998*, DOE/EIA-0383(98) (Washington, DC, December 1997).

[6] See web site www.state.gov/www/global/oes/fs_kyoto_climate_980115.html.

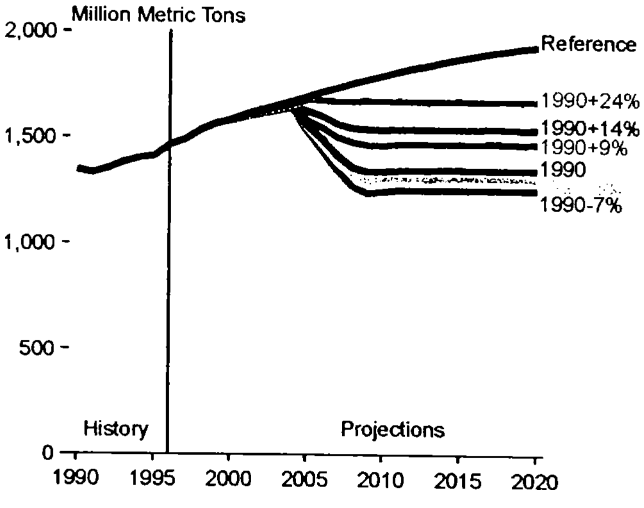
[7] See web site www.house.gov/commerce/database.htm.

based on the reference case from *AEO98*, there are small differences between this case and *AEO98*, in order to permit additional flexibility in response to higher energy prices or to include certain analyses previously done offline directly within the modeling framework, such as nuclear plant life extension and generating plant retirements. Also, some assumptions were modified to reflect more recent assessments of technological improvements and costs. As a result of these modifications, the projection of energy-related carbon emissions in 2010 is slightly reduced from the *AEO98* reference case level of 1,803 million metric tons to 1,791 million metric tons.

- **24 Percent Above 1990 Levels (1990+24%).** This case assumes that carbon emissions can increase to an average of 1,670 million metric tons between 2008 and 2012, 24 percent above the 1990 levels. Compared to the average emissions in the reference case, carbon emissions are reduced by an average of 122 million metric tons each year during the commitment period.
- **14 Percent Above 1990 Levels (1990+14%).** This case assumes that carbon emissions average 1,539 between 2008 and 2012, approximately at the level estimated for 1998 in *AEO98*, 1,533 million metric tons. This target is 14 percent above 1990 levels and represents an average annual reduction of 253 million metric tons from the reference case.
- **9 Percent Above 1990 Levels (1990+9%).** This case assumes that energy-related carbon emissions can increase to an average of 1,467 million metric tons between 2008 and 2012, 9 percent above 1990 levels, an average annual reduction of 325 million metric tons from the reference case projections.
- **Stabilization at 1990 Levels (1990).** This case assumes that carbon emissions reach an average of 1,345 million metric tons during the commitment period of 2008 through 2012, stabilizing approximately at the 1990 level of 1,346 million metric tons. This is an average annual reduction of 447 million metric tons from the reference case.
- **3 Percent Below 1990 Levels (1990-3%).** This case assumes that energy-related carbon emissions are reduced to an average of 1,307 million metric tons between 2008 and 2012, an average annual reduction of 485 million metric tons from the reference case projections.
- **7 Percent Below 1990 Levels (1990-7%).** In this case, energy-related carbon emissions are reduced from the level of 1,346 million metric tons in 1990 to an average of 1,250 million metric tons in the commitment period, 2008 to 2012. Compared to the reference case, this is an average annual reduction of 542 million metric tons of energy-related carbon emissions during that period. This case essentially assumes that the 7-percent target in the Kyoto Protocol must be met entirely by reducing energy-related carbon emissions, with no net offsets from sinks, other greenhouse gases, or international activities.

In each of the carbon reduction cases, the target is achieved on average for each of the years in the first commitment period, 2008 through 2012 (Figure ES1). Because the Protocol does not specify any targets beyond the first commitment period, the target is assumed to hold constant from 2013 through 2020, the end of the forecast horizon (although more or less stringent requirements may be set by future Conferences of the Parties). The target is assumed to be phased in over a 3-year period, beginning in 2005, because the Protocol indicates that demonstrable progress toward reducing emissions must be shown by 2005. The phase-in allows energy markets to begin adjustments to meet the targets in the absence of complete foresight; however, a longer or more delayed phase-in could lower the adjustment costs—an option that is not considered here. In this analysis, some carbon reductions are expected to occur before 2005 as the result of capacity expansion decisions by electricity generators that incorporate their expectations of future increases in energy prices.

Figure ES1. Projections of Carbon Emissions, 1990-2020



Sources: **History:** Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1996*, DOE/EIA-0573(96) (Washington, DC, October 1997). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

There are three ways to reduce energy-related carbon emissions: reducing the demand for energy services, adopting more energy-efficient equipment, and switching to less carbon-intensive or noncarbon fuels. To reduce emissions, a carbon price is applied to the cost of energy. The carbon price is applied to each of the energy fuels relative to its carbon content at its point of consumption. Electricity does not directly receive a carbon fee; however, the fossil fuels used for generation receive the fee, and this cost, as well as the increased cost of investment in generation plants, is reflected in the delivered price of electricity. In practice, these carbon prices could be imposed through a carbon emissions permit system.

In this analysis, the carbon prices represent the marginal cost of reducing carbon emissions to the specified level, reflecting the price the United States would be willing to pay in order to purchase carbon permits from other countries or to induce carbon reductions in other countries. In the absence of a complete analysis of trade and other flexible mechanisms to reduce carbon emissions internationally, the projected carbon prices do not necessarily represent the international market-clearing price of carbon permits or the price at which other countries would be willing to offer permits.

The projections in *AEO98* and in this analysis were developed using the National Energy Modeling System (NEMS), an energy-economy modeling system of U.S. energy markets, which is designed, implemented, and maintained by EIA.[8] The production, imports, conversion, consumption, and prices of energy are projected for each year through 2020, subject to assumptions on macroeconomic and financial factors, world energy markets, resource availability and costs, behavioral and technological choice criteria, costs and performance characteristics of energy technologies, and demographics. NEMS is a fully integrated framework, capturing the interactions of energy supply, demand, and prices across all fuels and all sectors of U.S. energy markets. NEMS provides annual projections, allowing the representation of the transitional effects of proposed energy policy and regulation.

NEMS includes a detailed representation of capital stock vintaging and technology characteristics, capturing the most significant factors that influence the turnover of energy-using and producing equipment and the choice of new technologies. The residential, commercial, transportation, electricity generation, and refining sectors of NEMS include explicit treatments of individual known technologies and their characteristics, such as initial cost, operating cost, date of commercial availability, efficiency, and other characteristics specific to the sector. Unknown technologies are not likely to be developed in time to achieve significant market penetration within the time frame of this analysis. Higher energy prices, as a result of carbon prices, for example, do not alter the characteristics or availability of energy-using technologies. However, higher prices induce more rapid adoption of more efficient or advanced technologies, because consumers would have more incentive to purchase them.

In addition, for new generating technologies, the electricity sector accounts for technological optimism in the capital costs of first-of-a-kind plants and for a decline in the costs as experience with the technologies is gained both domestically and internationally. In each of these sectors, equipment choices are made for individual technologies as new equipment is needed to meet growing demand for energy services or to replace retired equipment. In the other sectors—industrial, oil and gas supply, and coal supply—the treatment of technologies is somewhat more limited due to limitations on the availability of data for individual technologies; however, technology progress is represented by efficiency improvements in the industrial sector, technological progress in oil and gas exploration and production activities, and productivity improvements in coal production.

Carbon Reduction Cases

Carbon Prices

In 2010, the carbon prices projected to be necessary to achieve the carbon emissions reduction targets range from $67 per metric ton (1996 dollars) in the 1990+24% case to $348 per metric ton in the 1990-7% case (Table ES1 and Figure ES2). In the 1990+24% case, carbon prices generally increase from 2005 through 2020 (Table ES2 and Figure ES2). In the 1990+14% and 1990+9% cases, the carbon prices increase through 2013 and then essentially flatten.

In the three other carbon reduction cases, the carbon price escalates more rapidly in order to achieve the more stringent carbon reductions in the commitment period. The carbon price then declines as cumulative investments in more energy-efficient and lower-carbon equipment, particularly in the electricity generation sector, reduce the marginal cost of compliance in the later years of the forecast. These investments reduce the demand for carbon permits over an extended period of time, offsetting growth in energy demand and moderating the carbon prices. Figure ES3 shows the average carbon prices required to achieve the average carbon reductions.

Sectoral Impacts

As a result of the carbon prices and higher delivered energy prices, the overall intensity of energy use declines in the carbon reduction cases. Energy intensity, measured in energy consumed per dollar of gross

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[8] Energy Information Administration, *The National Energy Modeling System: An Overview 1998*, DOE/EIA-0581(98) (Washington, DC, February 1998).

Table ES1. Selected Variables in the Carbon Reduction Cases, 1996 and 2010

Variable	1996	2010						
		Reference	1990 +24%	1990 +14%	1990 +9%	1990	1990 -3%	1990 -7%
U.S. Carbon Emissions								
(Million Metric Tons)	1,463	1,791	1,668	1,535	1,462	1,340	1,300	1,243
Emissions Reductions								
(Percent Change From Reference Case)	—	—	6.9	14.3	18.4	25.2	27.4	30.6
Total Energy Consumption								
(Quadrillion Btu)	93.8	111.2	106.5	101.9	99.6	95.2	93.9	91.7
(Percent Change From Reference Case)	—	—	-4.2	-8.4	-10.4	-14.4	-15.6	-17.5
Carbon Price								
(1996 Dollars per Metric Ton)	—	—	67	129	163	254	294	348
Carbon Revenue[a]								
(Billion 1996 Dollars)	—	—	110	195	233	333	374	424
Gasoline Price								
(1996 Dollars per Gallon)	1.23	1.25	1.39	1.50	1.55	1.72	1.80	1.91
(Percent Change From Reference Case)	—	—	11.2	20.0	24.0	37.6	44.0	52.8
Average Electricity Price								
(1996 Cents per Kilowatthour)	6.8	5.9	7.1	8.2	8.8	10.0	10.5	11.0
(Percent Change From Reference Case)	—	—	20.3	39.0	49.2	69.5	78.0	86.4
Actual Gross Domestic Product[b]								
(Billion 1992 Dollars)	6,928	9,429	9,333	9,268	9,241	9,137	9,102	9,032
(Percent Change From Reference Case)	—	—	-1.0	-1.7	-2.0	-3.1	-3.5	-4.2
(Annual Percentage Growth Rate, 2005-2010)	—	2.0	1.8	1.7	1.6	1.4	1.3	1.2
Potential Gross Domestic Product								
(Billion 1992 Dollars)	6,930	9,482	9,469	9,455	9,448	9,429	9,420	9,410
(Percent Change From Reference Case)	—	—	-0.1	-0.3	-0.4	-0.6	-0.7	-0.8
(Annual Percentage Growth Rate, 2005-2010)	—	2.0	2.0	1.9	1.9	1.9	1.9	1.9
Change in Energy Intensity								
(Annual Percent Change, 2005-2010)	—	-1.0	-1.6	-2.0	-2.1	-2.7	-2.8	-3.0
(Percent Change From Reference Case)	—	—	55.6	96.4	108.2	161.8	177.0	199.0

[a] The carbon revenues do not include fees on the nonsequestered portion of petrochemical feedstocks, nonpurchased refinery fuels, or industrial other petroleum.

[b] Carbon permit revenues are assumed to be returned to households through personal income tax rebates.

Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, FD07BLW. D080398B.

domestic product (GDP), declines (i.e., improves) at an average annual rate of 1 percent between 2005 and 2010 in the reference case due to the availability and adoption of more efficient equipment. In the carbon reduction cases, higher rates of improvement are projected—from 1.6 percent a year in the 1990+24% case to triple the reference case rate at 3.0 percent a year in the 1990-7% case.

In 2010, reductions in carbon emissions from electricity generation account for between 68 and 75 percent of the total carbon reductions across the cases. Electricity consumption is projected to be lower than in the reference case, with more efficient, less carbon-intensive technologies used for electricity generation. In all the carbon reduction cases except the 1990+24% case, carbon emissions from electricity generation in 2010 are lower than the actual 1990 level of 477 million metric tons of carbon emissions from the electricity supply sector. Electricity generators are expected to respond more strongly than end-use consumers to higher prices because this industry has traditionally been cost-minimizing, factoring future energy price increases into investment decisions. In contrast, the end-use consumers are assumed to consider only current prices in making their investment decisions and to consider additional factors, not only price, in their decisions. In addition, there are a number of more efficient and lower-carbon technologies for electricity generation that become economically available as the cost of generating electricity from fossil fuels increases.

Total electricity generation is lower in the carbon reduction cases because electricity sales range from 4 to 17 percent below the reference case in 2010 (Figure ES4). Reduction in electricity demand in response to higher electricity prices is somewhat mitigated by the change in relative prices. In 2010, electricity prices are between 20 and 86 percent above the reference case across the

Table ES2. Selected Variables in the Carbon Reduction Cases, 1996 and 2020

Variable	1996	2020						
		Reference	1990 +24%	1990 +14%	1990 +9%	1990	1990 -3%	1990 -7%
U.S. Carbon Emissions								
(Million Metric Tons)	1,463	1,929	1,668	1,535	1,468	1,347	1,303	1,251
Emissions Reductions								
(Percent Change From Reference Case)	—	—	13.5	20.4	23.9	30.2	32.5	35.1
Total Energy Consumption								
(Quadrillion Btu)	93.8	117.0	108.6	105.6	103.8	100.9	99.9	98.8
(Percent Change From Reference Case)	—	—	-7.2	-9.7	-11.3	-13.8	-14.6	-15.6
Carbon Price								
(1996 Dollars per Metric Ton)	—	—	99	123	141	200	240	305
Carbon Revenue[a]								
(Billion 1996 Dollars)	—	—	162	184	202	263	306	372
Gasoline Price								
(1996 Dollars per Gallon)	1.23	1.24	1.42	1.45	1.49	1.60	1.67	1.80
(Percent Change From Reference Case)	—	—	14.5	16.9	20.2	29.0	34.7	45.2
Average Electricity Price								
(1996 Cents per Kilowatthour)	6.8	5.6	7.3	7.8	8.1	8.7	8.9	9.3
(Percent Change From Reference Case)	—	—	30.4	39.3	44.6	55.4	58.9	66.1
Actual Gross Domestic Product[b]								
(Billion 1992 Dollars)	6,928	10,865	10,815	10,808	10,796	10,799	10,793	10,782
(Percent Change From Reference Case)	—	—	-0.5	-0.5	-0.6	-0.6	-0.7	-0.8
(Annual Percentage Growth Rate, 2005-2020)	—	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Potential Gross Domestic Product								
(Billion 1992 Dollars)	6,930	10,994	10,968	10,961	10,954	10,940	10,933	10.925
(Percent Change From Reference Case)	—	—	-0.2	-0.3	-0.4	-0.5	-0.6	-0.6
(Annual Percentage Growth Rate, 2005-2020)	—	1.7	1.6	1.6	1.6	1.6	1.6	1.6
Change in Energy Intensity								
(Annual Percent Change, 2005-2020)	—	-0.9	-1.4	-1.4	-1.5	-1.6	-1.7	-1.7
(Percent Change From Reference Case)	—	—	46.3	54.0	55.7	72.1	76.9	80.9

[a] The carbon revenues do not include fees on the nonsequestered portion of petrochemical feedstocks, nonpurchased refinery fuels, or industrial other petroleum.

