

# Opportunities and Challenges for the 20<sup>th</sup> Anniversary of the Montreal Protocol\*

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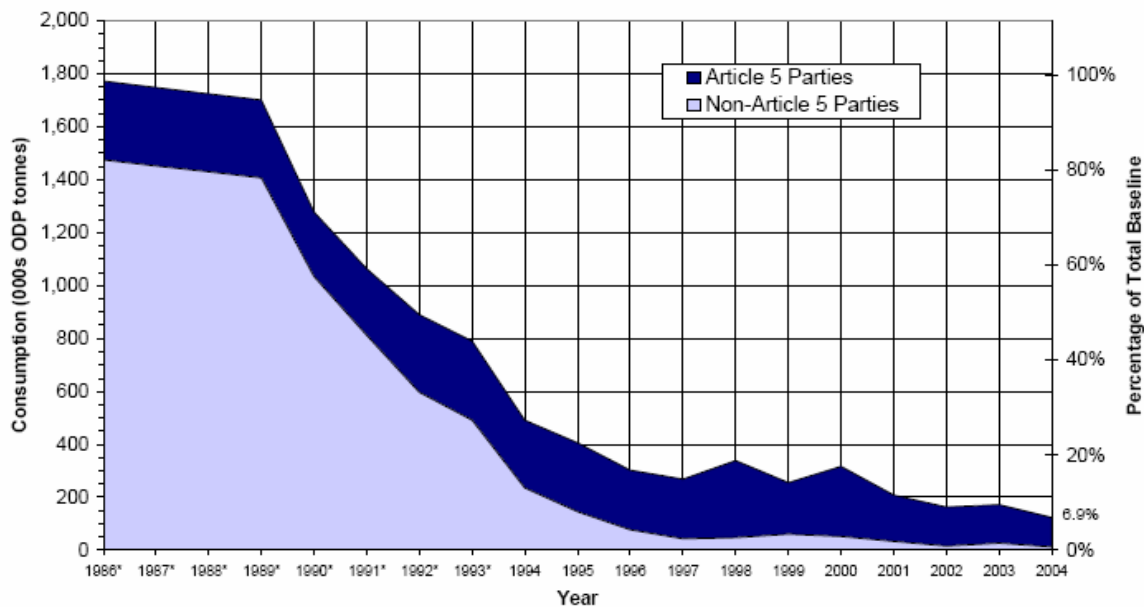
## I. Background

When the Montreal Protocol was signed in 1987, scientific understanding of the effects of anthropogenic emissions of CFCs and other halogenated chemicals on the ozone layer was incomplete. The full effects of ozone depletion on human health, other species, and ecosystems was not known. Large uncertainties surrounded estimates of the economic costs of phasedown of ozone-depleting substances (ODSs), in part because of an absence of proven technical alternatives for many of the applications of ozone-depleting compounds. Over the past twenty years, many of these gaps in scientific knowledge and technological capability have been filled in. The Montreal Protocol itself has undergone significant evolution, increasing in stringency and participation as evidence on both the severity of the ozone depletion problem and the range of possibilities for substitution away from ODSs has become available. The Protocol is now widely viewed as the most successful international environmental agreement to date. It has near-universal membership, an excellent record of compliance, a history of promoting cooperation in the development and diffusion of ozone-friendly technologies, and a record of effective multilateral funding of ODS-reducing investments in developing countries.

The success of the Protocol is most clearly evident in the massive reductions in ODS use worldwide since 1986. Ninety percent of ODS use is now in developing countries with access to Multilateral Fund (MF) monies. Figure 1, from UNEP's *2005 Consumption and Production Report* (p. 16), illustrates the overall trend. Table 1 reports a breakdown of recent usage by annex and Article 5(1) status (exclusive of quarantine and pre-shipment (QPS) uses, feedstock, and process agent uses).

**Figure 1**

**Consumption of All Controlled ODSs (All Annex Groups)**



**Table 1**

2003-2004 Average Reported ODP Consumption\*

	Article 5(1) Countries	Non-Article 5(1) Countries	Major Uses	% total ODP
CFCs	69753	2051	MDIs, refrigeration	48.3
<i>region share of total</i>	<i>0.97</i>	<i>0.03</i>		
Halons	7406	-3952	Specialised fire extinguisher	2.3
HBFCs	0	0		0
<i>region share of total</i>				
HCFCs	17825	12874	Refrigerant	20.7
<i>region share of total</i>	<i>0.58</i>	<i>0.42</i>		
Methyl Bromide**	6694	9884	Soil and building fumigant	11.2
<i>region share of total</i>	<i>0.40</i>	<i>0.60</i>		
Methyl Chloroform	1332	-262	Inhaled anesthetic during surgery	0.7
Other Fully Halogenated CFCs	7	-722		0
Bromochloromethane	37	-36	Fire extinguisher fluids	0
Carbon Tetrachloride	25950	-311	Solvent, for production of CFCs	17.3

\* Consumption is production plus imports minus exports and thus can be negative as stocks are drawn down.

\*\* Excludes QPS

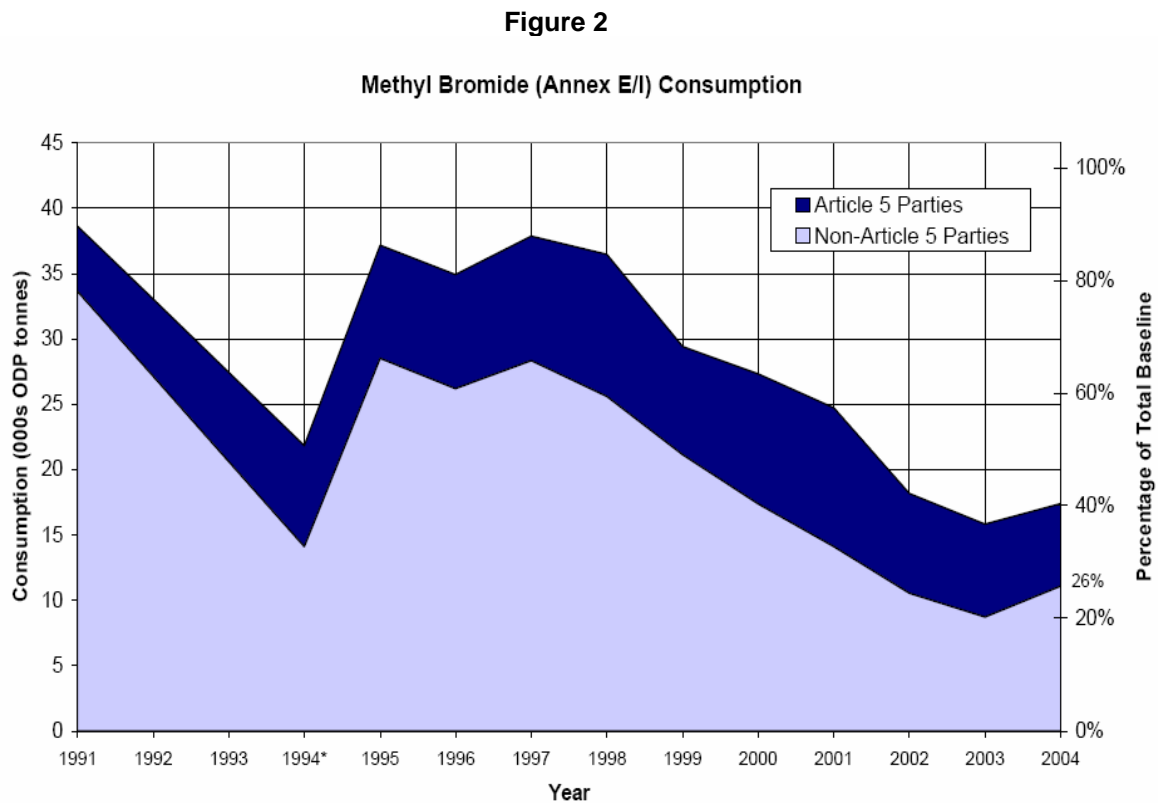
Despite the success to date, new opportunities are available to further protect the ozone layer and climate. The large historic ODS production and consumption reductions should not obscure the fact that considerable work remains to be done. Remaining significant uses include CFCs, HCFCs, methyl bromide and carbon tetrachloride, as shown in Table 1. Of these, HCFCs and MeBr are still fairly widely used in non-Article 5(1) countries. Methyl Bromide for (QPS) fumigation is not yet controlled under the Protocol in any of the Parties. CFCs are scheduled for 85% phaseout in Article 5(1) countries this year and complete phaseout by 2010; in these countries, 2004 (the last year for which complete reporting is available) levels of consumption were over 40% of baseline. Carbon tetrachloride is scheduled for 85% reduction from the 1998-2000 baseline in 2005 and elimination by 2010, though there is a provision for exemptions totaling less than 15% of baseline extending indefinitely.

