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AEI-BROOKINGS JOINT CENTER FOR REGULATORY STUDIES

## **Clean Air for Less:**

Exploiting Tradeoffs Between Different Air Pollutants

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## **Executive Summary**

The Administration's Clear Skies initiative and all competing legislative proposals take a pollutant-by-pollutant approach to address air pollution problems caused by emissions of both nitrogen oxides (NO<sub>x</sub>) and sulfur dioxide (SO<sub>2</sub>). As a result they miss an important opportunity to cut compliance costs without reducing expected environmental protection.

For a scenario where firms could use permits to emit three tons of NO<sub>x</sub> instead of one ton of SO<sub>2</sub>, we estimate that compliance costs would fall by more than \$1 billion per year relative to emissions caps like those in Clear Skies. Yet expected environmental damages would not increase because the projected damages from three tons of NO<sub>x</sub> are roughly the same as from one ton of SO<sub>2</sub>. To ensure that new air pollution legislation is cost-effective, Congress should allow firms to exchange NO<sub>x</sub> and SO<sub>2</sub> permits at a rate that reflects relative environmental damages.

## Clean Air for Less: Exploiting Tradeoffs Between Different Air Pollutants

Randall Lutter and Dallas Burtraw

### Introduction

President Bush has announced his Administration's Clear Skies Initiative to regulate power plant emissions, including nitrogen oxides ("NO<sub>x</sub>") and sulfur dioxide ("SO<sub>2</sub>").<sup>1</sup> This initiative was introduced in the 107<sup>th</sup> Congress in a bill sponsored by Senator Bob Smith (R-NH).<sup>2</sup> A competing bill proposed by Senator James Jeffords (I-VT) narrowly passed the Senate Environment and Public Works Committee in June 2002.<sup>3</sup> Both the Clear Skies Initiative and the Jeffords' Proposal take a "cap and trade" approach<sup>4</sup> to achieve dramatic emission reductions by limiting emissions on a pollutant-by-pollutant basis.<sup>5</sup> These approaches, however, both miss an opportunity to simultaneously reduce compliance costs and environmental damages because they do not

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<sup>1</sup> See White House Clear Skies Initiative Fact Sheet, President Bush Announces Clear Skies & Global Climate Change Initiatives (February 14, 2002) (announcing President George W. Bush's plan to reduce NO<sub>x</sub> and SO<sub>2</sub> by 70%), available at [http://www.epa.gov/clearskies/clear\\_skies\\_factsheet.pdf](http://www.epa.gov/clearskies/clear_skies_factsheet.pdf) (last visited Dec. 20, 2002).

<sup>2</sup> S. 2815, 107<sup>th</sup> Cong. (2002). Companion legislation was introduced in the House of Representatives as H.R. 5266, 107<sup>th</sup> Cong. (2002) by Rep. Joe Barton (R-TX).

<sup>3</sup> See Press Release, Senate Environment and Public Works, Majority Office, Jeffords Moves Clean Power Act Out of Committee (June 27, 2002) (announcing the passage of the Clean Power Act through the Senate Environment and Public Works Committee), available at [http://epw.senate.gov/maj\\_pr\\_062702b.htm](http://epw.senate.gov/maj_pr_062702b.htm) (last visited Dec. 20, 2002). Jefford's Proposal differs from the Clear Skies Initiative in that it calls for mandatory carbon emission cuts. See Senator James Jeffords, Statement on Clear Skies Proposal for the Senate Committee On Environment and Public Works (July 29, 2002), available at [http://jeffords.senate.gov/~jeffords/press/02/06/07292002clear\\_skies.html](http://jeffords.senate.gov/~jeffords/press/02/06/07292002clear_skies.html) (last visited Dec. 20, 2002).

<sup>4</sup> The cap and trade program establishes federally enforceable emissions limits for each pollutant and allows sources to transfer these among themselves to achieve the required reductions at the lowest cost. See EPA, Fact Sheet on Clear Skies Initiative (2002) (describing Clear Skies Initiative mandatory emissions reduction plan based on a cap and trade program), available at [http://www.epa.gov/clearskies/clearskiesfactsheet\\_3\\_26.pdf](http://www.epa.gov/clearskies/clearskiesfactsheet_3_26.pdf) (last visited Dec. 20, 2002); see also Clean Power Act of 2001, S. 556, 107th Cong. § 132(b) (2001) (providing the objectives, guidelines, and authority for EPA activity in this area).

<sup>5</sup> S. 2815, 107<sup>th</sup> Cong. § 403 (2002); Press Release, Senate Environment and Public Works, Majority Office, Jeffords Moves Clean Power Act Out of Committee (June 27, 2002), available at [http://epw.senate.gov/maj\\_pr\\_062702b.htm](http://epw.senate.gov/maj_pr_062702b.htm) (last visited Dec. 20, 2002).

allow trading between pollutant limitations. In particular, the legislative proposals prohibit tradeoffs between two pollutants that cause similar environmental problems, NO<sub>x</sub> and SO<sub>2</sub>.<sup>6</sup>

We recommend allowing trading between pollutants. Market forces would not only act to affect the supply of NO<sub>x</sub> and SO<sub>2</sub> permits but also the relative stringency of controls for each pollutant. Trading between pollutants could both reduce compliance costs and increase expected environmental benefits.<sup>7</sup> Cost savings from integrating NO<sub>x</sub> and SO<sub>2</sub> markets could exceed \$1.1 billion per year without a reduction in expected environmental benefits.<sup>8</sup>

Trading between NO<sub>x</sub> and SO<sub>2</sub> emissions makes sense for three reasons. First, these pollutants have similar environmental effects. For example, the biggest reason, by far, for stringent new emissions limits is that both NO<sub>x</sub> and SO<sub>2</sub> raise concentrations of fine particulate matter (PM),<sup>9</sup> which in turn boosts mortality risk<sup>10</sup> and restricts visibility.<sup>11</sup> Both pollutants also contribute to high levels of acidity in lakes and forests.<sup>12</sup> And while it is true that nitrogen, but not sulfur, contributes to eutrophication of water bodies,<sup>13</sup> controlling this eutrophication through better farm practices is likely to be much

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<sup>6</sup> See, e.g., S. 2815, 107<sup>th</sup> Cong. § 403 (2002) (omitting trading between NO<sub>x</sub> and SO<sub>2</sub>).

<sup>7</sup> See *infra* Environmental Damages section.

<sup>8</sup> See *id.* We believe that these may be the first estimates of cost savings from trading a permit to emit one type of pollutant for a permit to emit another type.

<sup>9</sup> NAT'L CTR. FOR ENVTL. ASSESSMENT-RTP OFFICE, OFFICE OF RESEARCH AND DEV., U.S. ENVTL. PROT. AGENCY, EPA/600/P-99/002AC, THIRD EXTERNAL REVIEW DRAFT OF AIR QUALITY CRITERIA FOR PARTICULATE MATTER Vol.1, page E-5 (APRIL, 2002), available at [http://www.epa.gov/ncea/pdfs/partmatt/VOL\\_I\\_AQCD\\_PM\\_3rd\\_Review\\_Draft.pdf](http://www.epa.gov/ncea/pdfs/partmatt/VOL_I_AQCD_PM_3rd_Review_Draft.pdf)

(last visited Dec. 20, 2002).

<sup>10</sup> *Id.* at E-23.

<sup>11</sup> *Id.* at E-32.

<sup>12</sup> *Id.* at E-28.

<sup>13</sup> Eutrophication is an increase in the rate of supply of organic matter to a water body, and usually refers to an increase in the rate of algal production. See Chris Clement, S. B. Bricker & D.E. Pirhalla, *Eutrophic Conditions in Estuarine Waters*, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, STATE OF THE COAST REPORT (2001), at [http://state-of-coast.noaa.gov/bulletins/html/eut\\_18/intro.html](http://state-of-coast.noaa.gov/bulletins/html/eut_18/intro.html)

cheaper than regulations on power plants.<sup>14</sup> Furthermore, while NO<sub>x</sub>, but not SO<sub>2</sub>, raises ozone concentrations,<sup>15</sup> the public health implications of ozone are quite small compared with the public health effects of elevated PM.<sup>16</sup>

Second, increasing one pollutant in exchange for reductions in the other would affect only a fraction of total anthropogenic emissions because utilities are only one of many sources of NO<sub>x</sub> and SO<sub>2</sub>.<sup>17</sup> To the extent that legislative proposals reduce NO<sub>x</sub> and SO<sub>2</sub> emissions from power plants, they make these emissions sources increasingly unimportant relative to other sources.<sup>18</sup>

Third, the Clean Air Act still requires states to implement federally approved plans to attain health-based air quality standards by reducing emissions in those areas where air quality does not adequately protect public health.<sup>19</sup> Continued enforcement of

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(last visited Dec. 20, 2002); Nitrogen but not sulfur is a plant nutrient. *See* FLORIDA COOPERATIVE EXTENSION SERVICE, INSTITUTE OF FOOD AND AGRICULTURAL SCIENCES, UNIVERSITY OF FLORIDA, A BEGINNER'S GUIDE TO WATER MANAGEMENT – NUTRIENTS n.2 (2002), *available at*, URL: [http://edis.ifas.ufl.edu/BODY\\_FA079#FOOTNOTE\\_2](http://edis.ifas.ufl.edu/BODY_FA079#FOOTNOTE_2) (last visited Dec. 20, 2002). N.B.: this reference does not explicitly state that sulfur is not a nutrient.

<sup>14</sup> A variety of studies substantiate this point, although they all poorly address the costs of implementing and enforcing control measures. *See, e.g.*, COASTAL OCEAN PROGRAM, NAT'L OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEP'T OF COMMERCE, DECISION ANALYSIS SERIES NO. 20, EVALUATION OF THE ECONOMIC COSTS AND BENEFITS OF METHODS FOR REDUCING NUTRIENT LOADS TO THE GULF OF MEXICO Tables B.1, B.3 (1999), *available at* [http://www.nos.noaa.gov/pdf/library/hpox\\_t6final.pdf](http://www.nos.noaa.gov/pdf/library/hpox_t6final.pdf) (last visited Dec. 20, 2002).

<sup>15</sup> *See* EPA National Ambient Air Quality Standards for Ozone: Final Rule, 62 Fed. Reg. 38,858 (July 18, 1997); 40 C.F.R. §§50.1-50.12.

<sup>16</sup> Office of Air Quality Planning and Standards, EPA, Regulatory Impact Analyses for the Particulate Matter and Ozone National Ambient Air Quality Standards and Proposed Regional Haze Rule 16-17 (1997) (Executive Summary), *available at* <http://www.epa.gov/ttn/oarpg/naaqsfin/ria.html> (last visited Dec. 20, 2002).