[b] Carbon permit revenues are assumed to be returned to households through personal income tax rebates.

Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, FD07BLW. D080398B.

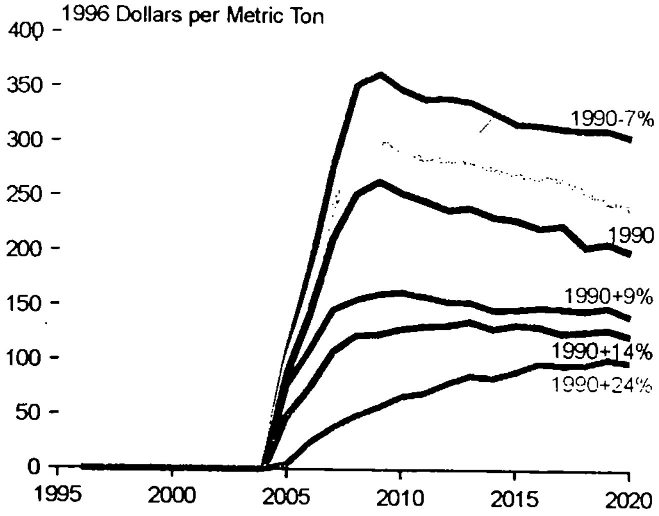
carbon reduction cases; however, delivered natural gas prices are higher by between 25 and 147 percent. With a smaller percentage price increase, electricity becomes more attractive in those end uses where it competes with natural gas, such as home heating.

Although reduced demand for electricity and efficiency improvements in the generation of electricity contribute to the total reductions in carbon emissions from electricity generation, fuel switching accounts for most of the reductions (Figure ES5). The delivered price of coal to generators in 2010 is higher by between 153 and nearly 800 percent in the carbon reduction cases relative to the reference case. As a result, coal-fired generation, which accounts for about half of all generation in 2010 in the reference case, has a share between 42 percent and 12 percent in 2010 in the carbon reduction cases. To replace coal plants, generators build more natural gas plants, extend the life of existing nuclear plants, and dramatically increase the use of renewables in the more stringent reduction cases, particularly biomass and wind energy systems, which become more economical with higher carbon prices.

Assuming that carbon emissions from the generation of electricity are shared to each of the end-use demand sectors, based upon their consumption of electricity, the industrial and residential end-use demand sectors account for most of the carbon reductions, and the transportation sector accounts for the least (Figure ES6). In response to higher energy prices, consumers have an incentive to reduce demand for energy services, switch to lower-carbon energy sources, and invest in more energy-efficient technologies.

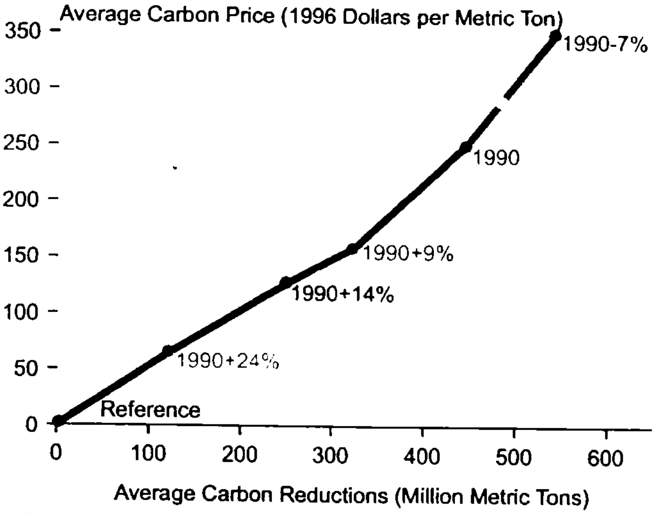
Because coal is the most carbon-intensive of the fossil fuels, delivered coal prices are most affected by the

Figure ES2. Projections of Carbon Prices, 1996-2020



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

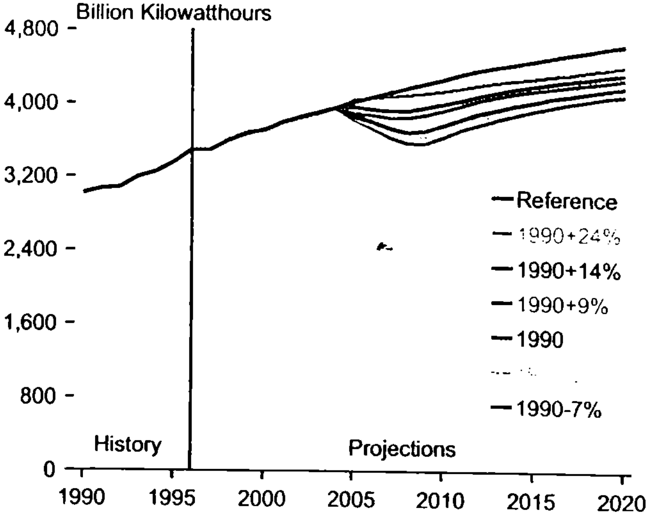
Figure ES3. Average Projected Carbon Prices and Annual Carbon Emission Reductions, 2008-2010



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

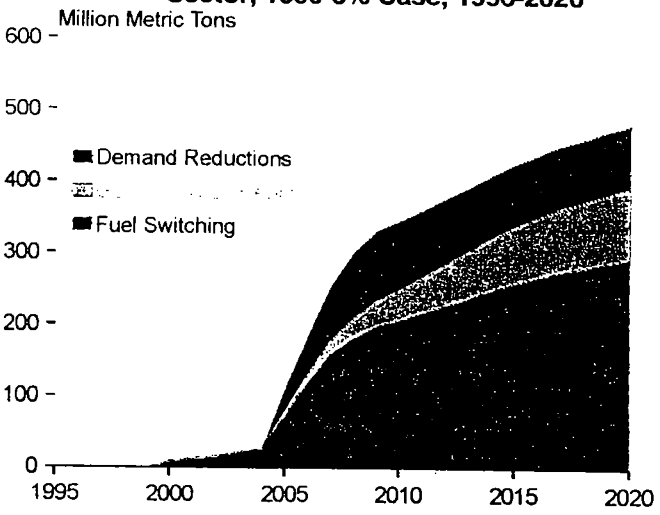
carbon prices (Figure ES7). Higher electricity prices reflect the increased costs of fossil fuels for generation and the incremental cost of additional investments, although the increase is mitigated by generation from renewables and nuclear power, because their fuel prices are not affected by carbon prices. Although the average carbon content of petroleum products is higher than that of natural gas, the percentage increase in the price of natural gas is higher than that of petroleum. Higher prices for petroleum are partially offset by lower world oil prices, and Federal and State taxes on gasoline also serve to mitigate the percentage increase.

Figure ES4. Projections of U.S. Electricity Generation, 1990-2020



Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

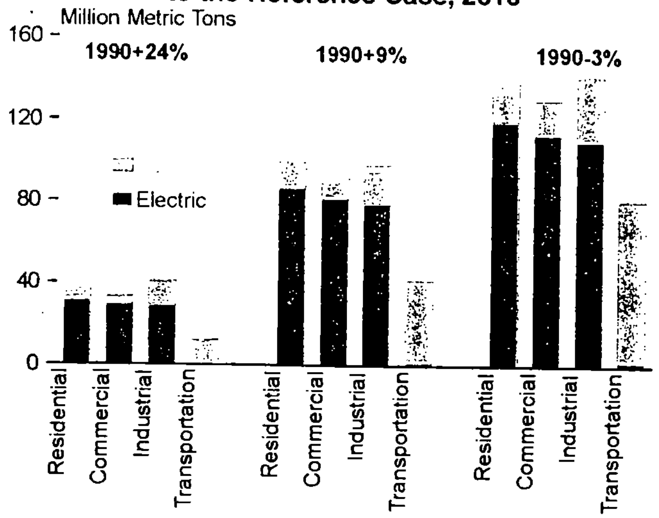
Figure ES5. Projected Reductions in Carbon Emissions From the Electricity Supply Sector, 1990-3% Case, 1996-2020



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD03BLW.D080398B.

Total carbon emissions from the industrial sector are lower by between 7 and 28 percent in 2010 in the carbon reduction cases, relative to the reference case. Total industrial output is lower because of the impact of higher energy prices on the economy. As energy prices increase, industrial consumers accelerate the replacement of productive capacity, invest in more efficient technology, and switch to less carbon-intensive fuels. In 2010, industrial energy intensity is reduced from 7.6 thousand British thermal units (Btu) per dollar of output in the reference case to between 7.4 and 7.1 thousand Btu in the carbon reduction cases.

Figure ES6. Projected Reductions in Carbon Emissions by End-Use Sector Relative to the Reference Case, 2010



Note: Electricity emissions are from the fuel used to generate electricity and are attributed to the sectors relative to their shares of electricity consumption.

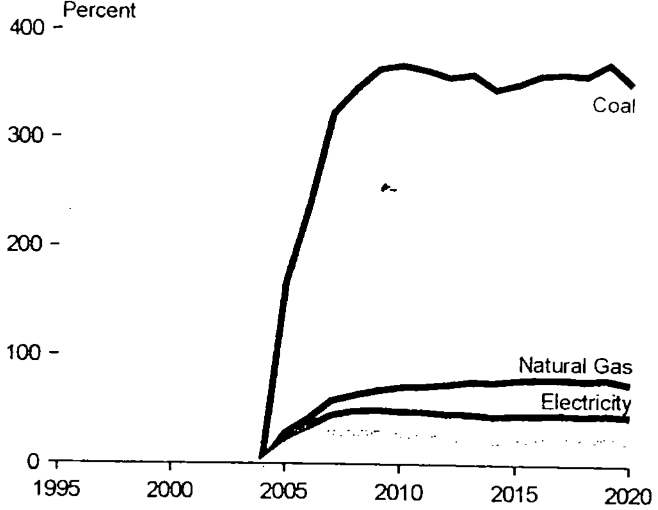
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW. D080398B.

In both the residential and commercial sectors, higher energy prices encourage investments in more efficient equipment and building shells and reduce the demand for energy services. Total carbon emissions in the residential sector are reduced by 11 percent in the 1990+24% case and by 45 percent in the 1990-7% case, relative to the reference case. Because of reduced demand for energy and improved end-use efficiencies, total energy use in 2010 ranges from 145 to 173 million Btu per household in the carbon reduction cases, compared with 184 million Btu per household in the reference case. Space heating and cooling account for the largest share of the change in energy demand; however, energy demand for a variety of miscellaneous appliances, such as computers, televisions, and VCRs, is also reduced.

In the commercial sector, total carbon emissions are lower by between 12 and 51 percent in the carbon reduction cases, compared to the reference case. Total energy use per square foot of commercial floorspace, which is 206 thousand Btu in 2010 in the reference case, is reduced to between 148 and 192 thousand Btu across the cases. Similar to the residential sector, most of the reduction occurs for space conditioning—heating, cooling, and ventilation; however, more efficient lighting and office equipment and reduced miscellaneous electricity use—for example, for vending machines and telecommunications equipment—also contribute to lower energy consumption.

The average price of gasoline in 2010 across the carbon reduction cases is between 11 and 53 percent higher than the projected reference case price. Carbon reductions in the transportation sector in 2010 range from 2 to 16 percent, primarily as the result of reduced travel and the purchase of more efficient vehicles. The relatively low carbon reductions for transportation result from the continued dominance of petroleum, although some increase in market share is projected for alternative-fuel vehicles. Improvements in average fuel efficiency are slowed by vehicle turnover rates. Although new car efficiency in 2010 improves from 30.6 miles per gallon in the reference case to between 32.0 and 36.4 miles per gallon in the carbon reduction cases, total light-duty fleet efficiency rises only from 20.5 miles per gallon to between 20.7 and 21.7 miles per gallon. The impact of carbon prices on the economy lowers light-duty vehicle and airline travel and freight requirements while inducing some efficiency improvements.

