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How (and why) do climate policy costs differ among countries?

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23.1 Introduction

There have been many studies of the cost to Annex B countries of meeting Kyoto Protocol commitments. Unfortunately for these analyses, the Protocol has proved to be a moving target in terms of its interpretation and likely implementation. In addition, the economic performance and future expectations for some parties also are changing, and with these changes come revisions in reference emissions, which have a strong influence on the projected cost of meeting Protocol requirements. Looking back across these studies, the progression of work can be divided into three broad phases. The first studies were conducted soon after the Protocol was signed in 1997, and they focused on carbon emissions from fossil fuels. Often they assumed an idealized system of harmonized carbon taxes, or cap-and-trade among all the Annex B parties, contrasting such systems with implementation without international permit trade but with an idealized trading system operating within each country (see, for example, Weyant and Hill [1999]). These studies showed a high cost of the Protocol with autarkic compliance, but huge benefits of international trading because it made Russian "hot air" (potentially tradable emission quotas in excess of their anticipated emissions) accessible to other Annex B parties.

A second phase of studies followed the final negotiations in Marrakech in 2001 (Manne and Richels, 2001; Babiker *et al.*, 2002; Bohringer, 2002). By that time, the United States had withdrawn from the Protocol, and the potential contribution of Article 3.4 carbon sinks had been defined for each party. Progress in economic modeling also made it possible to consider the economic cost and contribution of non-CO_2 greenhouse gases (GHGs). These changes – US withdrawal, added sinks, and the consideration of non-CO_2 GHGs – led to downward revisions in the cost of meeting the Protocol, particularly if idealized trading among the remaining Annex B parties was assumed (Babiker *et al.*, 2002). In fact, many analyses concluded that credits from Russian hot air, and to lesser extent from Eastern European Associates of the EU, could be sufficient to meet Kyoto targets without additional effort.

We are now in a third phase of this work, where studies seek to estimate the cost under a more realistic representation of how the target reductions might actually be achieved. These studies seek to understand the cost of a mixed set of policies that almost certainly will differ among Kyoto parties and across economic sectors, and that may thus be more costly than the idealized systems studied earlier. Under some conditions costs may be less, if the policy is structured to avoid exacerbating pre-existing distortions. Some elements of such "imperfect" implementation have been considered in past studies. Examples include the potential for the exercise of monopoly or monopsony power in the permit market (e.g., Ellerman and Sue Wing, 2000; Bernard *et al.*, 2003), the impact of pre-existing tax distortions on labor and capital (e.g., Shackleton *et al.*, 1993; Goulder, 1995; Fullerton and Metcalf, 2001) or on energy (Babiker *et al.*, 2000a), and policies focused on particular technologies or sectors (e.g., Babiker *et al.*, 2000b, 2003a). In this analysis, we extend and interpret this work.

To study these latter aspects of cost realistically requires attention to the exact set of policies and measures likely to be implemented, and representation of ways they will interact with existing tax policies. Because circumstances can differ among countries and across sectors, a result that holds in one country may not hold in another. For example, much analysis

Human-induced Climate Change: An Interdisciplinary Assessment, ed. Michael Schlesinger, Haroon Kheshgi, Joel Smith, Francisco de la Chesnaye, John M. Reilly, Tom Wilson and Charles Kolstad. Published by Cambridge University Press.

of the double-dividend (from the use of carbon revenue to reduce distorting capital and labor taxes) has been conducted in the United States, and these studies have found evidence of at least a weak double-dividend. But recent work has shown a much smaller double-dividend effect in other Annex B countries (Babiker *et al.*, 2003b). This result occurs because reducing labor taxes within a particular fiscal structure may further distort relative prices by widening the divergence between labor rates and energy prices (tax inclusive). Where this happens, the distorting effect may offset other potential gains of revenue recycling.

Furthermore, the presence of varying distortions and fragmented policy implementation across countries raises questions about the degree to which a party can take advantage of the various international flexibility mechanisms, and if they do whether such trading is in fact welfare enhancing. Without comparable trading systems that can be linked, and without the willingness of parties to permit unrestricted cross-border trading, international flexibility may exist only on paper. Recent studies emphasize that extreme care is needed in the design of policies to make them economically efficient, and they highlight the difficulty of realistically achieving the low costs found under idealized cap-and-trade systems. Thus, the Protocol could end up being relatively costly for some parties but, without the United States involved, it will not achieve the environmental benefit imagined when it was signed in Kyoto. While international emissions trading has been shown to be beneficial for all parties *when trading includes the hot air from Russia and Eastern European Associate nations*, this result has not held up in more limited trading scenarios. In these cases trading may not be beneficial to all parties, even if they enter into the system voluntarily – a result that can be traced to the interaction of the carbon policy with existing energy taxes (Babiker *et al.*, 2004).

As the set of issues addressed by these economic modeling studies has become richer and more complex, the definition of economic cost itself and how it is estimated in economic models has presented a puzzle, particularly to those outside the economic modeling community. Depending on the study, cost results may be reported in various ways, e.g. in terms of the carbon or carbon-equivalent price of GHGs, as the integrated area under an abatement curve, or applying broader measures of economy-wide welfare such as the reduction in consumption or GDP. Adding to the confusion thus created is the fact that the costs of a policy as estimated by different concepts, even using a single model, often appear inconsistent. For example, early studies examining Kyoto costs without international emissions trading showed Japan to have the highest carbon price, followed by the United States and other OECD regions and the EU. But among this group the cost in percentage loss of welfare was lower in Japan than in the EU. The apparent inconsistency of these results, where the ranking of cost by one measure is reversed when another is used, emphasizes the importance of distinguishing among these cost concepts.

In this paper we explore these concepts and the differences among them. We consider sector-specific policies, using the example of Japan to explore the implication of alternative domestic implementation strategies. The results reported here are in the domain of the third phase of studies outlined above, where more complex and more realistic policies (not necessarily designed for economic efficiency) are the focus of analysis. To be sure, even after Kyoto's entry into force much remains in doubt, with the domestic policy details of most parties still not specified, so possible costs to Japan or any other party remain speculative. Nevertheless, this work can pave the way toward a likely fourth phase of studies where it will be necessary to investigate the costs and effectiveness of policies actually implemented – whether intended to achieve the Kyoto targets or other goals.

