*MIT Joint Program on the Science and Policy of Global Change*

# Supplementarity: An invitation to monopsony?*

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Reprint Series Number JP 00-008

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This report is one of a series intended to communicate research results and improve public understanding of climate issues, thereby contributing to informed debate about the climate issue, the uncertainties, and the economic and social implications of policy alternatives.

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# Supplementarity: An Invitation to Monopsony?

*A. Denny Ellerman* and Ian Sue Wing***

*Article 17 of the Kyoto Protocol allows Annex B parties to meet their greenhouse gas emissions commitments by emissions trading so long as such trading is "supplemental" to domestic abatement actions. Whether and how "supplemental" should be defined is one of the most contentious issues in the post-Kyoto climate negotiations. We demonstrate that implementing supplementarity by imposing concrete ceilings on permit imports in a market for tradable emissions rights gives rise to monopsonistic effects similar to those that characterize a buyers' cartel. We assess the EU proposal on supplementarity in this context. Our results show that, under the most favorable assumptions, the proposal avoids the redistributive effects of an import limit, albeit at added cost. Under less favorable assumptions, namely, that the required demonstrations of verifiable abatement cannot be made, the EU proposal severely limits emissions trading and the associated reductions in the costs of achieving the Kyoto commitments.*

## INTRODUCTION

Article 17 of the Kyoto Protocol allows Annex B parties to meet their commitments under the Protocol by greenhouse gas (GHG) emissions trading so long as such trading is "supplemental" to domestic emissions control. Supplementarity in this context refers to the level of imports of tradable emission permits relative to abatement undertaken domestically.

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We are greatly indebted to Matti Vainio, Peter Zapfel, John Reilly, Erik Haites, Henry Tulkens and three anonymous referees for valuable comments on earlier versions of this paper. None are responsible for remaining errors. Funding for the research underlying this paper was provided by the corporate and government sponsors of MIT's Joint Program on the Science and Policy of Global Change.

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The language of Article 17 clearly prohibits any party from relying entirely upon imported permits to meet its commitment, but this limiting case is implausible. Each party faces a schedule of identifiable GHG abatement opportunities, ranging in cost from near-zero to very high, and it is reasonable to assume that parties would utilize these opportunities in a cost-effective manner. Since every party would undertake some cheap domestic abatement, further elaboration of the meaning of the supplemental provisions of the Kyoto Protocol could be deemed unnecessary. Indeed, the Umbrella Group, consisting of non-European Annex B parties plus Iceland, Norway, Russia and the Ukraine, have adopted this interpretation; however, the EU and its members maintain that something more is required: an explicit quantitative limit, commonly referred to as a "concrete ceiling." To this end, the EU advanced a specific proposal to implement the supplemental provisions of the Kyoto Protocol at the June 1999 meeting of the Subsidiary Bodies in Bonn.

This paper analyzes the effects of a limit on permit imports under the usual analytic assumptions: namely, that all Annex B parties meet their Kyoto Protocol obligations and that free trade in permits among these parties is a realistic possibility. In particular, we emphasize an aspect of supplementarity that has remained implicit in previous analyses: the inherently monopsonistic effects of a restriction[1] on permit imports. The body of the paper consists of three sections. The first presents a simple theoretical model of the effects of import restriction. The second section illustrates these effects using marginal abatement cost functions derived from a computable general equilibrium model. We then present and explain the EU proposal, which is more complicated than the simple quantitative limits that have been analyzed in earlier studies. We also examine how various provisions of the EU proposal affect the aggregate gains from permit trading and the split of those gains between exporters and importers in an Annex B market. A final section of the paper concludes, and a mathematical appendix presents proofs for the essential points made in the body of the paper.

## 2. A SIMPLE THEORETICAL MODEL

A number of studies have examined the effect of restricting permit imports,[2] and they present broadly similar conclusions, namely,

1. To avoid confusion in terminology, we use the term "restrict" in all its forms when referring to the effect of the supplementarity provisions, while "constrain" and all its forms refers to the emission reduction obligations under the Protocol.

2. In particular, see the articles by Bernstein et al. (1999) and Bollen et al. (1999) in the special issue of *The Energy Journal* devoted to the Kyoto Protocol. Criqui et al. (1999), Ellerman and Decaux (1998), and Ellerman, Jacoby, and Decaux (1998) also address the effects of supplementarity in broader discussions of emissions trading.

- Misallocation of resources that increases the global cost of compliance with the Kyoto target,
- Reduction in the gains from emissions trading for exporters of permits, and
- Reduction in the cost of meeting importers' emissions-control obligations for *some* levels of restriction.

The last point is an important one; however, several studies missed it entirely (Ellerman and Decaux, 1998; and Ellerman, Jacoby and Decaux, 1998), and others observed the effect without drawing the full implications. Both Bernstein et al. (1999) and Bollen et al. (1999) note the irony of results they obtain in which the US, which opposes such restriction, is made better off by it, while the EU, which advocates such restriction, benefits less or not at all. Criqui et al. (1999) produce results indicating that *all* importers of tradable permits gain for *some* level of restriction. They describe a U-shaped curve whereby the total cost for importers declines initially, as an import restriction of increasing severity is imposed, and then rises until it reaches the higher cost level associated with autarky.

These results describe the effects of the exercise of market power by buyers, what we loosely term "monopsony,"[3] yet none of these studies state explicitly that the implementation of supplementarity necessarily entails monopsonistic effects. Bernstein et al. (1999) dismiss their result as accidental ("very sensitive to assumptions about baselines and a variety of elasticities and other parameters", p. 247) and they stress that it should not be taken "as a strong guide to policy." Criqui et al. (1999) correctly identify the effects as a more general consequence of implementing restrictions, but cloud this central insight with a discussion of compensation of exporters. Bollen et al. (1999) mention monopsony, only to dismiss the effects by arguing that "restrictions are not the result of monopsonistic optimizing behavior." Other studies have discussed the potential exercise of market power in permit markets, but the focus has been on the relationship between market power and the allocation of permits given the abatement possibilities of the parties receiving permits.[4] None of these analyses have developed what is the central point of this paper, which is that a concrete ceiling provides a coordinating mechanism for restricting demand that could be as effective as overt collusion among buyers or the exercise of market power by a significant importer.

3. To be precise, the behavior being observed is analogous to that of a successful buyers' cartel. Whatever the number of buyers and the mechanism by which buying behavior is coordinated, the crucial common element is that the restriction of demand affects the price of the good being purchased and the returns to both buyers and sellers.

4. For examples, see Westskog (1996); Bohm and Larsen (1994); and Baron (1999).

Monopsonistic effects are illustrated most easily by assuming a competitive market in which all agents are price takers. Such a market structure would be more likely to obtain if governments allocated assigned amounts to companies and other legal entities within each economy and those agents were free to trade within or across borders. With no restrictions on emissions trading, a free-trade equilibrium would obtain in which the marginal costs of abatement would be equalized across sources and the total cost of compliance would be minimized.

Any effective restriction on permit imports will change total cost for the restricted party, as well as for all other market participants. The total cost of meeting the Kyoto limit for the *j*th party is given by equation (1), where the sum of domestic abatement from baseline emissions $a_j$ and imports of emission rights $m_j$ equals the difference between business-as-usual emissions and the Kyoto limit for that party, and $f_j(a_j)$ is that party's marginal abatement cost function

$$TC_j = \int_0^{a_j} f_j(\omega)\,d\omega + pm_j \tag{1}$$

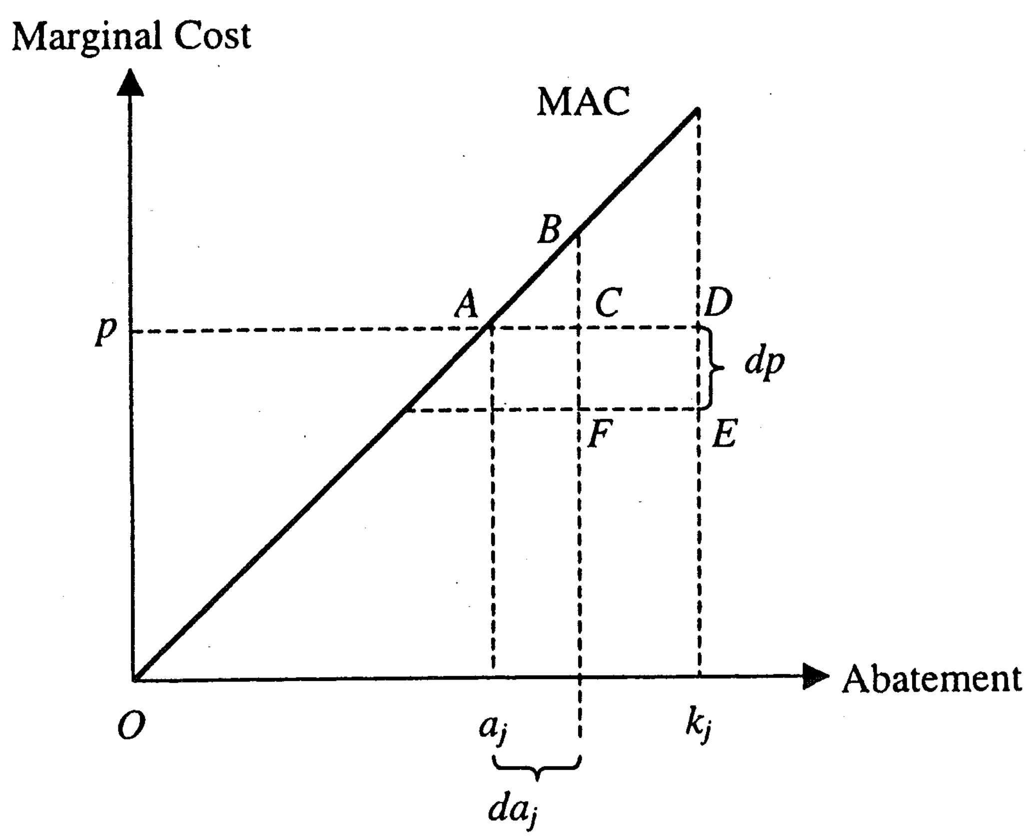
The total differential in equation (2) expresses the change in cost for any change in permit imports recognizing that for compliance with a given Kyoto limit any change in imports will lead to a corresponding change in domestic abatement or $dm_j = -da_j$.