<sup>17</sup> *See* WHITE HOUSE CLEAR SKIES INITIATIVE POLICY BOOK 3 (February 14, 2002) (stating that power plants emit 67% of all SO<sub>2</sub> emissions and 25 % of all NO<sub>x</sub> emissions), *available at* [http://www.epa.gov/clearskies/ro\\_clear\\_skies\\_book.pdf](http://www.epa.gov/clearskies/ro_clear_skies_book.pdf) (last visited Dec. 20, 2002). The proposed new legislation would reduce power plant emissions by 75 %. *See infra* Legislative Proposal section. The share of SO<sub>2</sub> and NO<sub>x</sub> emissions from power plants after reductions would fall to about 34% and 8%, respectively, assuming that emissions from other sources do not change. A hypothetical increase in emissions of 20% of these values would be less than 5% for SO<sub>2</sub> and less than 2% for NO<sub>x</sub>.

<sup>18</sup> *See* Press Release, *supra* note 5.

<sup>19</sup> *See* Clean Air Act § 110(a)(1), 42 U.S.C. § 7410 (2002).

the Clean Air Act implies that, even under a trading regime, states still enforce limits that attain health-based air quality standards.

Market prices for NO<sub>x</sub> and SO<sub>2</sub> emissions permits do not correspond with available information on environmental damages. In 2001, SO<sub>2</sub> allowances traded for between \$152 and \$211,<sup>20</sup> while NO<sub>x</sub> permits in the northeast regional market traded at around \$2,000.<sup>21</sup> Yet a ton of SO<sub>2</sub> causes environmental damages 3 to 5 times larger than a ton of NO<sub>x</sub>, according to government estimates.<sup>22</sup> Thus, it is not economically sensible for the more damaging pollutant to be subject to less costly controls. Allowing tradeoffs between NO<sub>x</sub> and SO<sub>2</sub> is one way to avoid such outcomes.

The idea that NO<sub>x</sub> and SO<sub>2</sub> emissions permits can be traded for one another is not new. Amendments to the Clean Air Act provide: “Not later than January 1, 1994, the Administrator shall furnish to the Congress a study evaluating the environmental and economic consequences of amending this subchapter to permit trading sulfur dioxide

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<sup>20</sup> See EPA Clean Air Market Programs, Cumulative SO<sub>2</sub> Trading Activity Table, at <http://www.epa.gov/airmarkt/trading/so2market/cumchart.html> (last visited Dec. 20, 2002) (charting estimates of year 2000 SO<sub>2</sub> allowance trading volume); EPA Clean Air Market Programs, Monthly Average Price of Sulfur Dioxide Allowances, at <http://www.epa.gov/airmarkt/trading/so2market/pricetbl.html> (last visited Dec. 20, 2002) (noting that price information originated with the brokerage firm Cantor Fitzgerald and Fieldston Publications market survey).

<sup>21</sup> No centralized source exists for market price information. This is a conservative estimate reflecting discussions with staff at trading firms, government economists, and some independent reports. See generally EPA Clean Air Market Programs, NO<sub>x</sub> Allowance Market Analysis (April, 2001), at <http://www.epa.gov/airmarkt/trading/noxmarket/pricetransfer.html> (last visited Dec. 20, 2002) (showing estimates of market information). N.B.: NO<sub>x</sub> emissions allowance trading currently pertains to a five-month seasonal program, rather than the annual restrictions included in legislative proposals. Allowance prices are greater under a seasonal program because capital costs must be recovered over a smaller amount of emission reductions. See Dallas Burtraw *et al.*, *Cost-Effective Reduction of NO<sub>x</sub> Emissions from Electricity Generation*, 51 J. AIR & WASTE MANAGEMENT 1482-84 (2001); see also DALLAS BURTRAW, RANJIT BHARVIRKAR & MEGAN MCGUINNESS, UNCERTAINTY AND THE COST-EFFECTIVENESS OF REGIONAL NO<sub>x</sub> EMISSIONS REDUCTIONS FROM ELECTRICITY GENERATION 29-31 (Resources for the Future Discussion, 2002), available at [http://www.rff.org/disc\\_papers/PDF\\_files/0201.pdf](http://www.rff.org/disc_papers/PDF_files/0201.pdf) (last visited Dec. 20, 2002).

<sup>22</sup> See U.S. OFFICE OF MGMT. AND BUDGET, REPORT TO CONGRESS ON THE COSTS AND BENEFITS OF FEDERAL REGULATIONS 46 (June 2000), available at <http://www.whitehouse.gov/omb/infoereg/2000fedreg-report.pdf> (last visited Dec. 20, 2002) (presenting ranges of monetary benefits for reducing emissions of NO<sub>x</sub>, SO<sub>2</sub>, particulate matter, and hydrocarbons).



allowances for nitrogen oxides allowances.”<sup>23</sup> Unfortunately, the Environmental Protection Agency (“EPA”) has not implemented this directive.<sup>24</sup> Independent researchers have studied economic gains from inter-pollutant trading but have been unable to persuade policymakers to adopt this type of trading.<sup>25</sup>

The rest of the paper is organized as follows. Section I shows that current legislative proposals to limit power plant emissions do not allow trading between pollutants or any integration of the markets for both pollutants. In Section II we argue that trading of NO<sub>x</sub> and SO<sub>2</sub> emissions can create economic and environmental benefits. Section III presents a quantitative analysis showing that the integration of NO<sub>x</sub> and SO<sub>2</sub> markets could save more than \$1 billion annually. Before concluding, we show, in Section IV, that integrating markets could also increase environmental protection.

## **I. Legislative Proposals to Limit Power Plant Emissions Do Not Allow Trading Between Pollutants.**

Current law allows for trading of SO<sub>2</sub> emissions from fossil-fired power plants, subject to an aggregate emission cap established under Title IV of the 1990 Clean Air Amendments.<sup>26</sup> Affected facilities may trade and bank SO<sub>2</sub> allowances, but the aggregate cap is fixed without regard to how much NO<sub>x</sub> emission reduction the facilities might be willing to offer in exchange for an increase in SO<sub>2</sub>. Emissions of NO<sub>x</sub> from fossil-fired

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<sup>23</sup> Clean Air Amendments of 1990 § 403c, 42 U.S.C. § 7651(b) (1990), *available at* <http://www.epa.gov/oar/caa/caaa.text> (last visited Dec. 20, 2002).

<sup>24</sup> Phone conversation with EPA staff member, EPA Clean Air Markets, Office of Air and Radiation, October 18, 2001.

<sup>25</sup> *See generally, e.g.*, ALAN KRUPNICK, ET AL., COST-EFFECTIVE NO<sub>x</sub> CONTROL IN THE EASTERN UNITED STATES 21 (Resources for the Future, 2000), *available at* [http://www.rff.org/CFDOCS/disc\\_papers/PDF\\_files/0018.pdf](http://www.rff.org/CFDOCS/disc_papers/PDF_files/0018.pdf) (last visited Dec. 20, 2002) (suggesting that the EPA should consider altering its trading policy to achieve greater economic efficiency).

plants are also regulated under Title IV, but according to an emission rate standard rather than an emission cap.<sup>27</sup> Emission trading is allowed for NO<sub>x</sub> under regulations that are specified by the Environmental Protection Agency.<sup>28</sup>

Most current bills addressing air pollution of power plants apply a cap-and-trade approach to emissions of NO<sub>x</sub> and SO<sub>2</sub> individually<sup>29</sup> and none allow tradeoffs in the aggregate levels of emissions between different pollutants. The Senate Environment and Public Works Committee passed Senator Jeffords' S.556 to reduce power plant emissions of each pollutant by roughly 75% and to allow for trading of emissions allowances.<sup>30</sup> The Bush Administration's Clear Skies Initiative proposes final caps on SO<sub>2</sub>, NO<sub>x</sub>, and mercury emission allowances similar to those of the Jeffords' bill,<sup>31</sup> but allows a longer timeline over which to achieve them.<sup>32</sup> Whereas the Jeffords' bill would accomplish complete reductions by 2008, the Bush Clear Skies approach would not mandate final

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<sup>26</sup> Clean Air Act Amendments of 1990, 42 U.S.C. §§ 7401-7700 (1994). The annual cap pertains to the allocation of emission allowances. Annual emissions may be greater than actual annual allocations because of the opportunity to bank allowances from previous year allocations.

<sup>27</sup> Clean Air Act Amendments of 1990, 42 U.S.C. §§ 7401-7700 (1994).

<sup>28</sup> Finding of Significant Contribution and Rulemaking for Certain States in the Ozone Transport Assessment Group Region for Purposes of Reducing Regional Transport of Ozone, 40 C.F.R. pts. 51,72,75, 96 (2001).

<sup>29</sup> See, e.g., Clean Power Act of 2001, S. 556, 107<sup>th</sup> Cong. § 132(b) (2001); Clean Smokestacks Act of 2001, H.R. 1256, 107<sup>th</sup> Cong. § 2 (2001); Acid Rain Control Act of 2001, S. 588, 107<sup>th</sup> Cong. § 4(a) (2001); EPA Fact Sheet on Clear Skies Initiative 2-3, available at [http://www.epa.gov/clearskies/final\\_clearskiesfactsheetjul.pdf](http://www.epa.gov/clearskies/final_clearskiesfactsheetjul.pdf) (last visited Dec. 20, 2002) (noting that existing SO<sub>2</sub> cap and trade provisions served as a model for the Clear Skies Initiative). For a point-by-point comparison of the major proposals to regulate multiple pollutants from the electricity sector, see: Resources for the Future, Making Sense of Multipollutant Legislation, at <http://www.rff.org/multipollutants/> (last visited Dec. 20, 2002).

<sup>30</sup> See Clean Power Act of 2001, S. 556, 107<sup>th</sup> Cong. § 132(b) (2001).

<sup>31</sup> Compare the President's Clear Skies Initiative aims to cap SO<sub>2</sub> emission allowances at 3 million tons, NO<sub>x</sub> at 1.7 million tons, and mercury ("Hg") at 15 tons with Jefford's proposal.