We begin the analysis with an overview of the EPPA model used to perform the simulations. In Section 23.3 we lay out a set of policies designed to study possible implementation of the Kyoto Protocol in Japan and elsewhere, and compare these costs across countries and regions using two of the more common measures of cost. This Kyoto example yields some seemingly paradoxical results about the variation in cost among countries, the difference in relative burdens depending on the measures used and the effects of emissions trading on welfare. Therefore in Section 23.4 we construct a diagnostic case where precisely the same constraint is imposed across countries and use this example to resolve some of these puzzles about the factors that contribute to welfare cost in any country. Finally, Section 23.5 reflects back on the Kyoto assessment and draws some lessons for future analyses of issues of this type.

23.2 The EPPA model

The EPPA model is a recursive-dynamic multi-regional general equilibrium model of the world economy, which is built on the GTAP data set (Hertel, 1997) and additional data for greenhouse gas (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) and urban gas emissions (Mayer *et al.*, 2000). The version of EPPA used here (EPPA 4) has been updated in a number of ways from the model described in Babiker *et al.* (2001). The updates are presented in Paltsev *et al.* (2005). The various versions of the model have been used in a wide variety of policy applications (e.g., Jacoby *et al.*, 1997; Jacoby and Sue Wing, 1999; Reilly *et al.*, 1999; Paltsev *et al.*, 2003). Compared with the previous version, EPPA 4 includes (1) greater regional and sectoral disaggregation, (2) the addition of new advanced technology options, (3) updating of the base data to the GTAP 5 data set (Dimaranan and McDougall, 2002) including newly updated input–output tables for Japan, the United States, and the EU countries, and rebasing of the data to 1997, and (4) a general revision of projected economic growth and inventories of non-CO_2 greenhouse gases and urban pollutants.

EPPA 4 aggregates the GTAP data set into 16 regions and 10 sectors shown in Table 23.1. The base year for the EPPA 4 model is 1997. From 2000 onward, it is solved recursively at 5-year intervals. To focus better on climate policy the model is

Table 23.1 Regions and sectors in the EPPA model.

Country/Region	Sectors
Annex B	**Non-energy**
United States (USA)	Agriculture(AGRI)
Canada (CAN)	Services (SERV)
Japan (JPN)	Energy intensive products(EINT)
European Union + [a] (EUR)	Other industries products (OTHR)
Australia/New Zealand (ANZ)	Industrial transportation (TRAN)
Former Soviet Union (FSU)	Household transportation (HTRN)
Eastern Europe[b] (EET)	**Energy**
Non-Annex B	Coal (COAL)
India (IND)	Crude oil (OIL)
China (CHN)	Refined oil (ROIL)
Indonesia (IDZ)	Natural gas (GAS)
Higher income East Asia[c] (ASI)	Electric: fossil (ELEC)
Mexico (MEX)	Electric: hydro (HYDR)
Central and South America (LAM)	Electric: nuclear (NUCL)
Middle East (MES)	**Advanced Energy Technologies**
Africa (AFR)	Electric: biomass (BELE)
Rest of world[d] (ROW)	Electric: natural gas combined cycle (NGCC)
	Electric: NGCC with sequestration (NGCAP)
	Electric: integrated coal gasification with combined cycle and sequestration (IGCAP)
	Electric: solar and wind (SOLW)
	Liquid fuel from biomass (BOIL)
	Oil from shale (SYNO)
	Synthetic gas from coal (SYNG)

[a] The European union (EU-15) plus countries of the European Free Trade Area (Norway, Switzerland, Iceland).

[b] Hungary, Poland, Bulgaria, Czech Republic, Romania, Slovakia, Slovenia.

[c] South Korea, Malaysia, Philippines, Singapore, Taiwan, Thailand.

[d] All countries not included elsewhere: Turkey, and mostly Asian countries.

disaggregated beyond that provided in the GTAP data set for energy supply technologies and for transportation, and a number of supply technologies are included that were not in use in 1997 but could take market share in the future under some energy price or climate policy conditions. All production sectors and final consumption are modeled using nested constant elasticity of substitution (CES) production functions (or Cobb–Douglas and Leontief forms, which are special cases of the CES). The model is written in the GAMS software system and solved using the MPSGE modeling language.

The regional disaggregation of EPPA 4 includes a breakout of Canada from Australia/New Zealand, and a breakout of Mexico to focus better on North America. Regional groupings of developing countries were altered to create groups that were geographically contiguous. New sectoral disaggregation includes a breakout of services (SERV) and transportation (TRAN) sectors. These were previously aggregated with other industries (OTHR). This further disaggregation allows a more careful study of the potential growth of these sectors over time and the implications for an economy's energy intensity. In addition, the sub-model of final consumption was restructured to include a household transportation sector. This activity provides transportation services for the household, either by purchasing them from TRAN or by producing them with purchases of vehicles from OTHR, fuel from ROIL, and insurance, repairs, financing, parking, and other inputs from SERV. While the necessary data disaggregation for TRAN is included in GTAP 5 (Dimaranan and McDougall, 2002), the creation of a household transportation sector required augmentation of the GTAP data as described in Paltsev *et al.* (2004a).

23.3 Policy scenarios

23.3.1 Cases studied

In order to study the potential cost of the Kyoto Protocol a number of assumptions are required. Exactly how countries will attempt to meet their commitments has not been fully determined, and it is not yet known which of the Kyoto Protocol's international flexibility mechanisms will in fact be

Table 23.2 Scenarios.

NoTrad	No emissions trading among parties. Reference average annual growth in GDP for Japan of 1.7%, the US of 3.2%, and the EU of 2.7% over the period 1997 to 2010. We assume an economy-wide cap-and-trade without CDM credits. The US is constrained to meet the Bush intensity target (18% emissions intensity improvement from 2000 to 2010).
NoTradR	NoTrad but with rapid economic recovery in Japan, with GDP growing at a rate of 2.6%/yr for 1997 to 2010.
ExTran	NoTrad but with Japan's transportation (TRAN) sector exempted from the cap.
N-30	NoTrad but with Japan's nuclear capacity reduced by 30% to reflect temporary shutdowns.
ExtEU	Extended EU bubble that includes EU expansion countries.[a] Japan and other regions continue to meet Kyoto targets with domestic, economy-wide cap-and-trade systems but do not trade with each other or ExtEU.
EUJ	Extended EU bubble includes Japan.
FullTrd	Full trade among Annex B parties to the Protocol, without US participation.