$$\begin{aligned} dTC_j &= \lim_{da_j \to 0} \left\{ \int_{a_j}^{a_j + da_j} f_j(\omega)\,d\omega - pda_j + \left(m_j - da_j\right)dp \right\} \\ &= \left(f_j(a_j) - p\right)da_j + m_j dp \end{aligned} \tag{2}$$

The change in total cost of abatement depends on two effects. The first term on the right-hand side describes the increase in cost caused by the import restriction as more expensive domestic abatement is substituted for imported permits. When stated as a discrete difference, this term is the increase in domestic abatement cost (the integration of $f_j(a_j)$ over the interval $da_j$) less the cost of an equal amount of imported permits at the pre-restriction market price. The restriction creates a positive difference between the two terms within parentheses for any party that is restricted, and abatement will increase for that party. As a result, the first term on the right hand side is positive. The second term describes the change in the cost of permits that the party continues to import. Appendix A1 shows that a binding restriction on any party's imports will reduce the total demand for permits and thereby the market price of permits, so long as all other parties remain price-takers and face upward sloping marginal abatement cost curves. The second term is therefore negative, and the restriction's net impact on total cost for a restricted importer depends on the balance between these two terms.

Figure 1 illustrates the same point graphically. For an unrestricted price $p$, a cost-minimizing constrained party would abate up to $a_j$ and import the balance of the reduction required to meet the Kyoto limit, $k_j$, or $k_j - a_j = m_j$. Total cost before the import restriction is represented by the area under the marginal abatement cost (MAC) function up to $a_j$ plus the cost of imports, $pm_j$. The import restriction causes domestic abatement cost to increase by the area beneath the MAC over the interval $da_j$; however, most of this increase in domestic abatement cost is offset by the reduced payments for permits that can no longer be imported. In effect, these payments are transferred from the foreign trade sector to domestic factors. The difference is the triangle *ABC* representing the increase in cost associated with the post-restriction level of domestic abatement. Since the market-clearing price for permits on the external market will be lower due to the restriction, the remaining permits imported will cost less than they would have without the restriction and the resulting cost savings is represented by the rectangle *CDEF*. The restricted importer gains whenever the triangle *ABC* is less than the rectangle *CDEF*.

**Figure 1. Effect of Import Limit on Restricted Importer**



The differential in equation (2) can also be used to explain the consequences of import restrictions for unrestricted importers and for exporters. Since internal marginal abatement cost will equal the market price of permits for these parties, the first right-hand-side term is zero. Consequently, the effect of the import restriction is determined by the last term on the right-hand-side. For unrestricted importers ($m_j > 0$) total cost is reduced, while for exporters ($m_j <$ 0) the negative cost (or benefit from trade) is diminished.

Figure 2a illustrates the effect of a discrete change in price and abatement on unrestricted importers. The cheaper price for permits leads these parties to import more and they gain both by the reduction in price for the previous level of imports and by the additional savings from displaced domestic abatement. An unrestricted importer is the demand-side equivalent of a non-cooperative fringe producer that produces more at the higher price maintained by a dominant monopolist. In this context, unrestricted importers buy more in response to the lower price and bid the price up somewhat, thereby diminishing the price-depressing effects of the supplementarity limit, as demonstrated formally in appendix A2.

Figure 2b illustrates the case of the price-taking exporter, but before we address the effect of the restriction on exporters, an important feature of the Kyoto Protocol, "hot air," needs to be introduced. Certain Annex B parties, generally the states of the former Soviet Union and Eastern Europe, were assigned limits that exceed the level of their predicted emissions in the first commitment period. The difference between these limits and what emissions would be without any effort at abatement is called hot air, which is depicted in Figure 2b as the point ($h_j$), located along the horizontal axis to the left of the origin of the marginal abatement cost function. In a free trade world, such unconstrained parties will export permits equal to the quantity of hot air and as much abatement as is justified by the market price of permits. Consequently, their supply function for permits consists of two segments: hot air, available at zero cost in an amount equal to the distance of $h_j$ from the origin of the marginal abatement cost function, and abatement available at positive cost as indicated by this latter function.

The fall in price due to the reduction in demand occasioned by a binding supplementarity limit causes exporters to abate less by the amount $da_j$. Exporters lose by the amount, *ABFCD*, most of which (*ABCD*) is an income transfer to importers. The small triangle, *CEF*, represents a deadweight loss on the exporters' side of the market, and there will be a corresponding loss on the importers' side of approximately equal magnitude.[5] For import restrictions that

5. The exact amount of the loss on the importer side would depend upon the slope of importer marginal abatement curves and the existence of unrestricted importers. If all importers were restricted and the slopes of importer and exporter MACs were equal, then the total global deadweight loss would be twice the sum of the exporter triangles corresponding to *CEF*. In fact, the slopes of the MACs are not greatly different.

**Figure 2a. Effect of Import Limit on Unrestricted Importer**

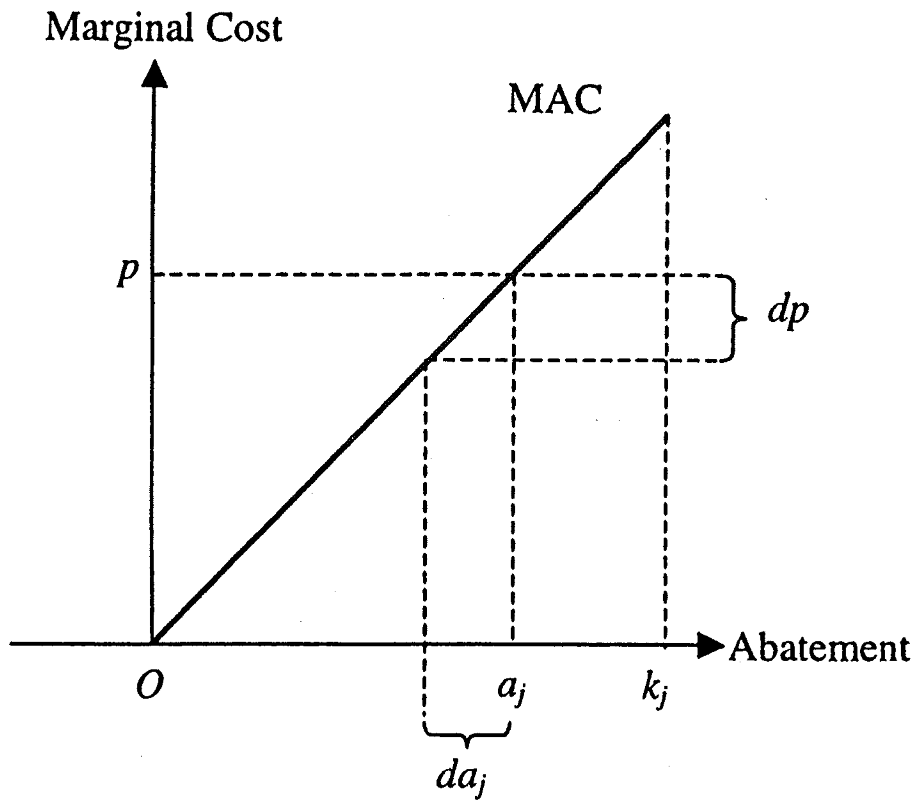
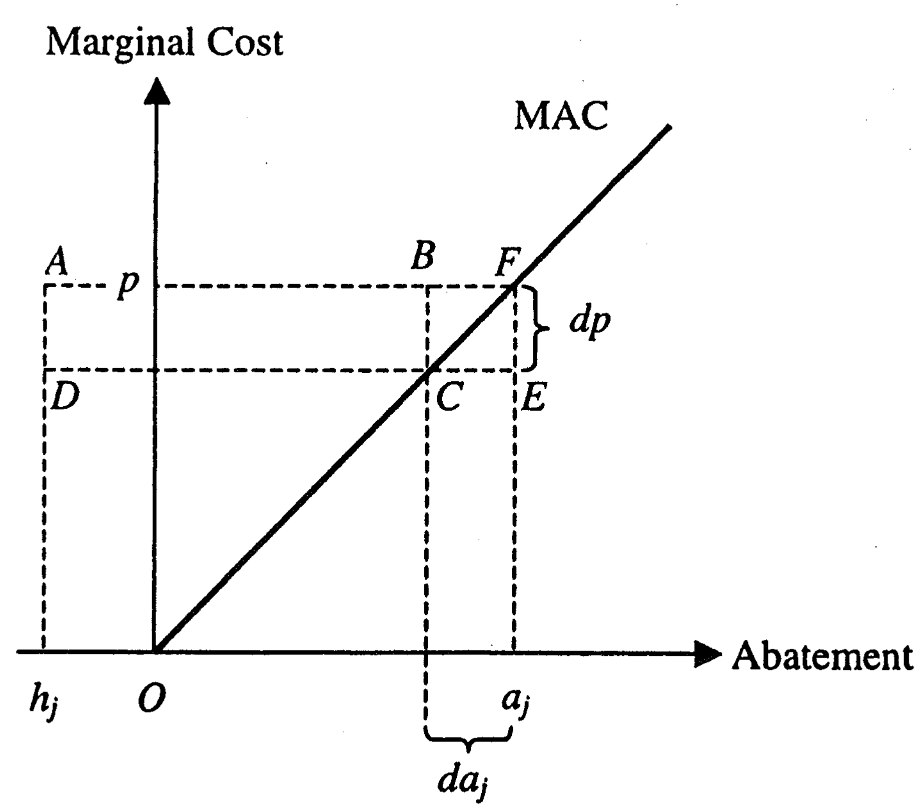



