Appendix B: Measuring the Cost of Climate Policy*

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This note provides an overview of different measures of costs of climate policy. While in our studies we stress emissions prices and welfare changes, here we illustrate the measures in most common use, showing results for the 167 bmt scenario from Paltsev *et al* (2009). Similar results for the other scenarios can be derived from Appendix A to that report. These are studies of mitigation costs only and do not consider climate benefits and potential ancillary non-climate benefits of greenhouse gas mitigation, e.g., through reduced urban air pollution.

1. Emissions Price

A price on greenhouse gas (GHG) emissions is usually stated per metric ton of CO_2, or in the case of multiple gases, per metric ton of CO_2-equivalent, or CO_2-e. Such a price may be established through a market that develops for emissions allowances issued under a cap-and-trade system (the allowance price) or through an emissions tax set directly by a regulating agency. Because CO_2 is the largest contributor among the long-lived greenhouse gases, the CO_2-e concept has come to be widely used. CO_2-e prices use Global Warming Potential (GWP) indices that take account of the different lifetimes and direct climate effects to calculate the amount of CO_2 that would have the same effect as, for example, a ton of methane or nitrous oxide.[1] Since the GWP index uses CO_2 as the numeraire (i.e., its index value is 1.0), there is no difference in CO_2 or CO_2-e prices for CO_2. The value of the CO_2-e measure is that it makes prices for other GHGs comparable, in terms of the warming avoided per ton, to that of CO_2. An example of CO_2-e prices for the 167 bmt scenario is provided in **Table B1**.

Table B1. CO_2-e Price.

	2020	2030	2040	2050
CO_2-E Price (2005$/t$CO_2$-e)	70.68	104.62	154.86	229.23

Emissions prices measure marginal cost, that is, the cost of an additional unit of emissions reduction. Emissions prices are an indicator of the relative scarcity of the allowances compared with the demand for them, but they are not a measure of "total cost" to the economy. Just as, for example, the price of a gallon of milk does not provide an indication of the total cost of all the

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[1] The convention in recent years has been to report prices per ton of CO_2. An earlier convention was to report prices in tons of C—counting only the carbon weight in the CO_2 molecule. A residual effect of this earlier convention is to sometimes see a reference to the "carbon price" applied even in the case where the price is stated per ton of CO_2 rather than per ton C. To convert from a per ton C price to a per ton CO_2 price multiply by the molecular weight of the CO_2 molecule (44) divided by the molecular weight of the carbon atom (12), or 3.667. A price of $27.27/ton CO_2 is thus the same as $100/ton C.

milk produced in the country. That is, prices convey no information about the physical volumes to which they apply or the magnitude of the cost compared to the level of activity (e.g., size of the firm or of the total economy). Just as the total cost of milk production depends on how much milk was produced, the total cost to the economy of greenhouse gas emissions reduction policy depends on how much reduction occurred. Note that what is being “produced” with a cap-and-trade system is abatement of emissions, i.e., emissions reduction. Determining the emissions reduction requires an assessment of what emissions would have been without the policy, whereas with milk production we can simply measure how much milk was produced.[2] Prices can also be a misleading indicator of the cost when they interact with other policies and measures — either those directed at greenhouse gas reduction (for example, renewable portfolio standards or subsidies to carbon-free technologies) or simply other policy instruments such as other taxes on energy, labor, or capital. This is no different than for other prices in the economy — our price of milk, for example. If there are no other policy measures, the price of milk will fully reflect the marginal cost, but if there are farm subsidies or price supports, the milk price will be a poor indicator of the marginal cost.

2. Welfare Change

For many economists the preferred measure of total economic cost of greenhouse gas abatement or of other policy measures is the change in consumer welfare[3], measured in terms of “equivalent variation”, as this measure considers the GHG price and the amount of abatement and can include the effect of interactions with other policy measures to the extent these other policy measures are modeled. And, whereas the CO_2 price measures the marginal cost, a welfare measure takes into account the fact that many of the reductions likely cost less than the last ton abated. Welfare is also generally a measure that is broader than just market activity and as such the change in welfare includes changes in both labor and leisure time. Leisure is considered a good and in models like EPPA it is represented by the monetary value of the non-working time. In coming up with a measure of change in welfare any reductions (increases) in the amount of work time are offset by increases (decreases) in the amount of leisure time. The welfare change in the 167 bmt scenario is provided in **Table B2**.

Table B2. Welfare Change.