[a] Modeled here as including the EET EPPA regional group, dominated by countries that will become part of the expanded EU.

available. For example, European policy regarding international trading of emissions permits is not yet fully specified, and even then the EU trading system does not cover all sectors but omits transportation and households and focuses only on large point sources of CO_2. Like Europe, other countries may adopt policies that differentiate among sectors, limiting domestic trading system to point sources. Government-to-government transfers of permits outside a market trading system may be considered, but the outcome of those negotiations cannot be known at this time.

With our focus on domestic implementation in Japan, we also consider other economic and energy changes that affect the estimation of economic costs of a greenhouse gas target. Japan's economy has not recovered as strongly as was projected a few years ago, substantially reducing its likely future emissions levels. On the other hand, early plans to achieve the emissions commitment put heavy reliance on increasing the contribution of nuclear power (e.g., Babiker *et al.*, 2000c). Even when originally proposed, these plans seemed difficult to achieve because they would have required licensing and building many new reactors within a decade, when the planning and construction of some recent capacity additions stretched to 20 years. To have any chance of bringing this capacity on line by the Kyoto commitment period, Japan would have to begin a massive reactor construction program immediately and seek ways to speed up licensing and construction. Even more troublesome, a large share of the existing nuclear capacity was recently shut down temporarily. Thus not only is additional nuclear capacity unlikely to provide a large contribution to meeting the Kyoto commitment, but any recurring plant closures will lead to even more emissions from electricity production.

Recognizing these uncertainties about the precise economic conditions during the first Kyoto commitment period, and uncertainties about access to flexibility mechanisms, we construct a set of scenarios in order to explore the range of possible outcomes. They are summarized in Table 23.2. These scenarios include a case without emissions trading across regions (NoTrad), and one with international trading among all Kyoto parties with full access to Russian hot air (FullTrd). Scenarios with idealized emissions trading systems operating in each Annex B party serve as a basis for comparison with other implementation options. In all the cases studied in this part of our analysis we assume that the United States does not return to its original Kyoto target, but only meets the GHG intensity target set out by the Bush Administration.[1] The implied change in emissions is shown in Figure 23.1 (White House, 2002). While the United States Administration anticipates meeting its target with voluntary programs, we find that meeting it will require a positive carbon-equivalent price. We achieve the intensity target with an economy-wide cap-and-trade system covering all greenhouse gases. We also assume that Protocol members make full use of the agreed sinks allocated under the final agreement at Marrakech (see Babiker *et al.*, 2002), and that both Protocol members and the United States include in their cap-and-trade systems all of the non-CO_2 greenhouse gases identified in the Protocol.

We then consider a number of implementation variants. Focusing first on Japan, we consider a high economic growth or "Recovery" scenario (NoTradR) that is consistent with expectations for growth when Kyoto was signed but now looks unlikely considering recent experience. Given 1997–2003 economic performance, to achieve a 2010 GDP level like that projected only a few years ago would require a large and immediate economic turn-around and continued rapid growth over the remaining 6 years. Next we consider the implications of omitting the transportation sector from the Japanese emissions cap (ExTran), and of the effect of a 30% reduction of nuclear capacity (N–30), as might be realized if some level of shutdown were to recur during the Kyoto commitment period.

The next set of scenarios considers trading schemes focused on the EU. To approximate planned EU expansion, we create an extended EU bubble including the EET (ExtEU) region in EPPA. This trading system immediately allows the EU to access hot air in the EET (Eastern European economies in transition). We then consider the implications for Japan if it can trade within this system (ExtEUJ).

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[1] A different set of assumptions is made in Section 23.4 where we decompose the factors contributing to national cost.

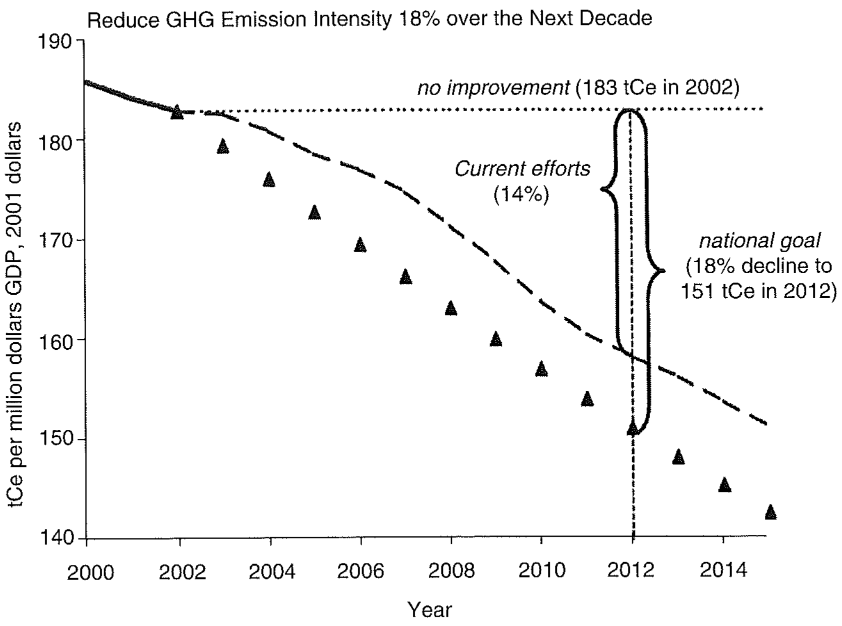

Figure 23.1 Bush administration intensity target for the United States (White House, 2002). tCe, metric tonnes carbon equivalent.