<sup>32</sup> See EPA Fact Sheet on Clear Skies Initiative 2-3, available at [http://www.epa.gov/clearskies/final\\_clearskiesfactsheetjul.pdf](http://www.epa.gov/clearskies/final_clearskiesfactsheetjul.pdf) (last visited Dec. 20, 2002); see also White House Clear Skies Initiative Fact Sheet, President Bush Announces Clear Skies & Global Climate Change Initiatives (February 14, 2002), available at [http://www.epa.gov/clearskies/clear\\_skies\\_factsheet.pdf](http://www.epa.gov/clearskies/clear_skies_factsheet.pdf) (last visited Dec. 20, 2002).

reductions till 2018.<sup>33</sup> Both Clear Skies and the Jeffords' Bill provide for limits that can be achieved by trading among sources within a particular pollutant but not between different pollutants.<sup>34</sup> Figure 1 summarizes the caps on NO<sub>x</sub> and SO<sub>2</sub> emissions that these bills would put in place alongside estimates of the emissions that would occur in 2007 without new legislation.<sup>35</sup>

Late in the 107<sup>th</sup> Congress Senator Tom Carper (D-DE) introduced S.3135 as an intended compromise proposal.<sup>36</sup> The bill would establish caps for SO<sub>2</sub> of 2.25 million tons, equivalent to S. 556, but not fully phased in until 2015. It would establish a cap of 1.7 million tons for NO<sub>x</sub>, the same as the Clear Skies Initiative, but this would be achieved by 2012. The bill includes mercury limits that are midway between the other bills and caps for carbon dioxide ("CO<sub>2</sub>"), a greenhouse gas, more moderate than S. 556. Like S. 556 and S. 2815, the bill would treat NO<sub>x</sub> and SO<sub>2</sub> as two separate pollution problems and prohibit tradeoffs in aggregate emissions of these two pollutants.

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<sup>33</sup> See White House Clear Skies Initiative Fact Sheet, President Bush Announces Clear Skies & Global Climate Change Initiatives (February 14, 2002), available at [http://www.epa.gov/clearskies/clear\\_skies\\_factsheet.pdf](http://www.epa.gov/clearskies/clear_skies_factsheet.pdf) (last visited Dec. 20, 2002). Senator Jeffords' bill, S.556, limits the three pollutants to 2.24 million, 1.51 million, and 4.8 tons, respectively, in 2007. See OFFICE OF ATMOSPHERIC PROGRAMS, OFFICE OF AIR AND RADIATION, U.S. ENVTL. PROT. AGENCY, ECONOMIC ANALYSIS OF A MULTI-EMISSIONS STRATEGY Table 1 (Prepared for Senators James M. Jeffords and Joseph I. Lieberman, October 31, 2001), available at <http://www.epa.gov/air/jeffordslieberm.pdf> (last visited Dec. 20, 2002). Both proposals allow banking so annual emissions may remain above annual allocations of emission allowances until the bank is exhausted.

<sup>34</sup> See EPA, Fact Sheet on Clear Skies Initiative (2002), available at [http://www.epa.gov/clearskies/clearskiesfactsheet\\_3\\_26.pdf](http://www.epa.gov/clearskies/clearskiesfactsheet_3_26.pdf) (last visited Dec. 20, 2002) (describing Clear Skies Initiative mandatory emissions reduction plan based on a cap and trade program). The cap and trade program establishes federally enforceable emissions limits for each pollutant and allows sources to transfer these among themselves to achieve the required reductions at the lowest cost. See also Clean Power Act of 2001, S. 556, 107th Cong. § 132(b) (2001) (providing the objectives, guidelines, and authority for EPA activity in this area).

<sup>35</sup> See generally ENERGY INFO. ADMINISTRATION, OFFICE OF INTEGRATED ANALYSIS AND FORECASTING, U.S. DEP'T OF ENERGY, SR/OIAF-2001-04, REDUCING EMISSIONS OF SULFUR DIOXIDE, NITROGEN OXIDES, AND MERCURY FROM ELECTRIC POWER PLANTS Table ES-1 (2001), available at [http://www.eia.doe.gov/oiaf/servicert/mepp/pdf/sroi\(2001\)04.pdf](http://www.eia.doe.gov/oiaf/servicert/mepp/pdf/sroi(2001)04.pdf) (last visited Dec. 20, 2002) (analyzing the impact of three scenarios for reducing power sector emissions of NO<sub>x</sub>, SO<sub>2</sub> and Hg).

<sup>36</sup> Clean Air Planning Act of 2002, S. 3135, 107<sup>th</sup> Cong. (2002).

Policymakers' neglect of trading between  $\text{NO}_x$  and  $\text{SO}_2$  is surprising because trading between two pollutants seems a textbook example of a cost-effective regulatory strategy that can create economic and environmental benefits.

## **II. Integrating $\text{NO}_x$ AND $\text{SO}_2$ Allowance Markets Can Create Economic and Environmental Benefits.**

### **A. Integrating $\text{NO}_x$ AND $\text{SO}_2$ allowance markets can avoid unnecessary costs imposed by FIXED statutory limits.**

Standard conditions for cost-effective environmental protection are that the incremental control cost relative to the incremental damages avoided must be the same for each pollutant.<sup>37</sup> Congressional proposals that specify caps on  $\text{NO}_x$  and  $\text{SO}_2$  without (apparent) regard to *relative* incremental costs and damages are therefore very likely to be unnecessarily costly.

To demonstrate this point, suppose emissions of  $\text{NO}_x$  and  $\text{SO}_2$  were capped at  $N_c$  and  $S_c$  respectively, i.e., point K on Figure 2. The rate that  $\text{SO}_2$  emissions can substitute for  $\text{NO}_x$  emissions (and  $\text{NO}_x$  emissions cuts for  $\text{SO}_2$  emissions cuts) without increasing environmental damages is given by the slope of the iso-damage curve reflecting all the combinations of emissions that give damages  $D_2$ . The rate that  $\text{SO}_2$  emissions can substitute for  $\text{NO}_x$  emissions (and  $\text{NO}_x$  cuts for  $\text{SO}_2$  cuts), without increasing compliance costs is the slope of the iso-cost curve reflecting control costs  $C_2$ . Any shift in emissions that decreases  $\text{NO}_x$  and increases  $\text{SO}_2$  while keeping emissions within the lens-shaped area formed by  $D_2$  and  $C_2$  would improve environmental protection while reducing compliance costs. In Figure 2, both environmental damages and compliance costs could

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<sup>37</sup> See WILLIAM J. BAUMOL & WALLACE E. OATES, THE THEORY OF ENVIRONMENTAL POLICY 47 (1988).

be reduced by an emissions control strategy that reduced NO<sub>x</sub> emissions and increased SO<sub>2</sub> emissions. Cost-effective NO<sub>x</sub> and SO<sub>2</sub> emissions caps occur only at points of tangency of iso-damage and iso-cost curves, like point J, which is at the point of tangency of C<sub>1</sub> and D<sub>1</sub>.<sup>38</sup> Thus, the relative costs and the relative effects of the two pollutants on environmental damages are crucial to ensuring that emissions control policies avoid unnecessary costs. Legislative proposals that arbitrarily fix the ratio of emissions forego opportunities simultaneously to lower costs and improve the environment.

Estimating the potential gains from integrating NO<sub>x</sub> and SO<sub>2</sub> markets requires information about how the costs and relative environmental benefits change with changes in the mix of emissions.<sup>39</sup> We address these below.

### **B. Estimating Benefits of Integrating NO<sub>x</sub> and SO<sub>2</sub> Markets Requires Information on Relative Control Costs.**

We review existing estimates of relative control costs and then present some of our own. Developing estimates of the potential gains from integrating NO<sub>x</sub> and SO<sub>2</sub> markets requires information about more than the relative incremental controls cost at emissions levels likely to result from legislative proposals. As we have just shown, it also requires information about how control costs change as the mix of emissions shifts. Government agencies have not yet estimated total incremental control costs for NO<sub>x</sub> and SO<sub>2</sub> for different mixes of these two pollutants, so we develop our own estimates of control costs after reviewing some estimates that government agencies have already completed.

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<sup>38</sup> See *id.* at 45-47, 169-72.

## 1. Recent Government Estimates.

The EPA and the Energy Information Administration (“EIA”) have prepared studies of permit pricing of NO<sub>x</sub> and SO<sub>2</sub> under various emission control scenarios. None of these reports are directly comparable, however, since they are based on different assumptions.

In its analysis of the Clear Skies Initiative, EPA estimated relative permit prices for NO<sub>x</sub> and SO<sub>2</sub> emissions that vary significantly by region and by stage of implementation.<sup>40</sup> Because the Bush Administration’s proposal would separate the NO<sub>x</sub> permit market into an eastern and western region, the relative costs of controlling the two pollutants differ by region.<sup>41</sup> EPA’s estimates show that the permit price of SO<sub>2</sub> relative to the permit price of NO<sub>x</sub>, given the Clear Skies Initiative emissions reductions of 67% for NO<sub>x</sub> and 73% for SO<sub>2</sub> by 2018, would be around 68% for the East and 266% for the West.<sup>42</sup> Table 1 presents EPA’s estimates of relative permit prices for the Clear Skies Initiative.

**Table 1**

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<sup>39</sup> See *id.* at 160-168 (highlighting the importance of considering complex factors in analyzing the marginal net damage of polluting activity).

<sup>40</sup> See EPA, IPM SYSTEM SUMMARY REPORT: IPM2000S153D\_C.DOC, ENVIRONMENTAL MEASURES REPORT OF CLEAR SKIES INITIATIVE 10.1, 10.29, 10.30, available at <http://www.epa.gov/airmarkets/epa-ipm/results.html> (last visited Dec. 20, 2002) (offering tables of emissions at certain plants of SO<sub>2</sub>, NO<sub>x</sub> East, and NO<sub>x</sub> West).

<sup>41</sup> See EPA Regional Differentiation in the Clear Skies Initiative, available at [http://www.epa.gov/clearskies/geo-scope4\\_11.pdf](http://www.epa.gov/clearskies/geo-scope4_11.pdf) (last visited Dec. 20, 2002); see also Clear Skies Act of 2002, S. 2815, 107<sup>th</sup> Cong. § 451-3 (2002).

<sup>42</sup> See EPA, *supra* note 40, at 10.1, 10.29, 10.30.