	2020	2030	2040	2050
% Change Welfare from Reference (EV)	-0.63	-1.52	-2.32	-2.52

Many features of the EPPA model (level of aggregation, nesting structure, elasticities, etc.) affect this result, but a couple of features are worth special mention. One is the influence of the

[2] The caution here is to avoid the temptation to estimate the cost to the economy on the basis of how many allowances were issued, which is directly observable.

[3] Change is measured in comparison to welfare without a climate policy.

tax interaction effect.[4] A price on greenhouse gases will increase producers' costs, effectively reducing the real returns to the factors of production, such as capital, labor, and energy. If, as is common, there are pre-existing taxes on these factors, the GHG price has the effect of an increase in factor taxes, compounding the distortion caused by the prior tax system. This tax interaction effect will influence both the net government revenue from an allowance auction or emissions tax and the welfare effect of the policy. This is an effect missed by single-sector analyses of environmental policy. It is, however, captured by the EPPA model (subject to possible limitations imposed by its level of sectoral aggregation) because of its multi-sector general equilibrium structure and the fact that pre-existing taxes are included in the underlying data base.[5]

A second feature concerns the effect of assumptions about the distribution of auction proceeds from a cap-and-trade system or the revenue from an emissions tax. In the EPPA model, a single agent represents the demands and behavior of the consumer side of the economy, and the value of emissions allowances (or tax revenue) is assumed to be returned to this representative consumer in a lump-sum transfer, equivalent to giving the allowances away for free in a lump sum manner. With lump-sum distribution the auction or tax revenues do not, by themselves, change the amount of total tax revenue or the size of the government. However, because overall economic activity (which is the tax base for all other taxes) is generally lower under a policy, the amount of total tax revenue and the size of a government will be lower unless tax rates are raised to compensate for the drop in the tax base. In analyses conducted here, we hold tax rates constant and allow the size of government revenue and expenditures to vary.

Many other assumptions about auction and tax revenue are possible and would lead to different estimates of welfare change. For example, if rather than lump-sum redistribution the revenue is used to reduce other taxes, the effect will be to lower the welfare cost because it reduces the distortionary effect of these taxes.[6] Free distribution of allowances raises the possibility that one may need to raise other tax rates to keep the total tax revenue constant so that the existing level of government can be maintained, and the higher taxes will increase the welfare cost by increasing the distortionary effect of these taxes. If, on the other hand, revenue is used for other purposes—e.g., supporting research and development (R&D), subsidizing low-emitting technologies, compensating low income consumers or affected industries, or funding unrelated government programs—then the welfare cost will depend on how effectively the funds are spent. If revenue is used for R&D, which is effectively directed to projects with high returns, welfare effects can be positive. But if allowance or tax revenue is spent on poorly managed programs of the little value, then the funds will be mostly wasted, raising the welfare cost. The value of government expenditure are difficult to measure and so there are widely differing views on whether and under what circumstances additional revenue can be used effectively. The debate

[4] For a summary of issues that arise in assessment of the cost of environmental policies see Goulder (2000).
[5] For an example of this effect, when a carbon charge is imposed on top of high fuel taxes, see Paltsev et al. (2004).
[6] A perfect foresight version of the EPPA model has been applied to exploration of the use of such revenue to the reduction of labor and/or capital taxes, see Gurgel et al. (2007) and Babiker et al. (2008).

on use of GHG auction or tax revenue taps into the conventional debate about the appropriate size and role of the government. Other cost measures, described below, are similarly influenced by the tax interaction effect and assumptions about revenue and/or permit distribution.

3. Consumption Change

Changes in macroeconomic consumption as a measure of cost is closely related to welfare changes described above. The only difference is that consumption change considers only the market impacts and so excludes changes in leisure time (i.e., the monetary value of the change in non-working time) that occur in response to the policy. The consumption change is usually larger than the welfare change because an increase in the price of consumption (due to an increase in energy prices) leads to a reallocation of time to non-market activities. The magnitude of the shift depends on the labor supply elasticity. Also, consumption change in percentage terms is higher than the welfare measure in percentage terms because the base (total consumption) excludes a value of leisure time and so the base against which the percentage is calculated is lower. The consumption change in the 167 bmt scenario is provided in **Table B3**.

Table B3. Consumption Change.