23.3.2 Simulation results

We focus our presentation of results on four regions, the United States, EU, Japan, and Canada, and on the effects in 2010. The top half of Table 23.3 shows the carbon-equivalent prices in each region for each scenario in $1997 per tonne C. Notably, Japan's carbon-equivalent price is much higher than the United States or the EU. Canada's carbon price is the highest of the group. Canadian emissions grew strongly from the mid-1990s up to the present, and our reference forecast for Canada continues this growth. The United States intensity target leads to a far smaller reduction than would its Kyoto target, but it still requires a $12 carbon price in the United States in 2010 given our EPPA reference growth in emissions. The US price varies only slightly across the scenarios because we assume that the United States does not engage in emissions trade with other regions. Similarly, Canada's carbon price varies little because we do not consider a case where Canada participates in emissions trading. (The policy variants do affect the United States and Canada through trade in other goods, yielding only a small effect on the carbon price.) The EU price in the NoTrad case is roughly half that of Japan while Canada's price is one-third higher. Note, however, that in the ExtEU case, which is intended to simulate the result of EU enlargement to include several Eastern European Associates, the EU's carbon-equivalent price falls to $21 per tonne. Thus, in carbon-price terms the EU Kyoto-target, with EU enlargement, requires only slightly more effort than the Bush intensity target in the United States. However, Japan's effort, as measured by the carbon-equivalent price, is five to ten times that in the EU or the United States, and Canada's is still higher.

The scenario variants for Japan show that a partial cap-and-trade system that (1) excludes transportation (ExTran), or (2) must be carried out with less than full nuclear capacity in operation (N-30), or (3) is implemented under conditions of more rapid economic growth (NoTradR) could cause Japan's carbon-equivalent price to increase by 50–100%. In some of the cases the carbon price exceeds that of Canada. Of course, uncertainties and implementation considerations are also present for the EU, the United States, and Canada. By focusing on Japan we can identify very specific issues facing Japan. At the same time, these issues are illustrative of the uncertainties any of these regions will face.

Access to international emissions trade, even if limited to the extended EU bubble, brings Japan's carbon-equivalent price down to $29. We estimate that full emissions trading, including full access to Russian hot air, would reduce the price in the Annex B parties to essentially zero. The very low price under full trading among the parties, absent the United States, is a finding of previous work (e.g., Babiker *et al.*, 2002).

We turn now to the results in terms of change in economic welfare in 2010, measured in terms of consumption and stated in percentage terms, also shown in the bottom half of Table 23.3. This measure shows a very different picture of economic burden. The NoTrad case results in a somewhat greater burden on the EU than on Japan, with Canada's cost by far the highest. The percentage consumption loss for Japan rises under the conditions described by the ExTran, N-30, and NoTradR cases, but still does not reach that of Canada. Of course the EU costs, even as a percentage, fall under ExtEU, and are thus much below Japan's costs in all scenarios based on NoTrad.

Table 23.3 Carbon-equivalent prices and consumption loss, 2010.

		NoTrad	NoTradR	ExTran	N-30	ExtEU	EUJ	FullTrd
Carbon-equivalent prices ($/tonne C)	Japan	100	217	141	186	99	29	0
	EU	52	52	52	52	21	29	0
	USA	12	12	12	12	12	12	9
	Canada	135	134	135	135	134	134	0
Consumption loss (%)	Japan	0.45	1.04	0.57	0.98	0.45	0.13	0
	EU	0.54	0.52	0.54	0.54	0.20	0.31	0
	USA	0.01	0.01	0.01	0.01	0.01	0.01	0
	Canada	1.32	1.33	1.32	1.32	1.29	1.29	0.01

Beyond the very different carbon price and percentage loss effects, there are two additional paradoxical sets of results in Table 23.3. The first is that the United States has virtually no consumption loss in any of these cases – a result attributable to changes in goods markets (explored below). The second is that the costs of climate policy *rise* for the EU when all of Europe trades with Japan (ExtEUJ), compared with the EU costs when there is trading only within Europe (ExtEU). This result contradicts the common expectation that trading benefits both buyers and sellers of permits. Here, because the ExtEU bubble has a lower carbon price than Japan, expanding the bubble to include Japan will mean that ExtEU will be a net seller and Japan a net buyer of permits. Babiker *et al.* (2004) found a similar result: in a study of the implications for the EU parties of trading among themselves, the selling countries lost from entering a trading regime. In order to understand these paradoxical results we turn now to a discussion of what lies behind these different cost concepts.

23.4 Cost concepts and why countries differ

23.4.1 An equal-reduction comparison

To investigate the various factors that can lead to differences in cost among countries we first create a new set of scenarios that allows a focus on the energy efficiency question and other factors affecting the energy markets, isolating them from differences in the emissions growth and from the effects of non-CO_2 GHGs and sinks. Cost differences among studies have often been traced to different assumptions about emissions growth (e.g., Weyant and Hill, 1999). While many of the Kyoto Parties adopted very similar reductions from the 1990 level, it was clear even as the Protocol was signed that some regions were on a growth path that would lead to their emissions being as much as 30% above this target in 2010 (e.g. the United States) whereas others were likely to be only 10 or 15% (or less) above the target (e.g. the EU). Not surprisingly analysts who assumed rapid growth for some countries usually found higher costs than those who assumed lower growth.

We would like to look beyond these obvious reasons for cost differences and thus we conduct a new set of simulations where each region (including the United States) is assumed to reduce its emissions by an equal 25% from the reference level in 2010 (the projected level in the absence of any action). We also focus only on carbon, excluding the non-CO_2 greenhouse gases and any consideration of sinks. The non-CO_2 GHGs often offer inexpensive abatement options (Babiker *et al.*, 2002), and emissions of these gases relative to CO_2 vary among countries. Their influence is not large enough to explain the cost phenomena summarized in Table 23.3, however, and their omission simplifies the analysis. As can be seen in a comparison with the emissions price of the NoTrad case in Table 23.3, the 25% reduction is much larger than that implied by the Bush intensity target. The cut is somewhat more stringent than Kyoto for Japan and is roughly equivalent for the EU and Canada.

One of the important ways these countries differ is in their emissions intensity (emissions per dollar of GDP). Japan, which relies less on coal and is very energy efficient, has a much lower intensity than the United States or Canada. Table 23.4 shows how energy efficiency can be responsible for high costs (in terms of carbon price) or low costs (in terms of consumption loss). In terms of carbon price (Column 1), from highest to lowest the order is Japan followed by the United States, then the EU, and finally Canada. Note that for a comparable percentage reduction in emissions from reference, Canada has a lower price than the others, whereas in the Kyoto results of Table 23.3 (excluding the cases showing Japan with higher growth or various restrictions) Canada's carbon price was much higher. This comparison shows that the carbon price in Canada under Kyoto is high because of the high reference growth in emissions, rather than from a lack of technological options.