HCFCs are scheduled for phaseout in non-Article 5(1) countries according to the following schedule: 35%, 1/1/04; 65%, 1/1/10; 90%, 1/1/15; 99.5%, 1/1/20; and 100%, 1/1/30. 2003 and 2004 reported consumption were 40 and 30% of baseline, respectively. In Article 5(1) countries, use can continue to expand prior to a 2016 freeze. Full phaseout is scheduled for 2040.

Methyl Bromide is available for non-QPS use in non-Article 5(1) countries only under Critical Use Exemptions (CUEs) agreed to by the Parties. With the exception of CUEs, phaseout was to be complete in 2005. Nonetheless, the process of negotiating these exemptions has proven to be complicated, and the CUEs have been and continue to be

significant. In Article 5(1) countries, 20% reductions from the baseline were required by 2005 and full phaseout is scheduled for 2015. Reported total use in 2005 was just over 40% of baseline.

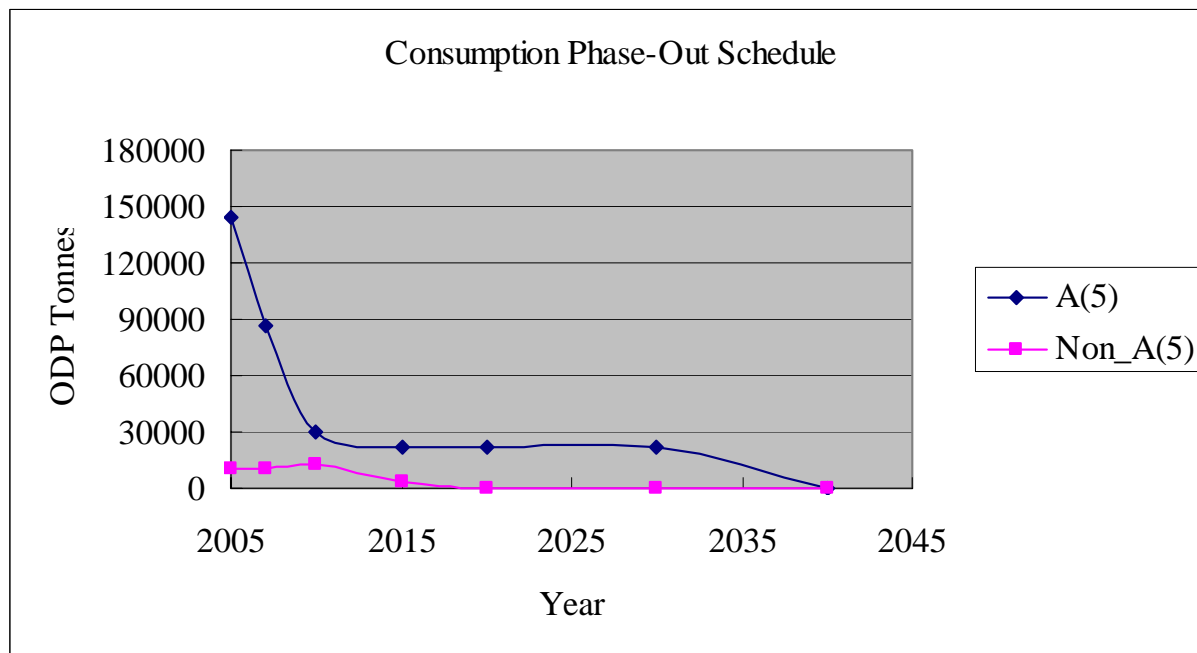
Total MeBr consumption actually increased from 2003 to 2004; Figure 2 shows that the reductions in use have not been as rapid in this sector as in others.<sup>1</sup> In the United States, which has received the largest exemptions thus far, 2004 consumption more than doubled 2002 consumption, and 2005-2007 CUEs, while declining from year to year, are for amounts greater than 2004 consumption.



Current projections show that the ODS phaseout will proceed in an orderly fashion moving forward in time if current goals are met. Figure 3 plots maximum permissible ODS consumption levels in Article 5(1) and non-Article 5(1) countries through 2040, including maximum permitted exemptions where specified. Note that this illustrative figure assumes HCFC use is fixed at 2005 levels through 2030 in Article 5(1) countries and that no further EUEs or CUEs will be granted.

<sup>1</sup> Figure 2 is from the UNEP Production and Consumption of Ozone Depleting Substances: 1986-2004 (2005, p. 15). The 1994 dip reflects a reporting anomaly rather than an actual reduction.

Figure 3



The achievements of the Protocol are deeper and more far-ranging than the story told by the data alone, impressive as that is. The Multilateral Fund provides a working example of how developed and developing countries can cooperate to solve a vital global environmental problem while simultaneously promoting economic development. The diplomatic formula for the Fund's financing of "agreed incremental costs" has proven workable in the consensus framework of the Fund's decision-making process. Political and economic support for the Fund has remained strong, with its periodic replenishments adequate for its financial requirements. On the ground, the Fund has supported thousands of projects to eliminate ODSs and develop institutional and technological capacity in Article 5(1) countries.

The Protocol has a flexible legal framework that allows Parties to incorporate, by Amendment, chemicals that were not included in the original 1987 list of regulated substances. The Parties agreed on several occasions to accelerate the phaseout schedule in the light of new scientific information that emerged during the 1990s and 2000s moving from eight initially-controlled compounds to more than 90 (Bird 2001). The Protocol has developed procedures for handling Critical Use Exemptions and Essential Use Exemptions. Its working committees operating under the Technical and Economic Assessment Panel (TEAP) have been a consistent source of reliable, high-quality information, and have greatly facilitated the transfer of technological information across national and corporate boundaries. The TEAP and the Scientific Assessment Panel

(SAP) of the Montreal Protocol have also worked with the IPCC to assess the interaction between ozone depletion and climate change.<sup>2</sup>

Implementation of the Protocol has also produced unanticipated benefits. In some cases, the stimulus provided by the phaseout schedule resulted in research breakthroughs that lowered cost and/or improved quality, and helped overcome institutional barriers that otherwise would have hindered the transition out of ODSs.<sup>3</sup> It has been observed that *ex ante* estimates of the costs of environmental regulations tend to be higher than the actual costs (Harrington et al. 2000, Goodstein 1997), and this pattern has been borne out for the ODS phaseout. Per unit costs of ODS abatement have fallen over time; this finding as reported in DeCanio and Norman (2005) based on statistical analysis of data from the Multilateral Fund through 2003 has been confirmed for Fund data extending through the end of 2006 (see Section III below). Any tendency to take advantage of low-cost abatement opportunities first (the so-called ‘low hanging fruit’ phenomenon) has been dominated by cost reductions over time associated with learning by doing, achievement of scale economies as the new technologies have become widespread, and the possibilities of applying more sophisticated techniques (e.g., computer controls) to problems such as the design and operation of HVAC systems.

Despite these successes, a number of concerns remain. The 2006 Antarctic ozone hole was of record or near record size for three months of 2006.<sup>4</sup> The continuing damage caused by previous ODS emissions and ODS “banked” in old equipment cannot be ignored, given that full recovery of the ozone layer is not predicted to occur until mid-century at the earliest.<sup>5</sup> The estimated date of recovery has recently been revised upward (NASA 2006). Most significantly, the threat posed by climate change has not yet been adequately addressed by the global community. James Hansen, a leading climate scientist at NASA in the US, stated in September 2006 that he believes the world has “no longer than a decade, at most” to take decisive action on anthropogenic climate change (MSNBC News Services 2006). The IPCC released a summary of the first part of its Fourth Assessment Report on February 2, 2007, reporting that climate change was happening rapidly and was being driven by anthropogenic factors, chiefly the use of fossil fuels for energy. The IPCC projects an increasing pace of change for a broad

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<sup>2</sup> Significant examples include the IPCC/SAP Special Report on *Aviation and the Global Atmosphere* (Penner *et al.*, eds., 1999) and the IPCC/TEAP *Special Report On Safeguarding the Ozone Layer and the Global Climate System* (Metz *et al.*, eds., 2005). These may be thought of as illustrations of the “Porter hypothesis” that regulatory pressure can stimulate innovation (Porter 1991; Porter and van der Linde 1995a,b).

<sup>3</sup> For examples of the technological progress and increased productivity brought about by Protocol-induced research, see Cook (1996) and Andersen and Zaelke (2003). For institutional innovations (such as the replacement of a 113-based standard in military specifications by a performance standard), see Wexler (1996).

<sup>4</sup> See <http://www.cpc.ncep.noaa.gov/products/stratosphere> for updates.

<sup>5</sup> Estimates are subject to considerable uncertainty about the impacts of changes in climate patterns on ozone accumulation and depletion.

number of future growth and development scenarios. Given that the health of the ozone layer and the global climate are inextricably connected, the open-endedness of the climate risk means that there is no room for complacency regarding the Montreal Protocol's success to date.