**Figure 2b. Effect of Import Limit on Competitive Exporter**



are not too stringent, it is easy to see that the magnitude of the income transfer will be far larger than the global deadweight loss. Nevertheless, as the restriction binds more tightly, the deadweight loss on both sides of the permit market increases until this effect overwhelms the income transfer. An interesting point is reached when the import demand is restricted to a level that is less than the quantity of hot air. The clearing price for permits will not be well defined at this point since permits have great value to importers but the supply available at zero cost exceeds demand.[6] At this point, the free market value of the hot air has been entirely transferred to the importers and all the remaining cost of the restriction occurs on the importer side. The term *dp* in equation (2) becomes zero, and there are no further income transfers to reduce the costs incurred by importers as the restriction is tightened.

Figure 3 illustrates the incremental cost effects of an import restriction on an importer as the restriction increases in stringency from the point where it is first binding to when it becomes a complete prohibition. The light dashed and solid lines trace the evolution of the two components of equation (2), and of the corresponding triangle and rectangle in Figure 1, as explained more fully in appendix A3. The heavy line shows the net effect on total cost, which is an initial reduction in total cost for the restricted importer followed inevitably by an increase. With linear or strictly convex marginal abatement cost functions, the increase in cost caused by the required increment of domestic abatement rises monotonically, while the cost savings on remaining imports rises, reaches a maximum, and then diminishes to vanishing as the quantity of allowed imports approaches zero. Initially, the cost increase associated with the required increment of domestic abatement is small while the savings on remaining imports is comparatively large. Only later, as increasingly more expensive domestic abatement is substituted for imported permits, and as the level of imported permits diminishes, does the increased cost component overwhelm the import savings component. The savings on total costs are maximized at $a_r$*, and any restriction up to the point $a_r$** will reduce importers' total cost of abatement relative to the cost associated with unrestricted trade in permits.

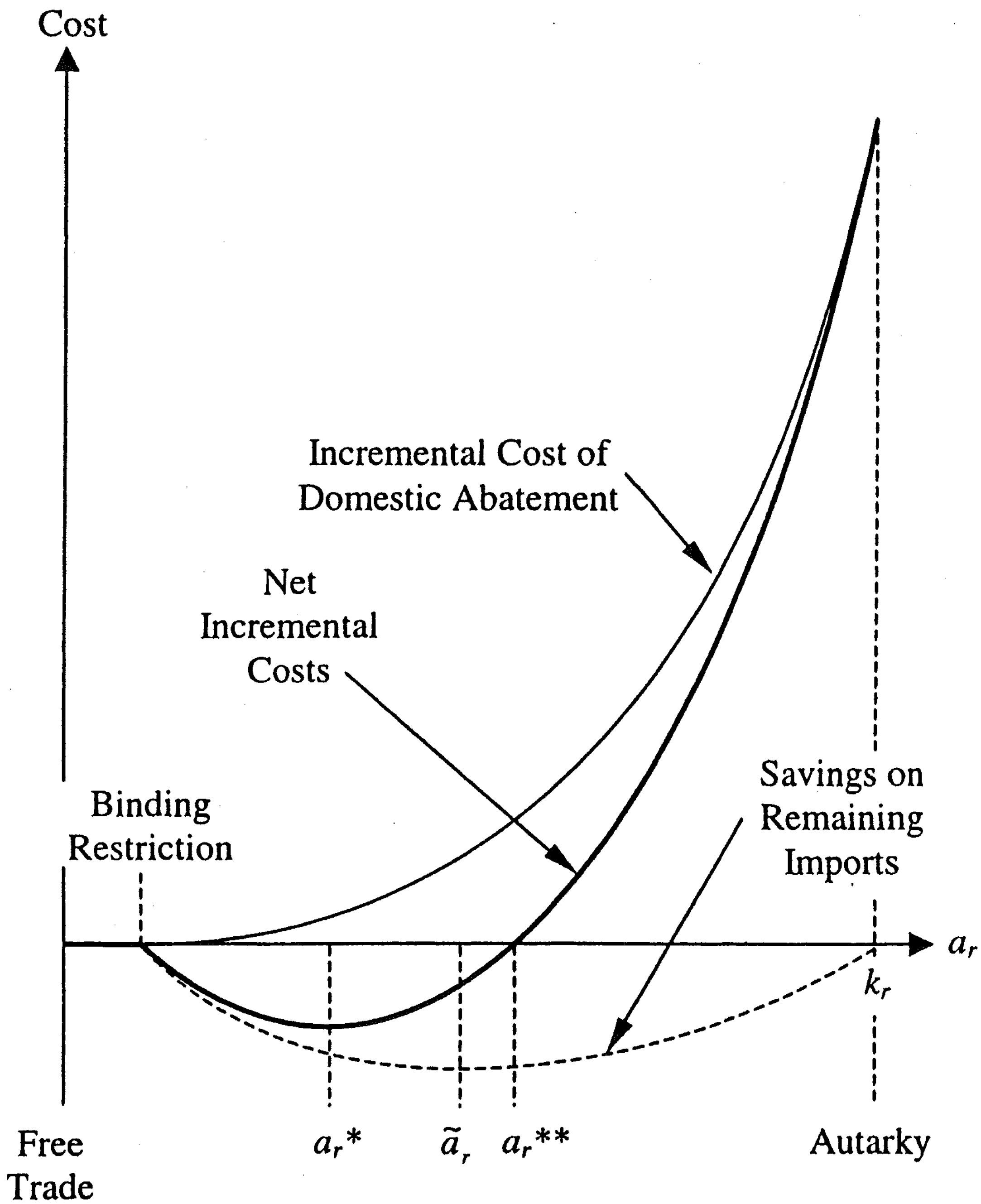
## 3. AN ILLUSTRATIVE SIMULATION

The explanation of monopsonistic effects presented above can be made more concrete by simulating the effect of varying levels of restriction on the prices and quantities that clear the permit market. To do this we employ a set of marginal abatement cost (MAC) curves, a prediction of business-as-usual(BAU) emissions, and a set of Kyoto commitments for aggregate Annex B

6. In the subsequent analysis we maintain the assumption of price-taking behavior, and assume a price of *epsilon* (equal to one dollar per ton of carbon) to cover transaction costs and to clear the market for the permits that can be exported.

regions.[7] The technique of solving for the market equilibrium using MAC curves is described in appendix A4. The MAC curves are generated for the year 2010 from runs of the MIT Emissions Prediction and Policy Analysis (EPPA) model version 3.0.

**Figure 3. Evolution of Cost-Increasing and Cost-Decreasing Components with Progressive Restriction of Permit Imports**




7. The same effects will obtain in a global market. To the extent that credits are available from outside Annex B, the market price will be lower and free trade import levels higher than what would characterize a pure Annex B market.

EPPA is a recursive-dynamic computable general equilibrium simulation of global economic activity, energy production and use, and carbon emissions (Babiker et al., in progress). It divides the world into 12 regional economies, each represented by eight production sectors and inter-linked by trade in energy and non-energy commodities. EPPA also predicts emissions of non-$CO_2$ greenhouse gases, but these are omitted from this analysis in order to maintain the transparency of the central results.[8] EPPA solves for the vectors of prices and quantities that achieve a sequence of static, full employment equilibria in which markets are assumed to function perfectly. The full model captures no-regret possibilities only in so far as changes in the structure of taxes or subsidies may induce lower prices for carbon in 2010, but in order to generate the reduced-form MACs used in this paper these policy instruments were held constant at their pre-existing levels in the benchmark data. Finally, the model's high degree of sectoral aggregation limits its ability to capture key details of the institutional structure of the Kyoto agreement. In particular, project-by-project abatement activities under joint implementation (JI) or the Clean Development Mechanism (CDM) are not represented within EPPA. For the purpose of the model and this analysis, it does not matter whether a permit originated from JI or CDM activities or from initial allocations of assigned annual amounts (AAUs). All are equal, as indeed they will be in determining compliance with the Kyoto Protocol.