In terms of percentage consumption loss (Column 2), on the other hand, the United States cost is by far the lowest, less than 25% of that in the EU. Japan's percentage consumption loss falls about midway between these two extremes. Canada's loss is very similar to Japan's. Using market exchange rates (1997 US$), the economies of the United States and EU are of comparable size, with that of the United States somewhat larger, and thus the absolute consumption loss for the EU is roughly four times larger than for the United States (Column 3). Japan's economy in 2010 is approximately 60% of the EU or the United States. Even with the smaller economy, the absolute consumption loss is larger than in the United States.[2] Canada's economy is smaller still: less than one-fifth that of Japan.

In fact, energy efficiency – or more specifically the difference in carbon emissions intensity (Column 4) resulting from a combination of lower energy intensity and less reliance on coal in Japan than in the United States or the EU – can explain this difference in consumption loss. Japan's carbon intensity is less than half that of the United States, and about 70% of Europe. On one hand, Japan's already emissions-efficient economy is the main reason its carbon price is much higher. For example, whereas the United States, the EU, and Canada can fuel-switch from coal to natural gas, reducing CO_2 emissions for the same energy output, that option is limited in Japan. On the other hand, the absolute reduction required in million metric tonnes (mmt) of carbon is 70% larger in the United States than in Europe even though the economies are comparable in size. In contrast, Japan's reduction is only 20% of that required in the United States and only 32% of that required in Europe. Thus, while the carbon price is higher in Japan, any measure of total cost (cost per tonne times the number of tonnes) will be proportionally less because of the smaller number of tonnes reduced. Canada is the most GHG-intensive of the four regions shown. This fact is reflected in a required reduction in mmt that is more than one-half that of Japan even though the economy is less than one-fifth as big. Thus the carbon price level, often casually used as an indicator of relative cost among countries, is an exceptionally poor indicator.

There is a still deeper paradox, shown in Column (6). The *average* consumption loss per tonne is the total consumption loss (Column 3) divided by the number of tonnes reduced (Column 5). By this measure the cost turns out to be very similar in Japan and the EU, but this value is about six times the cost in the United States. Canada's social cost is roughly twice that in the United States but not nearly as high as that in the EU and Japan.

23.4.2 *The influences on national cost*

To explore these differences we need to consider in more detail how these different measures of cost are defined. First, the carbon price is a marginal cost, and an average cost will differ from the marginal. We can see this divergence with reference to a marginal abatement curve (MAC), shown in Figure 23.2, for Japan and the EU. (These curves are derived using the EPPA model, again focusing only on carbon.) We derive the MAC by running the model with successively tighter emissions constraints and plotting the emissions reduction on the horizontal axis and the carbon price on the vertical axis.[3] A dashed horizontal line is drawn at the price in Table 23.3 associated with a 25% cut from reference for each country. We then draw a vertical line from the point where it intersects that MAC to the horizontal axis to confirm that this approach can accurately estimate the abatement quantity for each. Thus, such curves are a useful way to summarize the relationship between the carbon-equivalent price and emissions reduction (Ellerman and Decaux, 1998).

In a partial equilibrium analysis (focusing only on the energy sector and ignoring other effects) it is possible under some conditions to consider the area under the MAC curve, up to the required reduction, to be the total cost of the policy. The area is the sum of the marginal cost of each tonne, the first tonnes costing very little (approaching zero) and the cost of the last tonnes approaching the carbon price. We can take this total cost as estimated and divide by the number of tonnes to get an average cost per tonne. Because the very highest cost reduction is the last tonne of removal required to meet the target, the average cost derived in this way will necessarily be lower than the carbon price. If the MAC is bowed as in Figure 23.2, as it typically is when estimated from models of this type, then the average cost will be somewhat less than one-half of the marginal cost. Without an estimate of the full MAC, a rough approximation of the total cost of a policy can be constructed by assuming the MAC is not bowed in this way but is simply a straight line. The area is then the formula for a triangle:

$$\text{Total cost} = \frac{1}{2}PQ, \tag{23.1}$$

where P is the price of carbon, and Q is the quantity of carbon abated. Dividing by Q on both sides of Eq. (23.1) shows that, in this case, the average cost is exactly $1/2P$. For the United States, Table 23.3 shows that indeed the average consumption cost per tonne is somewhat less than one-half of the carbon price. The consumption cost is thus roughly consistent with an integrated area under the abatement curve.

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[2] It is important to note that these cross-country comparisons of the absolute cost (or size of the economy) depend heavily on the exchange rate. Given that the GTAP base year data are for 1997, and we must balance trade flows with capital accounts, we use 1997 market exchange rates (MERs). The US dollar has fallen against the Yen and Euro since 1997, so these absolute comparisons would change, widening further the relative reduction cost in absolute dollars between the United States and the EU. For comparing the "real" cost purchasing power parity (PPP) conversions are often used and these are at least more stable than MERs. In emissions trading scenarios we assume international trades of permits are at MERs, and to the extent that the price of permits do not represent the "real" cost to a domestic purchaser or seller, this presents a further distortion between equalized marginal cost at MER and the real social cost of the trade.

[3] One complicating factor that immediately emerges is how to construct a MAC when multiple countries are involved in the policy. One can simultaneously tighten the policy gradually on all parties; one can assume that all other parties are meeting a policy constraint and alter only the policy in the country for which one is constructing the MAC; or one can assume no policy in any party except for the party for which one is constructing the MAC. Because a policy can have spillover economic effects, the existence of a policy or not, and its severity, outside the country of interest will affect the emissions of that country and these different approaches to estimating the MAC will give somewhat different results. Here we have constructed the MACs assuming other parties are meeting their Kyoto commitments and that the United States meets the Bush intensity target.