Figure ES7. Projected Changes in Average Delivered Prices for Energy Fuels in the 1990+9% Case Relative to the Reference Case, 1996-2020



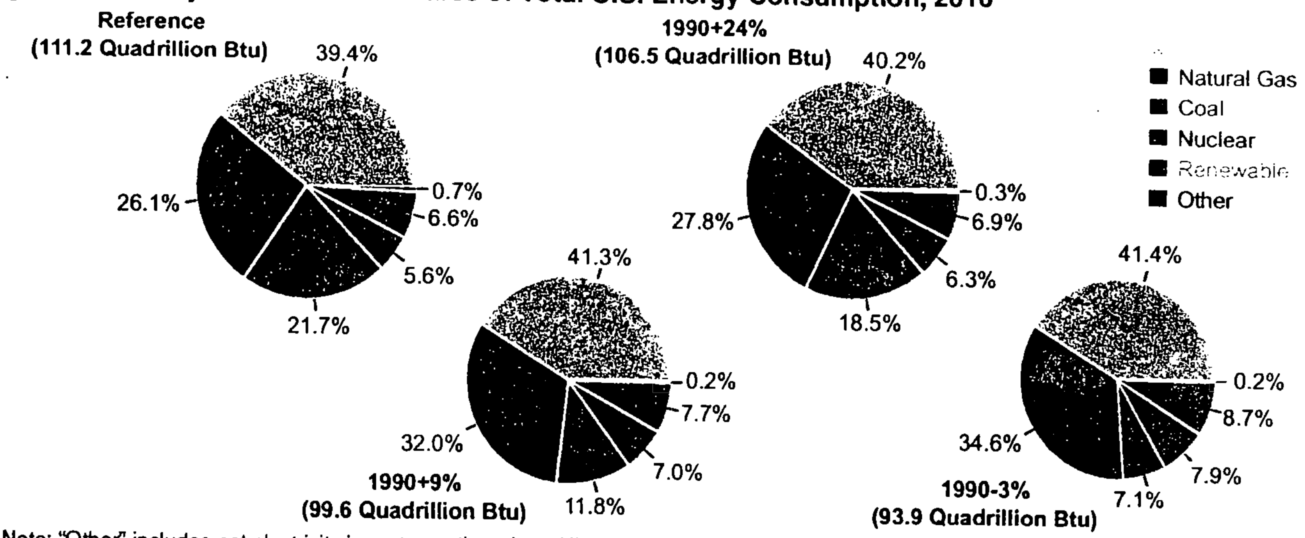
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A and FD09ABV.D080398B.

Impacts by Fuel

In order to achieve carbon emission reductions, the slate of energy fuels used in the United States is projected to change from that in the reference case (Figure ES8). Because of the higher relative carbon content of coal and petroleum products, the use of both fuels is reduced, and there is a greater reliance on natural gas, renewable energy, and nuclear power. Although the use of petroleum declines relative to the reference case, it increases slightly as a share because most petroleum is used in the transportation sector, where fewer fuel substitutes are available.

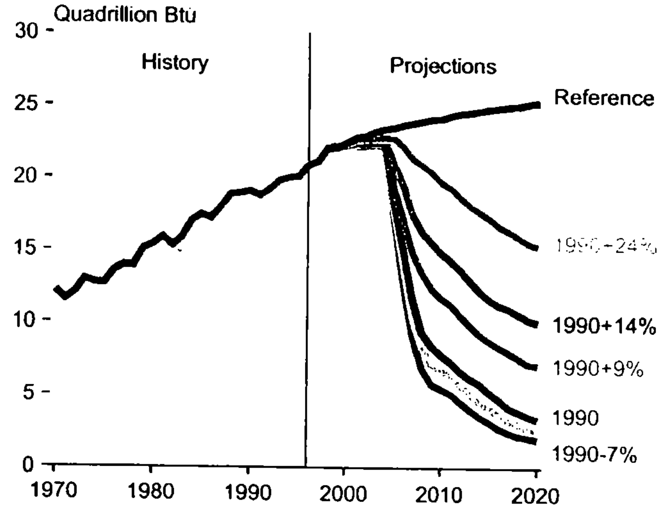
Because of the high carbon content of coal, total domestic coal consumption is significantly reduced in the carbon reduction cases, by between 18 and 77 percent relative to the reference case in 2010 (Figure ES9). Most of the reductions are for electricity generation, where coal is replaced by natural gas, renewable fuels, and nuclear power; however, demand

Figure ES8. Projections of Fuel Shares of Total U.S. Energy Consumption, 2010



Note: "Other" includes net electricity imports, methanol, and liquid hydrogen.
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW.D080398B.

Figure ES9. Projections of U.S. Coal Consumption, 1970-2020



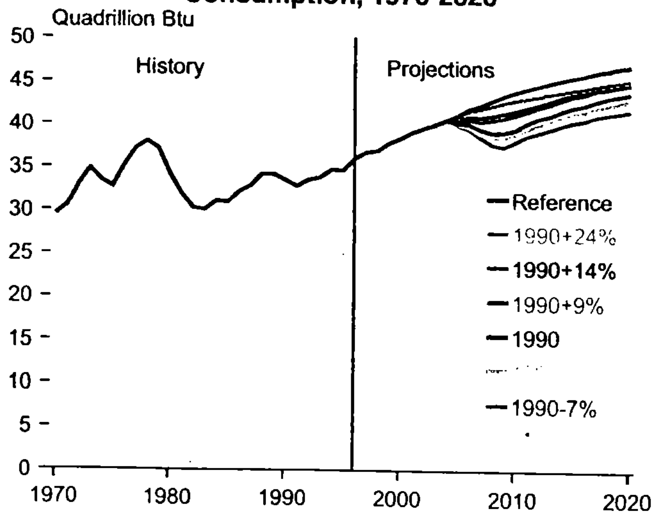
Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV .D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW. D080398B.

for industrial steam coal and metallurgical coal is also reduced because of a shift to natural gas in industrial boilers and a reduction in industrial output. Coal exports are also lower in the carbon reduction cases, by between 21 and 32 percent, due to lower demand for coal in the Annex I nations.

Although total U.S. coal production is reduced, the average minemouth coal price rises in the carbon reduction cases, by between 3 and 28 percent in 2010, because a larger share of production is from higher-cost eastern coal mines that tend to serve the remaining markets. Production of western coal is further discouraged by the higher cost of fuels used for rail transportation and by reduced incentive for investment in new mines, which are primarily in the West. Because of lower coal production, coal mine employment in 2010 is projected to be 15 to 63 percent lower than in the reference case; however, employment in the energy industry related to the production of natural gas and renewable fuels is likely to increase.

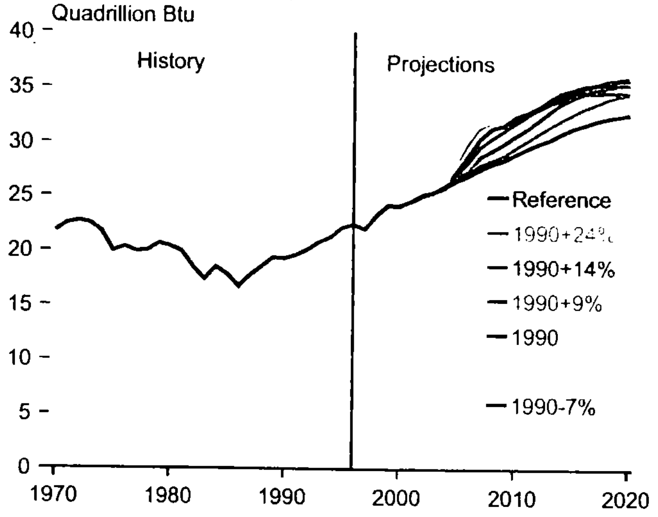
Petroleum consumption is lower in all the carbon reduction cases than in the reference case, by between 2 and 13 percent (Figure ES10). Because most of the petroleum is used for transportation, between 68 and 82 percent of the total reduction is in the transportation sector, as travel and freight requirements are reduced and higher-efficiency vehicles are used. Because of lower petroleum demand in the United States and in

Figure ES10. Projections of U.S. Petroleum Consumption, 1970-2020



Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV. D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW. D080398B.

Figure ES11. Projections of U.S. Natural Gas Consumption, 1970-2020

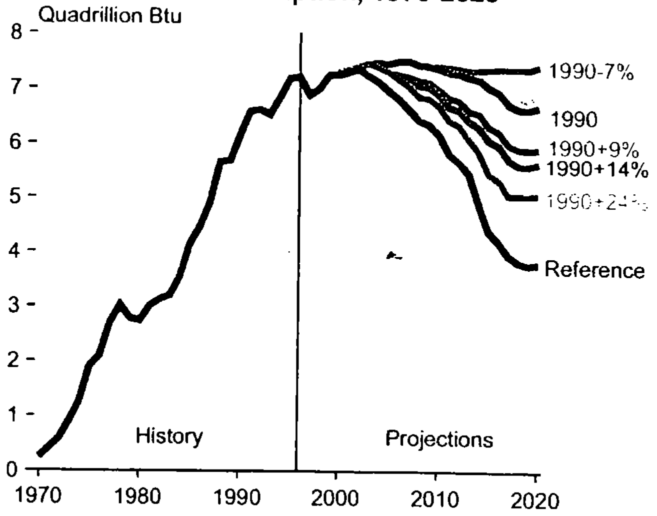


Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

other developed countries that are committed to reducing emissions under the Kyoto Protocol, world oil prices are lower by between 4 and 16 percent in 2010, relative to the reference case price of $20.77 per barrel. In 2010, net crude oil and petroleum product imports are lower by a range of 3 to 22 percent relative to the reference case. Consequently, the dependency of the United States on imported petroleum is reduced from the reference case level of 59 percent to as little as 53 percent in 2010.

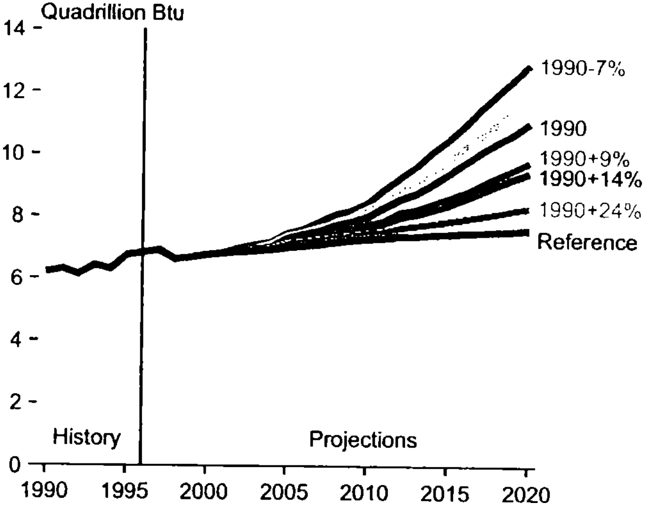
In 2010, natural gas consumption is higher than in the reference case, by a range of 2 to 12 percent across the carbon reduction cases (Figure ES11). Increased use of natural gas in the generation sector is only partially offset by reductions in the end-use sectors. Later in the forecast period, continued growth in natural gas consumption for electricity generation is mitigated by the increasing use of renewables and nuclear power, particularly in the more stringent carbon reduction cases. As a result, in 2020, natural gas use does not necessarily increase with higher levels of carbon reductions. As the result of higher demand, the average wellhead price of natural gas in 2010 is higher in all the carbon cases than in the reference case, by a range of 2 to 30 percent. Although meeting the levels of production that may be required will be a challenge for the industry, sufficient natural gas resources are available. The potential increases in both drilling and pipeline capacity are within levels achieved historically (or about to be achieved) and are not likely to be a constraint, given appropriate incentives and planning.

Figure ES12. Projections of U.S. Nuclear Energy Consumption, 1970-2020



Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

Figure ES13. Projections of U.S. Renewable Energy Consumption, 1990-2020



Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

Nuclear power, which produces no carbon emissions, increases with carbon reduction targets by between 8 and 20 percent in 2010, relative to the reference case (Figure ES12). Although no new nuclear plants are assumed to be built in the carbon reduction cases, extending the lifetimes of existing plants is projected to become more economical with higher carbon prices. In the more stringent carbon reduction cases, most existing nuclear plants are life-extended through 2020, in contrast to the gradual retirement of approximately half of the nuclear plants projected in the reference case.

Consumption of renewable energy, which results in no net carbon emissions, is projected to be significantly higher with carbon reduction targets (Figure ES13). Across the carbon reduction cases, renewable energy consumption increases by between 2 and 16 percent in 2010 and by between 9 and 70 percent in 2020. Most of this increase occurs in electricity generation, primarily with additions to wind energy systems and an increase in the use of biomass (wood, switchgrass, and refuse). In the carbon reduction cases, the share of renewable generation is as much as 14 percent in 2010, compared with 10 percent in the reference case, increasing to as high as 22 percent in 2020, compared with 9 percent in the reference case. Because additional renewable technologies become available and economical later in the forecast period, the share of renewable generation continues to increase through 2020.

Macroeconomic Impacts

In the energy market analyses, the projected carbon prices reflect the prices the United States would be willing to pay to achieve the Kyoto targets, without addressing the international trade in carbon permits. The macroeconomic analysis assumes that the carbon permit trading system would function as an auction run by the Federal Government, and that the United States would be free to purchase carbon permits in an international market at the marginal abatement cost in the United States. The U.S. State Department's assessment of the accounting of carbon-absorbing sinks and offsets from reductions in other greenhouse gases is assumed to reduce the U.S. emissions target to 3 percent below 1990 levels. The 3-percent target is then achieved through a combination of domestic actions and the purchase of permits on the international market. Thus, two flows of funds occur—domestic and international.

On the domestic side, U.S. permits are sold in a competitive auction run by the Federal Government, raising large sums of funds. In the 1990-3% case, where the revenues come entirely from the domestic market, the revenue collected in 2010 is projected to total $585 billion nominal dollars and $317 billion and $128 billion in the 1990+9% and 1990+24% cases, respectively. The collection of this money necessitates a careful consideration of appropriate fiscal policy to accompany the permit auction. Two approaches are considered: first, returning collected revenues to consumers through a personal income tax lump sum rebate and, second, lowering social security tax rates as they apply to both employers and employees. The two policies are meant only to be representative of a set of possible fiscal policies that might accompany an initial carbon mitigation policy.

The second flow of funds is associated with U.S. purchases of international carbon permits and assumes that the carbon price determined in the U.S. energy market analysis is the international price at which permits would be traded. The differences between the reduction level in the 1990-3% case and those in the other cases are assumed to be met by purchases of permits in international markets. Table ES3 shows average carbon reductions, purchases of international permits, and the carbon price for the three cases considered in the macroeconomic assessment for the 2008-2012 period.

The energy market analysis in this report does not address the international implications of achieving a particular target at the projected carbon price. For the macroeconomic assessment, the simplifying assumption is made that in each case the domestic carbon price is the same as the international permit price when different levels of trading are used to achieve the Kyoto target, implying that different international supplies of permits would be available in the alternative cases considered. This is an important simplifying assumption, and the value placed on the overseas transfer of funds to purchase international permits is subject to considerable uncertainty. However, this element must be considered a key factor in performing any assessment of the impacts on the economy, and therefore it is explicitly factored into the analysis.