	2020	2030	2040	2050
% Change Consumption from Reference	-1.13	-2.24	-3.25	-3.49

4. GDP Change

The change in Gross Domestic Product (GDP) is a measure of cost often used by non-economists because GDP is the measure of economic activity that is most familiar to a general audience. It is a less satisfactory indicator of cost than welfare loss or consumption change for several reasons. It is useful to recognize that GDP is defined as Consumption (as in Section 3 above) + Investment + Government + (Exports-Imports). The welfare and consumption measures are preferred by economists because they measure the amount of goods people consume. GDP is a measure of output, which is not necessarily consumption. Investment goods produced in a given year add to the availability of consumption goods over many years and hence changes in investment are not directly comparable to a loss of consumption in a year. Government is not a final consumer but through transfer programs (e.g., Social Security) or provision of public services (e.g. education and police) provides money or goods and services to final consumers. As for international trade, how many foreign goods can be bought for a given amount of domestic money is more relevant to consumption than the net of exports over imports. The amount of foreign goods depends on how the terms-of-trade (i.e., the price of domestic to foreign goods) changes. Higher terms-of-trade means we can purchase more foreign goods for every dollar, whereas deteriorating terms-of-trade means we can purchase less. As climate policy affects energy prices, for large energy exporters or importers these trade effects may be substantial but are not captured by the GDP measure as normally computed. Moreover, what is relevant for welfare is the consumption of the imports and how income from exports is used for consumption today or for investment and future consumption. Direct consumption of imports by households (and indirect use of imports through their use as intermediate inputs to domestic goods) is included in the measure of consumption described in Section 3. Any net export income that is saved and invested contributes to future consumption. While many of these changes net out, GDP changes can lead to double counting of the cost of a policy, particularly if GDP impacts over time are considered. Then the change in investment is counted in the year when investment is affected (i.e., reduced) because it is part of GDP, and that effect is counted again in future years as reduced consumption because of the lower capital stock due to less investment in earlier years. The GDP changes in the 167 bmt scenario are provided in **Table B4**.

Table B4. GDP Change.

	2020	2030	2040	2050
% Change GDP from Reference	-1.45	-2.45	-3.34	-3.70

5. Per Capita and Per Family Costs

Whereas we reported the above changes in welfare, consumption and GDP as percentage changes, these can also be converted into absolute dollar levels and then divided by population or the number of households to arrive at a per capita or per household cost. This measure can then be compared with GDP per capita[7] or household income and may be a number that is more compelling to the average person or family. The GDP per capita cost in the 167 bmt scenario is provided in **Table B5**.[8] A similar per capita calculation can be made for welfare or consumption.

Costs per household are similar where instead of dividing by population one divides by the number of households (or by population and then multiply by average household size or for different assumed household sizes — family of four for instance). **Table B6** provides a cost for a household with a family size of four and family size of 2.57 (an average U.S. household size in 2005). A similar calculation for household welfare change can be made for households of different sizes.

[7] This study focuses on the US. Sometimes there is an interest in comparing absolute costs among countries. For this reason it is important to consider the relative purchasing power of different currencies as market exchange rates are highly variable and can provide misleading indication of relative well-being among countries. To reflect differences in relative incomes among countries when incomes are expressed in common monetary units, several indexes can be constructed. The most popular is a purchasing-power parity (PPP) index. Conventionally in using these indices the U.S is set to 1.0, so per capita GDP measured at PPP or at market-exchange rates is the same. For other countries these two measures may differ. Although widely accepted estimates of current PPP rates are available, there is no standard method for projecting how they may change in the future.

[8] All the caveats about the GDP measure described in Section 4 are applied here as well. The GDP calculation is provided here for illustrative purposes to compare with a popular measure of GDP per capita. As discussed above, welfare and consumption calculations are preferred.

Table B5. GDP Per Capita Cost.

	2020	2030	2040	2050
Population (billion)	0.34	0.37	0.41	0.44
Reference GDP (trillion 2005$)	17.48	22.57	29.25	37.53
Policy GDP (trillion 2005$)	17.23	22.02	28.28	36.15
Change in GDP from Reference (trillion 2005$)	-0.25	-0.55	-0.98	-1.39
Reference Per capita GDP (2005$)	51271	60513	72050	85496
Per capita GDP cost (2005$)	745	1480	2405	3160

Table B6. Change in Household Consumption.