In the absence of radically new energy generating technology, socially and politically feasible ways to reduce energy use without massive quality of life reductions are critical. The Kyoto Protocol has proposed reductions but has had limited success in reaching agreement among major greenhouse gas emitters and in achieving success for those countries that have committed to the process. Kyoto's agreed-upon provisions run out in 2012, and the recent agreement by the European Union to achieve a 20% reduction in greenhouse gas emissions from the 1990 baseline does not include the United States, China, India, and other major emitters (Bilefsky 2007). Reductions in CFCs already undertaken by Parties to the Montreal Protocol amount to significant reductions in direct greenhouse effects; CFC-12 emissions, for instance, have been nearly eliminated and this chemical has a direct GWP estimated at 10,720 (relative to carbon dioxide). The IPCC/TEAP *Special Report* (2005) cited previous estimates that ODS reductions under Montreal accounted for a 0.5 GtCO<sub>2</sub>-equivalent annual reduction in greenhouse emissions from 1990 to 2000. The Montreal Protocol has accounted for GHG reductions equivalent to approximately five times the reductions that would be accomplished by meeting the first Kyoto target.<sup>6</sup>

Some large sources of greenhouse gas emissions are only covered by the Montreal Protocol; Kyoto, which regulates atmospheric emissions of six greenhouse gases, explicitly excludes all substances listed under Montreal. However, most of the Montreal substances are powerful greenhouse gases, and many of the substances that replace phased-out ODSs are also drivers of climate change. Major sectors using ODS and HFC/PFC substitutes include refrigeration, air conditioning, foams, aerosols, fire protection and solvents (IPCC/TEAP 2005, p. 2). Nevertheless, even in the light of these clear connections between climate and ozone protection, co-investment to realize joint benefits has been difficult to accomplish under the current treaty frameworks.

## **II. Multi-objective policies for global environmental protection under the Montreal Protocol**

### *A. Analytical framework<sup>7</sup>*

In this section, we first lay out a rationale for using information on the value placed on climate and ozone protection by the global community to consider the two impacts simultaneously for particular projects or uses. We present data on expenditures on

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<sup>6</sup> Computed from Velders et al. (2007, Table 2), under the assumption that the Kyoto target is approximately 2 GtCO<sub>2</sub>-eq. per year.

<sup>7</sup> This section reproduces some parts of DeCanio and Norman (2007a).

abatement and emissions permits to estimate the implicit stringency of joint regulation that takes these values into account, and show how a decision rule that incorporates these values might work in practice.

Currently, technology exists to support continued progress on ODS reduction with simultaneous significant improvements in energy uses that contribute indirectly to climate change. Further, it is possible that allowing a small increase in anthropogenic ODS emissions might be socially desirable if climate benefits were sufficiently positive. The next section will discuss how, for instance, the large variation in the energy efficiency of refrigerants for chillers, air conditioners, and refrigeration – where in many cases the indirect effects account for most of the global warming effect associated with use of the refrigerant<sup>8</sup> – implies a significant climate impact as well as ozone impacts for decisions taken under the Montreal Protocol. However, the current framework of international environmental agreements does not facilitate joint consideration of climate and ozone layer protection: the Montreal Protocol does not focus on issues related to climate, and some of the potential efficiency gains would be associated with slight increases in uses of ODS relative to alternate technology. There is currently no structure in place to assess ozone/climate tradeoffs systematically.

Parties to the Protocol are aware of the issue; the 2004 Chiller Task Force report (UNEP 2004) notes with concern the risks to the climate associated with HFC-134a, and in 2005 the Intergovernmental Panel on Climate Change issued a special report in collaboration with the TEAP of the Montreal Protocol, prompted by decisions made within each body. The special report called for the “development of simplified standard methodologies” “to identify cost-effective reduction options” in the future (IPCC/TEAP 2005, p. 11).

The calculation of control levels under the Protocol (Article 3, a) and the definition of production (Article 1, 5) together create a “destruction offset” that allows new production of ODS when offset by destruction an equal or greater ODP-weighted ODS from within the same ‘Group’ of controlled substances if both production and destruction occur during the accounting year. For example, two kilograms of halon 1211 (Group II, ODP=3) can be produced for each kilogram of halon 2402 (Group II, ODP=6) destroyed in the same year. This provision could facilitate progress on climate change while remaining consistent with the Protocol’s focus on stratospheric ozone protection.

If the “destruction offset” provision in the Montreal Protocol were implemented with flexibility and appropriate incentives across groups and time, ozone protection could be unaffected or improved while reducing risks of climate change, e.g. by use of an energy-efficient refrigerant with some ozone-depleting potential. The energy efficiency (and thus climate) gains would be ozone-neutral if an ODP-weighted amount of ODS were destroyed equal to what would be emitted from leak-tight equipment offering superior energy efficiency.

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<sup>8</sup> See the IPCC/TEAP (2005, pp. 276-279), which includes detailed illustrations for air conditioning across different refrigerants, technologies, and climate conditions.

Of course, the energy efficiency gains would be ozone-positive if a greater ODP-weighted amount of ODS were destroyed than what would be emitted. Trading schemes can be designed to encourage the proper balance of incentives.

Limited offset credits for ODS destruction are currently embodied in the international framework developed by the Parties to the Montreal Protocol, but have not been implemented by national governments. Nevertheless, current stockpiles of ODS (both in storage and in existing equipment) are large enough to allow considerable room for such efforts. In the case of large building chillers, for example, there is ample existing ODS (which will eventually be released into the atmosphere) to more than offset decades of use of the HCFC-123 that would be used in the most energy-efficient chillers. Offsetting this HCFC-123 with destruction of equivalent ODS would enable progress towards both ozone protection and climate stabilization goals.<sup>9</sup>

Other examples of the potential value of a destruction tradeoff can be considered. Rather than going through a contentious process of application for Critical Use Exemptions for Methyl Bromide each year, the Parties to the Protocol could agree to new flexibility across ODS and over time to allow MeBr emissions offset by assured destruction of other ODS not otherwise scheduled to be destroyed, at an agreed amount of MeBr production for each quantity of ODS destroyed. The costs of the destruction could be borne by the Parties' governments, thereby alleviating the economic burden on MeBr users, or could be financed from user fees. In other cases, unpredictable technological change makes it likely that the precise substitution possibilities will not be known in advance. This speaks for the desirability of a general policy rule, rather than repeatedly going back to the Protocol Parties for specific exceptions. Thus, a flexibility mechanism built into the Protocol stating the circumstances under which an ODS can be used provided an equivalent or greater amount of ODS is destroyed would minimize regulatory uncertainty and the costs of negotiation. An improved market for recovered ODS would also allow governments to protect the ozone layer by paying for collection and destruction and retiring the credits.

While acknowledging the general desirability of a broad destruction offset mechanism, it is also possible to evaluate tradeoffs between the global warming and ozone impacts of the chemicals regulated exclusively under the Montreal Protocol. Implicitly, values on reductions of ODP and GWP/TEWI/LCCP<sup>10</sup> have been and are being determined by

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<sup>9</sup> The Parties may choose, for example, a policy rule requiring that the total estimated depleting effects produced by offsets and trading are equal to or less than those under the business-as-usual regime (Solomon and Albritton 1992). This might require flexibility among groups of ODS and the ability to carry forward unused credits (such that production and destruction need not occur in the same calendar year).

<sup>10</sup> The "life-cycle climate performance" or LCCP is a measure of the total effect on GHG emissions of a change in technologies, including both the direct global warming impact of the emissions and differences in indirect emissions due to differences in the energy efficiency of the technologies over their lifetimes. Reduction of LCCP mitigates climate change. LCCP is more comprehensive than the earlier concept of "total equivalent warming impact" (TEWI), which ignored the energy embodied in product materials, the greenhouse gas emissions during chemical manufacturing, and the impacts of weight on energy consumption of mobile equipment. LCCP was defined by the HFC and PFC Task Force of the TEAP (1999 *op. cit.*). It is being incorporated into a consensus methodology for evaluating mobile air

member parties to both Kyoto and Montreal as well as the carbon markets being established in Europe, the United States, and elsewhere. Our framework makes it relatively easy to accomplish investment with two or more objectives (such as ozone and climate protection, energy independence, local air quality, and reduced toxic emissions).

The most direct approach, to compare the benefits of climate change mitigation and ozone layer protection, is not operationally possible because these benefits are extraordinarily difficult to quantify.<sup>11</sup> The aggregate benefits can be monetized only by making highly contestable assumptions about the “value of a statistical life” across countries at different stages of development; there is no consensus method for comparing costs and benefits across generations; and a major component of the benefit of climate stabilization depends on what assumptions are made about risk aversion.<sup>12</sup> Furthermore, estimates of the macroeconomic cost of greenhouse gas reductions range from negative to positive, with the magnitudes of the positive cost estimates differing by as much as a factor of four.<sup>13</sup>

Even if the aggregate impacts were known with more certainty than seems possible with today’s information and analytical capabilities, the response curves of impacts to changes in greenhouse gas or ODS emissions are almost certainly non-linear, so the marginal effect of specific projects cannot be inferred from aggregate effects. More fundamentally, it is debatable whether cost-benefit analysis is the appropriate tool for analysis of problems that are global in scope, non-marginal in impact, cover centuries of time, and involve the fate of non-human species as well as human beings.<sup>14</sup>

Fortunately, we can infer social values based on the real money has been and is being spent to reduce both ODS and GHG emissions.<sup>15</sup> The current expenditures for emissions

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conditioning efficiency by a VDA [Verband der Automobilindustrie, or German Association of the Automotive Industry]/SAE [Society of Automotive Engineers]/JAMA [Japan Automobile Manufacturers’ Association] team chaired by General Motors (Hill 2006). Descriptions of the original TEWI methodology are in S. K. Fischer *et al.* (1991). This was the first of three such joint studies, the other two published in 1994 and 1997.