As explained in Ellerman and Decaux (1998), the MACs are constructed by simultaneously imposing on each region $j$ an autarkic constraint, calculated as a fraction of its baseline carbon emissions. Imposing an identical, progressively increasing fraction on all regions in 2010 generates a sequence of solutions that trace out a series of coordinates in carbon tax-abatement space. Functions of the form $mc_j = \alpha_j a_j^{\beta_j}$ are fit to the response trajectories of each region within the model using a least-squares procedure. The coefficients for the six Annex B regions are shown in Table 1.[9]

8. The net effect of including the non-$CO_2$ gases on both permit imports and the incidence of import restrictions is unclear, since their inclusion not only augments cost-effective domestic abatement options but also increases the quantity of GHGs that parties are required to control. As shown by Reilly et al. (1999), inclusion of these gases leads to lower autarkic marginal costs of abatement and lower total costs of meeting the Kyoto commitments.

9. The six regions are the United States, Japan, the 15 states of the European Union, other OECD nations (Canada, Australia, New Zealand, Iceland, Norway, Switzerland and Turkey), the former Soviet Union, and European Economies in Transition.

**Table 1. Parameter Values for EPPA 3.0 Marginal Abatement Cost Curves: 2010**

| | USA | JPN | EEC | OOE | FSU | EET |
|---|---|---|---|---|---|---|
| $\alpha$ | 0.0113 | 0.1164 | 0.0373 | 0.1444 | 0.0643 | 0.1883 |
| $\beta$ | 1.5682 | 1.6809 | 1.4903 | 1.5914 | 1.3918 | 1.5511 |

The prediction of BAU carbon emissions is taken from the reference scenario in EPPA 3.0. This is a relatively high emissions forecast, which results in greater abatement and higher costs than some others. For comparison, we include the recently published reference forecast of carbon emissions in the 2000 International Energy Outlook (hereafter, IEO2000) published by the Energy Information Administration of the US Department of Energy (USDOE, 2000). In each region, the required amounts of abatement from this reference are computed using the Annex B Kyoto emission targets in the 1999 International Energy Outlook (USDOE, 1999). The cost implications of these commitments using the EPPA-generated MACs and the reference emissions from EPPA and the IEO2000 forecast are given in Table 2.

Several points from the comparison of these two forecasts should be kept in mind in an analysis of supplementarity. First, relatively small changes in predicted emissions can have large effects on parties' abatement requirements and the characteristics of an emissions trading market. Annex B emissions are only 7% less in the IEO2000 forecast than in the EPPA 3.0 reference case (4.41 GTC (gigatons of carbon) vs. 4.76 GTC), but the amount of abatement required to meet the Kyoto commitments is 40% less (0.52 GTC vs. 0.87 GTC) and the market-clearing price half as much. Since the ceiling is fixed, the difference between the forecasts is fully reflected in the amount of required abatement, which is the primary determinant of cost. Second, since lower growth implies less required abatement, lower permit prices, and greater reliance on imported permits, the probability that any given concrete ceiling would be binding increases with lower growth forecasts. Thus, in the higher emissions growth EPPA Reference case, none of the four constrained Annex B regions imports as much as 50% of the abatement requirement, whereas in the lower emissions growth IEO2000 forecast, three of the four regions import 50% or more of their abatement requirements. Third, assumptions about the growth in emissions have a much greater effect on total cost when trading is assumed than otherwise. For instance, when no trading is assumed, total Annex B cost is about 80% as much with the lower growth IEO2000 forecast as with the higher growth EPPA reference case. When unrestricted trading is assumed, total cost in the low growth forecast is 45% of that in the higher growth case. Without trading, hot air and cheap abatement from non-constrained parties play no role in the total cost incurred by constrained parties. With trading, both hot air and low cost abatement from the non-constrained parties are available, and there is more hot air with lower emissions growth.

**Table 2. Cost Projections with EPPA MACs (EPPA and IEO2000 Reference Emissions): 2010**

| | EPPA Reference | IEO2000 Reference | EPPA Reference | IEO2000 Reference |
|---|---|---|---|---|
| | Baseline Emissions MT Carbon | | Kyoto Reduction[1] MT Carbon | |
| Annex B | 4,762 | 4,412 | 865 | 515 |
| USA | 1,850 | 1,787 | 598 | 535 |
| Japan | 351 | 331 | 93 | 73 |
| Western Europe | 1,189 | 1,016 | 327 | 154 |
| Other OECD | 309 | 286 | 94 | 71 |
| Eastern Europe | 275 | 264 | -45 | -56 |
| FSU | 788 | 728 | -202 | -262 |
| | Autarkic Marginal Cost[2] 1995 US$ | | Autarkic Total Cost Billion 1995 US$ | |
| Annex B | 94 | 43 | 69.3 | 56.7 |
| USA | 256 | 215 | 38.2 | 44.7 |
| Japan | 238 | 158 | 5.6 | 4.3 |
| Western Europe | 208 | 68 | 20.0 | 4.2 |
| Other OECD | 201 | 128 | 5.5 | 3.5 |
| Eastern Europe | - | - | - | - |
| FSU | - | - | - | - |
| | Free Trade Total Cost[3] Billion 1995 US$ | | Free Trade Import Share % | |
| Annex B | 32.5 | 8.8 | | |
| USA | 38.2 | 18.0 | 47 | 64 |
| Japan | 5.6 | 2.2 | 42 | 54 |
| Western Europe | 20.0 | 3.7 | 41 | 26 |
| Other OECD | 5.5 | 2.1 | 38 | 50 |
| Eastern Europe | -7.4 | -3.3 | - | - |
| FSU | -29.5 | -13.9 | - | - |

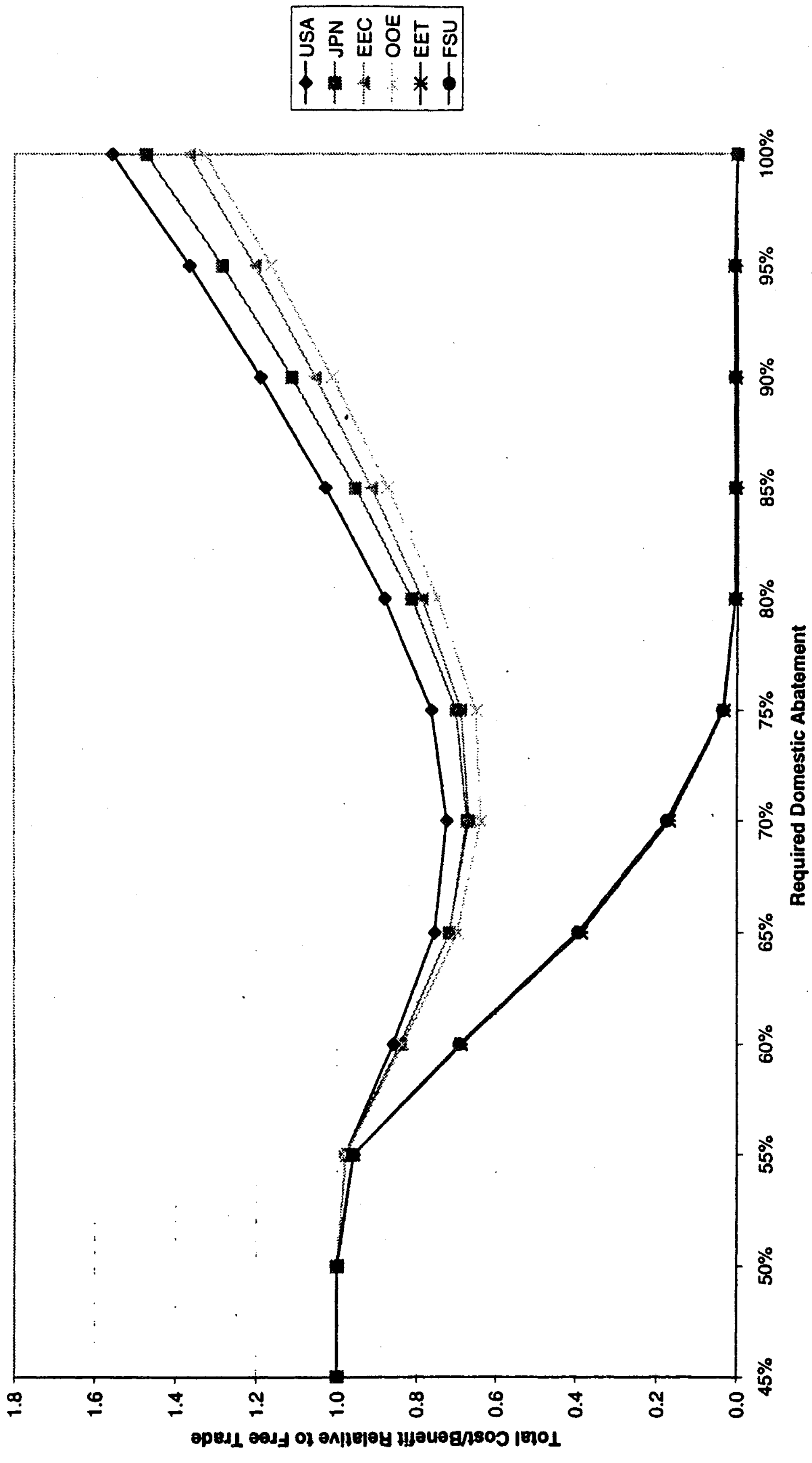
1. Negative entries indicate predicted emissions below assigned amount, or "hot air."
2. Annex B entries for autarkic marginal cost are the clearing prices for an Annex B market with trading.
3. Negative entries denote net benefits, or export revenues less abatement cost.