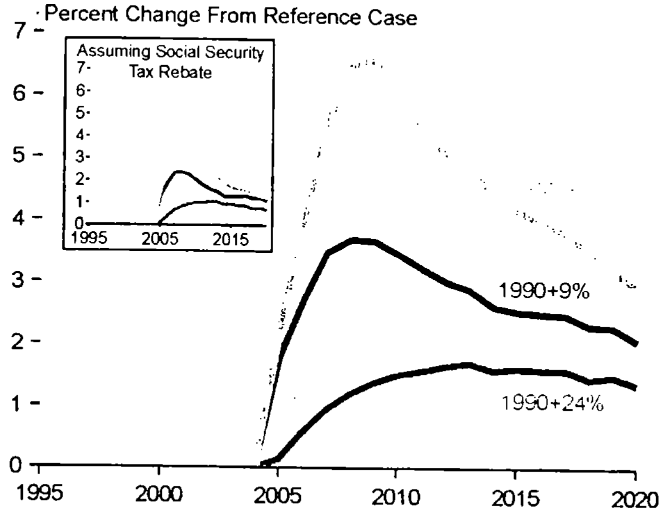
As a direct consequence of the carbon price, aggregate energy prices in the U.S. economy are expected to rise. One way to measure this effect is to look at the percentage change in prices in the economy. For example, in the 1990+9% case, energy prices are 56 percent higher than the reference case projection in 2010 and remain more than 50 percent above the reference case over the rest of the forecast period. The projected energy price increases would also affect downstream prices for all goods and services in the economy as

Table ES3. Energy Market Assumptions for the Macroeconomic Analysis of Three Carbon Reduction Cases, Average Annual Values, 2008 through 2012

Analysis Case	Binding Carbon Emissions Reduction Target (Million Metric Tons)	Average U.S. Carbon Emissions Reductions (Million Metric Tons)	U.S. Purchases of International Permits (Million Metric Tons)	Carbon Price		Value of Purchased International Permits (Billion 1992 Dollars)
				1996 Dollars per Metric Ton	1992 Dollars per Metric Ton	
1990-3%.	485	485	0	290	263	0
1990+9%	485	325	160	159	144	23
1990+24%	485	122	363	65	59	21

Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System.

Figure ES14. Projected Changes in Consumer Price Index Relative to the Reference Case, 1998-2020



Note: Carbon permit revenues are assumed to be returned to households through reductions in personal income taxes.

Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

measured by the producer price index. The projected increase in producer prices relative to the reference case in 2010 is 9 percent in the 1990+9% case. Final prices for goods and services in 2009, as shown by the consumer price index (CPI) series, are about 4 percent higher in the 1990+9% case (Figure ES14). Expressed as a rate of change, CPI inflation rises by 0.7 percentage points between 2005 and 2010, as the reference case CPI rises by 3.6 percent a year and the 1990+9% case rises by 4.3 percent a year. These figures suggest the following rule of thumb for the year 2010: each 10-percent increase in aggregate prices for energy may lead to a 1.5-percent increase in producer prices and a 0.7-percent increase in consumer prices.

One aspect of the CPI is particularly noteworthy. The CPI measures the prices that consumers face, regardless of the country of origin of the product. Import prices, to the extent that they do not rise at the rate of domestic prices because non-Annex I countries do not face carbon constraints, would dampen the price effects as lower-priced imports find their way into U.S. markets.

Because energy resources are used to produce most goods and services, higher energy prices can affect the economy's production potential. Long-run equilibrium costs are associated with reducing reliance on energy in favor of other factors of production—including labor and capital, which become relatively cheaper as energy costs rise. Short-run adjustment costs, or business cycle costs, can arise when price increases disrupt capital or employment markets. Long-run costs are considered unavoidable. Short-run costs might be avoidable if price changes can be accurately anticipated or if appropriate compensatory monetary and fiscal policies can be implemented. The economic assessment in this analysis considers both the short-run and long-run costs to the economy and focuses on the 1990-3%, 1990+9%, and 1990+24% carbon reduction cases.

The possible impacts on the economy are summarized in Table ES4, which shows average changes from the reference case projections over the period from 2008 through 2012 in the three carbon reduction analysis cases. The *loss of potential GDP* measures the loss in productive capacity of the economy directly attributable to the reduction in energy resources available to the economy. The *macroeconomic adjustment cost* reflects frictions in the economy that may result from the higher prices of the carbon mitigation policy. It recognizes the possibility that cyclical adjustments may occur in the short run. The *loss in actual GDP* for the economy is the sum of the loss in potential and the adjustment cost. The *purchase of international permits* represents a claim on the productive capacity of domestic U.S. resources. Essentially, as funds flow abroad, other countries have an increased claim on U.S. goods and services. The loss

Table ES4. Macroeconomic Impacts in Three Carbon Reduction Cases, Average Annual Values, 2008-2012 (Billion 1992 Dollars)

Analysis Case	Loss In Potential GDP	Macroeconomic Adjustment Cost	Loss In Actual GDP	Purchases of International Permits	Total Cost to the Economy
1990-3%					
Personal Income Tax Rebate	58	225	283	0	283
Social Security Tax Rebate	58	70	128	0	128
1990+9%					
Personal Income Tax Rebate	32	137	169	23	192
Social Security Tax Rebate	32	59	91	23	114
1990+24%					
Personal Income Tax Rebate	12	76	88	21	109
Social Security Tax Rebate	12	44	56	21	77

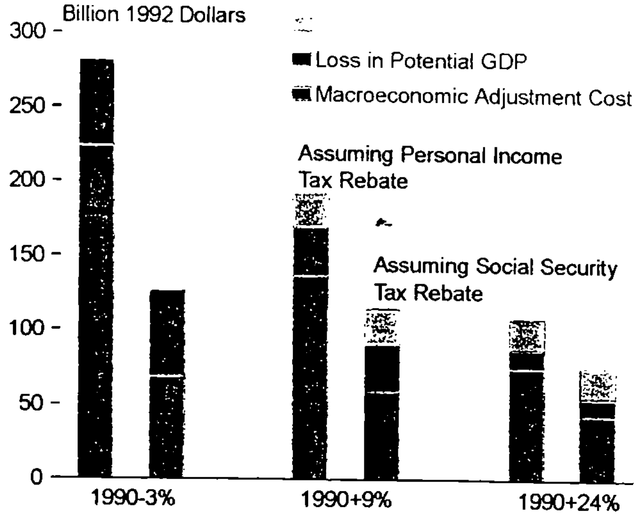
Note: Loss in potential GDP plus the macroeconomimc adjustment cost equals the loss in actual GDP. The actual GDP loss plus purchases of international permits equals the total cost to the economy.

Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

of potential GDP plus the purchase of international permits represent the long-run, unavoidable impact on the economy. The *total cost to the economy* is represented by the loss in actual GDP plus the purchase of international permits (Figure ES15). These costs need to be put in perspective relative to the size of the ecomomy, which averages $9,425 billion between 2008 and 2012. Tables ES5 and ES6 summarize the macroeconomic impacts projected for the years 2010 and 2020.

In the long run, higher energy costs would reduce the use of energy by shifting production toward less energy-intensive sectors, by replacing energy with labor and capital in specific production processes, and by encouraging energy conservation. Although reflecting a more efficient use of higher-cost energy, the gradual reduction in energy use would tend to lower the productivity of other factors in the production process. The derivation of the long-run equilibrium path of the economy can be characterized as representing the

Figure ES15. Total Projected Costs of Carbon Reductions to the U.S. Economy, 2008-2012



Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

Table ES5. Projected Impacts on Gross Domestic Product, 2005 and 2010

Variable	1996	2005 Reference	2010 Reference	1990 +24%	1990 +14%	1990 +9%	1990	1990 -3%	1990 -7%
Potential GDP									
(Billion 1992 Dollars)	6,930	8,585	9,482	9,469	9,455	9,448	9,429	9,420	9,410
(Percent Change From Reference Case)	—	—	—	-0.1	-0.3	-0.4	-0.6	-0.7	-0.8
(Annual Growth Rate, 2005-2010, Percent)	—	—	2.0	2.0	1.9	1.9	1.9	1.9	1.9
Actual GDP, Assuming Personal Income Tax Rebate									
(Billion 1992 Dollars)	6,928	8,525	9,429	9,333	9,268	9,241	9,137	9,102	9,032
(Percent Change From Reference Case)	—	—	—	-1.0	-1.7	-2.0	-3.1	-3.5	-4.2
(Annual Growth Rate, 2005-2010, Percent)	—	—	2.0	1.8	1.7	1.6	1.4	1.3	1.2
Actual GDP, Assuming Social Security Tax Rebate									
(Billion 1992 Dollars)	6,928	8,525	9,429	9,369	9,337	9,326	9,291	9,281	9,247
(Percent Change From Reference Case)	—	—	—	-0.6	-1.0	-1.1	-1.5	-1.6	-1.9
(Annual Growth Rate, 2005-2010, Percent)	—	—	2.0	1.9	1.8	1.8	1.7	1.7	1.6

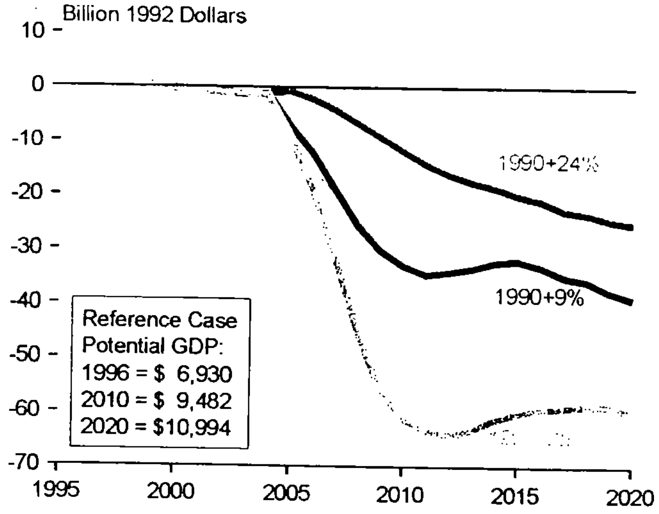
Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

Table ES6. Projected Impacts on Gross Domestic Product, 2005 and 2020

Variable	1996	2005 Reference	2020 Reference	1990 +24%	1990 +14%	1990 +9%	1990	1990 -3%	1990 -7%
Potential GDP									
(Billion 1992 Dollars)	6,930	8,585	10,994	10,968	10,961	10,954	10,940	10,933	10,925
(Percent Change From Reference Case)	—	—	—	-0.2	-0.3	-0.4	-0.5	-0.6	-0.6
(Annual Growth Rate, 2005-2020, Percent)	—	—	1.7	1.6	1.6	1.6	1.6	1.6	1.6
Actual GDP, Assuming Personal Income Tax Rebate									
(Billion 1992 Dollars)	6,928	8,525	10,865	10,815	10,808	10,796	10,799	10,793	10,782
(Percent Change From Reference Case)	—	—	—	-0.5	-0.5	-0.6	-0.6	-0.7	-0.8
(Annual Growth Rate, 2005-2020, Percent)	—	—	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Actual GDP, Assuming Social Security Tax Rebate									
(Billion 1992 Dollars)	6,928	8,525	10,865	10,840	10,832	10,828	10,833	10,835	10,842
(Percent Change From Reference Case)	—	—	—	-0.2	-0.3	-0.3	-0.3	-0.3	-0.2
(Annual Growth Rate, 2005-2020, Percent)	—	—	1.6	1.6	1.6	1.6	1.6	1.6	1.6

Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

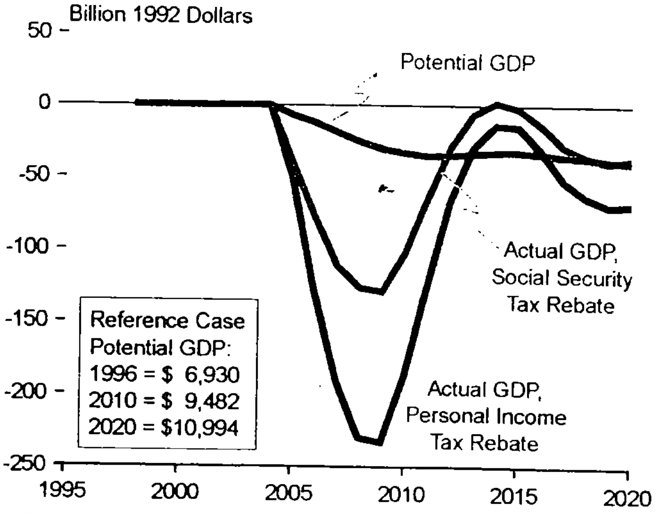
Figure ES16. Projected Dollar Losses in Potential GDP Relative to the Reference Case, 1998-2020



Note: Carbon permit revenues are assumed to be returned to households through reductions in personal income taxes.

Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

Figure ES17. Projected Changes in Potential and Actual GDP in the 1990+9% Case Relative to the Reference Case Under Different Fiscal Policies, 1998-2020



Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

"potential" output of the economy when all resources—labor, capital, and energy—are fully employed. As such, potential GDP is equivalent to the full employment concept in other analyses that focus on long-run growth while abstracting from business cycle behavior. Figure ES16 shows the losses in the potential economic output, as measured by potential GDP, for the three carbon reduction cases. The shapes of the three trajectories mirror the carbon price trajectories.

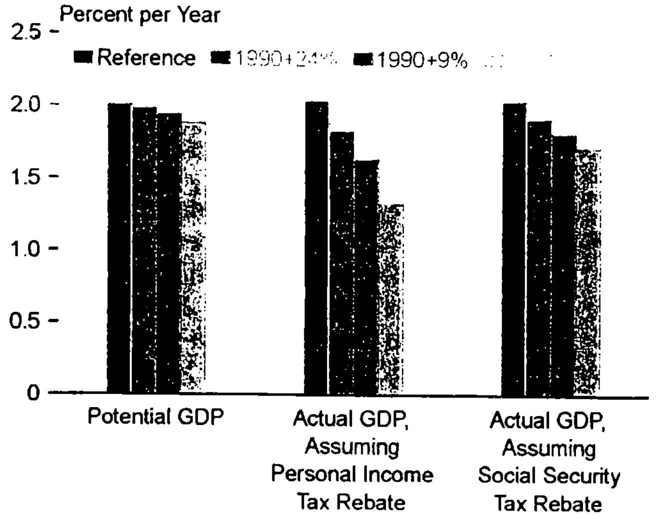
The ultimate impacts of carbon mitigation policies on the economy will be determined by complex interactions between elements of aggregate supply and demand, in conjunction with monetary and fiscal policy decisions. As such, cyclical impacts on the economy are bound to be characterized by uncertainty and controversy. However, raising the price of energy and downstream prices in the rest of the economy could introduce cyclical behavior in the economy, resulting in employment and output losses in the short run. The measurement of losses in actual output for the economy, or actual GDP, represents the transitional cost to the aggregate economy as it adjusts to its long-run path. Resources may be less than fully employed, and the economy may move in a cyclical fashion as the initial cause of the disturbance—the increase in energy prices—plays out over time.