<sup>11</sup> Computations of the net losses from ozone depletion and global temperature increases have been published (for the ozone case, see DeCanio (2003a); for climate, see IPCC (1996, pp. 178-224; 2001, pp. 913-967), and HM Treasury (2006, Chapter 6). It should be kept in mind that very large uncertainties must be attached to these numbers, for reasons given in the references cited.

<sup>12</sup> With regard to the treatment of risk aversion, see in particular the forthcoming review by Martin Weitzman (2007) of the *Stern Review*.

<sup>13</sup> See Baker and Ekins (2004), DeCanio (2003b), and Sanstad et al. (2001) for extended discussions of macroeconomic cost estimates.

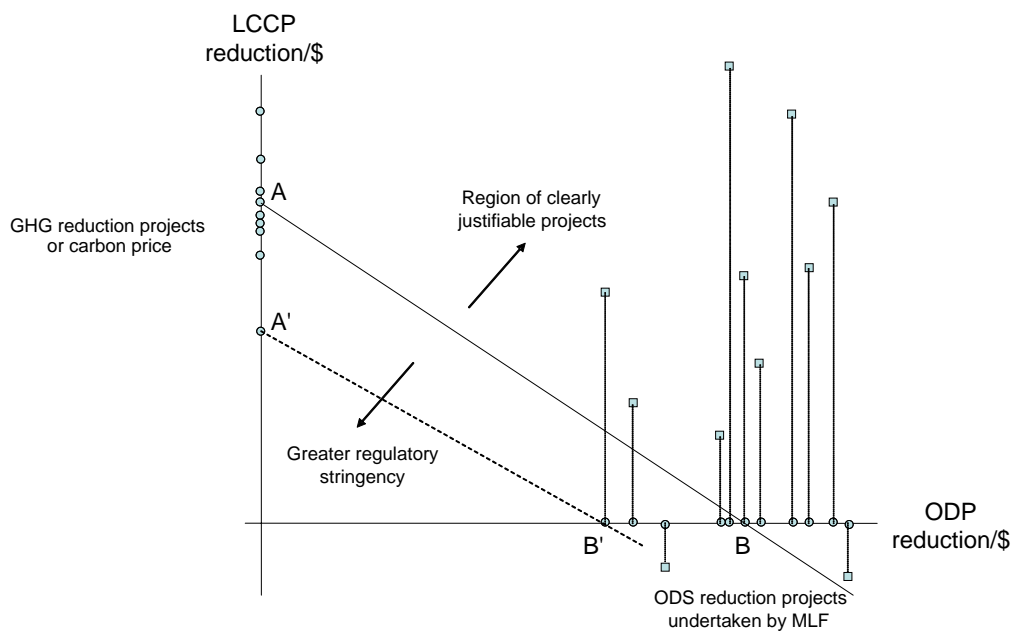
<sup>14</sup> On the limitations of cost-benefit analysis, see Ackerman and Heinzerling (2005) and DeCanio (2006).

<sup>15</sup> It should be noted that in this paper we will assume the automatic desirability of those emissions-reduction projects that can be undertaken at a pure profit by private-sector firms or governmental agencies. These “no regrets” opportunities should be seized regardless of their environmental benefits, and are uncontroversial from a policy perspective. There is an extensive literature documenting the existence of

reductions provide a benchmark of the “political willingness to pay” (PWTP) of present-day governments (DeCanio and Norman 2005). Political willingness to pay reflects collective decisions to finance the most important functions of society such as homeland security, national defense, public health, education, and environment, even when traditional cost-benefit calculations are inappropriate or impossible. Although the decisions to invest in ozone layer protection and climate change mitigation have been made independently, the expenditures on these projects provide a basis for estimating the current level of combined regulatory stringency of the two Protocols.

Consider a two-dimensional mapping of project characteristics with reductions in ODP per dollar spent on one axis and reductions in emissions according to “life-cycle climate performance” or LCCP per dollar on the other. Data on the money spent to eliminate or reduce ODSs are available in the database maintained by the Multilateral Fund operating under the Montreal Protocol,<sup>16</sup> or from case studies of ODP reduction projects undertaken by firms or government entities. From these data it is possible to infer the maximum PWTP to reduce ODP, as well as various measures of the central tendency of this PWTP. Similarly, information is available on the cost of GHG reduction projects undertaken by private firms, international projects certified under the Clean Development Mechanism of

**Figure 4 - Balancing ODS and GHG Reductions**



these no-regrets opportunities for both GHG and ODS emissions reductions. See IPCC, Contribution of Working Group III (1996, Chapters 8 and 9) and Interlaboratory Working Group on Energy-Efficient and Clean-Energy Technologies (2000) for GHG opportunities, and Cook (1996) for ODS cases.

<sup>16</sup> This institution finances the “agreed incremental cost” of ODS replacement projects in developing countries with contributions from the developed countries according to the UN funding formula. See Andersen and Sarma (2002) and Benedick (1998).

the Kyoto Protocol, and the prices of CO<sub>2</sub> emissions permits where sold. The ODP or LCCP reductions per dollar spent on these projects can be represented by points along the two axes as shown in Figure 4. The circles on the axes represent the emissions changes per dollar of the different projects (either ODP or LCCP reductions).<sup>17</sup> The square “dots” reflect the fact that most ODP reductions have also reduced the global warming impact of the transformed processes, either because the replacement technologies have used gases with a lower direct global warming potential than the CFCs they replaced, or the new technologies have been more energy-efficient, or both. Nevertheless, it is possible for an ODP reduction to be associated with an increase in GHG emissions due to indirect effects associated with energy use, so that the “improvement” in LCCP/\$ is negative. Cases of this type would show square dots below the horizontal axis.

The diagonal “stringency tradeoff line” AB is drawn to reflect the combined degree of stringency implicit in the two regulatory regimes. This line connects the central tendencies (e.g., the means or medians) of the distributions of the LCCP reduction project points and the ODP reduction project points. Shifting the AB line towards the origin represents an increase in regulatory stringency; if the axes had been drawn in units of \$/ODP reduction and \$/LCCP reduction, increasing regulatory stringency would be expressed by a movement away from the origin.<sup>18</sup> The slope of AB is a rough measure of the dollar tradeoff between LCCP reductions and ODP reductions embodied in current levels of PWTP.

The tradeoff line could also have been drawn in other ways. For example, the dotted line A'B' connects the most expensive emissions reduction projects.<sup>19</sup> It could be maintained that A'B' more accurately reflects the PWTP frontier than AB, because all projects currently funded lie above and to the right of A'B'. Alternatively, if it were decided under the successor to Kyoto that there should be (for example) a fixed global emissions charge per tonne of CO<sub>2</sub> production, the anchoring point of the AB line on the vertical axis would be at the reciprocal of the fee, with the LCCP axis scaled in tonnes of CO<sub>2</sub> equivalent per dollar.

The area above and to the right of the AB line (or A'B', if the more inclusive definition of PWTP is used as the standard) represents those projects that are clearly justified at the current levels of regulatory stringency of the two Protocols, while projects falling in the area below and to the left of the line AB (or A'B') are not so clearly justified.