	2020	2030	2040	2050
Reference Consumption (trillion 2005$)	11.83	15.16	19.59	25.09
Policy Consumption (trillion 2005$)	11.70	14.82	18.95	24.22
Change in Consumption (trillion 2005$)	-0.13	-0.34	-0.64	-0.88
Change in Consumption per family of 4 (2005$)	-1565	-3635	-6279	-7983
Change per U.S. Average Household Consumption (2005$)	-1005	-2336	-4034	-5129

6. Discounted Costs

Climate policies are typically specified over a period of several years or even decades, and because the level of the policy is changing over time the costs are changing from year to year. To compare costs over time, conventional economic practices apply a discounts rate to future costs on the basis that money today would earn a return over time. One also may be interested in a summary measure of the cost to be borne over the life of the policy. A useful measure is thus the average annual discounted GDP, welfare, or consumption change either as a percentage, an aggregate total or per household. A key variable in this calculation is a discount rate, i.e., how much less we value the future payments in comparison to the present payments of the same size, and there are different views on what the appropriate rate is for climate policy (see, for example, Nordhaus (2007) for a discussion about a discount rate). **Table B7** provides the discounted household welfare to 2005 using a 4% discount rate, for the policy effects to 2050, for an average U.S. household. One can also calculate an average discounted welfare change for a certain period of time (which, for 2020-2050, is a reduction of $700 compared to an average discounted household welfare of about $44,000 in the 167 bmt scenario). A similar calculation for a discounted GDP and consumption change can be made. A related measure is a net present value (NPV) of welfare (consumption, GDP) or welfare change, where all variables are summed over a certain period and discounted to the present values.

Table B7. Discounted Household Welfare Change.

	2020	2030	2040	2050
Reference Welfare (trillion 2005$)	14.30	18.67	24.23	31.12
Policy Welfare (trillion 2005$)	14.21	18.38	23.67	30.33
Change in Welfare (trillion 2005$)	-0.09	-0.28	-0.56	-0.78
Change per U.S. Average Household Welfare (2005$)	-680	-1960	-3564	-4582
Change per U.S. Average Household Welfare (2005$), discounted to 2005 at 4 percent	-378	-735	-903	-784

7. Change in Energy Prices

Prices of all goods will change in the economy as a result of climate policy, and in response to these changes consumers will adjust their consumption of goods. Climate policy will have the strongest effect on energy prices as fossil-based fuels will have an additional charge due to their carbon content and that change in price can have strong effects on the demand for these fuels. As a result, there is often interest in how fuel and electricity prices will change. That said, it is important to note that changes in energy prices are not a cost in addition to those discussed above (welfare, GDP, consumption): to the extent fuel and electricity price increases lead to an increase expenditure on energy by consumers or reduce the income and rents received by producers of energy, these effects are captured in broader measures of economic cost discussed above.

CO_2 pricing will in general increase the wedge between the prices consumers pay (which includes the CO_2 charge) and the price producers receive for fuels. Consumers will face higher CO_2-inclusive prices for energy and reduce their demand for fossil fuels. This will tend to lower the producer price received for fuels. **Table B8** provides energy prices in the reference (i.e., no climate policy) scenario, producer prices (exclusive of carbon charge), and consumer prices (inclusive of carbon charge) in the case of the 167 bmt policy. The consumer prices are calculated based on the CO_2 price and the carbon content of the fuel, here using factors from the US CCSP scenario study (see Table 4.7 in US CCSP, 2007). Electricity price effects depend on abatement costs and CO_2 emissions from electricity which change significantly because the intent of the policy is to greatly reduce these emissions. EPPA models the impact on the electricity price directly.

Table B8. Energy Prices.

Natural Gas Price ($/tcf)	Reference	Policy Producer Price	Policy Consumer Price
2010	7.09	7.09	7.09
2020	7.70	6.85	10.75
2030	9.72	8.55	14.32
2040	13.01	9.36	17.90
2050	17.47	9.10	21.75
Crude Oil price ($/bbl)	**Reference**	**Policy Producer Price**	**Policy Consumer Price**
2010	65.09	65.09	65.09
2020	88.20	82.10	114.03
2030	120.47	109.45	156.72
2040	142.83	125.28	195.26
2050	159.32	139.20	242.78
Coal Price ($/short ton)	**Reference**	**Policy Producer Price**	**Policy Consumer Price**
2010	32.23	32.23	32.23
2020	34.00	31.17	175.93
2030	35.70	30.67	244.95
2040	37.59	31.13	348.31
2050	39.71	32.06	501.56
Electricity Price (c/kWh)	**Reference**		**Policy Consumer Price**
2010	9.14		9.14
2020	10.82		16.21
2030	12.05		18.49
2040	12.49		18.97
2050	12.85		19.02