Collection of money from a permit auction system necessitates a careful consideration of appropriate fiscal policy to accompany the carbon reduction policy. Two alternative fiscal policies are analyzed, both returning collected revenue back to agents in the economy: a cut in personal income taxes and a cut in social security taxes as they apply to both employers and employees. In both cases, the Federal deficit is maintained at reference case levels. The personal income tax cut essentially returns collected revenues to consumers, helping to maintain personal disposable income. Like the personal income tax cut, the social security tax cut returns collected funds to the private sector of the economy, ameliorating the near-term impacts of higher energy prices. Although consumers and businesses still would face much higher relative prices for energy than for other goods and services, disposable income is maintained near reference case values to the extent that funds flow back to consumers.

In the fiscal policy settings, higher prices in the economy place upward pressure on interest rates. The Federal Reserve Board seeks to balance the consequences of higher energy prices on the economy and possible adverse effects on output and employment by making adjustments to the Federal funds rate. The adjustments would be designed to moderate the possible impacts on both inflation and unemployment, and to return the economy to its long-run growth path.

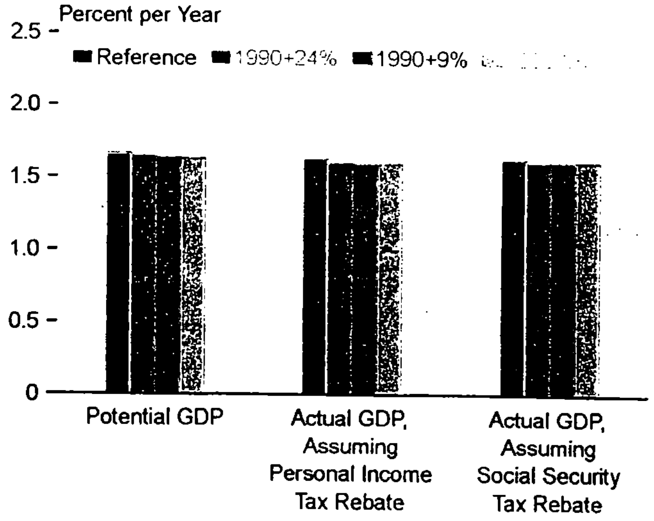
Figure ES17 shows the projected impacts on both actual and potential GDP for the two hypothetical fiscal policies (income tax and social security tax cuts) in the 1990+9% case. The figure indicates that, in the 2008 to 2012 period, the short-run cyclical impact on actual GDP is larger than the long-run impact on potential GDP; however, the two output concepts begin to converge by 2015, and by 2020 they have merged into a steady-state path reflected by potential GDP. Monetary policy is instrumental in balancing inflation and unemployment impacts through the adjustment period, acting in a manner to bring the economy back to its long-run growth path.

Figure ES18. Projected Annual Growth Rates in Potential and Actual GDP, 2005-2010



Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

Figure ES19. Projected Annual Growth Rates in Potential and Actual GDP, 2005-2020



Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

Table ES7. Projected Losses in Potential and Actual GDP per Capita, Average Annual Values, 2008-2012 (1992 Dollars per Person)

Analysis Case	Loss in Potential GDP per Capita	Loss in Actual GDP per Capita, Personal Income Tax Rebate	Loss in Actual GDP per Capita, Social Security Tax Rebate
1990-3%	193	947	428
1990+9%	106	567	305
1990+24	40	294	187

Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

The choice of the accommodating fiscal policy is also key to the assessment of the ultimate impacts on the economy. While the personal income tax option moderates the impacts through a return of funds to consumers, the social security tax option has cost-cutting aspects of lowering the employer portion of the tax, which serves to reduce inflationary pressures in the aggregate economy. On the employer side, the reduction in employer contributions to the social security system would lower costs to the firm and, thereby, moderate the near-term price consequences to the economy. Since it is the price effect that produces the predominately negative effect on the economy, any steps to reduce inflationary pressures would serve to moderate adverse impacts on the aggregate economy.

Another way to view the macroeconomic effects is by looking at the effects of the carbon reduction cases on the growth rate of the economy, both during the period of implementation from 2005 through 2010 and then over the entire period from 2005 through 2020 (Figures ES18 and ES19). In the reference case, potential and actual GDP grow at 2.0 percent per year from 2005 through 2010. In the 1990+9% case, the growth rate in potential GDP slows to 1.9 percent per year, and the growth rate in actual GDP slows to 1.6 percent per year when the personal income tax rebate is assumed or 1.8 percent per year when the social security tax rebate is assumed. However, through 2020, with the economy rebounding back to the reference case path, there is no appreciable change in the projected long-term growth rate. The results for the 1990+24% and 1990-3% cases are similar.

Aggregate impacts on the economy, as measured by potential and actual GDP, are shown in Table ES7 in terms of losses in GDP per capita. In the 1990+9% case, the loss in potential GDP per capita is $106; however, the loss in actual GDP for in the 1990+9% case is $567 assuming the personal income tax rebate and $305 assuming the social security tax rebate. Again, the lower value (loss in potential GDP) represents an unavoidable loss per person, and the higher values (loss in actual GDP) reflect the highly uncertain, but significant, impacts that individuals could experience as the result of frictions within the economy. To provide perspective, actual GDP per capita averages $31,528 in the reference case between 2008 and 2012.

Sensitivity Cases

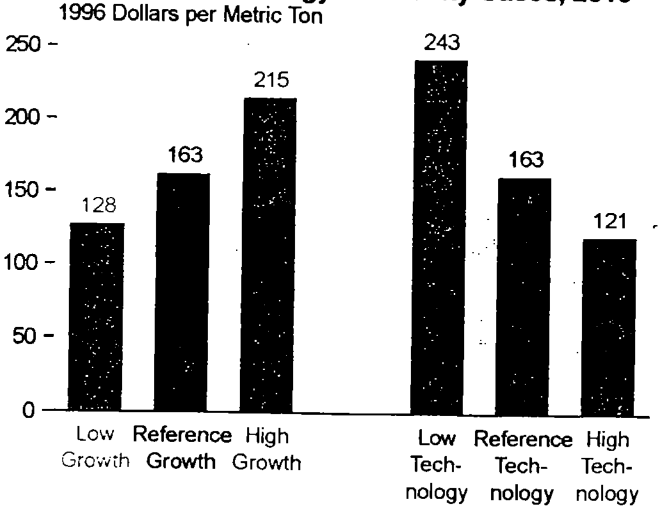
This analysis includes several sensitivity cases designed to examine alternative assumptions that may have significant impacts on energy demand and carbon emissions over the next 20 years, including higher and lower economic growth, faster and slower availability and rates of improvement in technology, and the construction of new nuclear power plants. The sensitivity cases illustrate how such factors influence the results of the carbon reduction cases. With the exception of the nuclear power case, the sensitivity cases are analyzed relative to the 1990+9% case.

Because each sensitivity case is constrained to the same level of carbon emissions as the case to which it is compared, the primary impact is not on the carbon emissions levels, or even on aggregate energy consumption, but rather on the carbon price required to meet the emissions target. For example, in the high technology case, projected carbon emissions during the compliance period are the same as in the corresponding reference technology case. What differs is the cost of meeting the target, as reflected in the required carbon price.

Macroeconomic Growth

The assumed rate of economic growth has a strong impact on the projection of energy consumption and, therefore, on the projected levels of carbon emissions. Two sensitivity cases explore the effects of higher and lower economic growth on the cost of reducing carbon emissions to the 1990+9% level. Higher economic growth results from higher assumed growth in population, the labor force, and labor productivity, resulting in higher industrial output, lower inflation, and lower interest rates. As a result, GDP increases at an average rate of 2.4 percent a year through 2020, compared with a growth rate of 1.9 percent a year in the reference case. With higher macroeconomic growth, energy demand grows faster, as higher manufacturing output and higher income increase the demand for energy services, resulting in higher carbon emissions. Assumptions of lower growth in population, the labor force, and labor productivity result in an average annual growth rate of 1.3 percent in the low economic growth case, resulting in lower carbon emissions.

Figure ES20. Projected Carbon Prices in the 1990+9% High and Low Economic Growth and High and Low Technology Sensitivity Cases, 2010



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs FD09ABV.D080398B, LMAC09.D080698A, HMAC09.D080598A, FREEZE09.D080798A, and HITECH09.D080698A.

With higher economic growth, both industrial output and energy service demand are higher. As a result, carbon prices must be correspondingly higher to attain a given carbon emissions target. In the high macroeconomic growth case, the carbon price in 2010 is $215 per metric ton, $52 per metric ton higher than the carbon price of $163 per metric ton in the 1990+9% case with reference growth assumptions (Figure ES20). In the low macroeconomic growth case, the carbon price in 2010 is $128 per metric ton. The higher carbon prices necessary to achieve the carbon reductions with higher economic growth have a negative impact on the economy and the energy system. Nevertheless, total energy consumption in 2010 is higher with higher economic growth, by 2.2 quadrillion Btu relative to the 1990+9% case, which assumes the same economic growth rate as the reference case. In the low economic growth case, total energy consumption is lower by 2.2 quadrillion Btu in 2010.

In order to meet the carbon reduction targets with higher economic growth, there is a shift to less carbon-intensive fuels and higher energy efficiency. On a sectoral basis, higher economic growth affects total energy consumption in the industrial and transportation sectors more significantly than in the other end-use sectors. Total consumption of both renewables and natural gas is higher, primarily for electricity generation but also in the industrial sector. Coal use for generation is lower, and the use of nuclear power is higher as a result of the higher carbon prices. Petroleum consumption is also higher with higher economic growth, both in the transportation and industrial sectors.

Total energy intensity is lower in the high economic growth case, partially offsetting the increases in the demand for energy services caused by the higher growth assumption. With higher economic growth, there is greater opportunity to turn over and improve the stock of energy-using technologies. In addition, the higher carbon price induces more efficiency improvements and some offsetting reductions in energy service demand, moderating the impacts of higher economic growth. With higher economic growth, aggregate energy intensity declines at an average annual rate of 1.9 percent through 2010, compared to 1.6 percent with reference economic growth. The opposite effects on energy intensity occur with lower economic growth, with the decline in energy intensity slowing from 1.6 percent to 1.3 percent between 1996 and 2010.

Technological Progress

The rates of development and market penetration of energy-using technologies have a significant impact on projected energy consumption and energy-related carbon emissions. Faster development of more energy-efficient or lower-carbon-emitting technologies than assumed in the reference case could reduce both consumption and emissions; however, because the reference case already assumes continued improvement in both energy consumption and production technologies, slower technological development is also possible.

To analyze the impacts of technology improvement, high technology assumptions were developed by experts in technology engineering for each of the energy-consuming sectors, considering the potential impacts of increased research and development for more advanced technologies. The revised assumptions included earlier years of introduction, lower costs, higher maximum market potential, and higher efficiencies than assumed in the reference case.[9] Also, this sensitivity case assumed the availability of carbon sequestration technology for coal- and natural-gas-fired power plants, which would remove carbon dioxide and store it in underground aquifers; however, the technology is uneconomical relative to other technologies because of its high operating and storage costs.

These technological improvements were developed under the assumption of increased research and development, and they are distinct from the more rapid adoption of advanced technologies that occurs with higher energy prices in the carbon reduction cases. It is possible that further technology improvements could occur beyond those in the high technology sensitivity case if a very aggressive research and development effort were established. The low technology sensitivity case assumes that all future equipment choices are made from the end-use and generation equipment available in 1998, with new building shell and industrial plant efficiencies frozen at 1998 levels. Comparing this sensitivity case to a case with reference technology assumptions demonstrates the importance of technology improvement in the reference case.

Because faster technology development makes advanced energy-efficient and low-carbon technologies more economically attractive, the carbon prices required to meet carbon reduction levels are significantly reduced. Conversely, slower technology improvement requires higher carbon prices (Figure ES20). With high technology assumptions, the carbon price in 2010 is $121 per metric ton, $42 per metric ton lower than the carbon price of $163 per metric ton in the 1990+9% case with the reference technology assumptions. With the low technology assumptions, the carbon price increases to $243 per metric ton in 2010.

In the high technology sensitivity case, total energy consumption in 2010 is lower by 2.1 quadrillion Btu, or about 2 percent, than in the 1990+9% case with reference technology. Delivered energy consumption in both the industrial and transportation sectors is lower as efficiency improvements in industrial processes and most transportation modes outweigh the countervailing effects of lower energy prices. In the residential and commercial sectors, the effect of lower energy prices balances the effect of advanced technology, and consumption levels are at or near those in the reference technology (1990+9%) case. In the generation sector, coal use for generation is 40 percent higher than with reference technology assumptions, due to efficiency improvements and the lower carbon price.

In the low technology sensitivity case, the converse trends prevail. In 2010, total energy consumption is higher by 1.5 quadrillion Btu than in the 1990+9% case with reference technology assumptions. Delivered energy consumption is higher in the industrial and transportation sectors and lower in the residential and commercial sectors, suggesting that industry and transportation are more sensitive to technology changes than to price changes, and the residential and commercial sectors are more sensitive to price changes. With the higher carbon prices in the low technology case, coal use is further reduced in the generation sector, and more natural gas, nuclear power, and renewables are used to meet the carbon reduction targets.