Figure 4 uses the curves first developed by Criqui et al. (1999) to show the effect on total cost of the Kyoto reduction as the import restriction moves from none at all to complete prohibition, given EPPA reference case emissions. The vertical axis expresses the total cost of the Kyoto reduction associated with given levels of restriction relative to the total cost under free trade, or in the case of the exporting regions, the total benefit with free trade. The level of import restriction is expressed on the horizontal axis as the percent of required domestic abatement. Given a prediction of BAU emissions, any import ceiling can be equivalently stated as a percentage of the abatement required to meet the Kyoto emission limits that must be performed domestically. For instance, a limitation restricting permit imports to no more than 25% of the required abatement can be expressed equivalently as a requirement to abate at least 75% domestically.

For importers, the consequences of a concrete ceiling fall into one of three categories. The first includes levels of restriction that would not bind on any importing region, such as, in the EPPA 3.0 reference forecast, a ceiling requiring up to 53% domestic abatement (prohibiting imports of more than 47% of the total requirement). Any concrete ceiling requiring this much domestic abatement will have no effect on costs since all importing parties would be abating as much domestically. The second category contains all levels of restriction that result in lower total cost for importers than that associated with free trade. Using the EPPA 3.0 reference forecast, this range begins at 53% required domestic abatement for all parties, but ends at 84% for the US and at 90% for the "other OECD countries" (OOE) listed in Table 2. The third subset includes all levels of restriction that increase importers' total cost above that associated with free trade. This subset is the complement to the second, and it runs from 84% to 100% for the US and from 90% to 100% for the OOE. As should be clear from the explanation of equation (2), the cost effects of a binding restriction are not limited to the restricted importer. All participants in the permit market experience some change in cost as soon as one importer is restricted.

The experience of the exporting regions is the same as that for importing parties over the first interval—no effect—but it is quite different as soon as the first importing party is actually restricted. Thereafter, the benefits associated with free trade are diminished continually until the point is reached, in this case when 80% domestic abatement is required, at which the demand for imports is less than the available hot air. At this point, exporters undertake no abatement, and, with price-taking behavior, they are assumed to sell whatever hot air is demanded for a token sum of one dollar per ton.

**Figure 4. Effect of Import Restriction on Total Cost (EPPA Reference)**

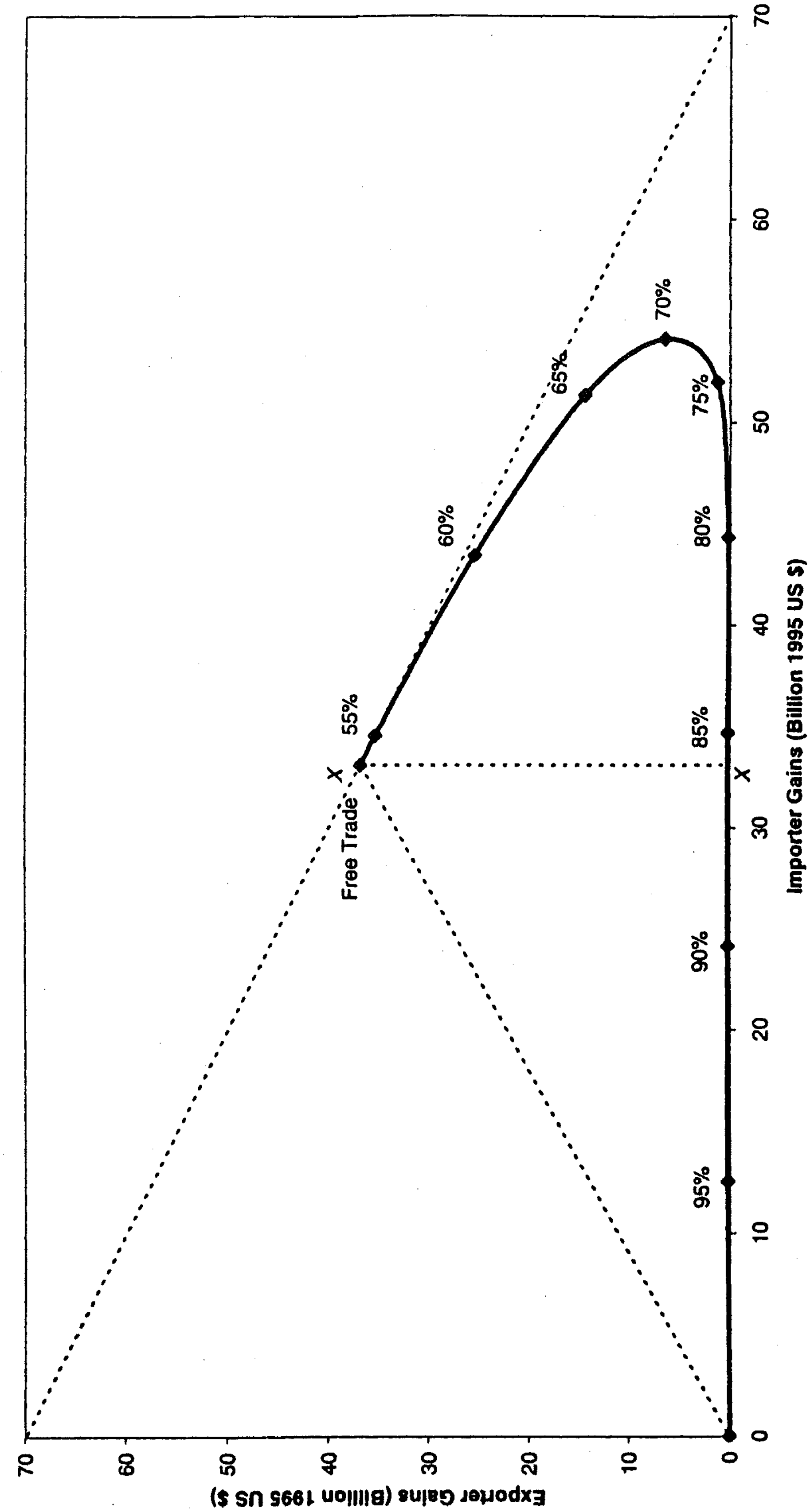


The impact of import restriction on the magnitude and distribution of the gains from emissions trading is illustrated on Figure 5, which plots the aggregate gains by importers (the four OECD regions) and exporters (FSU and EET) along the horizontal and vertical axes, respectively. The point labeled free trade identifies the maximum gains from trade and the distribution of those gains conditional on the Kyoto allocation of AAUs and EPPA 3.0 reference emissions. The two dashed lines passing through the free trade point can be used to illustrate the aggregate economic cost of the restriction and the distribution of the remaining gains from permit trading between exporters and importers. The downward-sloping line is the emissions trading equivalent of a budget line representing all possible allocations of the maximum gains from free trade between importers and exporters.[10] Points lying between this line and the origin indicate reduced gains from permit trading, or equivalently higher total costs of compliance, with points closer to the origin indicating greater losses than those closer to the cost-minimizing frontier. The line connecting the origin to the free trade point indicates the split of the gains from permit trade between importers and exporters associated with free trade. In the EPPA reference scenario the total gains from unrestricted permit trading are $69.9 billion of which $36.9 billion, or approximately 53%, accrue to exporters, and the remaining $33.0 billion accrue to importers. Points lying below this line represent a split of the gains more favorable to importers, and points lying above this line represent a split of the gains more favorable to exporters.

The curve in Figure 5 indicates the effect of an increasingly stringent, uniform import restriction on the aggregate gains from trade and the distribution of those gains between importers and exporters. The free trade point prevails for any uniform restriction mandating up to 53% domestic abatement. Slight restrictions requiring 55%-60% domestic abatement entail little loss in the aggregate gains from emissions trading, but induce a significant redistribution of those gains in favor of importers. The maximum gain for importers—and their least cost of complying with the Kyoto Protocol—will be achieved with a limit requiring 70% domestic abatement. Still tighter restrictions on importers move the locus of gains back towards the origin and eventually to the loss of all gains from emissions trading, which is the definition of autarky. The vertical line *XX* separates this curve into ranges over which importers gain (to the right) or lose (to the left) relative to free trade. In this example, aggregate importer gains are possible over a wide range of restriction, from 53% to slightly over 85% required domestic abatement.

10. Given the EPPA 3.0 reference forecast and the assumption of competitive market structure, any other point on this line could be attained by a redistribution of assigned amounts between importers and exporters in what is a simple illustration of the Coase Theorem applied to GHG emissions trading. For instance, if the allocation of AAUs agreed to at Kyoto resulted in greater allocations to the OECD economies and commensurately fewer to the FSU and Eastern Europe, the free trade point would have been moved to the right along this line, and vice versa.

Figure 5: Effect of Restriction on Importer and Exporter Gains From Trade (EPPA Reference)



The specific results shown in Figures 4 and 5 reflect the particular forecast used and the allocation of AAUs in the Kyoto Protocol. Different forecasts and allocations would lead to a different free trade equilibrium point, which may be closer or farther from the origin and closer to one axis or the other than depicted in Figure 5. Also, depending on the forecast and the allocation, the point at which a concrete ceiling would bind may be higher or lower. What should be clear, however, is that, as soon as the import restriction binds, the monopsonistic effects shown in Figures 4 and 5 will appear. Furthermore, the restriction on imports reduces the total costs for importers over a considerable interval of restriction as a result of the monopsonistic redistribution of the (reduced) gains from trade that is inherent in a restriction on demand.