Marginal Costs of Controlling SO <sub>2</sub> Emissions Relative to Marginal Costs of Controlling NO <sub>x</sub> Emissions (In Percent) Bush Administration Clear Skies Initiative <sup>43</sup>		
NO <sub>x</sub> Region	2008-2012	2018-2022
East	50	68
West	75	266

EIA recently estimated SO<sub>2</sub> and NO<sub>x</sub> permit prices implicit in various emission control scenarios, and showed the price of NO<sub>x</sub> emissions permits would be less than the price of SO<sub>2</sub> emissions permits.<sup>44</sup> These estimates provide information about the relative marginal control costs, since permit prices reflect marginal control costs.<sup>45</sup> The report analyzes three scenarios: 50%, 65% and 75% cuts in both NO<sub>x</sub> and SO<sub>2</sub> emissions. The estimated marginal cost of reducing SO<sub>2</sub> emissions would be 17%, 29% and 14% in 2010, respectively, of the marginal cost of reducing NO<sub>x</sub> emissions.<sup>46</sup> In 2020 the report estimated the marginal cost of reducing SO<sub>2</sub> emissions would be 65%, 95%, and 62%, respectively, of the marginal cost of reducing NO<sub>x</sub> emissions.<sup>47</sup>

EPA also estimated permit prices for pollutant emissions cuts of interest to different Senators, and found that SO<sub>2</sub> permit prices relative to NO<sub>x</sub> permit prices varied with different scenarios for emissions reductions.<sup>48</sup> Since the President remains opposed

<sup>43</sup> See EPA, *supra* note 40, at 10.1, 10.29, 10.30 (providing tables of emissions at certain plants of SO<sub>2</sub>, NO<sub>x</sub> East, and NO<sub>x</sub> West).

<sup>44</sup> See ENERGY INFO. ADMINISTRATION, *supra* note 35, at Table B14, C14, D14.

<sup>45</sup> See ENERGY INFO. ADMINISTRATION, *supra* note 35, at Table B14, C14, D14. These numbers were used in calculating marginal control costs for this article.

<sup>46</sup> See ENERGY INFO. ADMINISTRATION, *supra* note 35, at Table B14, C14, D14. The EIA also assumed in these scenarios that mercury emissions would be cut by 50 percent, 65 percent, and 75 percent, respectively. See *id.* at vii.

<sup>47</sup> See ENERGY INFO. ADMINISTRATION, *supra* note 35, at Tables B14, C14, and D14.

<sup>48</sup> See EPA, ANALYSIS OF MULTI-EMISSIONS PROPOSALS FOR THE U.S. ELECTRICITY SECTOR REQUESTED BY SENATORS SMITH, VOINOVICH, AND BROWNBACK 9-10 (2001), available at

to mandatory carbon emissions cuts,<sup>49</sup> we focus here on the scenarios without them. Relative marginal control costs for SO<sub>2</sub> and NO<sub>x</sub> for different emissions reduction scenarios are reported in Table 2. EPA attributes the differences between its estimates and EIA's estimates to a variety of factors.<sup>50</sup>

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<http://www.epa.gov/air/meproposalsanalysis.pdf> (last visited Dec. 20, 2002) (reporting in response to request by the senators for analyses of reductions of SO<sub>2</sub>, NO<sub>x</sub>, and Hg emissions). In a separate report, the EPA estimated compliance costs and permit prices for emissions cuts of 75% for both NO<sub>x</sub> and SO<sub>2</sub> in response to a request from Senators Jeffords and Lieberman. *See* Office of Atmospheric Programs, Office of Air and Radiation, EPA, Economic analysis of a Multi-Emissions Strategy Table 3 (Prepared for Senators James Jeffords and Joseph Lieberman; October 31, 2001), *available at* <http://www.epa.gov/air/jeffordslieberm.pdf> (last visited Dec. 20, 2002) (showing incremental policy costs). The estimates in response to Senators Jeffords and Lieberman, however, are not directly comparable to those in the Clear Skies Initiative, the EIA's, or the Smith/Voinovich/Brownback report because the EPA considered scenarios that included mandatory cuts in carbon dioxide emissions. *See id.*

<sup>49</sup> *See* letter by George W. Bush to Senators Hagel, Helms, Craig, and Roberts (May 13, 2001), *available at* <http://www.whitehouse.gov/news/releases/2001/03/20010314.html> (last visited Dec. 20, 2002).

<sup>50</sup> *See* EPA, Office of Air and Radiation, Comparison of Jeffords-Lieberman and Smith-Voinovich-Brownback 6-9 (2001), *available at* <http://www.epa.gov/air/finalanalyses.pdf> (last visited Dec. 20, 2002). N.B.: None of the factors distinguishing the EPA and EIA analysis is directly relevant to an analysis of inter-pollutant trading.



**Table 2**

Emissions Control Scenarios: Percent cut in emissions, NO <sub>x</sub> and SO <sub>2</sub>	Marginal Costs of Controlling SO <sub>2</sub> Emissions Relative to Marginal Costs of Controlling NO <sub>x</sub> (In Percent)		
	EIA Analysis <sup>51</sup> (2020)	EPA: Smith/ Voinovich/Brownback Request <sup>52</sup>	EPA: Jeffords/Lieberman Including Carbon Cuts <sup>53</sup>
50	65	212	NA
65	95	134	NA
75	62	110	17 to 20

## 2. Modeling Predicts Relative Incremental Control Costs.

As the recent government analyses offer inadequate information to estimate the efficiency gains from integrating NO<sub>x</sub> and SO<sub>2</sub> markets, we also use Haiku, a model of electricity markets developed by researchers at Resources for the Future, to generate estimates of permit prices and compliance costs.<sup>54</sup> The model has been compared with

<sup>51</sup> See ENERGY INFO. ADMINISTRATION *supra* note 35, at tables B14, C14, and D14.

<sup>52</sup> See EPA, ANALYSIS OF MULTI-EMISSIONS PROPOSALS FOR THE U.S. ELECTRICITY SECTOR REQUESTED BY SENATORS SMITH, VOINOVICH, AND BROWNBACK 9-10 (2001), available at <http://www.epa.gov/air/meproposalsanalysis.pdf>

<sup>53</sup> See Office of Atmospheric Programs, Office of Air and Radiation, EPA, Economic analysis of a Multi-Emissions Strategy 14 (Prepared for Senators James Jeffords and Joseph Lieberman; October 31, 2001), available at <http://www.epa.gov/air/jeffordslieberm.pdf> (last visited Dec. 20, 2002) (showing incremental policy costs).

<sup>54</sup> See generally ANTHONY PAUL & DALLAS BURTRAW, THE RFF HAIKU ELECTRICITY MARKET MODEL 1 (Resources for the Future, 2002), available at [http://www.rff.org/reports/PDF\\_Files/haiku.pdf](http://www.rff.org/reports/PDF_Files/haiku.pdf) (last visited Dec. 20, 2002). The model has been used extensively in journal articles published in the peer-reviewed economics literature. See, e.g., Dallas Burtraw et al., Uncertainty and the Cost-Economics of Regional NO<sub>x</sub> Emissions Reductions from Electricity Generation (Resources for the Future, 2002), available at [http://www.rff.org/disc\\_papers/PDF\\_files/0201.pdf](http://www.rff.org/disc_papers/PDF_files/0201.pdf) (last visited Dec. 20, 2002); see also Dallas Burtraw, et al., Ancillary Benefits of Reduced Air Pollution in the United States from Moderate Greenhouse Gas

other simulation models in two series of meetings of Stanford University's Energy Modeling Forum.<sup>55</sup> The Haiku electricity model simulates equilibrium in regional electricity markets and inter-regional electricity trade with an integrated algorithm for SO<sub>2</sub> and NO<sub>x</sub> emission control technology choice.<sup>56</sup> The model calculates electricity demand, electricity prices, the composition of electricity supply, inter-regional electricity trading activity among 13 regions of the United States, and emissions of NO<sub>x</sub>, SO<sub>2</sub>, and carbon dioxide from electricity generation.<sup>57</sup> Three customer classes are represented: residential, industrial, and commercial.<sup>58</sup> Detail about demand functions is provided and supply curves are calculated for four time periods (super-peak, peak, shoulder, and baseload hours) in each of three seasons (summer, winter, and spring/fall).<sup>59</sup> The model determines investment in new generation capacity and retirement of existing facilities, based on capacity-related costs of providing service in the future ("going forward

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Mitigation Policies in the Electricity Sector (Resources for the Future, 2002) available at [http://www.rff.org/disc\\_papers/PDF\\_files/0161.pdf](http://www.rff.org/disc_papers/PDF_files/0161.pdf) (last visited Dec. 20, 2002); see also Dallas Burtraw, et al., *Cost-Effective Reduction of NO<sub>x</sub> Emissions from Electricity Generation*, 51 JOURNAL OF AIR & WASTE MANAGEMENT 1476-89 (2001). The model was also used for a study sponsored by the State of Maryland Department of Natural Resources. See Karen Palmer, et al., *Electricity Restructuring, Environmental Policy, and Emissions*, (Resources for the Future 2002), available at, <http://www.rff.org/reports/2002.htm> (last visited Dec. 20, 2002). Further information on the model is available from the authors. See also SPENCER BANZHAF, ET AL., *EFFICIENT EMISSION FEES IN THE U.S. ELECTRICITY SECTOR 2*, 11-12 (Resources for the Future, 2002); see also, Karen Palmer, et al., *Capping Emissions: How Low Should We Go?*, PUBLIC UTILITIES FORTNIGHTLY, Dec. 2002, at 28-36 (2002).

<sup>55</sup> See ENERGY MODELING FORUM, FINAL REPORT OF EMF WORKING GROUP 15, A COMPETITIVE ELECTRICITY INDUSTRY 22 (Stanford Univ., 1998), available at <http://www.stanford.edu/group/EMF/home/index.html> (last visited Dec. 20, 2002) (summarizing a comparison of simulation models); see also ENERGY MODELING FORUM, FINAL REPORT OF EMF WORKING GROUP 17, PRICES AND EMISSIONS IN A RESTRUCTURED ELECTRICITY MARKET 1-6, 31 (Stanford Univ., 2001), available at <http://www.stanford.edu/group/EMF/home/index.html> (last visited Dec. 20, 2002).

<sup>56</sup> See ANTHONY PAUL & DALLAS BURTRAW, THE RFF HAIKU ELECTRICITY MARKET MODEL 1 (Resources for the Future Report, June 2002), available at [http://www.rff.org/reports/PDF\\_Files/haiku.pdf](http://www.rff.org/reports/PDF_Files/haiku.pdf) at 1 (last visited Dec. 20, 2002) (providing model documentation).

<sup>57</sup> See *id.* at 5.

<sup>58</sup> See *id.* at 7, 15, 16.