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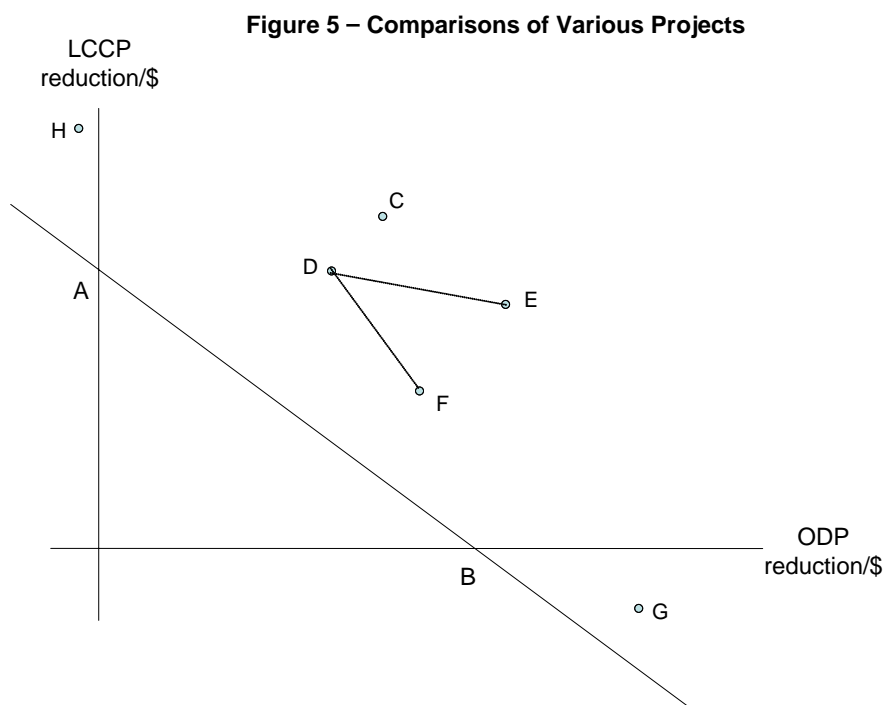
<sup>17</sup> The “data points” shown in Figure 4 are indicative only. Note also that the larger the LCCP reduction per dollar (i.e., the farther up the vertical axis), the greater the environmental benefit. Figure 6 below shows the same framework with actual data.

<sup>18</sup> The choice of whether to use ODP/\$ and LCCP/\$ or \$/ODP and \$/LCCP as units on the axes is arbitrary. The substantive application of the methodology being proposed here is not affected, so long as consistency is maintained in describing the projects. Of course, the tradeoff line could have curvature, but that is a second-order consideration that will not be discussed here.

<sup>19</sup> Note that AB and A'B' are not necessarily (or even likely to be) parallel.

This is not to suggest that projects on the axes below point A or to the left of point B should not have been undertaken. Indeed, if A and B are central tendencies, a considerable number of projects will lie on either side of the stringency boundary by definition. It may also be the case that PWTP has not yet caught up with the socially desirable degree of emissions reductions, so that a shift of AB (or A'B') down and to the left would improve general welfare. Note also that if only the Montreal Protocol proceeds to complete phaseout of the substances controlled under it, the line AB would rotate about point A until it coincides with the vertical axis. Similarly, a complete ODS phaseout under A'B' would pivot on A' until the point B' coincides with the origin.

This conceptual framework offers two advantages. First, it enables policy-makers to evaluate projects having both global warming and ozone-protection benefits in a unified way, given the current levels of regulatory stringency implicit in the two Protocols. Second, it shows how projects might be compared in the cases in which one is not preferable to the other along both dimensions. Thus, in Figure 5, Project C is preferable to Project D because C results in more cost-effective reductions of both ODP and LCCP.



But what about comparisons between Project D and Project E, or between Project D and Project F? All three lie in the region above and to the right of line AB, so in one sense all three should be undertaken at current levels of regulatory stringency. However, E is preferable to D at the current tradeoff rate between LCCP/\$ and ODP/\$ as indicated by the slope of AB. On the other hand, D is preferred to F at the tradeoff rate illustrated by AB, but F could be preferred to D if the slope of the tradeoff line were steep enough (i.e., sufficiently negative). Figure 5 also shows the case of point G, a project with a large

enough ODP-reduction potential to be worth undertaking even though it has an undesirable global warming impact, and point H for which a small addition to ODP would be justified by the global warming benefit of a large LCCP reduction.

The policy boundary can reflect a single objective goal of climate protection or ozone protection, or a combined policy that pursues both objectives simultaneously. The latter strategy allows us to rank projects that are not distinguished on purely ODP grounds or purely LCCP grounds but have clear rankings when both objectives are considered by the same decision maker, e.g. when considering two projects which have identical effects in one dimension but different impacts in the other. Further, it provides a framework in which to consider, for example, how much destruction of unrelated ODP or other complementary abatement effort would need to be included in a project to make it desirable.

#### *B. Aggregated data from the Multilateral Fund and global carbon reduction markets*

The Multilateral Fund of the Montreal Protocol was established to help accelerate phaseout in less-developed countries. Non-Article 5(1) countries make payments to fund the agreed incremental costs of eliminating uses of ODS in Article 5(1) countries. The decisions made by this body form a rich dataset on the actual costs of ODS abatement thus far.<sup>20</sup> Decisions made to date suggest that a conservative estimate of the political willingness to pay for reductions in ozone depleting chemicals, based on central

<b>Table 2 – Summary Statistics ODP-tonnes/1,000 USD*</b>			
Min	0.000247	Max	14.093
Mean(Raw; $n = 2,296$ )	0.158	Median	0.105
Fifth percentile	0.021	Ninety-fifth percentile	0.413
Mean(central 90% of data points; $n = 2,068$ )	0.121		
Mean(central 90% weighted by Grant)	0.105		
Mean(central 90% weighted by ODP ton)	0.107		
Tenth percentile	0.037	Ninetieth percentile	0.273
Mean(central 80% of data points; $n = 1,838$ )	0.114		
Mean(central 80% weighted by Grant)	0.087		
Mean(central 80% weighted by ODP ton)	0.075		
* Prices converted to 2006 dollars			

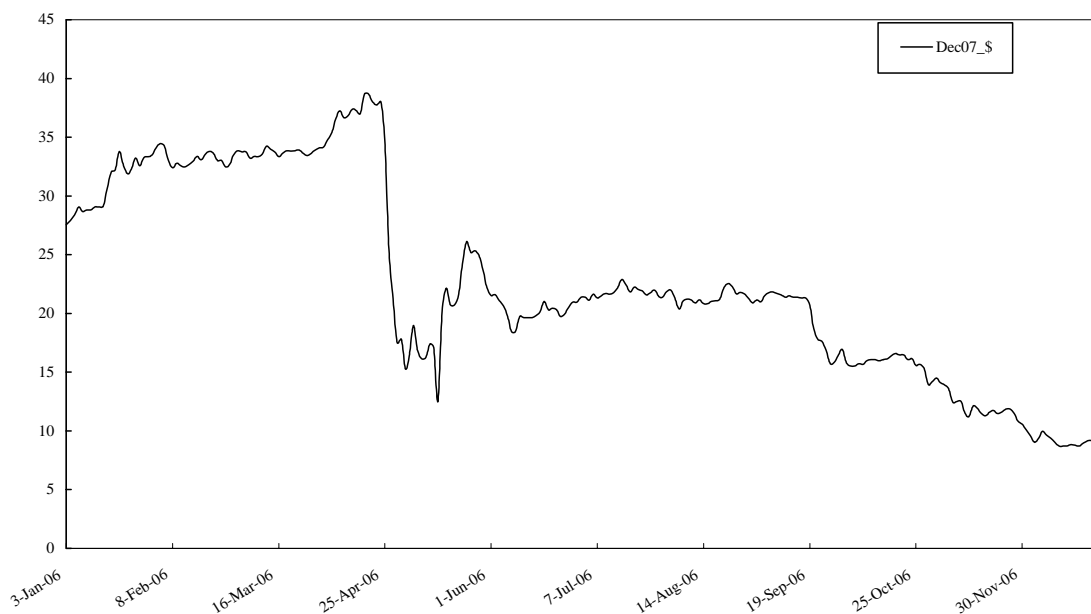
<sup>20</sup> The authors would like to thank Julia Anne Dearing for providing this data and updates to it on several occasions.

tendencies, lies around \$8,300 to \$10,000 per ODP tonne (1,000/0.12 to 1,000/0.10). Table 2 shows summary statistics for projects reducing ODS usages under the Multilateral Fund.

There is less data available on amounts paid to reduce GHG emissions. Hasselknippe and Roine (2006) provide some insight into payments under the Kyoto CDM, with the caveat that their survey suggests many players in the markets do not view them as fully mature yet. Trading in CO<sub>2</sub> emissions markets has been increasing rapidly, with the (proprietary) Point Carbon records showing 94 million tonnes traded internationally on all markets in 2004 and 799 million tonnes traded internationally in 2005. Carbon prices have averaged about \$6.30/TnCO<sub>2</sub>-eq in recent years, or 0.157 GWP/\$ with GWP measured in TnCO<sub>2</sub>-eq. Lecocq and Capoor (2005) show project-based funding averaging from less than \$ 2 to \$ 6 per tonne, depending on the type of project, from January 2004 through April 2005. Current and futures values from carbon markets, though volatile, are also available.<sup>21</sup>

Figure 6 shows prices for current carbon allowances on ECX, the best developed and largest of the carbon exchange markets. Other significant markets exist, both in countries committed to Kyoto reductions and in uncommitted countries; as would be expected, the largest US market, the Chicago Climate Exchange (CCX), has lower prices than the carbon markets in locations with regulatory caps on emissions.

**Figure 6 - ECX Allowance Carbon Market Price 2006**



<sup>21</sup> Allowance market data comes from European Climate Exchange (2007), ECX historical data, averaged and weighted by each period's trade volume.