## 4. THE EU PROPOSAL ON SUPPLEMENTARITY

At the June 1999 meeting of the Subsidiary Bodies, the EU and some central and eastern European countries advanced a specific proposal to implement the supplemental provisions of the Kyoto Protocol.[11] This proposal is considerably more complicated than the single uniform limit used in the preceding section and in prior published analyses of supplementarity. Therefore, we quote it in full.

> "Net acquisitions by an Annex B Party for all three Kyoto mechanisms together must not exceed the higher of the following alternatives:
>
> - 5% of its baseline emissions multiplied by five and its assigned amount (over five years) divided by two, or
>
> - 50% of the difference between its annual actual emissions in any year of the period from 1994 to 2002, multiplied by five, and its assigned amount.
>
> "Net transfers by an Annex B Party for all three Kyoto mechanisms together must not exceed:
>
> - 5% of its baseline emissions multiplied by five and its assigned amount divided by two.

11. Submission by Germany on Behalf of the European Community, its Member States, and Croatia, Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovak Republic and Slovenia on Emissions Trading (Art. 17 KP); Principles, Modalities, Rules, and Guidelines for the Mechanisms Under Articles 6, 12, and 17 of the Kyoto Protocol, Note by the Secretariat, Addendum (FCCC/SB/1999/MISC.3/Add.3).

> "However, the ceiling on net acquisitions and on net transfers can be increased to the extent that an Annex B Party achieves emission reductions larger than the relevant ceiling in the commitment period through domestic action undertaken after 1993, if demonstrated by the Party in a verifiable manner and subject to the expert review process to be developed under Article 8 of the Kyoto Protocol."

There are three distinct components: a restriction on imports, a restriction on exports, and the however clause. The last two have a significant effect on the monopsonistic consequences of supplementarity.

The conventional import component of the EU proposal would limit a party's imports of tradable permits during the first commitment period to no more than the greater of the two formula quantities. These formulae may appear complicated, but they are a reasonable attempt to deal with an inherent problem in implementing an import restriction. Analysts typically model a restriction as a percent of the reduction required by the Kyoto Protocol, but the counterfactual emissions implicit in such a formulation are never observed in practice and must be forecast. The EU proposal avoids this problem by referring to quantities already agreed upon or to emissions that will be observed before the proposed restriction becomes applicable. For any given forecast, such as the EPPA 3.0 reference case, the EU limits for both imports and exports can be readily calculated and converted to percentages of the required emission reduction in 2010, as shown in Table 3. The EU import limit would not be uniform among parties, but would vary depending on each party's growth of emissions since 1990. Using the EPPA 3.0 reference forecast, domestic abatement would be required for 72-77% of an importing party's reduction requirement, or equivalently, imports would be limited to 23% to 28% of the requirement.

The second, export component of the EU proposal would limit a party's permit exports to the first of the two formulae applying to imports, or to a total of 66 megatons of carbon (MTC). Restricting permit exports as a means of implementing supplementarity is a novel interpretation of the language of the Kyoto Protocol, but it does reflect a concern often expressed about the export of hot air.[12] Moreover, it might be argued that an export limit provides an indirect way of implementing supplementarity since the higher market price associated with restricted exports of hot air would reduce permit imports from

12. The specific text is "[emissions trading] shall be supplemental to domestic actions for the purposes of meeting commitments..." (cf. Art. 6.1(d) and Art. 17). Since only constrained parties have commitments requiring action, the plain language of the statute would appear to apply to imports only.

what they would be otherwise.[13] The proposed export limit also effectively redefines the assigned amounts for would-be exporters in the Kyoto Protocol, at least to the extent that they or others anticipated trading hot air in the first commitment period in excess of the proposed limit.

**Table 3. Calculation of the EU Supplementarity Limits in EPPA 3.0 Reference Case**

| | USA | EEC | JPN | OOE | EET | FSU |
|---|---|---|---|---|---|---|
| 5% formula amount (MTC) | 65 | 43 | 13 | 11 | 16 | 50 |
| 50% formula amount[1] (MTC) | 169 | 75 | 27 | 24 | - | - |
| Greater of the two (MTC) | 169 | 75 | 27 | 24 | - | - |
| Required emission reduction (MTC) | 598 | 327 | 93 | 94 | - | - |
| Import % of required reduction | 28% | 23% | 28% | 26% | - | - |

1. Based on actual emissions through 1998 and interpolated amounts for later years.

The third component of the EU proposal, the however clause, raises the proposed ceilings on both imports and exports to the extent that an Annex B party undertakes verifiable domestic abatement. An importing party can exceed the formula limit to the extent it can demonstrate domestic abatement greater than the formula level of imports. Thus, the clause effectively raises the import ceiling, and reduces the domestic abatement requirement, to 50% of the total abatement required from BAU emissions. By implication, a party importing more than the formula amount but meeting less than 50% of its requirement by domestic abatement would receive credit for imports equal only to the level of domestic abatement. For instance, a party that had imported valid permits to cover emissions 60 MTC over the Kyoto limit but that could demonstrate only 40 MTC of domestic abatement, would receive credit for only 40 MTC of imported permits and presumably be judged to have exceeded its Kyoto limit by 20 MTC.

On the export side, the however clause operates in a similar manner. Annex B parties could export more than the formula amount if verifiable domestic abatement by the exporting party can be demonstrated. Assuming that hot air can be distinguished from real abatement, unconstrained parties would be limited to exporting only the formula amount of hot air, but they would not

13. Although the export limit will result in greater Annex B abatement during the first commitment period, the provision leads to no greater cumulative abatement given the ability of any party to bank unused assigned amounts against presumed reduction requirements in later commitment periods by Article 3.13 (See Manne and Richels, 1998, for an analysis of the relative benefit of banking versus selling in the first commitment period).

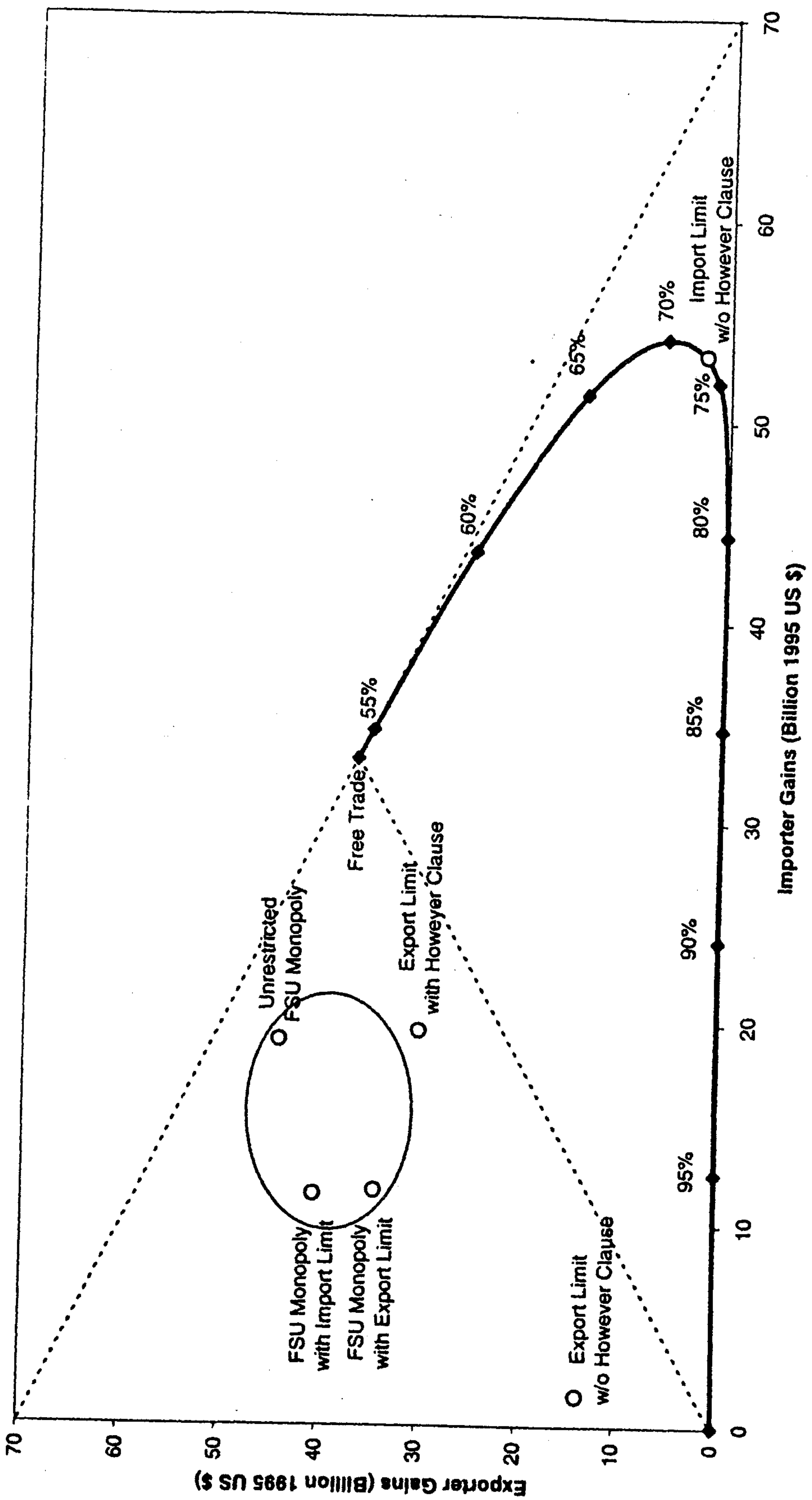
otherwise be restricted. Constrained parties (those with no hot air), which might export due to low marginal cost, would be protected up to the formula amount from challenges based on additionality, but for exports in excess of the formula amount, verifiable abatement would need to be shown.