<sup>59</sup> See *id.* at 15-18.

costs”).<sup>60</sup> Generator dispatch in the model is based on minimization of short run variable costs of generation.<sup>61</sup> The variable costs of emission controls plus the opportunity cost of emission allowances under cap-and-trade programs are added to the variable cost of generation in establishing the operation of generation capacity.<sup>62</sup>

The algorithm for compliance with NO<sub>x</sub> emissions caps in Haiku solves for the least cost set of post-combustion investments from among three control options: selective catalytic reduction (SCR), selective noncatalytic reduction (SNCR) and reburn.<sup>63</sup> For control of SO<sub>2</sub>, the model distinguishes coal-burning model plants by the presence or absence of flue gas desulfurization (scrubbers). Unscrubbed coal plants have only one potential SO<sub>2</sub> post-combustion abatement technology, a retrofit scrubber, but firms also may select from a series of coal types that vary by sulfur content and price as a strategy to reduce SO<sub>2</sub> emissions.<sup>64</sup>

Estimates derived from the Haiku model for a scenario that is close to the Administration’s Clear Skies Initiative suggest relative incremental control costs, similar to EPA’s estimates.<sup>65</sup> For simplicity, we model only one scenario, picking emissions caps that approximate those we believe the 108<sup>th</sup> Congress might adopt. For the year 2015, we assume caps for NO<sub>x</sub> and SO<sub>2</sub> of 1.5 million and 2.5 million tons, respectively,

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<sup>60</sup> *See id.* at 18-22, 32.

<sup>61</sup> *See* ANTHONY PAUL & DALLAS BURTRAW, THE RFF HAIKU ELECTRICITY MARKET MODEL 16-18 (Resources for the Future, June 2002), available at [http://www.rff.org/reports/PDF\\_Files/haiku.pdf](http://www.rff.org/reports/PDF_Files/haiku.pdf) (last visited Dec. 20, 2002) (providing model documentation).

<sup>62</sup> *See id.* at 25-26.

<sup>63</sup> *See id.* at 38-42.

<sup>64</sup> *See id.* at 36, 43-46.

<sup>65</sup> Unlike the Clear Skies Initiative, our scenario does not include an emissions cap for mercury. *See* White House Clear Skies Initiative Fact Sheet, President Bush Announces Clear Skies & Global Climate Change Initiatives (2002), available at [http://www.epa.gov/clearskies/clear\\_skies\\_factsheet.pdf](http://www.epa.gov/clearskies/clear_skies_factsheet.pdf) (last visited Dec. 20, 2002) (predicting that implementation of the President’s Clear Skies Initiatives would reduce NO<sub>x</sub> emissions to 1.7 million tons and SO<sub>2</sub> emissions to a cap of 3 million tons in 2018).

but exclude caps for carbon and mercury emissions from our baseline analysis.<sup>66</sup> In this case, the price of SO<sub>2</sub> allowance relative to the price of NO<sub>x</sub> allowances, that is the relative incremental control cost, is 1.4.<sup>67</sup> Compared with the relative incremental control cost estimates for the Clear Skies Initiative presented in Table 1, this estimate is greater than the figure for the East and less than the figure for the West.

### **B. Estimating Unnecessary Costs Requires Information on Relative Incremental Environmental Damages from NO<sub>x</sub> and SO<sub>2</sub>.**

Existing estimates of the marginal damages of NO<sub>x</sub> and SO<sub>2</sub> are at best approximations, but they indicate that the benefits of reducing SO<sub>2</sub> are greater than the benefits of reducing NO<sub>x</sub>. The government has provided recent estimates of the relative incremental damages from NO<sub>x</sub> and SO<sub>2</sub>. The federal Office of Management and Budget (“OMB”) reported estimates of the benefits of reducing NO<sub>x</sub> that were arguably methodologically superior to estimates that ignored the effects of NO<sub>x</sub> on particulates, and ranged from \$960 to \$2500 per ton for the emissions reductions from one rule, and from \$1,350 to \$2,100 per ton for the emissions reductions from another rule (issued under Section 126) in 2007.<sup>68</sup> We disagree with OMB estimates that depend on an assumption that NO<sub>x</sub> reductions have no particulate matter concentrations, because we believe that this assumption is indefensible. The federal Office of Management and

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<sup>66</sup> The Clear Skies Initiative has an SO<sub>2</sub> cap of 3.0 million tons and a NO<sub>x</sub> cap of 1.7 million tons. *See* S. 2815, 107<sup>th</sup> Cong (2002). The Jeffords proposal has an NO<sub>x</sub> cap of 1.51 million tons and a SO<sub>2</sub> cap of 2.25 million tons. *See* S. 556, 107<sup>th</sup> Cong. (2002). The timing of the two proposals varies, with Jeffords’ proposal achieving its ultimate reduction targets nearly a decade earlier. *See* BILLY PRIZER & DALLAS BURTRAW, A SIDE-BY-SIDE COMPARISON OF S. 556 AND S. 2815 (Resources for the Future, 2002), at <http://www.rff.org/Jeffords-Clear%20Skies%20table%209-25-02.pdf> (last visited Dec. 20, 2002). Also, both proposals include the opportunity for banking, which means that annual emissions would not approximate annual allowance allocations until after the bank reaches equilibrium. *Id.*

<sup>67</sup> The numbers that we present are the arithmetic averages of the relevant values for the 11 year period from 2010 to 2020.

Budget recently reported that the monetary benefits of reducing emissions of SO<sub>2</sub> were \$3,768 to \$11,539 per ton.<sup>69</sup> Taking the ratio of lower bounds and upper bounds respectively suggests that SO<sub>2</sub> damages are between 2.8 and 5.5 times greater than NO<sub>x</sub> damages.<sup>70</sup>

An analysis by EPA also supports the conclusion that reducing SO<sub>2</sub> emissions is more valuable than reducing NO<sub>x</sub> emissions.<sup>71</sup> It suggests that mortality-related benefits per ton of NO<sub>x</sub> reduced are around \$1,300 and the benefits per ton of SO<sub>2</sub> reduced are around \$7,300 for electricity generating units.<sup>72</sup> These estimates, which were intended to provide an “order of magnitude approximation rather than a precise estimate,”<sup>73</sup> reflect only the mortality-related benefits because the author believes these accounted “for over 90 percent of monetary benefits in previous analyses.”<sup>74</sup> This EPA analysis suggests that the environmental damages from a ton of SO<sub>2</sub> emissions are about 5.6 times greater than damages from a ton of NO<sub>x</sub> emissions.<sup>75</sup>

Academic research confirms these government estimates. Economists report that reductions in sulfates, or more generally reductions in emissions of SO<sub>2</sub>, yield about 3.2 times more benefits per ton than reductions in nitrates, or more generally

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<sup>68</sup> U.S. OFFICE OF MGMT. AND BUDGET, REPORT TO CONGRESS ON THE COSTS AND BENEFITS OF FEDERAL REGULATIONS 46 (2000), available at <http://www.whitehouse.gov/omb/infoereg/2000fedreg-report.pdf> (last visited Dec. 20, 2002).

<sup>69</sup> U.S. OFFICE OF MGMT. AND BUDGET, REPORT TO CONGRESS ON THE COSTS AND BENEFITS OF FEDERAL REGULATIONS 46 (2000), available at <http://www.whitehouse.gov/omb/infoereg/2000fedreg-report.pdf> (last visited Dec. 20, 2002).

<sup>70</sup> See generally *id.* (presenting information from which damage estimates can be calculated).

<sup>71</sup> See Memorandum from Bryan Hubbell of the EPA’s Innovative Strategies and Economics Group entitled Benefits Associated with Electricity Generating Emissions Reductions Realized Under the NSR Program 1 (2002) (on file with the Fordham Environmental Law Journal).

<sup>72</sup> See *id.*

<sup>73</sup> See *id.*

<sup>74</sup> See *id.*

<sup>75</sup> See generally *id.* (providing information from which damage estimates were calculated).

reductions in emissions of NO<sub>x</sub>.<sup>76</sup> An integrated assessment model, the Tracking and Analysis Framework (TAF), is used to explore a wide range of SO<sub>2</sub> and NO<sub>x</sub> emission levels and locations.<sup>77</sup> Estimates of the marginal benefits of emission reductions generally vary widely with geography and with the modeler's choice of parameters to describe atmospheric transport of pollutants, epidemiology, and economic valuation of health effects.<sup>78</sup> Yet, a robust relationship between the potency of sulfates and nitrates with respect to marginal benefits is reported.<sup>79</sup> Interestingly, their estimate may be relatively insensitive to new scientific information about the health risks or economic valuations of changes in health status. New information that affects the incremental benefits of SO<sub>2</sub> and NO<sub>x</sub> by the same proportion will leave the relative incremental benefits unchanged.<sup>80</sup>

The true uncertainty is greater than implied by the range of existing estimates because the biological mechanism by which fine particles might cause mortality at the

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<sup>76</sup> See SPENCER BANZHAF, ET AL., EFFICIENT EMISSION FEES IN THE U.S. ELECTRICITY SECTOR 2, 11-12 (Resources for the Future, 2002), available at [http://www.rff.org/disc\\_papers/PDF\\_files/0245.pdf](http://www.rff.org/disc_papers/PDF_files/0245.pdf) (last visited Dec. 20, 2002) (noting that differences in geographic location of emission cause large differences in marginal benefits).

<sup>77</sup> Tracking and Analysis Framework ("TAF") was developed in support of the National Acid Precipitation Assessment Program ("NAPAP") and is the work of a team of more than 30 modelers and scientists from institutions around the country. See NATIONAL SCIENCE AND TECHNOLOGY COUNCIL, NATIONAL ACID PRECIPITATION ASSESSMENT PROGRAM BIENNIAL REPORT TO CONGRESS: AN INTEGRATED ASSESSMENT A-2, A-4 (1998), available at <http://www.nnic.noaa.gov/CENR/NAPAP/> (last visited Dec. 20, 2002); see also *id.* at A-7. Each module of TAF was constructed and refined by a group of experts in that field. As the framework in which these literatures are integrated, TAF itself was subject to an extensive peer review in December 1995, which concluded that "TAF represent[s] a major advancement in our ability to perform integrated assessments" and that the model was ready for use by NAPAP. See OAK RIDGE NATIONAL LABORATORY, PEER REVIEW OF THE TRACKING AND ANALYSIS FRAMEWORK (TAF) FOR USE IN THE 1996 NAPAP INTEGRATED ASSESSMENT 3 (ORNL/M-4994, 1995). N.B.: The entire model is available at <http://www.lumina.com/taflist> (last visited Dec. 20, 2002). See generally, Cary Bloyd, ANL/DIS/TM-36, Tracking and Analysis Framework (TAF) Model Documentation and User's Guide (Argonne National Laboratory, 1996).