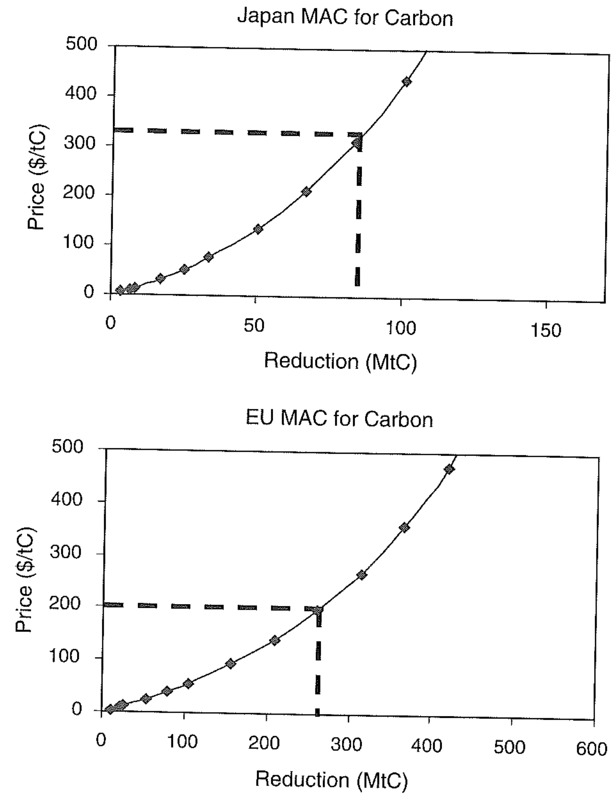

Figure 23.2 Marginal abatement curves for carbon, Japan and the EU.

Table 23.4 Measures of cost in 2010: 25% reduction from reference of carbon only.

	C-price, 1997$/tonne	Consumption loss,[a] %	Consumption loss, billions of 1997$	Carbon intensity, tonne/million 1997$[b]	Carbon reduction MtCe	Average consumption cost, 1997$ tonne
Japan	323	1.5	48	68	89.6	538
EU	205	2.2	160	96	275.1	586
USA	231	0.5	43	155	461.2	93
Canada	127	1.1	7	199	49.0	137

[a] Macroeconomic consumption loss as a percentage of total consumption.
[b] GDP intensity: carbon emissions/GDP.

But this result does not hold true either for Japan or for the EU. In fact the average consumption cost per tonne is *larger* than the carbon price, and thus clearly cannot be an average of the marginal cost of each tonne as represented in the MAC. Similarly, Canada's average consumption cost per tonne is also above the carbon price. Integrating under the MACs for Japan and Europe, up to a 25% reduction, and dividing by the tonnes reduced, we find the average cost derived is $150 for Japan and $100 for Europe. As expected, the average costs calculated from the MAC are slightly less than one-half the carbon price. Thus, there are other considerations, not captured in the MAC, that increase the consumption cost of climate policy in these regions.

Before continuing our explanation of this difference it now can be seen why, under these conditions, a region that sells permits can be made worse off, as happens to the EU in the ExtEUJ case. Using the carbon prices from Table 23.4 a private firm at the margin in the EU sees the direct additional cost of reducing emissions to be $205, whereas a Japanese firm at the margin sees the cost as $323. The EU firm is willing to undertake reductions that cost $205 or more (let us assume $205) and sell them to the Japanese firm, and the Japanese firm would at the margin be willing to pay as much as $323 for these credits to avoid making the reductions themselves. We would expect an equilibrium market price to fall somewhere in between $205 and $323; let us suppose it is $250. The EU firm

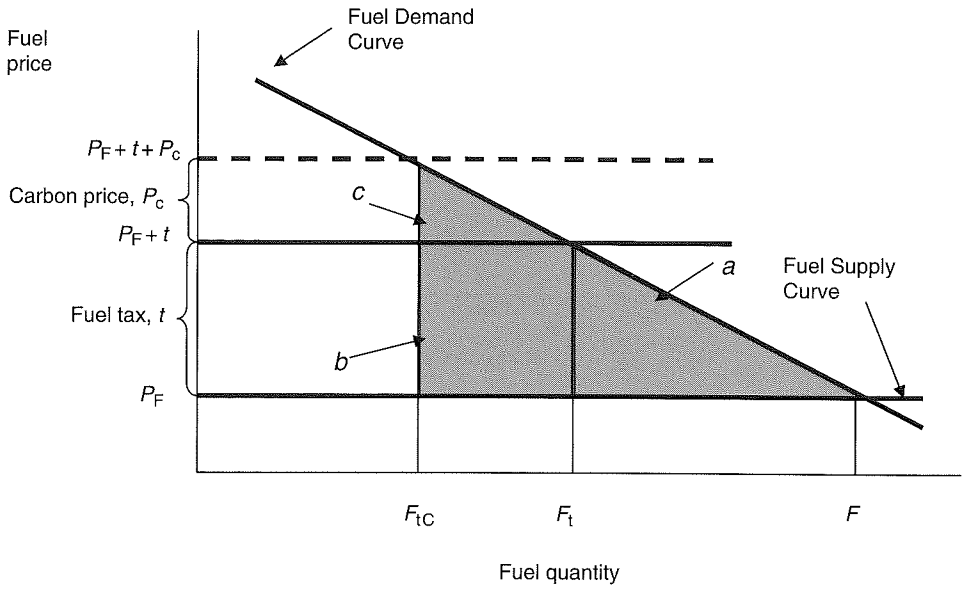

Figure 23.3 Effects of existing fuel taxes on the cost of carbon policy. The economic cost of the fuel tax (t) added to the fuel price (P_F) is given by area *a*. Adding a carbon constraint, with a price of carbon (P_C), raises the total fuel price, inclusive of the tax and carbon price, to $P_F + t + P_C$. Without the fuel tax, the economic cost of the carbon policy would be just the area labeled *c*. But, the pre-existing tax means that the cost represented by the area *b*, in excess of the actual cost of the fuel, is also an added economic cost of the policy. A marginal abatement curve (MAC) for carbon will include only area *c*.

thus profits $45 per permit by selling at $250 a reduction that cost it only $205. The Japanese firm benefits $73 per permit purchased by paying only $250 for reductions that would have cost it $323. But the *average social cost* of that tonne in the EU is $586, so the EU has a net loss from the trade, on average, of $\$586 - \$250 = \$336$. On the other hand, Japan gains not only the avoided direct cost but the avoided social cost of $\$538 - \$250 = \$288$. In this example, the result of trading, summing across the two regions, is to reduce total consumption because the gain of $288 in Japan is less than the loss of $336 in the EU.