The loosening effect of the however clause is entirely dependent on the possibility of proving that abatement is real. If verifiable abatement could be demonstrated with relatively little cost, the however clause would operate as intended: to relax the otherwise restrictive formula limits on emissions trading. Such is its effect in the first-best world of model simulations in which all abatement is real and trading is frictionless; however, in a less perfect world—where the counterfactual emissions required to establish verifiable reductions can never be definitively proven—the added test invites mischief that would frustrate the intent of the clause. Importers who would use the clause may find themselves embroiled with challengers in an ultimately irresolvable duel of competing model projections concerning what domestic emissions would have been had no domestic actions been undertaken to comply with the Kyoto Protocol. Exporters who would take advantage of the however clause may find themselves in the same dilemma for the distinction between hot air and real abatement depends similarly on establishing what exporter emissions would have been without any abatement in response to the Kyoto Protocol. At best, the added test needlessly increases transaction costs for levels of trading in excess of the formula amounts; at worst, it will prove the however clause's promise of relief to be illusory.

The several components of the EU proposal have a large effect on the aggregate cost reductions achieved through emissions trading and the distribution of the gains from that trading. Four points on Figure 6 can be used to illustrate the effects of the import and export limits alone and of the however clause. The two points labeled "w/o however clause" indicate the division of the gains between exporters and importers when either the import or export limit is applied. The import limit diminishes the global gains from trade by about 15% relative to the unfettered market equilibrium, but the income transfer is such that, from the standpoint of the importers, a nearly optimal monopsonistic restriction is achieved. The export limit without the however clause would restrict the supply of cheap abatement from the non-constrained Annex B parties to 66 MTC, but that small amount is sold at a very high price: high enough in this case to cause two of the constrained Annex B regions to become small exporters.[14] The two non-constrained regions, the FSU and eastern Europe, are better off than with the import limit, but the importers are much worse off, and nearly all the potential gains from emissions trading have been given up.

14. With a market-clearing price of $212, both the EEC and OOE become small exporters since their autarkic marginal costs are $208 and $201, respectively, as shown in Table 1.

**Figure 6: Importer and Exporter Gains From Trade with EU Limits (EPPA Reference)**



The however clause moves both of these points toward the free trade equilibrium. When applied to the import limit, no importing party would be restricted in the EPPA 3.0 reference case since all constrained parties would abate at least 50% of their emission reduction requirements domestically. As a result, the point representing the import limit with the however clause is the same as that for the free trade equilibrium. When applied to the export limit, the however clause would allow exporting parties to sell as much verifiable abatement as importers are willing to buy. As shown by the point labeled "export limit with however clause," all parties gain significantly, although not as much as under free trade which would allow all the available hot air to be sold.

When the however clause operates with both the import and export limits, as would be the case with the EU proposal, only the export limit is binding since the market-clearing price is high enough to cause all importing regions to abate more than 50% of their emission reduction requirement domestically. Thus, this last point, "export limit with however clause," also represents the full EU proposal under the set of assumptions used for this analysis. Compared to free trade, the EU proposal reduces aggregate cost savings by about 28% to $50 billion, roughly 60% of which would accrue to exporters.

The point representing the full EU proposal (export limit with however clause) can be usefully compared to the three points within the oval on Figure 6, which represent solutions in which the FSU is assumed no longer to be a price taker but to exercise its potential for monopoly power. Each dot within the oval reflects a different assumption about importer behavior: no restriction, the EU limit on imports without the however clause, and the EU limit on exports with the however clause.[15] The exercise of monopoly power by the largest supplier always entails higher cost, but the principal effect is to redistribute the gains from buyers to sellers, as can be seen by comparing each point to the corresponding position where the FSU is assumed to be a price taker.[16] Although suppliers can always gain by exploiting potential market power, if they are unable to do so, the proposed EU export limit approximates the result by providing the requisite mechanism for restricting supply. Such would be the effect in an Annex B market, in which case, the EU export limit succeeds in transforming the unwelcome invitation to monopsony into a self-abnegating invitation to monopoly.

15. With the set of assumptions used here, the import limit with the however clause is the same as being unrestricted. The export limit without the however clause is not illustrated because it places exporters in a region where they cannot gain by further reductions in export levels.

16. Conversely, the dots within the oval indicate the effect of the proposed EU limits if monopolistic behavior is assumed from the beginning. Neither restriction improves importer gains.

## 5. CONCLUSION

The answer to the question in the title to this paper is yes. The supplementarity condition in the Kyoto Protocol is an invitation to the exercise of monopsonistic power. Monopsonistic effects require only that demand be restricted, not that the restriction be optimal in any sense, nor that the buyers had some other objective in mind. These effects occur with price-taking behavior by both buyers and sellers so long as an effective coordinating or restraining mechanism is in place. A concrete ceiling on permit imports provides such a mechanism, and with it, all buyers will be better off over some range of restriction, although most assuredly there is a point beyond which further restriction imposes higher costs on importers than they would experience under free trade. The unexpected results noted by many analysts are not accidental features, but unavoidable consequences of import restriction.

The EU proposal avoids the monopsonistic effects that are identified in this paper, but it does so only by introducing a supply-side restriction to neutralize the redistributive effects of the import limit and an escape valve to restore most of the cost reductions available through emissions trading. Even so, this happier result rests on the workability of the however clause, which presumes that verifiable abatement can be demonstrated with little transaction cost. If abatement cannot be so easily shown, then the beneficial effects of emissions trading for both exporters and importers will be greatly diminished as the formula limits become the operative restrictions.

Although well-intentioned and in many ways a clever interpretation of a vague provision of the Kyoto Protocol, the EU proposal on supplementarity illustrates how good intentions and bad assumptions can make things worse. The good intention is the very goal of the Kyoto Protocol: that parties undertake real abatement. The bad assumption is that emissions trading could lead a party to avoid undertaking any real abatement at all. It is hard to imagine how this latter circumstance could occur, other than by permits that are fraudulent, in which case the problem is fundamental and more severe than can be addressed by restrictions on emissions trading. In the end, the appropriate distribution of emissions reductions achieved domestically versus abroad and now versus later (e.g., hot air) is a decidedly secondary concern to the more important issue of creating the monitoring and accounting mechanisms to ensure that all traded permits are excess to each issuing country's requirement to cover its own emissions. In focusing on secondary concerns, and in introducing worrisome distinctions, the EU proposal detracts from the main task, which is to build a workable and effective international structure to encourage parties to undertake actions to reduce GHG emissions.

## APPENDIX

In region $j$ the domestic supply price $p_j$ of a quantity of abatement $a_j$ is determined by its marginal abatement curve $f_j(a_j)$. We assume that each function $f$ passes through the origin, is invertible, strictly increasing in abatement, and possesses a non-negative second derivative. Every region has a Kyoto emissions limit and a forecast of counterfactual, BAU emissions. The difference between these two emission levels defines either an emissions reduction requirement $k_j$, when the limit is less than BAU emissions, or an amount of surplus permits, known as hot air, $h_j$ when the limit is greater than BAU emissions. The quantity of abatement $a_j$ undertaken by a party depends upon the market price of permits when trading is allowed. When trading is not allowed, abatement will equal the emissions reduction requirement $k_j$ for parties so constrained and abatement will be zero for parties with hot air.

***A1. Import restrictions generate a fall in the permit price in the presence of competitive supply:***

With emissions trading, $j$'s net imports of emissions permits $m_j$ are defined by the market clearance condition

$$m_j = k_j - h_j - a_j = k_j - h_j - f_j^{-1}(p_j) \tag{3}$$

and the aggregate excess demand for permits by

$$\sum_j m_j = \sum_j (k_j - h_j) - \sum_j f_j^{-1}(p_j) \tag{4}$$

Let the set of $j$ regions in the market be partitioned into $i$ importers and $e$ exporters. Assuming constancy of parties' commitments and endowments of hot air, indicated by a bar over the relevant variables, we can split equation (4) into an aggregate demand function

$$\sum_i m_i = \sum_i \left(\bar{k}_i - f_i^{-1}(p_i)\right) \tag{5}$$

and an aggregate supply function

$$\sum_e m_e = \sum_e \left(\bar{k}_e - \bar{h}_e - f_e^{-1}(p_e)\right) \tag{6}$$

Using the sign convention that $m_i > 0$ and $m_e < 0$, import restrictions imply that $dm_i < 0$. We assume that sellers adjust their output for the market to clear, which implies that

$$\sum_e dm_e = -\sum_i dm_i > 0 . \tag{7}$$

With restricted trade, let $p^{RT}$ be the price at which the marginal cost of abatement is equalized across exporters, such that the market clears. Linear additivity of abatement allows us to define a function $A_e$ of the price, so that we can rewrite equation (6) as

$$\sum_e m_e = \sum_e (\bar{k}_e - \bar{h}_e) - A_e(p^{RT}) \tag{8}$$

Taking the total differential yields

$$\sum_e dm_e = -A_e^{\prime}(p^{RT})dp^{RT} . \tag{9}$$

Since the functions $f_e^{-1}$ are strictly increasing, $A_e' > 0$, which requires that $dp^{RT} < 0$.