<sup>78</sup> See BANZHAF, ET AL., *supra* note 77, at 13-15. See also Dallas Burtraw & Erin Mansur, *Environmental Effects of SO<sub>2</sub> Trading and Banking*, 33 ENVIRONMENTAL SCIENCE & TECHNOLOGY 3489-94 (1999).

<sup>79</sup> See BANZHAF, ET AL., *supra* note 77, at 11-12, Figures 2a, 2b.

<sup>80</sup> See BANZHAF, ET AL., *supra* note 77, at 14.

relevant concentration (for example, 15 micrograms per cubic meter of particulate matter with a diameter of less than 2.5 microns) has not yet been identified.<sup>81</sup>

### **III. Quantitative Analysis Shows Reduced Compliance Costs From Integrating NO<sub>x</sub> AND SO<sub>2</sub> Permit Markets.**

Integrating NO<sub>x</sub>-SO<sub>2</sub> permit markets can generate significant cost savings. The government cannot provide these savings simply by legislating an emissions cap because relative control costs will change over time, and such changes will alter the most cost-effective combination of emissions controls.<sup>82</sup> Integrating the two markets with an appropriate trading ratio will allow for the greatest possible cost savings irrespective of how developing control technologies may affect the relative cost of reducing NO<sub>x</sub> and SO<sub>2</sub>.

#### **A. Baseline Assumptions.**

For simplicity, we focus on one scenario, picking emissions caps that approximate those we believe the 108<sup>th</sup> Congress might adopt. In our judgment, however, our quantitative estimates would change only slightly with small variations in NO<sub>x</sub> and SO<sub>2</sub> caps, although they might vary significantly if carbon emissions were also subject to a stringent cap. For the year 2015, we assume caps for NO<sub>x</sub> and SO<sub>2</sub> of 1.5 million and 2.5 million tons, respectively, but exclude caps for carbon and mercury emissions from our baseline analysis.<sup>83</sup> In this case, the price of SO<sub>2</sub> allowance relative to the price of NO<sub>x</sub>

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<sup>81</sup> See NAT'L CTR. FOR ENVTL. ASSESSMENT-RTP OFFICE, OFFICE OF RESEARCH AND DEV., U.S. ENVTL. PROT. AGENCY, EPA/600/P-99/002BB, SECOND EXTERNAL REVIEW DRAFT OF AIR QUALITY CRITERIA FOR PARTICULATE MATTER Vol.II, page 8-10 (March, 2001), available at [http://www.epa.gov/ncea/pdfs/partmatt/VOL\\_II\\_AQCD\\_PM\\_2nd\\_Review\\_Draft.pdf](http://www.epa.gov/ncea/pdfs/partmatt/VOL_II_AQCD_PM_2nd_Review_Draft.pdf) (last visited Dec. 20, 2002) (discussing limited available data to discern mortality rates).

<sup>82</sup> See BAUMOL & OATES, *supra* note 37, at 41.

<sup>83</sup> The Clear Skies Initiative has an SO<sub>2</sub> cap of 3.0 million tons and a NO<sub>x</sub> cap of 1.7 million tons. See S. 2815, 107<sup>th</sup> Congress (2002). The Jeffords Proposal has an NO<sub>x</sub> cap of 1.51 million tons and a SO<sub>2</sub> cap of 2.25 million tons. See S. 556 107<sup>th</sup> Congress (2002). The timing of the two proposals varies, with the

allowances, that is the relative incremental control cost, is 1.4.<sup>84</sup> Under such an approach, the market is willing to reduce SO<sub>2</sub> emissions by one ton in exchange for increasing NO<sub>x</sub> emissions by 1.4 tons.<sup>85</sup> We also presume that the relative incremental environmental damage from SO<sub>2</sub> is 3 times as great as from NO<sub>x</sub>,<sup>86</sup> although we address in a later section the implications of uncertainty in this estimate.

### **B. Calculating Savings from Integrating NO<sub>x</sub> and SO<sub>2</sub> Markets.**

The level of NO<sub>x</sub> and SO<sub>2</sub> emissions as they may be capped by the 108<sup>th</sup> Congress is shown as point B – the baseline scenario – in Figure 3. Points on a line with a slope of –3 that goes through the baseline scenario at point B thus have emissions levels that offer environmental protections equivalent to point B. Allowing firms to acquire one SO<sub>2</sub> permit in exchange for three NO<sub>x</sub> permits, or vice versa, would shift emissions along this line. Such shifts would continue until the relative incremental cost of controlling emissions equals the exchange rate of three NO<sub>x</sub> to one SO<sub>2</sub>. At any other level of emissions firms could make money by buying the relatively inexpensive permit from the market, exchanging it for the relatively more expensive one, and then selling it for cash. We identify two points (J and K) on this trading line that have ratios of marginal costs illustrated by the isocost curves that have slopes somewhat less than and somewhat

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Jeffords Proposal achieving its ultimate reduction targets nearly a decade earlier. See BILLY PIZER & DALLAS BURTRAW, A SIDE-BY-SIDE COMPARISON OF S. 556 AND S. 2815 (2002), at

<http://www.rff.org/Jeffords-Clear%20Skies%20table%209-25-02.pdf> (last visited Dec. 20, 2002) Also, both proposals include the opportunity for banking, which means that annual emissions would not approximate annual allowance allocations until after the bank reaches equilibrium.

<sup>84</sup> The numbers that we present are the arithmetic averages of the relevant values for the 11 year period from 2010 to 2020.

<sup>85</sup> See *supra* note 67 and accompanying text (discussing relative permit prices). The relative permit price is 1.4, which means that the incremental cost of controlling one ton of SO<sub>2</sub> is 1.4 times the incremental cost of controlling one ton of NO<sub>x</sub>. Thus, increasing NO<sub>x</sub> emissions by 1.4 tons will lower control costs by the same amount as a reduction in SO<sub>2</sub> emissions of one ton. Since such a change in emissions would not raise control costs, we assume that emissions sources would be willing to undertake such a change.

<sup>86</sup> See BANZHAF, ET AL., *supra* note 77, at 2, 11-12; see, e.g., OMB, *supra* note 22, at 46.



greater than  $-3$ . The lowest cost point on this line lies between these two points J and K in Figure 3, where an isocost curve with a slope of  $-3$  is just tangent to the line.

This analysis suggests that integrating markets for  $\text{NO}_x$  and  $\text{SO}_2$  permits could reduce compliance costs by at least \$1.1 billion annually, from \$11.8 billion to \$10.6 billion.<sup>87</sup> The \$1.1 billion excludes changes in the consumer surplus from higher electricity prices, which are typically smaller than compliance costs.<sup>88</sup> From a baseline scenario that resembles Clear Skies, market integration (shown by points J and K) would increase  $\text{NO}_x$  emissions between 1.5 million and 2 million tons per year, while lowering  $\text{SO}_2$  emissions by 0.5 million to 0.67 million per year according to analysis using the Haiku model. Given the evidence that the benefits of reducing  $\text{SO}_2$  are about three times as large as the benefits of reducing  $\text{NO}_x$ , this change in the mix of emissions would not reduce expected environmental protection.

### C. Dealing With Uncertainty

Montero (2002) analyzes in detail the merit of integrating related pollutant markets when regulators face uncertainty about the marginal benefits of different pollutants.<sup>89</sup> He shows that even with uncertainty about the benefits, as long as the marginal cost curve is steeper than the marginal benefits curve - that is, the absolute value of marginal costs are greater than marginal benefits in the vicinity of emissions

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<sup>87</sup> These estimates reflect the average of the annual cost savings over the years 2010 to 2020. During this period the Clear Skies Initiative involves increasingly stringent caps. See EPA, Clear Skies Initiative Summary 6,12 (2002), available at <http://www.epa.gov/clearskies/clearskiessummary04-11.pdf> (last visited Dec. 20, 2002) (graphing the cost of  $\text{SO}_2$  and  $\text{NO}_x$  reductions for 2010-2020). N.B.: Cost savings in a particular year are not necessarily representative.

<sup>88</sup> See Karen Palmer, et al., Restructuring and the Cost of Reducing  $\text{NO}_x$  Emissions in Electricity Generation (Resources for the Future, 2001), available at [http://www.rff.org/disc\\_papers/PDF\\_files/0110REV.pdf](http://www.rff.org/disc_papers/PDF_files/0110REV.pdf) (last visited Dec. 20, 2002).

<sup>89</sup> See Juan Pablo Montero, *Multipollutant Markets*, 32 RAND J. ECON. 762-74 (2002).

targets - the economically optimal policy is to integrate the pollutant control markets.<sup>90</sup> The rationale is that interpollutant trading provides flexibility to firms to avoid high control costs by shifting control efforts to a pollutant that is relatively inexpensive to control. If the marginal cost curves are steeper than the marginal benefit curves, the regulator should pay more attention to the cost of control rather than the amount of control, and therefore, markets should be integrated.<sup>91</sup>

There are several reasons to believe that marginal cost curves are steeper than the marginal benefit curves. The marginal benefit curves are essentially flat, because the values of the risk reduction from exposure to fine particles, which are the vast majority of all benefits, appear to vary linearly with concentration.<sup>92</sup> In addition, NO<sub>x</sub> and SO<sub>2</sub> from power utilities are only a relatively small share of total emissions, so the change in emissions from these sources will have a diluted impact on aggregate emissions and air quality.<sup>93</sup>

#### **IV. Adverse Environmental and Health Effects of Trading Can Be Controlled.**

Integrating NO<sub>x</sub> and SO<sub>2</sub> markets is only a small departure from current policy. All major legislative proposals allow NO<sub>x</sub> and SO<sub>2</sub> emissions from any given plant to depend in large part on market conditions, while setting national emissions rates by statute.<sup>94</sup> However, current programs do not fix national NO<sub>x</sub> levels. For example, plants

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<sup>90</sup> See *id.* at 762.

<sup>91</sup> See *id.* at 763. In the other case, where the marginal benefit curves are steeper, the regulator should pay more attention to the amount of control in each market, and therefore the markets should be separated. *Id.*

<sup>92</sup> See OFFICE OF POLICY, OFFICE OF AIR AND RADIATION, U.S. ENVTL. PROT. AGENCY, EPA-410-R-99-001, BENEFITS AND COSTS OF THE CLEAN AIR ACT: 1990-2010, EPA REPORT TO CONGRESS, p. 57, D-8, D-9 (1999), available at <http://www.epa.gov/air/sect812/1990-2010/frullrept.pdf> (last visited Dec. 20, 2002).