Prices on ECX for current permits have recently fallen to all-time lows, concerning some observers. The drop in the Spring of 2006 was associated with a downward revision of the baseline emissions levels in the countries of the EU. Prices for Phase 2 permits, which will be less numerous than Phase 1 permits, (Phase 1 permits cannot be carried forward) are higher – December 2008 permits are selling for around USD20/tonne, and prices past 2011 (when jet fuel use will require permits) are still higher. There is little doubt that some sort of Phase 3 will be implemented (Morrison 2007).

It is important to note that carbon permit prices quoted on the ECX are for a single *annual* tonne of emissions, while the data from the MF are from projects to eliminate usage of an ODS for the indefinite future. Thus, a tonne of abatement under the MF is a tonne of ODS every year from the present onward. For comparability between the two types of data, it is necessary to convert the ECX data to a price for permanent removal of the annual emissions stream. In the absence of detailed project information, a rough approximation might consider the anticipated lifetime of the equipment changed, so CO<sub>2</sub> emissions of a project to switch refrigerants in a chiller expected to last twenty years would be valued at twenty times the annual emissions price per tonne. An alternative might be to sum up futures prices over twenty years, but given the rapid evolution of the carbon markets this seems unlikely to add meaningful precision (as well as the fact that futures contracts this far out are not being traded). Either method could be discounted using an agreed discount rate. Under conventional discounting, impacts more than 25 years out are very small contributors to total value of abatement of a stream. It is more consistent with considerations of intergenerational equity to base the conversion of annual emissions permits to “permanent” CO<sub>2</sub> reductions on equipment lifetimes rather than discounted future values.<sup>22</sup>

Data from the MF on abatement projects can be used to illustrate this approach. Figure 7 displays a subset of the MLF data, as well as estimated costs of CO<sub>2</sub> reductions from a variety of markets, both permit-based and project based, which are plotted on the vertical axis. Each tonne of ODS eliminated is assigned a direct global warming impact based on its GWP only, not its full LCCP.

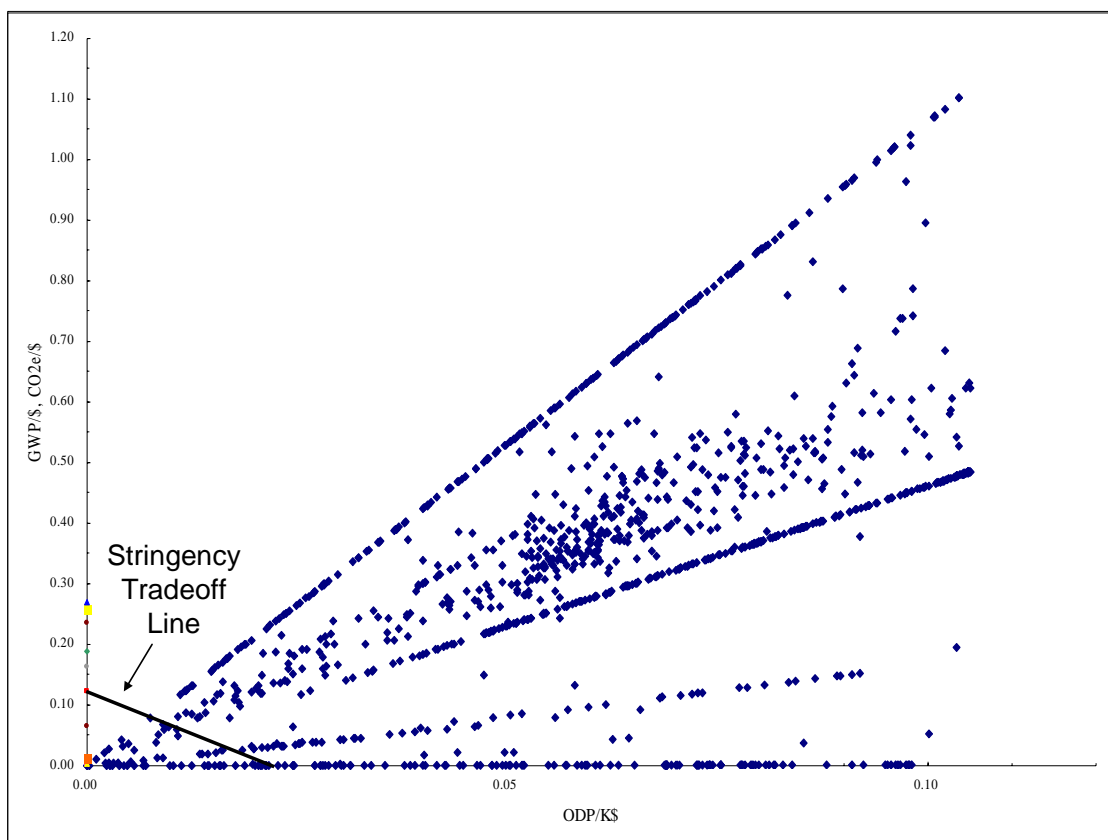
The blue diamonds in Figure 7 reflect the direct effects of MF projects. Only *half* the MF projects (the most expensive half in terms of cost per unit of ODP eliminated) in the current MF database are represented; the other half of the projects are so cost-effective they are literally “off the chart” because if they were plotted, these points would be so far above and to the right of the stringency tradeoff line that they would not fit into the diagram with the axes as drawn. The multicolored points on the vertical axis are based on estimated carbon prices converted into GWP/\$ units. To be consistent with the project-based market price, permit-based prices for 2005 through 2007 are multiplied by a lifetime of 20 years, which makes the unit dollar effects on global warming potential benefit so small that they clustered on the range of 0.001-0.01GWP/\$ of the vertical line. Prices from aggregate data on project-based reductions are treated as ongoing reductions,

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<sup>22</sup> See the *Stern Review* (HM Treasury 2006), and the reviews of it by Weitzman (2007) and Dasgupta (2006) for discussion of discounting complexities.

as some of these are intended to provide ongoing abatement. Improvements in the procedure for converting the market-based emissions price data into permanent LCCP reductions prices are part of our ongoing research, and will be incorporated subsequently.

**Figure 7 – Actual MF Projects and GWP Reduction Costs**



The two sharp lines in the data are CFC-12 (upper) and CFC-11 (lower). All projects that involve replacement of a single ODS will lie along a straight line, because the ratio of a chemical's ODP per tonne and its GWP per tonne is fixed by its physical characteristics. The CFC-12 and CFC-11 replacement projects are the most numerous, so the straight lines marking projects to replace these two chemicals stand out in Figure 6. The linear relationships between ODP/\$ and GWP/\$ for the other chemicals are not as sharply visible because of the multiplicity of compounds covered and the fact that many projects entail changes in use of several compounds simultaneously, at ratios varying from project to project.

Using central tendencies of this data (as in DeCanio and Norman 2005) would be a quite conservative approach to estimating PWTP; in some sectors, such as MeBr phaseout,

costs have been considerably higher, and in principle the highest-cost projects undertaken by the MF (which operates by consensus) could be considered a better measure of PWTP. However, some funding may have been associated with considerations other than or in addition to ozone protection, or may reflect uncertainty of what constituted reasonable costs in the earliest stages of the phaseout. For this reason we have drawn the stringency line from the 95th percentile on the ODP axis (at 0.021 ODP tonnes/thousand dollars) to the point of the “average” \$7.66/TnCO<sub>2</sub>-eq (or 0.131 GWP TnCO<sub>2</sub>-eq/dollar) on the LCCP axis. This point is somewhat arbitrary; the carbon price data is quite noisy, and more work is needed to obtain a fully consistent set of data that would enable calculation with any confidence of the PWTP for CO<sub>2</sub> reductions based on observed behavior.<sup>23</sup>

Agreeing on a stringency line could also highlight worthwhile abatement efforts in countries without access to the MLF monies. Consider also that Parties to the Protocol allow uses by enterprises in developed countries that are less expensive to eliminate per ODP tonne than the price paid to phase out the same quantity of ODS through the MLF. For example, if farmers of tomatoes in Florida and strawberries in California paid a surcharge on the methyl bromide they use, they would likely shift to alternatives more rapidly. This price sensitivity results from the fact that pest control is a small part of total product cost and because in many cases the alternatives are nearly cost competitive or cost saving after investment costs and training are recovered.

### *C. Some particular examples*

Calculating global warming impacts correctly is not just a matter of the chemistry of the substance considered. In many if not most cases, the prime drivers of climate change are the fuels that produce energy to manufacture and use the chemicals. This ‘indirect’ effect is in some cases the dominant source of climate impacts for an application. The importance of the indirect effect can be seen by consideration of the case of large centrifugal building chillers. Before the Montreal Protocol, this equipment mostly used CFC-11 as its working fluid.