The trading result for the ExtEUJ case depends on the divergence of the direct cost, as measured by the marginal abatement cost, from the social cost as measured by the consumption loss. Two factors are mainly responsible for this phenomenon. One is the interaction of the GHG policy with existing taxes (or subsidies) and the other is change in the terms of trade.[4] A major difference for the United States compared with the EU and Japan is that US fuel taxes are quite low, and thus we would immediately suspect that the fuel tax distortion effect is a major contributor to the high average consumption loss in Europe and Japan.[5]

Figure 23.3 graphically depicts how existing energy taxes can increase the cost of a carbon policy. Here we represent the demand for a carbon-containing fuel and its supply. The economic cost of a tax is the lost value of consumption of the good, less the cost of producing it. It is the area under the demand curve from the market equilibrium without the tax up to the market equilibrium point with the tax. The cost of the fuel tax is thus the shaded area, labeled *a*. Adding a carbon price results in additional loss of the area labeled *c*, the direct economic loss associated with the carbon constraint, plus the area labeled *b*, the increase in the loss due to the original fuel tax.[6]

If we consider that there is an area, here labeled *c*, under the demand for each fuel for each sector (and final consumption), the sum of all of these areas for an economy will approximately equal the area under the MAC for carbon.[7] Here we

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[4] A country's terms of trade is the ratio of the weighted average of its export prices divided by the weighted average of the prices of its imports. An increase in the ratio (more imports from the same physical quantity of exports) will increase welfare, and vice versa.

[5] There can also be a further interaction with capital and labor taxes, but this does not occur in EPPA because of the particular formulation of the model. Labor supply is fixed in each period, and thus taxes or changes in the wage rate do not affect the quantity supplied. Thus, there is no deadweight loss with labor taxes directly represented in EPPA, and so with changes in the wage rate there is no additional deadweight loss from this source. Similarly, the formulation of EPPA as a recursive-dynamic model means that capital in a period is a fixed supply, determined by the previous period's capital, less depreciation, plus investment, with investment equal to the previous period's level of savings.

[6] To some degree the fuel tax may represent other externalities (e.g., congestion) that are being managed using this instrument. We do not compensate for this potential effect of the tax, as discussed below.

[7] To imagine this, consider a single fuel and a single market for that fuel. We could measure the fuel, instead of in gallons or exajoules, in terms of the tonnes of carbon contained in the fuel. We could also compute the fuel price, instead of in dollars per gallon or exajoule, as the cost of the fuel per tonne of carbon in it. The demand curve so transformed and plotted as price rose from the initial market price without the carbon constraint would be exactly the

have drawn the demand curves as strictly linear, but as usually represented it will be convex with respect to the origin.[8] This non-linear relationship of demand to price gives rise to the curvature of the MAC. The important implication, however, is that if there are pre-existing energy taxes, the area under the MAC will underestimate the cost of a climate policy by a significant amount because the excluded cost is a rectangle whereas direct cost is approximately a triangle.

Paltsev *et al.* (2004b) develop a decomposition analysis and apply it to these EPPA scenarios. They show that in the cases evaluated in this section, for Japan the distortion cost is about 2.5 times the direct cost measured by the area under the MAC; for the EU it is over 4.5 times the direct cost; and for Canada it is about the same size, whereas there is no distortion loss for the United States. However, there is an offsetting oil market benefit due to changing terms of trade of between approximately 3.5 and 6% for Japan, the EU, and the United States, whereas Canada suffers in terms of trade loss in the oil market because it is a net exporter. How can these extra distortion costs be so large for the EU and Japan? The answer is that fuel taxes are extremely high. A numerical example can illustrate the importance of these distortions. Given the carbon content of gasoline, a \$100/tonne carbon charge equates to \$0.34/gallon of gasoline. Thus a \$100 carbon price is the equivalent of a \$0.34 per gallon gasoline tax. Gasoline taxes in the EU ranged from \$2.80 to \$3.80 per gallon as of 2004 (OECD/IEA, 2004). That is the equivalent of an \$800 to \$1200/tonne carbon tax. In the gasoline market, then, a \$100 carbon tax would cause a direct cost loss of approximately 1/2*\$100 = \$50/tonne at the margin, but the distortion cost would be the full rectangle of \$800 to \$1200 per tonne, 16 to 24 times the direct cost. Other fuels in the EU are not taxed at as high a rate, so the average social cost in Table 23.3 is an average across the economy, weighted by how much of the reduction occurs in each sector with a different fuel tax rate.

The existence of these high fuel taxes in transportation raises several issues. A first issue is whether these taxes are correcting some other external effects of fuel use such as issues of dependence on foreign fuel sources, urban congestion, or injury to others in automobile accidents. As reviewed in Babiker *et al.* (2004), analysts who have looked carefully at these taxes do not believe a good case can be made that they are optimally correcting for such externalities. If they were, the levels and changes in them would take some account of the marginal benefit in terms of externality reduction, which is not the case. Furthermore, for the most important externalities associated with vehicle use, a fuel tax would be an extremely blunt instrument. For example, all fuel users in a country pay the tax but congestion occurs only in urban areas during particular times of day. In the United States the gasoline tax revenue is designated to the Federal Highway Trust Fund that builds and maintains highways, and is best treated as a justified user fee. The high fuel taxes in Europe and Japan have a complex history but are now treated mainly as a source of government revenue. The high taxes through their influence on driving probably have some indirect effect of lowering externalities. We have not assessed the magnitude of these indirect benefits. However, because fuel taxes only at best bluntly correct the various externalities associated with automobile use, there will remain a substantial distortionary effect.

A second issue is how policies may be adjusted to deal with the influence of these existing distortions. We show that international emissions trading can decrease welfare compared with a non-trading situation, at least for the permit selling region and possibly for the entire trading block in a Pareto sense. That is, gains in those regions that are net purchasers may be insufficient to compensate losses in selling regions.[9] The proposed EU trading system currently exempts transportation and thus would avoid exacerbating the effects of high fuel taxes. However, avoiding the distortionary effect by exempting those sectors with fuel taxes means that the burden of reduction for the country must fall on the non-exempt sectors The EU trading system as so far specified is a test program designed to operate prior to the first Kyoto commitment period, and the cap levels are within 1 or 2% of the expected reference level of emissions. Discussions of "adequacy" of these caps in moving toward the goals of the first commitment period of the Kyoto Protocol appear to focus on whether the capped sectors are bearing an appropriate proportion of the country-wide reduction. But if, as national targets are tightened, the exemptions are to remain in place in order to avoid exacerbating distortions, emissions will need to be disproportionally reduced in the capped sectors. The problem is alleviated only if the cap on non-transport sectors can be met in some other way that does not exacerbate fuel tax distortions, perhaps through Joint Implementation or CDM (Clean Development Mechanism) credits.