<sup>93</sup> See POLICY BOOK, *supra* note 17. See footnote 101.

<sup>94</sup> See S. 556, 107<sup>th</sup> Cong. § 706 (2002); S. 588, 107<sup>th</sup> Cong. §§ 4(b), 7 (2002); S. 2815, 107<sup>th</sup> Cong. § 403 (2002); H.R. 5277, 107<sup>th</sup> Cong. § 403 (2002); H.R. 1256, 107<sup>th</sup> Cong. § 2(b)(B) (2002) (providing for trading); see also S. 556, 107<sup>th</sup> Cong. § 704 (2002); S. 588, 107<sup>th</sup> Cong. § 2 (2002); S. 2815, 107<sup>th</sup> Cong.

with dissimilar access to low-sulfur coal or with different incremental control costs would emit different mixtures of NO<sub>x</sub> and SO<sub>2</sub> for any given set of emission permit market prices. In this sense, an exchange of SO<sub>2</sub> permits for NO<sub>x</sub> permits is not qualitatively different in its effects on environmental protection than the type of trading already in place. Trading NO<sub>x</sub> for SO<sub>2</sub> is unlikely to weaken environmental protection relative to existing and likely programs.

### **A. Managing Risks**

Deriving an unbiased estimate of relative damages is difficult. For this reason, it may be worth considering approaches that reduce the risk that integrating NO<sub>x</sub> and SO<sub>2</sub> markets actually damages the environment. The simplest approach would be for a government office simply to exchange permits in a way that reduces expected environmental damages. For example, a government office could sell 30 NO<sub>x</sub> permits in exchange for 11 SO<sub>2</sub> permits (or sell 10 SO<sub>2</sub> permits for 33 NO<sub>x</sub> permits). Either trade would provide a tax “for the environment” of ten percent given that expected environmental damages from SO<sub>2</sub> are three times as great as from NO<sub>x</sub>. As long as the tax is not excessive, trades at these distinct exchange rates would reduce expected environmental damages.<sup>95</sup>

To illustrate the potential magnitude of environmental benefits from this approach, we consider a case where the government grants permits to emit two tons of NO<sub>x</sub> in exchange for a permit to emit a ton of SO<sub>2</sub>. As noted earlier, two tons of NO<sub>x</sub>

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§§ 413-4, 441 (2002); H.R. 5266, 107<sup>th</sup> Cong. §§ 413-4, 441 (2002); H.R. 1256, 107<sup>th</sup> Cong. § 2 (2002) (limiting emissions).

<sup>95</sup> Offset programs in areas that do not attain national ambient air quality standards already require such emission reduction ratios. Many analysts believe, however, that these ratios have significantly impeded trading. See Bob Hahn & Gordon L. Hester, *Where did all the Markets Go? An Analysis of EPA's Emissions Trading Program*, 6 YALE J. ON REG. 109,146 (1989) (analyzing the EPA's emissions trading

cause less expected environmental damage than a ton of SO<sub>2</sub>. In this case, from the baseline of 1.5 million tons of NO<sub>x</sub> and 2.5 million tons of SO<sub>2</sub>, firms would willingly exchange permits for a half million tons of SO<sub>2</sub> in order to obtain permits to emit an additional million tons of NO<sub>x</sub>. To see this, note that they could profit by such trades because our analysis with the Haiku model indicates that in the baseline scenario a permit to emit a ton of SO<sub>2</sub> is about 1.4 times as expensive as a permit to emit a ton of NO<sub>x</sub>. Firms that give up permits to emit 10 tons of SO<sub>2</sub> in exchange for permits to emit 20 tons of NO<sub>x</sub> would profit by the value of permits to emit 6 tons of NO<sub>x</sub>. Such profitable exchanges would continue until the cost of reducing SO<sub>2</sub> emissions rose to equal twice the cost of reducing NO<sub>x</sub> emissions.<sup>96</sup> Our analysis with the Haiku model implies that this condition would occur with annual NO<sub>x</sub> emissions of 2.5 million tons and annual SO<sub>2</sub> emissions of 2 million tons. The Haiku model indicates that the costs of achieving these emissions limits are \$800 million per year less than in the baseline scenario, but net environmental damages have also fallen by the equivalent of a half million tons of NO<sub>x</sub>. The reductions in SO<sub>2</sub> emissions of a half million tons per year from the baseline scenario have environmental benefits equivalent to 1.5 million tons of NO<sub>x</sub>, given the evidence summarized above that the incremental environmental damages of a ton of NO<sub>x</sub> emissions are about a third of the incremental damages of a ton of SO<sub>2</sub>. These benefits outweigh by an amount equivalent to about a half million tons of NO<sub>x</sub> the environmental damages from increased NO<sub>x</sub> emissions relative to the baseline scenario.

A refinement of this approach would allow different exchange rates for different ratios of NO<sub>x</sub> and SO<sub>2</sub> emissions. It may make sense to allow further increases in NO<sub>x</sub>

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program).

emissions only in exchange for progressively larger reductions in SO<sub>2</sub> emissions. For example, as NO<sub>x</sub> emissions from power plants increase, municipalities may find it harder to meet EPA's ozone air quality standard because NO<sub>x</sub>, but not SO<sub>2</sub>, contributes to ozone.<sup>97</sup> Regulators could allow firms to get 30 NO<sub>x</sub> permits for every 10 SO<sub>2</sub> permits, but only up to a given level, beyond which the rate might change to 30 to 11.

To further reduce the risk of adverse environmental effects from NO<sub>x</sub>-SO<sub>2</sub> exchanges, Congress, after authorizing trades between NO<sub>x</sub> and SO<sub>2</sub>, could charge EPA with reviewing new scientific evidence to assess whether exchange rates reflect unbiased estimates of relative incremental environmental damages. Congress could authorize EPA to change the exchange rate through rulemaking if it concluded that the exchange rate lowered air quality.

### **B. State and Local Health-Based Regulations Will Buttress Federal Trading Approaches**

Some public health advocates may oppose NO<sub>x</sub>-SO<sub>2</sub> trading because increases in emissions of NO<sub>x</sub> emissions - but not SO<sub>2</sub> emissions - can result in elevated ozone concentrations. Although ozone is a less significant health risk than particulates formed from sulfates and nitrates, ozone is associated with childhood asthma attacks.<sup>98</sup> There may be concerns that families should not bear increased risks of asthma attacks in children in exchange for reduced mortality from particulates that would primarily affect elderly parents.

There are several flaws with this argument. Although NO<sub>x</sub> may contribute to more frequent asthma attacks among children, NO<sub>x</sub> emissions from utilities under either

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<sup>96</sup> At this point the government would be offering to exchange SO<sub>2</sub> permits for NO<sub>x</sub> permits of equal value.

<sup>97</sup> See EPA Air Quality Standard For Ozone, 40 C.F.R. §§ 53.1-53.21, 58.1-58.32 (1997).

S.556 or the Clear Skies Initiative would be around 8 % to 10 % of total NO<sub>x</sub> emissions, so a given percentage increase in utilities' NO<sub>x</sub> emissions is a much smaller percentage increase in the total.<sup>99</sup> Further, the philosophy and strategy of Title I of the Clean Air Act is to allow states to choose how, but not whether, to meet federally mandated health-based ozone standards.<sup>100</sup> The multi-pollutant bills will be buttressed by additional local emissions reductions in locales where air quality is poor.<sup>101</sup>

## Conclusion

Congress should encourage changes in the mix of NO<sub>x</sub> and SO<sub>2</sub> emissions, in particular, reductions in emissions of the pollutant for which the bang for the buck is greater. Existing legislative proposals to control multiple pollutants from power plants do not take advantage of opportunities to reduce both environmental damages and compliance costs because they adopt a pollutant-by-pollutant approach, and prohibit shifts in the mix of NO<sub>x</sub> and SO<sub>2</sub> emissions.

While choosing the right NO<sub>x</sub>-SO<sub>2</sub> exchange rate may be difficult, there is no doubt that an outright prohibition of such transactions is excessively prescriptive and burdensome. It makes sense only given the irrational assumption that a reduction in

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<sup>98</sup> *See id.*

<sup>99</sup> We calculate 8 % as a ratio between the S.556 proposal of 1,550,000 tons of NO<sub>x</sub> emissions and total NO<sub>x</sub> emissions from all anthropogenic sources in 2007 as projected in the regulatory analysis for EPA's 2000 Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, or 20,600,000 tons. *See* OFFICE OF AIR AND RADIATION, U.S. ENVTL. PROT. AGENCY, EPA420-R-00-026, REGULATORY IMPACT ANALYSIS: HEAVY DUTY ENGINE AND VEHICLE STANDARDS AND HIGHWAY DIESEL FUEL SULFUR CONTROL REQUIREMENTS 145, Table II.B-27 (2000), *available at* <http://www.epa.gov/otaq/regs/hd2007/frm/ria-ii.pdf> (last visited Dec. 20, 2002) (listing total NO<sub>x</sub> emissions in 2007 along with components due to vehicles and other sources). Ten percent is the Clear Skies Initiative's emissions cap of 1,700,000 tons of NO<sub>x</sub> emissions in 2018 relative to the total emissions of NO<sub>x</sub> from anthropogenic sources in 2020 as projected in the same analysis, or 17,900,000 tons. *See* S. 556 107<sup>th</sup> Cong. § 704 (Jeffords Proposal NO<sub>x</sub> emissions levels); EPA Fact Sheet on Clear Skies Initiative 2 (2002), *available at* [http://www.epa.gov/clearskies/clearskiesfactsheet\\_3\\_26.pdf](http://www.epa.gov/clearskies/clearskiesfactsheet_3_26.pdf) (last visited Dec. 20, 2002) (Clear Skies Initiative NO<sub>x</sub> emissions levels).

<sup>100</sup> *See* Clean Air Act § 110(a)(1), 42 U.S.C. § 7410.