Nuclear Power

In the reference case, nuclear electricity generation declines significantly because 52 percent of the total nuclear capacity available in 1996 is assumed to be retired by 2020. A number of units are retired before the end of their 40-year operating licenses, as suggested by industry announcements and analysis of the age and operating costs of the units. In the carbon reduction cases, life extension of the plants can occur if it is economical; and there is an increasing incentive to invest in nuclear plant refurbishment with higher carbon prices. However, these cases do not allow the construction of new nuclear power plants, given continuing high capital investment costs and institutional constraints associated with nuclear power. A nuclear power sensitivity case examines the impact of allowing new plants to be constructed. Because nuclear plants still are not economically competitive with fossil and renewable plants in the 1990+9% case, the nuclear power sensitivity case was analyzed against the 1990-3% case. In addition to allowing new nuclear plants, the higher costs assumed in the

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[9] The design of the high technology sensitivity case differs from the high technology cases in *AEO98*, which generally did not include an analysis of improvements for specific technologies.

reference case for the first few advanced nuclear plants were reduced in this sensitivity.

Relative to the 1990-3% case, 1 gigawatt of new nuclear capacity is added by 2010 in the nuclear power sensitivity case, and 41 gigawatts, representing about 68 new plants of 600 megawatts each, are added by 2020. With most of the impact from the new nuclear plants coming after the commitment period of 2008 through 2012, there is little impact on carbon prices in 2010. By 2020, however, carbon prices are $199 per metric ton with the assumption of new nuclear plants, as compared with $240 per metric ton in the 1990-3% case with the reference nuclear assumptions. In 2010, total energy consumption is about the same in this sensitivity case as in the 1990-3% case, but in 2020 it is about 1.8 quadrillion Btu higher. Somewhat lower energy prices induce higher consumption in all sectors, and the availability of more carbon-free nuclear generation allows the carbon reduction target to be met with higher end-use consumption.

Uncertainties in the Analysis

The reference case projections in both *AEO98* and this analysis represent business-as-usual forecasts, given known trends in technology and demographics, current laws and regulations, and the specific methodologies and assumptions used by EIA. Because EIA does not include future legislative and regulatory changes in its reference case projections, the projections provide a policy-neutral baseline against which the impacts of policy initiatives can be analyzed.

Results from any model or analysis are highly uncertain. By their nature, energy models are simplified representations of complex energy markets. The results of any analysis are highly dependent on the specific data, assumptions, behavioral characteristics, methodologies, and model structures included. In addition, many of the factors that influence the future development of energy markets are highly uncertain, including weather, political and economic disruptions, technology development, and policy initiatives. Recognizing these uncertainties, EIA has attempted in this study to isolate and analyze the most important factors affecting future carbon emissions and carbon prices. The results of the various cases and sensitivities should be considered as relative changes to the comparative baseline cases.

In addition to the uncertainties concerning the final interpretation and implementation of the Kyoto Protocol, specific actions that might be taken to reduce greenhouse gas emissions in the United States have not been formulated. Actions taken by other Annex I countries to reduce emissions, future growth in worldwide energy consumption and emissions, and the opportunities for reducing emissions through joint implementation and the CDM are unknown, and they are likely to have important impacts on the international trade of carbon permits and the carbon permit price. This analysis assumes that auctioned permits will constrain carbon emissions and raise the price of fossil fuels, with revenues from the auction recycled to consumers either through personal income tax or social security tax rebates. Alternative carbon reduction programs and fiscal policies would be likely to change the cost of carbon reduction from the costs in this analysis. The timing of carbon reduction programs and the amount of adjustment time allowed could also be important in determining costs.

Future technology development also cannot be known with certainty and may have a significant effect on the cost of achieving carbon reductions. The technology sensitivity cases in this analysis explore some of the potential impacts, but even the high technology sensitivity does not include possible breakthrough or speculative technologies. On the other hand, even the reference case technology assumptions include continued development of more energy-efficient and renewable technologies, which serve to mitigate the costs of carbon reduction. Those technology improvements are likely, but not certain.

Finally, consumer response to carbon initiatives is uncertain. Because energy price changes that have occurred in the past may not provide sufficient evidence about the reaction of consumers to sustained high energy prices, changes in demand as a result of the higher carbon fees cannot be projected with confidence. In addition to price-induced changes, consumers might also respond to climate change initiatives and a national commitment to reduce emissions by adopting more energy-efficient or renewable technologies sooner than expected. Finally, public acceptance of large-scale renewable technologies or the continuation of nuclear power—both of which make important contributions to the achievement of the carbon emissions reductions at the costs projected in this analysis—cannot be known with certainty.

Office of Economic Policy

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Date: 9/24/98
Number of pages including cover sheet: 9

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REMARKS: ___ Urgent ___ For your review ___ Reply ASAP ___ Please comment

Zoranne's
ph

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1852

September 24, 1998

To: Early Action Group

From: Bob Cumby

Subject: Latest Draft, etc.

I have attached the latest draft of the early action memo. The following parts are new:

1. Guiding Principles – these were provide by Dirk. Let me know if they are agreeable and if it needs some prose to go along with the bullets.

2. The section on no penalty for early action and the section on credit for early action have been separated and the no penalty part is largely new.

3. The caps section is new. Please let me know if you think that this accurately reflects the view and if it does so in a way that is appropriate for this document.

4. The one size fits all section is new.

Please have a look, especially at the new pieces and let me know what further changes you would like to make. Fax (622-2633), phone (622-0572) or e-mail (robert.cumby@treas.sprint.com) are all fine.

In our discussion of caps at the last meeting, the need for some analysis of the potential size of an early credit program came up. I have also attached some analysis that was done by the EPA. Please have a look. I will schedule another meeting to see what kind of consensus we can reach. I believe that we reached consensus at our last meeting on only two issues: That if we have caps, first-come-first-served is better than true-up and that setting a setting a benchmark as change from BAU is the worst option among those listed.

Principles and Design Issues for an Early Credit Mechanism

President Clinton promised in his October 1997 speech that companies that "showed the way" in reducing emissions early would receive appropriate credit for their efforts. The Administration is committed to assuring that firms will not be penalized for acting early and is exploring ways to provide positive incentives to reduce emissions through voluntary, cost-effective measures. An early credit mechanism, while complementing efforts to reduce emissions through a cap and trade program during the commitment period, should not restrict or pre-judge the design of the cap and trade program.

Why Early Credit?

- To reduce the costs to the U.S. economy of compliance with the Kyoto Protocol. Economic costs are minimized when firms adjust more slowly over time to their required changes in production patterns, rather than suddenly in 2008. By acting early, firms can incorporate carbon considerations into their natural pattern of capital turnover.

- To provide the environmental benefit of earlier emissions reductions. The ultimate concentration of greenhouse gasses in the atmosphere determines global warming, so there benefits to reducing the flow of emissions in years prior to the commitment period. To the extent that an early credit mechanism reduces pre-2008 emissions below what they would otherwise have been, we reap these benefits.

Guiding Principles for Early Action Mechanisms

Any mechanism for providing credit for early action should:

- be market driven
- be simple and straightforward
- provide fair reward for real environmental gain
- have broad appeal to both historic and future emitters
- minimize free riders
- be transparent to the public
- avoid prejudging the design of a future domestic cap-and-trade system

No Penalty for Early Action

There are at least three ways to make sure that those acting early to reduce greenhouse gas emissions will not be penalized. It would not be necessary to specify what means would be chosen, but only to provide assurances that the approach ultimately adopted will not penalize early action.

- *Baseline protection.* If emissions allowances were allocated according to a formula based on past emissions, we could choose a reference year for the formula (the baseline) early enough so as not to penalize early action.
  - The exact year is subject to discussion. But it is worth noting that choosing a year before 1999 could lead to potentially large data difficulties, as there are not comprehensive and comparable data on emissions for all entities to whom permits may be allocated.
- *Performance standards.* If emissions allowances were allocated according to some performance-based benchmark, that standard could be set without reference to historical performance or the reference year for the standard could be set early enough so as not to penalize early action.
- *Auction.* If emissions allowances are auctioned in 2008, there would be no penalty for early action.

Credits for Early Action

- *Credits for early actions.* Explicit credits could be allocated for actions taken before 2008. These credits could be redeemed in some fashion for permits in 2008.
  - The total amount of permits that are given away through an early credit mechanism would be subtracted from the amount of permits allocated in 2008 through other mechanisms. But it is important to recognize that an early credit mechanism would not affect our assigned amount for the first commitment period. It would it only affect the distribution of the assigned amount by shifting some permits from those who would otherwise have been allocated permits in 2008 to those who took early actions.
- Credit for early action and allocation mechanism that do not penalize early action could be combined in some way.

A Two Part Early Credit System

We could implement a two part early action system.

- In the first part, we could give credit for actions taken before the system is announced. There could be a separate cap for credits for this period. This part would rely on the best available data from firms for the past, and could involve auditing firm-specific reports on emissions.

- In the second part, we could give credit for actions taken after the mechanism has been announced but before 2008. This part could have its own cap, but the value of that cap may depend on the level of early credits claimed for the first period. Before the beginning of the second part, we could establish a consistent data reporting system to ease the monitoring and measurement of early credit.

Issues with an Early Credit System

Caps vs. an Open-Ended System

We could establish a cap for the total quantity (measured in tons of assigned amount) of early action credits or we could leave the quantity the could be allocated unspecified.

- Caps would limit the quantity of "anyway tons" that are allocated in an early credit system both by restricting the total quantity allocated and by reinforcing a rigorous set of criteria for allocating early credit. A capped system would also reduce the risk that the early credit system would prejudge the ultimate allocation mechanism.

- On the other hand, a capped system—especially if only a relatively small fraction of available units are allocated to those seeking credit for early action—might create the mistaken impression that the system is not serious.

First Come First Served vs. "Truing Up" at End of Period

If caps are adopted, there could be at least two alternatives for allocating credits.

- One alternative would provide credits that have a set, predetermined value (such as one credit equals one ton of emissions) and would allocate the credits on a first-come-first-served basis. This approach provides firms certainty over the value of their actions, but could create substantial inequities across firms.

- An alternative would "true up" the quantity of credits at the end of the period, by comparing the number of credits claimed with the level of the cap. The credits could, for example, be worth up to one ton each, and perhaps less if there are more credits claimed than the size of the cap. This doesn't create inequities but does create uncertainty over the value of early action credits.

What is the Appropriate Measure for Early Credit?

Emissions Levels: This is the ultimate metric for meeting our Kyoto targets. But this approach could reward firms for shrinking and penalize firms for growing, potentially creating difficulties with mergers or divestitures, and firm definition.

Emissions Rates (e.g. carbon per unit of output): This approach could appropriately adjust for changes in scale of business to reward firm efforts to reduce carbon intensity. But it doesn't solve problems with firm definition and could create additional difficulties with aspects of measurement (e.g. what is a unit of output?).

Project-by-Project Evaluation (akin to JI): This approach could limit problems with defining the firm, since it doesn't require firm-wide baseline measurement and emissions tracking (as project is evaluated assuming no change in other firms' behavior). But it could be administratively unwieldy and non-comprehensive (if, for example, firms are able to claim credits for their activities that reduce emissions without claiming debits for activities that increase emissions).

Options for Defining the Baseline

Changes from Starting Point (reductions in emissions levels or rates from some base year credited for early action): This approach could provide relatively easy administration of the early action system, and it may make it relatively easy for firms to qualify because, for example, there is a naturally occurring level of emissions rate reductions over time.

Changes from Projected Reduction Schedule (e.g. firms only rewarded for early action if they reduce emissions rates by more than 1% per year): This remains relatively straightforward to administer, and could more tightly reward those firms that are truly increasing efficiency. But it may, for steep reduction schedules, limit the breadth of participation in an early action system and therefore potentially limit the economic and environmental gains.

Changes from Business As Usual (project business as usual trajectories for emissions levels or rates, and reward only improvements from those business as usual projections): This approach could account for changes in firm size and other developments over time that naturally affect emissions levels or rates. But it would likely introduce substantial administrative complexities.

Predefined set of eligible actions or technologies (set up a menu of actions that would be eligible to receive credit, e.g. improving the carbon efficiency of a boiler by a prespecified amount): This approach may be the easiest to administer, particularly for early action credits given for past actions. But it could run into potential administrative difficulties with "picking winners" (eligible actions or technologies), and may exclude legitimate but harder to define activities.

The Scope of Emissions Measurement

Direct and Indirect Emissions from Production: Firms are responsible for both direct emissions (those coming out of their stacks) and indirect emissions (those emissions occurring beyond the boundary of the firm as a result of the firm's activity). The question of whether to include these indirect emissions raises a tradeoff between comprehensiveness (including only direct emissions may preclude cost-effective indirect reduction opportunities) and administrative tractability (reporting indirect emissions could be very burdensome). It also raises difficult issues of double-counting across firms.

Emissions From Production vs. Consumption: On the one hand, firms could qualify for credits for emissions reduction related to their own energy use in production. On the other hand, firms may want credits for reducing the carbon intensity of their products, or for activities such as demand side management. Once again, there is a tradeoff here between comprehensiveness and administrative tractability. Double counting is also a concern.

One Size Fits All vs. Industry-Specific Programs

An early credit mechanism could allow for industry-specific programs with potentially different measures, choices of baseline, and scope of emissions measurement or it could adopt a common set of choices on these design issues.