Finally is the issue of whether existing models consider all the pre-existing distortions in the economy that might be affected by the climate policy or the introduction of emissions trading. The short answer is no. In recent work, some success toward including these externalities in the EPPA model has been made (Yang *et al.*, 2005). Uncontrolled externalities or externalities controlled very bluntly by a fuel tax may be worsened by removing the fuel tax completely. These externalities must be controlled in another way or the taxes partially removed (if the tax is an efficient means of dealing

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MAC plotted as a "demand for carbon", rather then the inverse – the willingness to do without carbon (i.e., abate).

[8] A fuel demand curve is not represented directly in a CGE model like EPPA, but is indirectly represented by the representation of the production technology, usually as a constant elasticity of substitution (CES) production function. To obtain the MAC from just the individual fuel demand functions, we required an uncompensated demand function that incorporates the changes in demand for downstream goods whose prices change.

[9] How to aggregate losses and gains in different regions depends, however, on having an accurate intercountry comparison if market exchange rates fail to accurately reflect real income comparisons.

with some of the externalities) to be sure that a country is indeed better off. Moreover, to the extent taxes are removed, new sources of revenue may need to be identified to make up for lost revenue, and these sources may themselves have a distortionary effect. A careful assessment of each country's domestic situation and how the climate policy will interact with it is needed. No doubt these details of country structure complicate climate policy negotiations. One country may see its policies as interventions to correct another problem, whereas another country may see them as an attempt to skew emissions trading or competitiveness.

In the end, while an efficiency case can be made for exemptions or other deviations from a country-wide cap-and-trade system, experience in trade negotiations would suggest that in practice the efficiency case for the policy deviation is often weak or non-existent. Instead, the exemption policy may represent a further distortion. Thus, caution is warranted in believing too easily either that equalizing the marginal cost of carbon across regions is necessarily a move toward improved efficiency, or that every case for deviation or exemption is legitimately based on efficiency grounds.

23.5 Conclusions

As implementation of the Kyoto Protocol or policies such as the Bush Administration's intensity target proceeds, economic analysis of mitigation policies must begin to deal with more realistic implementation, representing national economies with the varying levels of existing taxes and economic distortions. As the set of issues addressed by these economic modeling studies has become richer and more complex, the definition of economic cost itself, and how it is estimated in economic models, has presented a puzzle, particularly to those outside the economic modeling community. Results can seem paradoxical: focusing on carbon-equivalent price, Japan or Canada looks to be the high-cost region, and Europe the low-cost. But in terms of welfare loss Japan appears low-cost, Europe higher-cost, and Canada higher-cost still. These cost estimates are not independent of the specific policies by which targets will be achieved, and these policies are far from settled.

The diagnostic case developed in Section 23.4 illuminates the implications of the use of different measures of cost, and explains why the relative carbon price among Kyoto parties may not be an accurate measure of efficiency or of which country is bearing the largest cost burden. Relative emissions intensity, different levels of distortions in the form of fuel and other taxes, and different effects through trade are shown to be important factors. We show that existing distortions, particularly fuel taxes, greatly increase the cost of an economy-wide cap-and-trade applied in the EU or Japan. The United States has much lower fuel taxes so these distortions are negligible. Canada's costs are higher than the direct mitigation cost because it loses energy market export revenue owing to policy-induced reductions in world producer prices of energy. The United States gains from this fuel market effect because it is a net importer of fuel, particularly oil. These examples illustrate why integrating under a MAC captures only the direct cost, and thus can be highly misleading in the presence of large tax distortions or other important general equilibrium effects.

We consider comparable reductions across regions (25% from reference in 2010) to isolate the effect of difference reference growth in emissions on these cost calculations. We also consider the cases of the EU, Japan, and Canada meeting their Kyoto targets and the United States meeting the Bush intensity target. For a country with a low emissions intensity, as in Japan, the absolute reduction in tonnes is small relative to the total size of the economy, and this fact means that welfare loss is a smaller share of total welfare. Low emissions intensity (high energy efficiency) also means the economy has fewer options to reduce emissions further, resulting in a higher carbon price. Energy efficiency thus pushes in both directions, lowering the number of tonnes that need to be reduced but raising the direct cost per tonne. On net this lowers costs in Japan relative to the EU.

A country's economic cost of complying with Kyoto or pursuing any climate mitigation policy will depend on a number of characteristics, including its economic growth, how it implements its climate policies, and interactions with other taxes and uncontrolled externalities. Early studies of the Kyoto Protocol focused on the huge benefits of international emissions trading, but those benefits depended on access to Russian hot air and to a lesser extent on hot air and low-cost reductions from Eastern European Associates of the EU. Russian economic growth has been more rapid than some imagined, however, and Russia is concerned about the Protocol becoming a constraint on its economic growth. That worry and the difficulty of creating and enforcing a cap-and-trade system in Russia may prevent many of these permits from being available. With entry into the Union, the Eastern European Associates are under the EU bubble, and this extended EU region has thus become a source of low-cost permits for Japan should a trading system be established among these parties. Economic distortions come into play in this situation, however. While the EU's private cost of emissions reduction is lowered when the bubble is extended to include Japan, its average social cost is increased. That result raises the question of whether the EU will in fact create such a trading system with Japan.

The coverage of the European Trading System is different from the example represented here, as it includes only large point sources and, importantly, excludes the household sector and highly taxed transport sector. Thus the implications for the EU and Japan of opening trading in emissions might be different from the calculations shown here. Only when the cap for the EU's covered sectors and the mechanisms used to restrain other emissions have been specified in full, and similar details are determined for Japan, will it be possible to gain an accurate picture of Kyoto compliance and the effects of emissions trade. But one lesson is clear: caution is warranted in assessing the welfare effects of policies based on estimated greenhouse gas prices given the presence of pre-existing taxes and other distortions in the countries involved.

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