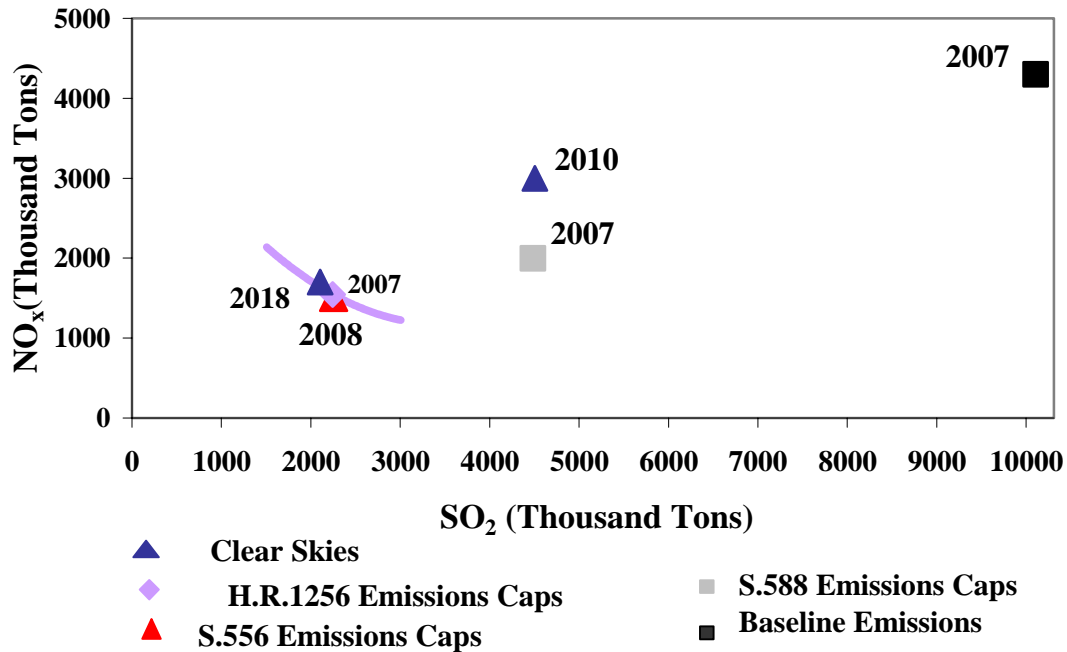
national emissions of NO<sub>x</sub> (or SO<sub>2</sub>), regardless of its size, could never compensate for a one-ton increase in emissions of SO<sub>2</sub> (NO<sub>x</sub>). Yet, all multi-pollutant proposals offered to date embody this approach. Since the appropriate exchange rate may be hard for Congress to set, it should direct EPA to set it in rulemaking to be equal to the ratio of expected incremental damages.

Congress should abandon the pollutant-by-pollutant approach that it has used to develop new emissions legislation because it is incompatible with cost-effective environmental protection. The mix of emissions should vary with control costs and not be set at absolute and unchanging statutory levels. Allowing markets to choose the lowest-cost set of NO<sub>x</sub> and SO<sub>2</sub> emissions from among ones with equivalent environmental effects will lower the costs of emissions controls. Economic modeling suggests that cost savings from integrating NO<sub>x</sub> and SO<sub>2</sub> markets could exceed \$1.1 billion per year without reductions in environmental benefits. This no-lose solution should interest both those environmentalists and industry representatives who promote cost-effective clean air policy.

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<sup>101</sup> The purposes of the bills do not include a goal to eliminate the need for additional local emissions reductions. *See, e.g.*, S. 556, 107<sup>th</sup> Cong. (2001) and H.R. 5266, 107<sup>th</sup> Cong. (2002).

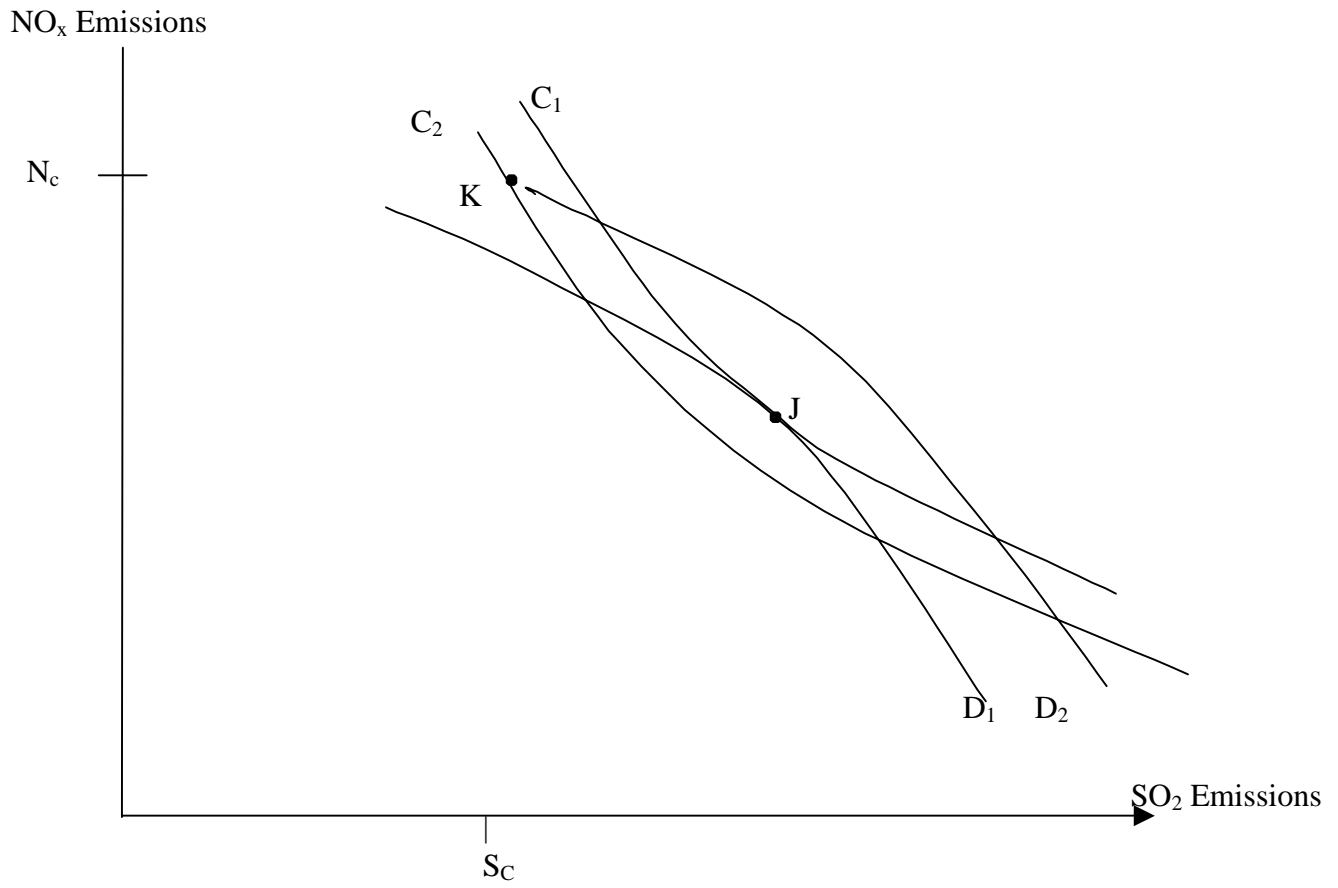
**Figure 1**  
**NO<sub>x</sub> and SO<sub>2</sub> Utility Emissions**



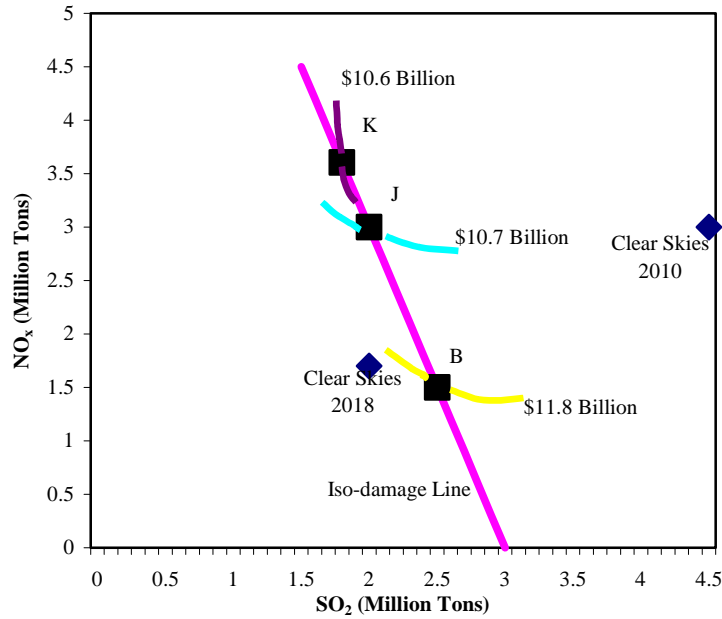
Note: The curve that goes through the H.R.1256 emissions cap represents the set of NO<sub>x</sub> and SO<sub>2</sub> emissions where compliance costs are approximately constant, based on EIA's estimates of SO<sub>2</sub> and NO<sub>x</sub> permit prices for the emissions reductions in an earlier version of S.556, which was identical to H.R. 1256. Effective dates for the bills differ slightly. Emissions allowance caps for S.556, which are very similar to those in H.R. 1256, would be effective in 2008; the NO<sub>x</sub> cap in S.588 would begin in 2004 and grow until 2007; H.R. 1256 would be effective in 2007, while the Administration's Clear Skies proposal would take effect in 2008 and specify increasingly stringent caps for 2010 and 2018. Banking enables emissions to remain above allowance caps until the bank is exhausted.



**Figure 2**  
**Improved Air Quality and Reduced Compliance Costs with NO<sub>x</sub>-SO<sub>2</sub> Trading**



**Figure 3**  
**NO<sub>x</sub>-SO<sub>2</sub> Permit Trading Saves More than \$1 Billion Annually**



Note: The diamonds labeled Clear Skies, “◆”, represent emissions in 2010 and 2018 under the Bush Administration’s proposal. The squares representing points B, J and K refer to annual levels of NO<sub>x</sub> and SO<sub>2</sub> emissions averaged over the years 2010 to 2020. The iso-cost curves going through these three points are the sets of NO<sub>x</sub> and SO<sub>2</sub> emissions where annual control costs are constant at \$11.8 billion, \$10.7 billion and \$10.6 billion respectively. The slopes of the various iso-cost curves at the points B, J and K represent the incremental costs of controlling SO<sub>2</sub> relative to the incremental costs of controlling NO<sub>x</sub>. The iso-damage line represents the combination of NO<sub>x</sub> and SO<sub>2</sub> emissions expected to offer the same protection to health and the environment as point B. It assumes that one ton of SO<sub>2</sub> is as damaging as 3 tons of NO<sub>x</sub>. Since points B, J and K all offer the same level of protection, but differ by at least \$1 billion annually in control costs, allowing firms collectively to increase NO<sub>x</sub> emissions in exchange for additional SO<sub>2</sub> reductions, should save at least \$1 billion annually without lowering environmental protection.