Replacement of CFC-based chillers still in use (and destruction of their embodied CFCs) would be of considerable benefit to the ozone layer. Worldwide in both developed and developing countries there are approximately 65,673 – 105,076 CFC chillers containing 24,173 – 38,676 ODP-weighted tonnes of CFC.<sup>24</sup> It has been estimated that there are

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<sup>23</sup> Of course, stabilization of global CO<sub>2</sub> emissions markets would be much more likely if negotiations for the successor to Kyoto bring all the major GHG emitting countries into the control regime.

<sup>24</sup> This conservative estimate was calculated from data in UNEP (2002). It is based on the estimates for the United States, Canada, and India given in that report, and the judgment that “[p]erhaps this accounts for 25-40% of the CFC chillers in service around the world” (*ibid.*, p. 108). Details of the calculation are available from the authors. This 2002 *Report* notes that “[a]ccurate inventories of equipment in service around the world, and the types and amounts of refrigerants used in these chillers, are not available” (*ibid.*, p. 108), so this sort of rough estimate may be the best that can be done in the absence of better data. Interestingly, UNEP (1994), using different sources and methods, estimated the 2007 inventory of CFC-11 in commercial chillers to be 26,583 tonnes, which is within the range given in the text.

15,000 – 20,000 of these chillers in Article 5(1) countries, where the CFC phaseout date is 2010 (UNEP 2004, p. 23). Globally, there were about 120,000 chillers using a variety of refrigerants in the mid-1990s; precise estimates after this period are not available. Minimum leakage estimates are one tonne of CFCs for every 20 chillers every year (with high end estimates of ¼ tonne each per year), so a considerable volume of CFC will be emitted even if the remaining CFCs were captured and destroyed when the chillers are replaced.

Today the two main competing replacement technologies are based on HCFC-123 and HFC-134a. HCFC-123 has a slight ODP, but the direct GWP of HFC-134a is ten times greater than that of HCFC-123. The relative direct ODP and GWP values are given in Table 3.

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**Table 3**

Data from 2004 TEAP Chiller Task Force Report: Tables 2-2: *Centrifugal Chiller Refrigerants and Charge Levels*, and 2-4: *Environmental Data for Chiller Refrigerants*

	Capacity	ODP Reg(Sci)*	GWP (100 year)
HCFC-123	.40kg/kW	.020 (.012)	120
HFC-134a	.36kg/kW	.000	1300

\* Reg is the official Protocol value; Sci is the value based on current science.

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Even though GWP applies only to direct emissions, it should be noted that these emissions are documented to be substantially higher in HFC-134a systems because these are high-pressure systems while HCFC-123 is un-pressurized or at vacuum pressure during normal chiller operation and is a liquid at common operating temperatures (UNEP 2002, p. 118). A leak in a HFC-134a system discharges the pressurized greenhouse gas refrigerant, while a leak in a HCFC-123 system draws air into the system which is separated from the refrigerant by a component unique to HCFC-123 machines.

The IPCC/TEAP *Special Report* estimates emissions from stationary air conditioning related to use of CFCs, HCFCs, and HFCs at a little less than 0.3 GtCO<sub>2</sub>-eq in 2002, and projects these emissions to increase to about 0.4 GtCO<sub>2</sub>-eq per year by 2015 under a business-as-usual scenario. These estimates are for direct effects only; the report notes that “[f]or individual applications, the relevance of indirect GHG emissions over a life cycle can range from low to high, and for certain applications may be up to an order of magnitude larger than direct GHG emissions.” (IPCC/TEAP 2005, p. 10)

The *Special Report* also notes that direct emissions associated with building cooling and heating can be reduced by 200 Megatonnes (Mt)CO<sub>2</sub>-eq/year relative to the BAU scenario, at costs (not accounting for savings associated with reduced energy

consumption) of up to 170 US\$/tCO<sub>2</sub>-eq, by better disposal, reduced refrigerant charges, better containment, and use of alternative refrigerants in some applications.

Furthermore, modern chillers using HCFC-123 are at least 10.5% more energy-efficient than HFC-134a chillers (UNEP 2004), so the indirect global warming impact of an HFC-134a chiller over its decades-long lifetime would be much greater than that of an HCFC-123 chiller. The ICCP/TEAP *Special Report* (p. 285) notes that “the major portion of LCCP [for chillers] is the indirect warming associated with energy consumption. Direct warming...amounts to between 0.2 and 3 percent of the total LCCP.” The lower range estimate is for HCFC-123 systems due to its relatively low GWP and high energy efficiency, while the high range estimate is for HFC-134a systems with greater leakage of higher GWP refrigerant and inferior energy efficiency. Refrigeration of varying sorts constitutes a significant fraction of electricity use globally, and coal-fired electricity generation is responsible for a large portion of global carbon emissions. As a result, the efficiency advantage of HCFC-123 chillers can make a significant contribution to protection of the climate.

Therefore, it is unequivocally in the interest of global environmental protection to allow the continuing use of HCFC-123 chillers if ODS emissions are offset, and it is arguably in the interest of global environmental protection to allow the continuing use of HCFC-123 chillers even if the emissions of refrigerant are not offset, depending on the tradeoff rate considered appropriate by the international community. This example demonstrates the power of a unified framework in guiding co-investment in technology that has multiple benefits.

Precise estimates of the differing lifetime impacts are difficult, as set temperatures, outdoor temperatures, and other characteristics of the building and the cooling system affect energy use for all types of refrigerants. However, the *Special Report* does present several case studies of ‘typical’ settings for different-capacity units in different climates, all of which show that total direct and indirect warming effects are meaningfully larger for HFC-134a than for HCFC-123. Generally HCFC-123 has the lowest total impact of all examined refrigerants (pp. 285-287).

However, under current rules, HCFC-123 (because it has a non-zero ODP) is scheduled for 99.5% phaseout by 2020 in non-Article 5(1) countries<sup>25</sup> and for full phaseout by 2040 in Article 5(1) countries. HFC-134a is regulated under Kyoto but not Montreal, and as such is not currently projected for phaseout. As long as this lack of coordination persists, investments in chillers are likely to favor HFC-134a, with consequences for emissions of greenhouse gases for decades. China’s growing chiller market, already the largest in the world, currently invests in HFC-134a chillers about 70% of the time (IPCC/TEAP 2005, p. 283). Chillers have a lifetime of up to 40 years; if the ability to maintain and service them is in doubt, the significant energy savings associated with a more efficient

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<sup>25</sup> In some major manufacturing countries phaseout is scheduled sooner; the US Clean Air Act calls for phaseout of HCFC-123 in new equipment by 2020.

refrigerant may not be sufficient to prompt investment at the level a multi-objective plan would find desirable.

### III. Other issues for a strong Montreal Protocol moving forward

Perhaps the most important lesson learned so far from experience in implementing the Montreal Protocol is that the technological and economic disruptions accompanying replacement of ODSs with ozone-friendly technologies have been much less serious than originally feared. Also, the Protocol has stimulated both R&D and institutional change that have improved product quality and profitability in unanticipated ways.

The progressive nature of the ODS replacement process is seen perhaps most clearly in the robust trend of falling costs per ODP eliminated. The magnitude of this trend can be estimated from the data on ODS replacement projects approved by the Multilateral Fund. Statistical analysis of this data reveals that the cost per unit of ODP eliminated has declined over time. Table 4 summarizes the analysis, and reproduces the results published in DeCanio and Norman (2005) for comparison. The earlier regression results, which were based on MLF data available through early 2003, are quite similar to the identical regression specifications estimated using the full body of MLF data through 2006. Estimating the parameters of the same regression model on an earlier, less complete dataset and a later, more extensive dataset constitutes a kind of “natural experiment” that is unusual in the study of social phenomena. Table 4 contains estimates for regressions on MeBr projects only, all-ODS projects without dummy variables for the sectors in which the ODSs were replaced (i.e., refrigeration, foams, solvents, etc.) and all-ODS regressions including dummy variables for the different application sectors. The variable denoting the time trend is *Meeting Number*, which advances at a rate of approximately three meetings per year.

Comparison of the two sets of regression results reveals a very clear declining trend in per-unit cost of ODP replacement, except in the case of the coefficient of *Meeting Number* in the all-ODS regression on the full dataset without the sectoral dummy variables. The trend does not appear in this regression because by the end of 2003 the composition of projects supported by the Multilateral Fund had changed because the phaseout of the ODSs in some applications was essentially complete. Hence, omission of the sector dummy variables conflates the change in composition of projects with the trend, rendering the estimate of the trend coefficient unreliable. The all-ODS regressions including the sectoral dummy variables (the rightmost column of Table 4) are the clearest manifestation of the results of the natural experiment.<sup>26</sup>

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<sup>26</sup> The MeBr and all-ODS regressions without the sectoral dummies are included to emphasize that the previously published results were simply replicated using the updated information from the MF. Identical regression models were run, and there was no “adjustment” of data or models to improve the appearance of the results.