***A2. Unrestricted ("fringe") importers diminish the permit price reduction caused by an import restriction that binds on other importers:***

From equation (2), the first-order condition of the optimal restriction for a restricted importer $r$ is given by

$$f_r(a_r) = p - m_r \frac{dp}{da_r} . \tag{10}$$

The derivative in this expression is a total derivative that takes into account the reaction of both exporters $e$ and unrestricted importers $u$ to $r$'s restriction. For simplicity, consider a market in which agents in each of these three classes of parties can be aggregated into representative individuals. Under the assumption that the price is determined by the change in abatement of the exporter

$$\frac{dp}{da_r} = f_e^{\prime} \frac{da_e}{da_r} . \tag{11}$$

Market clearing requires that

$$da_e = -(da_r + da_u) \tag{12}$$

which may be written equivalently as

$$\frac{da_e}{da_r} = -\left(1 + \frac{da_u}{da_r}\right). \tag{13}$$

The solution turns on the fact that the derivative within parentheses can be stated as

$$\frac{da_u}{da_r} = 1/f_u' \frac{dp}{da_r}. \tag{14}$$

Combining these formulae then yields

$$\left.\frac{dp}{da_r}\right|_u = -f_e'(1 + 1/f_u') = \frac{-f_e' f_u'}{f_u' + f_e'} \tag{15}$$

which is negative with strictly increasing marginal abatement curves ($f' > 0$).

This result may be compared to the equilibrium condition that obtains when there are no unrestricted importers in the market ($\neg u$). In this case

$$\frac{da_e}{da_r} = -1 \tag{16}$$

and

$$\left.\frac{dp}{da_r}\right|_{\neg u} = -f_e'. \tag{17}$$

The presence of unrestricted importers therefore attenuates the response of the market clearing price to import restrictions:

$$\left.\frac{dp}{da_r}\right|_{\neg u} > \left.\frac{dp}{da_r}\right|_u. \tag{18}$$

This result embodies the intuition that attempts by unrestricted importers to expand imports to take advantage of the fall in the permit price feed back negatively on the price reduction that can be achieved in the market.

***A3. With restricted trade, internal deadweight loss increases with domestic abatement, savings from permit imports achieve a maximum, and total abatement costs achieve a minimum:***

With reference to Figure 1, a restricted party $r$ suffers a deadweight loss *ABC* given by

$$DWL_r = \int_{a^{FT}}^{a_r} f_r(\omega)d\omega - p^{FT}(a_r - a^{FT}) \tag{19}$$

where $p^{FT}$ and $a^{FT}$ are, respectively, the permit price and level of domestic abatement under free trade. This increment to cost is offset by the gross savings on permit imports *CDEF* given by

$$S_r = \left(p^{FT} - p(a_r)\right)(k_r - a_r) \tag{20}$$

Differentiating these expressions yields first-order conditions

$$\hat{a}_r = f_r^{-1}(p^{FT}) \tag{21}$$

and

$$\tilde{a}_r = k_r - (p - p^{FT})\frac{1}{p'} \ . \tag{22}$$

The interpretation of these formulae is straightforward. First, the internal deadweight loss $DWL_r$ is minimized at the free-trade level of imports $\hat{a}_r = a^{FT}$. To see this, note that the second derivative of (19) is

$$\frac{d^2 DWL_r}{da_r^2} = f_r' > 0 \ . \tag{23}$$

Combined with the fact the derivative of $DWL_r$ is $f_r - p^{FT} > 0$, this condition implies the that deadweight loss is increasing and convex in $a_r$. This is shown by the thin solid line in Figure 3. Second, the gross savings on imports $S_r$ are maximized at a level of restriction $\tilde{a}_r$. By (15), $p' < 0$, implying that

$\tilde{a}_r \in (a^{FT}, k_r)$. Sufficient conditions for savings to be maximized can be found from the second derivative of (20):

$$\frac{d^2 S_r}{da_r^2} = 2p' - (k_r - a_r)p'' \tag{24}$$

where $p''$ is simply the derivative of equation (15). A negative value of this expression indicates that $S_r$ achieves a maximum. From A2 we know that

$$p' = \begin{cases} \dfrac{-f_e' f_u'}{f_u' + f_e'} < 0 \text{ if } u \text{ exists} \\ -f_e' < 0 \text{ if } u \text{ does not exist} \end{cases} \tag{25}$$

Therefore, all that is required is to determine the sign of $p''$. When there are no unrestricted parties

$$\frac{d^2 p}{da_r^2} = -f_e'' \frac{da_e}{da_r} = f_e'' > 0 . \tag{26}$$

When there are unrestricted parties the solution is more complicated

$$\frac{d^2 p}{da_r^2} = \frac{-1}{(f_e' + f_u')^2} \left[ \frac{da_e}{da_r} f_u'^2 f_e'' + \frac{da_u}{da_r} f_e'^2 f_u'' \right] \tag{27}$$

Again, A2 facilitates substitution for $\frac{da_e}{da_r}$ and $\frac{da_u}{da_r}$ to give

$$\frac{d^2 p}{da_r^2} = \frac{f_e'' f_u'^2 (f_e' + f_u') + f_u'' f_e'^3}{(f_e' + f_u')^3} > 0 \tag{28}$$

from which the second-order condition for maximum savings is met. The result is shown by the dashed line in Figure 3.

The difference between (19) and (20) gives the net increment to the total cost of compliance under import restrictions:

$$ITC_r = DWL_r - S_r \,. \tag{29}$$

The first order condition for this expression gives the optimal ceiling

$$a_r^* = k_r + (f_r - p)\frac{1}{p'} \,. \tag{30}$$

The second derivative is

$$\frac{d^2 ITC_r}{da_r^2} = f_r' - 2p' + (k_r - a_r)p'' \tag{31}$$

which, since $p' < 0$ and $p'' > 0$, implies that net incremental costs achieve a minimum. This is shown by the heavy line in Figure 3.

***A4. The existence and computation of equilibrium in a market for tradable permits:***

At the positive free-trade permit price $p^{FT}$ the sum of net imports is zero, so that equation (4) becomes

$$\sum_j (k_j - h_j) - \sum_j f_j^{-1}(p^{FT}) = 0 \tag{32}$$

Linear additivity of regions' emissions reductions allows us to express aggregate abatement as a single function $A$ of the price

$$\sum_j f_j^{-1}(p) = A(p) \tag{33}$$

From the definition of $f_j$, the functions $f_j^{-1}$ exist and are strictly increasing, so that $A(0) = 0$ and $A' > 0$. If $A$ is invertible, a closed-form solution exists for the market-clearing price as a strictly increasing function of the commitments of all regions, net of the aggregate endowment of hot air

$$p^{FT} = A^{-1}[\sum_j (k_j - h_j)] \,. \tag{34}$$

$A(\cdot)$ one-one is then sufficient for a unique solution.

In general, an analytic expression for $A^{-1}$ does not exist. In the paper we compute prices and quantities in market equilibrium by finding $p^*$ such that

$$\sum_j \left(k_j - h_j\right) - A(p^*) = 0 \tag{35}$$

This is equivalent to solving

$$\min_{p>0} \left| \sum_j \left(k_j - h_j\right) - A(p) \right| \tag{36}$$

by iterating over prices $p$. $A$ strictly increasing implies that the minimand possesses the single-crossing property that guarantees that if a solution exists, it will be unique. It is then straightforward to solve for the distorted equilibrium with supplementarity limits $l_j$ as a constrained minimization:

$$\min_{p>0} \left| \sum_j \left(k_j - h_j\right) - A(p) \right| \quad \text{s.t. } f_j^{-1}(p) \geq l_j \; . \tag{37}$$

A similar framework may be used to solve for the market equilibrium in the presence of a price-setting monopolistic exporter. For any exporting region $e$, the profit $\pi_e$ it receives will be given by revenues from permits sales net of the costs of actual abatement.

$$\pi_e = \left(a_e + h_e\right) \cdot p_e - \int_0^{a_e} f_e(\omega)\, d\omega \tag{38}$$

We assume that when a region $\hat{e}$ acts as a monopolist it manipulates the price $p_e$ across *all* exporters to maximize its own profit

$$\pi_{\hat{e}}(p_e) = [a_{\hat{e}}(p_e) + h_{\hat{e}}] \cdot p_e - \int_0^{a_{\hat{e}}(p_e)} f_{\hat{e}}(\omega)\, d\omega \tag{39}$$

subject to the permit market clearing on quantity. Importers $i$ are assumed to be acquiescent and to respond as if competitive market conditions prevailed, equalizing their marginal costs of abatement at a common buyer price $p_i$ that is determined by the aggregate quantity of exported permits. The monopolistic equilibrium may then be found by solving for prices $p_e$ and $p_i$ that simultaneously maximize $\hat{e}$'s profits while clearing the market, which is the simple maximization problem

$$\max_{p_e, p_i > 0} \pi_{\hat{e}} \text{ s.t. } \sum_i \left[ k_i - f_i^{-1}(p_i) \right] - \sum_e \left[ f_e^{-1}(p_e) + h_e \right] = 0 . \qquad (40)$$

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