Data and Measurement Issues

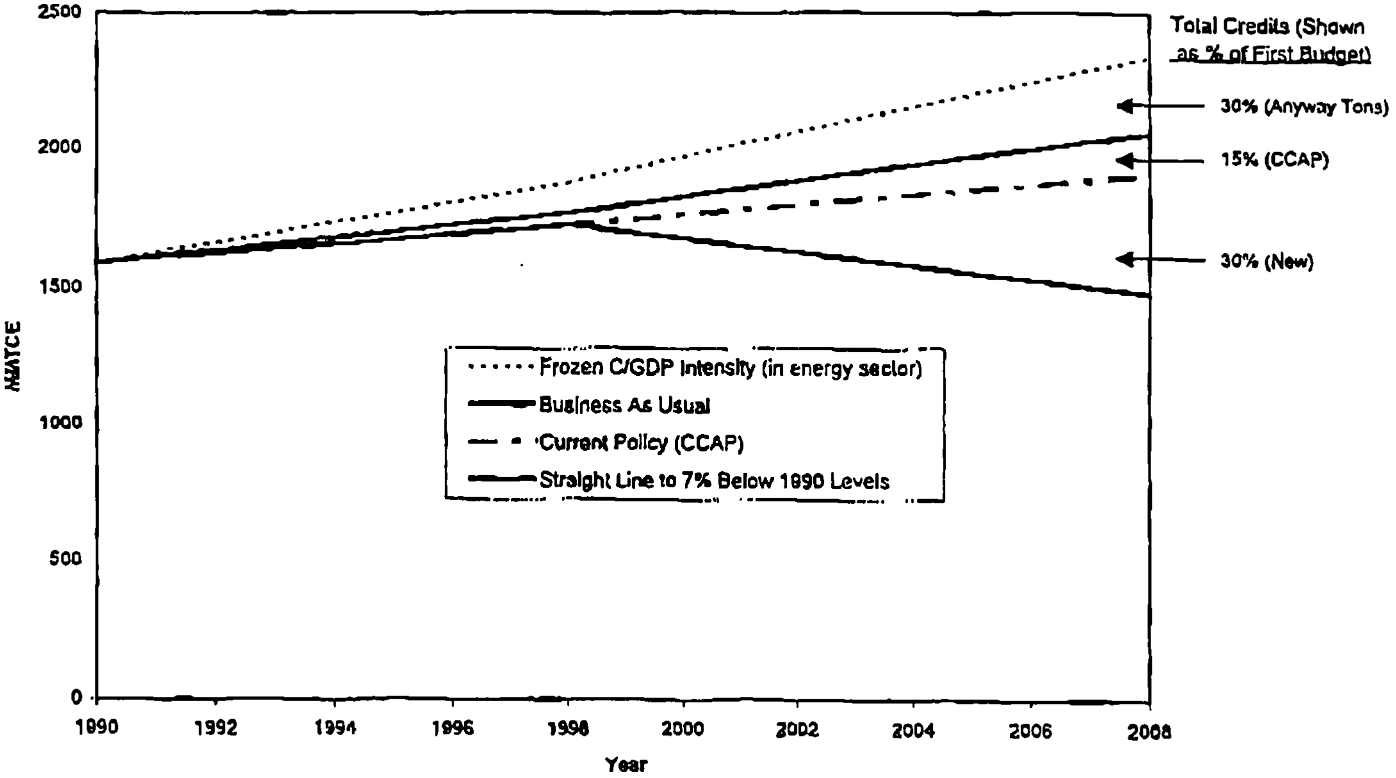
Defining a Firm: Firm level, rather than plant level, measurement could provide a more comprehensive system of accounting for early action. If, for example, the full range of a firm's activities are not taken into account, early credit might be granted to units that are performing well on emissions or efficiency but not subtracted for units that are not. But environmental regulation is traditionally focused at the plant level, and firm-level measurement raises a host of new issues such as joint ownership of plants and mergers and divestitures.

Measuring Carbon Efficiency: The basic concept of carbon efficiency is to compare carbon utilization to production. If production is measured by dollars of sales, this is fairly straightforward; but dollars of sales has a number of problems, such as the fact that changes in market prices which have nothing to do with energy or carbon efficiency will change the measured efficiency. For example, how would we account for the fact that auto prices are rising over time while computer prices are falling. If production is measured by units of sales or production, we face a new issue of how to measure units when a company's product mix may be changing.

Calculations of Potential Size of Early Credits

Several calculations are presented below to give a feel for how much credit might be given under a policy to reward early action, depending on how the program is structured. This paper compares the amount of claimed credit against an approximation of the first budget under the Kyoto Protocol (7700 mmtce from 2008-2012), although this estimate of the budget period does not include the impact of sinks or the Clean Development Mechanism. Note that the below analysis is based on the United States *Climate Action Report 1997*, which is calibrated to major economic assumptions in the *Annual Energy Outlook 1997*. The *Annual Energy Outlook 1998* projects significantly higher growth in U.S. greenhouse gas emissions.

U.S. Greenhouse Gas Emissions
All 6 Greenhouse Gases (Does Not Include Sinks)



Notes: Does not include updated N2O estimates based on revised IPCC guidelines

Source: Based on U.S. Climate Action Report, 1997

***** DRAFT – DO NOT QUOTE OR CITE *****
September 24, 1998

If credit is limited to reductions beyond normal intensity improvements. This calculation illustrates the importance of designing a system so that it encourages additional actions over baseline projections. Significant intensity improvements are forecasted to occur in baseline energy forecasts. If one assumes a frozen carbon intensity (c/gdp) in the energy sector at 1990 levels, then U.S. greenhouse gas emissions would be 2,380 mmtce higher than in the baseline (business-as-usual) scenario between 1990 and 2008. Thus, actions and structural changes that would have occurred in the economy anyway could account for up to 30% of the first budget period it the early credit system is not designed to account for baseline intensity improvements.

If credit were given for actions under the Climate Change Action Plan. Between 1990 and 2008, CCAP programs are expected to reduce cumulative U.S. greenhouse gas emissions by 1,160 mmtce, about 15% of the first budget period.

If credit were given for all actions beyond CCAP (assuming U.S. emissions declined on a straight line trajectory toward Kyoto). If, in the aggregate, the U.S. economy approaches the Kyoto target via a straight line reduction from 1998 levels, then these reductions would generate additional credits of about 2,300 mmtce, about 30% of the first budget. This is an outside estimate. Other, less aggressive pathways of U.S. emissions reductions are more likely to occur.

If credit were given only for actions taken beyond a straight Kyoto trajectory. Some proposals have suggested only giving credit for reductions beyond a Kyoto trajectory. The amount of credits awarded would depend on the dynamics of how individual firms respond to the credit. Regardless, the amount of credit would be much smaller than for other options.

Voluntary Reporting Under 1605(b)

Section 1605(b) of the 1992 Energy Policy Act created a database in which firms may report voluntary actions that reduced greenhouse gas emissions. Many firms have already reported voluntary reductions under this system. Through 1995, for example, 142 organizations have reported 967 projects. Amounts of reductions reported under these filings were calculated according to a variety of methodologies and were not subject to detailed government review. Nonetheless, they totaled about 20 MMTCE per year in 1994 and grew to 50 MMTCE per year in 1995 and in 1996. Because most projects already claimed will continue to deliver pollution reductions, projects already claimed could account for about 670 mmtce through 2007, or about 9% of the expected budget. Assuming the filings continued to increase, especially since there would be a policy of rewarding credit, the actual total might be many times that amount. To the extent that credits are awarded under 1605(b), they would likely fall into one of the three categories already explored above: some have already been anticipated in the business-as-usual baseline forecast, some have been counted towards the Climate Change Action Plan's impact, and additional credits might contribute to a Kyoto straight-line pathway scenario.

Additional Factors Affecting the Amount of Credits Claimed

- Impacts of an "Open" Crediting System. The numbers presented in this analysis are based on economy-wide averages and therefore understate the potential credits that could be claimed by individual companies. Additional actions that reduce emissions and could be claimed for credit are disguised in economy-wide averages by actions that increase carbon intensity (for example, AEO 1998 forecasts that coal generation will increase by 18% between 1996 and 2008). To the extent that firms with increasing emissions don't participate in the early credit program, then the credits that are claimed by other firms may exceed what economy-wide averages would suggest.

- Transaction Costs. The numbers presented in this analysis are based on "potential" claims against an early credit system. However, improvements in greenhouse gas intensity are widely dispersed throughout the economy. The scope of the early credit system, as well as transaction costs related to claiming and redeeming credits, would limit the number of credits that are actually claimed.

cc: JY, JA, SP, QF, Cong.

The
Aspen
Institute

Program on Energy, the Environment, and the Economy

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August 31, 1998

Dr. Jeffrey Frankel
Member
Council of Economic Advisors
17th & Pennsylvania Ave., NW
Room 314
Washington, DC 20502

Dear Jeff:

At this summer's Energy Policy Forum, the members of our Advisory Committee who attended suggested that a more aggressive dissemination of our results would improve our likelihood of affecting policy. In response, we tried to condense the highlights of our discussions, and particularly the agreements reached at our final session, into a concise list of conclusions.

Enclosed is a copy of that list, along with a copy of a transmittal letter to the President and the Congressional leadership that was signed by several of the participants.

While I believe that the conclusions are an accurate representation of the sense of the Forum, obviously not all 100 participants approved the list as written. This is noted directly in the disclaimer at the end of the list and indirectly in the introductory sentence of the transmittal letter.

We are also preparing the traditional report on the Forum, which will be sent to you when it is printed.

Sincerely,

Jack

Jack Riggs

September 1, 1998

The Honorable William Jefferson Clinton
President
The White House
Washington, DC 20500

Dear Mr. President:

We write on our own behalf as individuals and to convey what we consider to be the conclusions of 100 energy experts convened recently by the Aspen Institute to discuss global climate change. We are sending a virtually identical letter to the Speaker and Minority Leader of the House and the Majority Leader and Minority Leader of the Senate.

Preventing or limiting global climate change is a marathon, not a sprint. It requires a long-term approach and a national consensus that will not change with the results of every election. We recommend a high priority effort to increase public understanding of the issues, to moderate the political aspects of the debate, and to develop public consensus. One option for doing so would be the establishment, in consultation with Congressional leaders, of a bi-partisan, very high level, Blue Ribbon Commission.

This educational effort, and the subsequent policy actions, should be focused primarily on the long-term threat — unsustainable concentrations of greenhouse gases in the atmosphere. The Aspen group agreed not to debate the science of climate change, and many disagreed about the value and cost of substantial early emissions reductions, but we agreed on the importance of preventing unsustainable concentrations and of the need to begin action now.

We urge that the Kyoto Protocol not be submitted to the Senate in the near future, where pre-emptive rejection would remove the U.S. from a political leadership role and put America at a competitive disadvantage as the world develops a sustainable energy system in the 21st century.

This is not, however, a call for inaction. Pending submission of the treaty, the U.S. should move quickly to establish bilateral carbon reduction programs with key developing countries; to increase research and development on lower carbon and carbon-free fuels, technologies, and systems; to establish the rules for crediting early, voluntary emission reductions; and to remove environmental, tax, and regulatory barriers to the adoption of less carbon intensive technologies.

As these steps are being taken, national and international mechanisms and policies for achieving long-term goals must be developed and tested. These should be sufficiently flexible to adapt to changing scientific knowledge and to experience with implementation.

The participants in the Aspen dialogue were a diverse group with very different backgrounds and different views on climate change. We were encouraged to speak for ourselves and not to be bound by our organizations' positions, and we were surprised at the level of consensus we achieved. We believe a broad bi-partisan majority of Americans could also agree on these positive steps. The Aspen recommendations are attached.

Sincerely,

P J Adam
P.J. Adam
Chairman and CEO
Black & Veatch

Bennett Johnston
J. Bennett Johnston
Johnston & Associates
Former Chairman
Energy and Natural Resources Committee
U.S. Senate

Thomas R. Casten
Thomas R. Casten
President and CEO
Trigen Energy Corporation

Jonathan Lash
Jonathan Lash
President
World Resources Institute

Charles B. Curtis
Charles B. Curtis
Partner, Hogan & Hartson
Former Deputy Secretary of Energy
Clinton Administration

Kenneth L
Kenneth L. Lay
Chairman and CEO
Enron Corporation

John H Gibbons

John H. Gibbons
Former Assistant to the President
for Science and Technology
Clinton Administration

Jan W. Mares

Jan W. Mares
EOP Group
Former Assistant Secretary of Energy
Reagan Administration

Roger W. Sant
Chairman, The AES Corporation
Chairman, World Wildlife Fund

Amory B. Lovins
Director of Research and Vice President
Rocky Mountain Institute

Phil Sharp

Philip R. Sharp
Lecturer in Public Policy
Harvard University
Former Chairman
Energy and Power Subcommittee
U.S. House of Representatives

Eric R. Zausner
President
Energy Asset Management, L.L.C.
Former Deputy Federal Energy
Administrator, Ford Administration

Enclosure: Conclusions of the 1998 Aspen Institute
Energy Policy Forum on Global Climate Change

Participant List

Conclusions of the
1998 Aspen Institute Energy Policy Forum
on Global Climate Change

1. **Take a long term focus.**

Climate change is a long term problem, and the focus should be on achieving sustainable levels of greenhouse gas concentrations at the least cost, not only on near-term emission reductions. Nevertheless, certain early actions, based on industry and other public suggestions, are desirable to develop institutions, mechanisms, technologies, and domestic and international support for long-term programs.

2. **Do not reject the Kyoto Protocol nor submit it for ratification now.**

Submission to the Senate and pre-emptive rejection of the Protocol would remove the U.S. from a political leadership role and put America at a competitive disadvantage in the continuing development of a sustainable energy system.

3. **De-politicize the issue and educate the public.**

U.S. political and intellectual leadership should undertake a high priority effort to increase public understanding of the issues, moderate the political aspects of the debate, and develop public consensus. One option for the Administration to consider is the establishment, in consultation with Congress, of a bi-partisan, very high level, Blue Ribbon Commission to lead in the development of a national consensus.

4. **Establish bilateral programs with developing countries.**

The Administration should work aggressively and quickly to establish bilateral carbon reduction programs with key developing countries such as China, India, and Brazil, stressing an early start toward a cost-effective long-term reduction in the dependence on fossil fuels.

5. **Increase R & D.**

To reduce the cost of eventual stabilization of greenhouse gas concentrations, public and private spending for research and development of lower carbon and carbon-free fuels, technologies, and systems, including sequestration and end-use efficiency, should be increased significantly now. Coordination between public and private efforts should be enhanced. Commercial deployment should be left to market choices.

6. **Set the rules for crediting early voluntary reductions.**

The government, with broad industry and other public involvement, should quickly establish rules for crediting voluntary emissions reductions against any future standards.

7. **Review barriers to innovation.**

Many lower carbon technologies and more efficient systems are available now, but long-standing laws and regulations often discourage their adoption. These barriers should be reviewed and, where more valuable objectives are not being served, should be removed promptly.