8. Marginal Abatement Cost (MAC)

A Marginal Abatement Cost (MAC) curve is a relationship between tons of emissions abated and the CO_2 (or GHG) price. Under highly simplified assumptions, the area under a MAC curve provides an estimate of total cost — but this is best seen as the direct cost of abatement undertaken in that year as it does not capture distortion costs and terms-of-trade effects among other economy-wide effects (for a discussion, see for example, Paltsev *et al.*, 2004). MACs derived from the EPPA model are described in detail in Morris *et al.* (2008). Some studies show a negative part of MACs, like, for example McKinsey and Co analysis (2007), where "almost 40 percent of abatement could be achieved at 'negative' marginal costs". Jacoby (1998) discusses some of the ways such bottom-up based engineering studies can be misleading as a guide to an economy-wide policy. For more on a comparison of EPPA and a McKinsey MAC curve, see Appendix B of the MIT Joint Program Report 164 (available at: *http://globalchange.mit.edu/pubs/abstract.php?publication_id=972*).

In economy-wide modeling studies, zero cost or beneficial efficiency improvements are recognized through an exogenous energy efficiency improvement over time and so these are captured in the reference/no policy scenario. Thus, they do not appear as part of a policy scenario and, therefore, a MAC constructed from an economy-wide model generally does not have a negative cost component. However, in countries with positive terms-of-trade effects or if auction revenue is used to cut existing distortionary taxes, there can be welfare gains from climate policy even with a positive CO_2 price, especially for smaller reductions (e.g., see Babiker *et al*., 2003).

REFERENCES

Babiker, M., A. Gurgel, S. Paltsev and J. Reilly, 2008: A Forward-Looking Version of the MIT emissions Prediction and Policy Analysis (EPPA) Model. MIT Joint Program on the Science and Policy of Global Change *Report 161*. Cambridge, MA. Available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt161.pdf

Babiker, M., G. Metcalf and J. Reilly, 2003: Tax Distortions and Global Climate Policy. *Journal of Economic and Environmental Management*, **46**: 269-287.

Creyts, J., A. Derkach, S. Nyquist, K. Ostrowski, J. Stephenson (2007), Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost? McKinsey and Company (available at: http://www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf).

Gurgel, A., S. Paltsev, J. Reilly and G. Metcalf, 2007: U.S. GHG Cap-and-Trade Proposals: Application of a Forward-Looking Computable General Equilibrium Model. MIT Joint Program on the Science and Policy of Global Change, *Report 150*. Cambridge, MA. Available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt150.pdf

EPA [Environmental Protection Agency], 2009: EPA Preliminary Analysis of the Waxman-Markey Discussion Draft, Washington, DC. Available at: http://www.epa.gov/climatechange/economics/economicanalyses.html.

Goulder, L., 2008: Economic Impacts of Environmental Policies. NBER Research Summary. Available at: http://www.nber.org/reporter/spring00/goulder.html.

Jacoby, H., 1998: The Uses and Misuses of Technology Development as a Component of Climate Policy. MIT Joint Program on the Science and Policy of Global Change, *Report 43*. Cambridge, MA. Available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt43.pdf.

Morris, J., S. Paltsev and J. Reilly, 2008: Marginal Abatement Costs and Marginal Welfare Costs for Greenhouse Gas Emissions reductions: Results from the EPPA Model. MIT Joint Program on the Science and Policy of Global Change, *Report 164*. Cambridge, MA. Available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt164.pdf.

Nordhaus, W., 2007: A Review of the Stern Review on the Economics of Climate Change. *Journal of Economic Literature*, **45**(3): 686-702.

Paltsev, S., J. Reilly, H. Jacoby and K. Tay, 2004: The Cost of Kyoto Protocol Targets: The Case of Japan. MIT Joint Program on the Science and Policy of Global Change, *Report 112*, Cambridge, MA. Available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt112.pdf.

Paltsev, S., J. Reilly, H. Jacoby and J. Morris, 2009: The Cost of Climate Policy in the United States. MIT Joint Program on the Science and Policy of Global Change, *Report 173*. Cambridge, MA. Available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt173.pdf.

US CCSP [US Climate Change Science Program], 2007: U.S. Climate Change Science Program Synthesis and Assessment Product 2.1 a: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. In: L. Clark *et al*., Washington, DC. Available at: http://www.climatescience.gov/Library/sap/sap2-1/default.html.