<b>Table 4</b>			
<b>Ordinary least squares regressions of cost (1,000s of 2002 US \$) per ODP-tonne on meeting number, project size, and sector variables, Multilateral Fund-approved projects through <i>March 2003</i></b>			
Variable	Sample of Projects		
	MeBr only	All ODS	All ODS
Constant	99.91(3.97)**	18.47(20.78)**	20.94(13.36)**
<b>Meeting Number</b>	<b>-1.33(-1.80)<sup>†</sup></b>	<b>-0.19(-5.53)**</b>	<b>-0.19(-5.54)**</b>
Project Size	-0.76(-4.57)**	-0.024(-9.93)**	-0.023(-9.51)**
(Project Size) <sup>2</sup>	3.52E-03(3.15)**	6.60E-06(7.38)**	6.34E-06(7.09)**
(Project Size) <sup>3</sup>	-4.52E-06(-2.57)*	-4.40E-10(-5.98)**	-4.23E-10(-5.75)**
Sector Dummies	--	<b>No</b>	<b>Yes</b>
Observations	39	1960	1960
Adjusted R <sup>2</sup>	0.508	0.061	0.067
F Probability-Value	~ 0	~ 0	~ 0
<b>Ordinary least squares regressions of cost (1,000s of 2002 US \$) per ODP-tonne on meeting number, project size, and sector variables, Multilateral Fund-approved projects through <i>November 2006</i></b>			
Variable	Sample of Projects		
	MeBr only	All ODS	All ODS
Constant	87.45(9.11)**	13.30(18.54)**	18.45(9.82)**
<b>Meeting Number</b>	<b>-1.24(-5.40)**</b>	<b>0.026(1.06)</b>	<b>-0.14(-5.41)**</b>
Project Size	-0.45(-5.00)**	-0.022(-10.93)**	-0.022(-11.94)**
(Project Size) <sup>2</sup>	0.0018(3.20)**	5.92E-06(8.06)**	6.29E-06(9.55)**
(Project Size) <sup>3</sup>	-1.99E-06(-2.46)*	-3.95E-10(-6.38)**	-4.29E-10(-7.79)**
Sector Dummies	--	<b>No</b>	<b>Yes</b>
Observations	91	2265	2265
Adjusted R <sup>2</sup>	0.424	0.055	0.279
F Probability Value	~ 0	~ 0	~ 0
Notes: (1) Outliers with cost per ODP-tonne > US\$ 110k omitted			
(2) t-statistics in parentheses:			
* two-tailed Probability-value < 0.05			
** two-tailed Probability-value < 0.001			
† one-tailed Probability-value < 0.05			

Given that MF meetings to approve projects occur on average every four months, the all-ODS regression (with sectoral dummies) on the complete dataset indicates that the cost per ODP-tonne removed from the atmosphere has been declining at a rate of approximately \$ 420 per year since the Fund began supporting investment projects. This robust empirical result indicates the importance of regulatory certainty, economies of scale, and learning by doing in bringing down the costs of technologies to replace ODSs. It also supports the notion that regulatory stringency can be increased steadily as costs fall over time. Regulatory certainty makes it easier for firms to plan their investments, stimulates research and development, reduces wasteful rent-seeking behavior associated with negotiating each increase in stringency separately, and rewards innovators while promoting diffusion of the most environmentally friendly and cost-effective technologies. This is especially valuable for investments in technology that lasts for decades.<sup>27</sup>

In proceeding to the Protocol's "endgame," it is also important to avoid mixing together the phaseout regime with the issues of the equitable distribution of the costs of the final phaseout. For example, in the case of the phaseout of CFCs from metered-dose inhalers (MDIs), a distinction needs to be drawn between efficient policy to protect the global public good of the ozone layer and the policies of the individual Parties' governments required to insure that low-income citizens do not lose access to essential medicines as the price of non-CFC MDIs goes up (see DeCanio and Norman 2007b for a full discussion of this case; the point about the distribution of costs within countries is also made in DeCanio and Norman 2005). It is up to the individual Parties to assure equitable sharing of any burdens of the ODS phaseout among their citizens; it is not appropriate to ask the language of the Protocol (or the international institutions created by it) to solve the internal domestic political issues of distribution.

Most relevant to the present discussion of strengthening the Protocol is the necessity of coordinating international ozone protection and climate protection efforts. The two regulatory efforts are already connected implicitly (see Section II), but the coordination could be more effective than it has been.

For example, the provision of the Montreal Protocol's phaseout process that allows developing countries to increase their production and use of HCFCs through 2016 may seem reasonable from an ozone-only perspective, but in conjunction with provisions of the Kyoto Protocol it can create perverse incentives. A developing country might seek to expand production of HCFC-22 beyond its immediate needs, in order to obtain Clean Development Mechanism (CDM) credits under Kyoto by destroying the HFC-23 that is a byproduct of the HCFC-22 production process. The IPCC/TEAP *Special Report* notes that "destruction of byproduct emissions of HFC-23 from HCFC-22 production has a reduction potential of up to 300 MtCO<sub>2</sub>-eq per year by 2015 and specific costs below 0.2 US\$/tCO<sub>2</sub>-eq according to two European studies in 2000" (p. 15). Proper coordination of the two Protocols would entail simultaneous accounting for the adverse environmental

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<sup>27</sup> See DeCanio and Norman (2005) for references to the benefits of regulatory certainty, and for references to the large literature on learning by doing and economies of scale.

effects of the HCFC-22 and HFC-23 that are jointly produced. It would not then be possible to exploit the provisions of one the Protocols at the expense of the other. Wara (2006, 2007) discusses the intentions and outcomes of the CDM process, noting that revenue from the CDM was expected to promote the development of cleaner energy infrastructure in developing countries, which was presumed to be cheaper than retrofitting existing developed-world energy generation. Instead the bulk of the CDM monies have gone to relatively expensive subsidies for the destruction of chemical byproducts like HFC-23.<sup>28</sup>

We have already argued that increased flexibility for destruction offsets should be built into the Protocol. To do so in a consistent and verifiable framework would require much more active management of ODS stocks (including those embodied in existing equipment) rather than exclusive focus on production and consumption. End-of-life emissions are increasingly an area of opportunity for reductions. As a reflection of this reality, the Parties should consider (1) requiring regular estimation and reporting of ODS stocks along with their reporting of production and consumption and (2) permitting only ODS consumption that is offset by destruction of stocks that otherwise would be emitted (i.e., that are not already subject to required destruction, or, more stringently stocks that are uncontained and likely to be emitted in the near future) at an agreed-upon ratio. It is worth noting that better control and monitoring of stocks would facilitate more effective enforcement of other protocol provisions, particularly control of illegal trade in ODSs.

The Quarantine and Pre-Shipment application of Methyl Bromide is an application that is growing rapidly at this time. It should be possible for the MeBr TOC to work within the framework of the FAO/International Plant Protection Convention on QPS issues. International protocols such as International Standard for Phytosanitary Measure No. 15 (UN FAO 2002) that are process based rather than outcome based may have the effect of *increasing* MeBr use by requiring it for all shipments that use wood packaging. Wood pallets are widely used in trade due to their affordability and strength. Even after the implementation of ISPM 15, certified fumigated or heat treated wooden pallets remain less expensive than the alternatives and dominate the market. Plastic pallets are increasing their market share, but account for less than 5% of the market; corrugated pallets have an even smaller share. Here again, leveling the regulatory playing field through clear phasedown schedules, fees and/or required destruction offsets would promote innovation and environmental efficiency.

A number of additional issues warrant consideration in advancing the objectives of the Protocol. It would be desirable to have greater coverage and standardization in the reporting of data from and regulation of feedstock and process applications. New ozone-depleting chemicals may be developed, or as has been the case in the past, chemicals currently in use but not listed by the Protocol may be found to be ODSs. Currently, several compounds with known or suspected ODP are not subject to a phaseout timetable under the Protocol; some examples include hexachlorobutadiene, n-propyl bromide,

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<sup>28</sup> Wara (2006) also notes that HFC-23 destruction linked to HCFC-22 production accounts for 37% of current and projected CERs; non-CO<sub>2</sub> projects are more than 70% of the total.

1,3,3-trichloropropenes, and ethane. It might be advisable to include in the Protocol a generic provision to include such compounds in the phaseout as they are identified; here again, the possibility of using destruction credits to manage the timing of the phaseout of such ODSs would increase transparency and avoid unnecessary emissions. More research needs to be done on the role of regulation in technology forcing and technology transfer, so that the optimal mix of price incentives, regulatory standards, and voluntary initiatives can be brought to bear.<sup>29</sup>

Eventually, it might even be possible to imagine trading “across Protocols” in which ODP could be exchanged for LCCP according to the prevailing stringency tradeoff. Moving to such trading would be premature at the present time because there is no assurance that the current PWTP for either ODS or greenhouse gas emissions reductions corresponds to the social, economic, and environmental benefits of avoiding those emissions, but at least the possibility of trading across Protocols in the future should not be ruled out.

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<sup>29</sup> For example, the IPCC/TEAP report, p. 280, notes that “[i]n the absence of minimum efficiency standards, many purchasers choose to buy lower-cost, lower COP chillers.”

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