8. **Ensure that policies are flexible.**

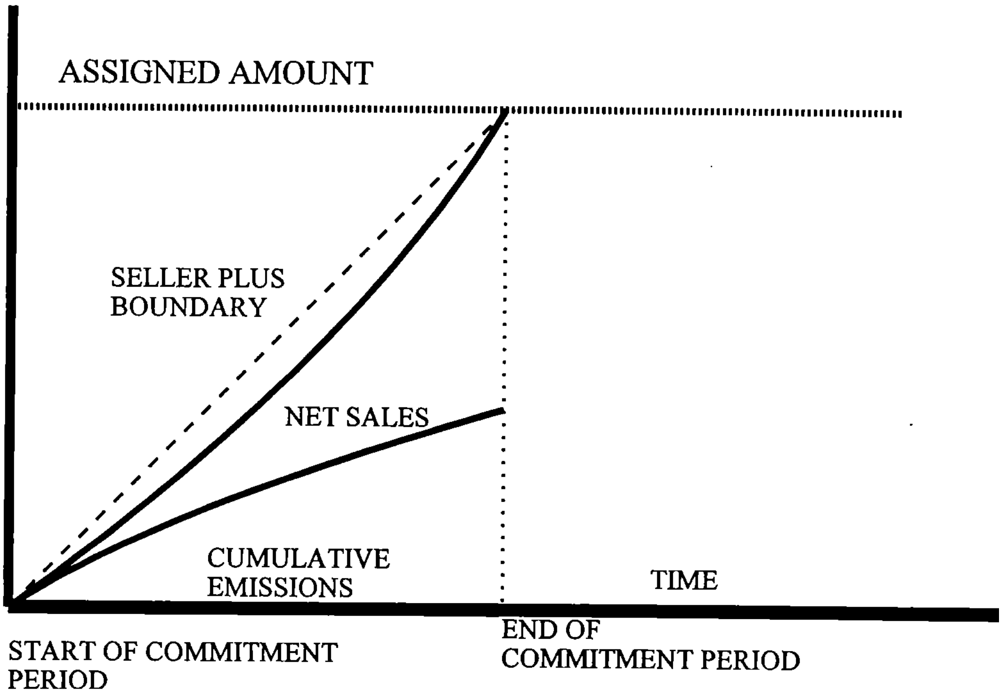
Any governance mechanisms and policies should be sufficiently flexible to adapt to changing scientific knowledge and experience with implementation.

These conclusions are issued under the auspices of The Aspen Institute and its Program on Energy, the Environment, and the Economy. They reflect agreements reached during the Energy Policy Forum, but the participants were not asked to sign off on the final wording. Individuals at the Forum were asked to speak for themselves, not for their organizations, and their participation should not imply the endorsement of their organizations.

The Aspen Institute is a non-profit, non-partisan educational organization that convenes people of diverse perspectives and views to seek new approaches to contentious policy issues. Except as a reflection of its participants' views, the Institute takes no position on policy issues.

- how would we implement the caps?

Seller Plus Plus – Net seller with continuous monitoring (theoretical case)

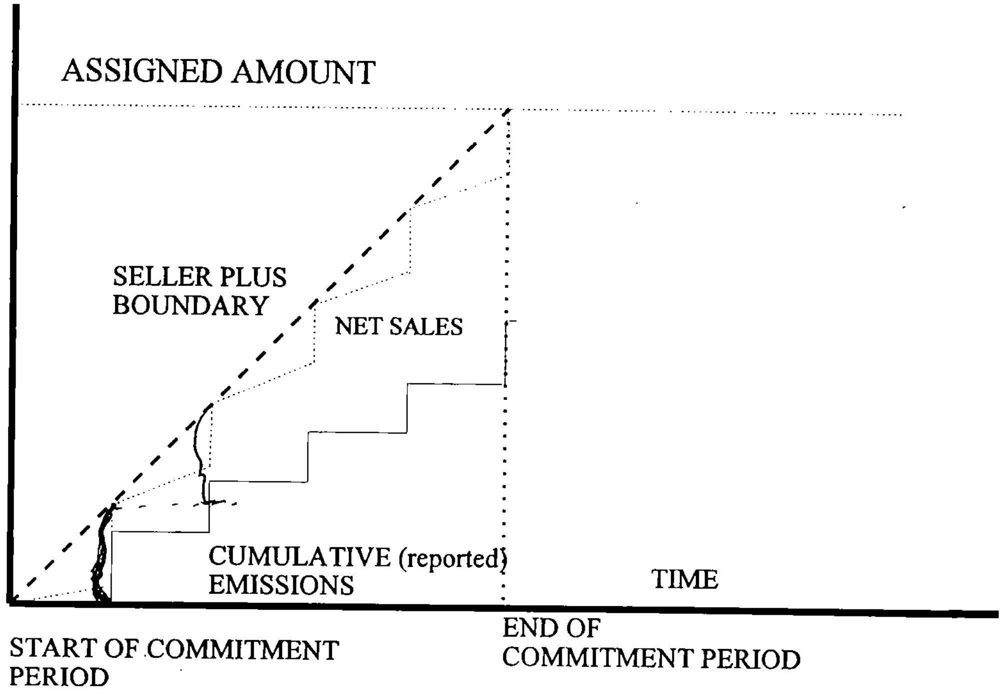


Trading restriction:

Net Sales + Cumulative Emissions > Boundary Line => Party cannot sell.

Pre-decisional draft. Do not cite or quote. October 1, 1998

Seller Plus Plus – Net seller with annual emissions reporting (no reporting lag)

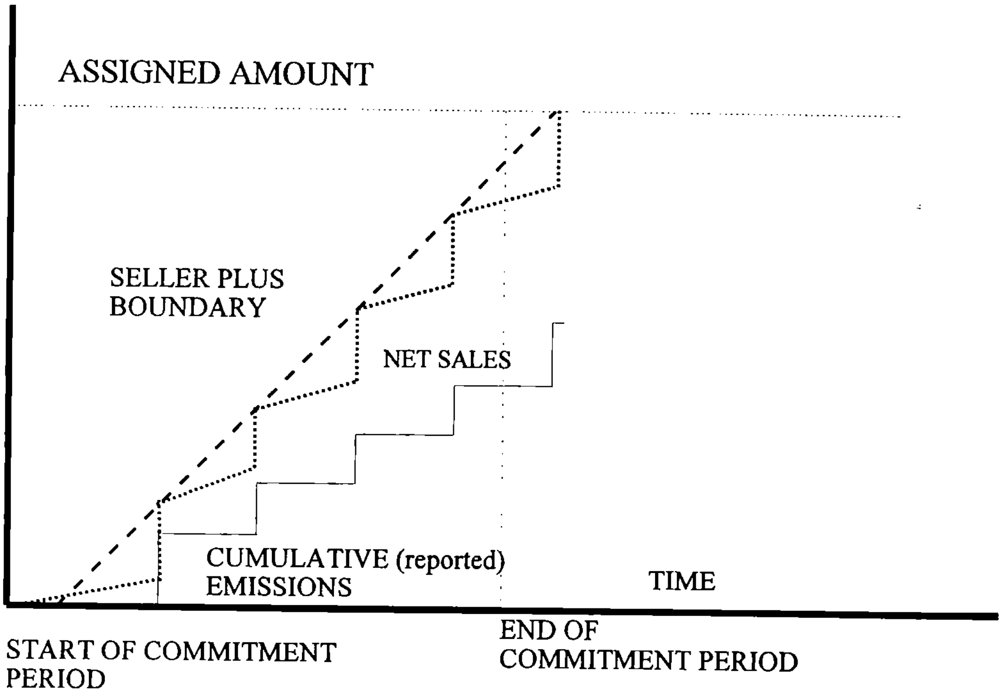


On implementation, these will the same.

Trading restriction:

Net Sales + Cumulative Reported Emissions > Boundary Line => Party cannot sell.

Seller Plus Plus - **Net seller with annual emissions reporting**
(6 month reporting lag & seller plus boundary shifted 6 months)



Trading restriction:

Net Sales + Cumulative Reported Emissions > Boundary Line => Party cannot sell.

PRESS RELEASE

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SP
JA
QF
Cong.

Remarks by Stuart E. Eizenstat Under Secretary for Economic, Business and Agricultural Affairs

September 18, 1998
Tokyo, Japan
(As prepared for delivery)

U.S. LAUDS TOKYO MINISTERIAL AND SHARES VIEWS ON COP4

The informal Ministerial on climate change held in Tokyo on September 17-18 proved very positive, and the United States thanked our Japanese hosts for putting together the meeting. Among the twenty-plus countries invited to attend, there was a strong spirit of cooperation and shared responsibility to continue the progress on climate change begun in Kyoto last December. There was interest in developing a work plan with timetables on the flexibility mechanisms - emissions trading, Joint Implementation and the Clean Development Mechanism.

An active discussion took place the domestic actions being taken by individual nations. The United States set forth in detail its ongoing and planned efforts, which include existing programs for energy labeling on major appliances, solar energy promotion and model energy conservation programs in the federal government itself, $1 billion in climate-related assistance to some 44 developing countries over the next five years, as well as President Clinton's $6.3 billion proposal for new, climate-related tax incentives and R&D measures. Both developing and developed countries -- from China and Indonesia to Japan and the United Kingdom -- made clear their concern about climate change and described national policies and programs that help address climate change.

Discussion of the Clean Development Mechanism, or CDM, which shows real promise as a bridge between the developed and developing countries in their efforts to address the global problem of climate change, was especially productive. Attendees recognized that the projects to be covered by the CDM can create emissions reductions with environmental benefits for us all. The Ministers and their representatives generally acknowledged CDM's potential to promote investments in clean growth in developing countries and to help developed countries meet their Kyoto goals, cost-effectively, through project-generated credits against their targets.

The Ministerial sparked a frank and lively discussion of emissions trading. It reflected an uncommonly clear sense of the balance needed between ensuring the trading system's integrity through strong rules, and maximizing its ability to generate emissions reductions worldwide by making it simple and transparent and allowing its full and flexible use. Trading is a complex issue and countries have different views on precisely how it should work. The Ministerial reflected this, yet also made clear that trading is greatly valued as an innovative and powerful approach to addressing climate change cost-effectively. On that basis, the group was quite positive on balance about the prospects for progress on trading at the Fourth Conference of the Parties -- COP4 -- coming up in November in Buenos Aires. Based upon improved understanding with the EU, we hope that emissions trading will not be a divisive issue at COP4.

The Ministerial gave the twenty-plus attendees an opportunity to consider what can be achieved at COP4 and beyond, but no formal conclusions were reached. A very business-like attitude was taken by the Ministers and their representatives, with a strong focus in discussions on identifying common interests and feasible results for COP4. In our meetings, the United States made clear that developing countries must be part of the solution. Meaningful participation by key developing countries is central, with their degree of commitment dependent upon their emissions level and state of development.

The United States sees COP4 as an opportunity to renew momentum on both the UN Framework Convention on Climate Change and the historic Kyoto Protocol. There seems to be a solid basis for developing an approach to completing the elaboration of the flexibility mechanisms -- emissions trading, the Clean Development Mechanism.

Our goal is to engage in frank discussions on the areas of shared interest, to develop a consensus on next steps in key areas, and to avoid unproductive arguments on issues that cannot be resolved at COP4. The United States hopes that at COP4, Parties will signal clearly their commitment to move forward, and their understanding of the need for greater certainty among our people and private firms about how the Kyoto mechanisms and processes will work.

The United States will encourage all countries -- both developed and developing -- to reiterate at COP4 the need for concerted, cooperative action to address this global problem. A concrete step in this regard would be for Parties to renew their commitment to taking actions in the context of the Framework Convention, which recognizes both the "common, but differentiated responsibilities" of developed and developing countries and the need for a global effort.

The United States would like to see greater evidence at COP4 of developed and developing countries working together on climate change. We are encouraging discussion of a broad array of developing country participation activities and acknowledgment of the specific contributions to limiting greenhouse gases many have made. We may also be able to build confidence and shared perspectives by engaging at COP4 with the private sector and the NGOs. These groups have many skills and insights to contribute, and can help us move forward on issues that are technically complex and politically sensitive.

The key to success will be to establish COP4 as a stepping stone to the future of our efforts on climate change, one which is both credible and effective.

JAPAN MUST PLAY STRONG ROLE AS GLOBAL ECONOMIC PARTNER

Over the last few days I have met with a number of senior Japanese Government officials, businesspeople and academics. I have come away from those meetings with a fresh sense that Japanese leaders understand the severity of Japan's economic problems and the urgency of effective action. My message is that Japan and the U.S. must be global economic partners to help the world avert a financial crisis. I have also detected a growing recognition within Japan that such effective action is important not only for Japan, but for the region and the world.

There appears to be an increasing sense of confidence that Japan will take action~~s~~ ~~in~~ the three critical areas we have identified: maintaining, and supplementing when necessary, fiscal stimulus; strengthening and reforming the banking system; and deregulating and opening its economy. In particular, I would like to reiterate Secretary Rubin's appeal two days ago, when he called on both opposition and majority parties to work out their differences over the banking bills to achieve a result that we hope will include provisions for substantial funding to deal with the bad debt and address the problem of weak but solvent banks.

The U.S.-Japan partnership has never been more important, as the world faces this looming crisis. The US will continue to do its part to strengthen the world financial and trading system. We will continue to pursue policies to maintain strong growth. We will continue to keep our markets open to the goods of East Asian emerging-market countries in distress. We will seek support for the full funding of our IMF package. And together with Japan and our other G-7 colleagues, we will step up our efforts to foster a strong, viable international financial and trade regime.

But Japan, as the largest economy in the region, must play its part. Plainly -- the recovery of Asia depends on the recovery of Japan, which in turn depends upon fiscal stimulus as long as needed until growth resumes, genuine deregulation and dealing with Japan's serious banking problems. This means Japan must absorb more of the exports from South Korea, Thailand, Indonesia, and other countries in the region. The burden cannot rest on our shoulders alone.

In order for our global partnership to be fully effective, we need to resolve bilateral differences in a spirit of cooperation and mutual respect -- as friends. We are deeply concerned about Japan's rising trade surplus with the U.S. and the world. Our trade deficit with Japan is likely to hit historic highs in 1998. It is critical that Japan's recovery be, as the government of Japan itself has insisted, domestic demand-led, not export-led. Rising deficits threaten a protectionist backlash. Japan is in a far different position than its East Asian neighbors, who must not only restructure their economies, but also increase exports to grow.

We also call on Japan to resolve outstanding issues in insurance, film, flat glass, and autos and auto parts in order to reduce tensions, to open its economy to foreign investment, and its government procurement and public investments to U.S. participation. Opening up to the know-how, capital and valuable technology and services of U.S. and other foreign firms will improve the growth and productivity of Japan's once vibrant economy. These actions would be in tune with Japan's needs into the 21st century.

Our country is committed to a positive course. My visit here has given me renewed hope that Japan is equally up to the task.

* * *