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Tax Distortions and Global Climate Policy

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Tax Distortions and Global Climate Policy

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Abstract

We consider the efficiency implications of policies to reduce global carbon emissions in a world with pre-existing tax distortions. We first show that the weak double dividend, the proposition that the welfare improvement from a tax reform where environmental taxes are used to lower distorting taxes must be greater than the welfare improvement from a reform where the environmental taxes are returned in a lump sum fashion, need not hold in a world with multiple distortions. A small analytic general equilibrium model is constructed to demonstrate this result. We then present a large-scale computable general equilibrium model of the world economy with distortionary taxation. We use this model to evaluate a number of policies to reduce carbon emissions. We find that the weak double dividend is not obtained in a number of European countries. Results also demonstrate the point that the interplay between carbon policies and pre-existing taxes can differ markedly across countries. Thus one must be cautious in extrapolating the results from a country specific analysis to other countries.

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1. INTRODUCTION

Over the past ten years, there has been a tremendous amount of interest in the interaction between distortionary taxation and optimal environmental policy. Much progress in our understanding of this interaction has taken place and general equilibrium modeling has played a key role. A popular but often ill-defined concept is the "double dividend." This is the concept that imposing an environmental tax can both improve economic performance and the environment.[1] The attraction of a double dividend arose in the 1980s from the conjunction of an increased concern in climate change and the consequent need for a policy response on the one hand and the U.S. federal budget deficit on the other hand. Environmental taxes appeared desirable given both these concerns.

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[1] Much of this subsequent discussion draws on Fullerton and Metcalf (1998).

Goulder (1995) provides a useful taxonomy of double dividends as well as an explanation of the dividend's appeal.[2] Goulder distinguishes a "strong" and "weak" double dividend. A strong double dividend occurs when welfare is increased in response to an environmental tax regardless of the improvement in environmental quality. Given the great difficulties associated with quantifying the economic benefits of an improved environment, a strong double dividend is appealing in that a case can be made for an environmental tax without having to worry about the magnitude of the environmental gains. It is possible for welfare (net of environmental improvements) to increase in response to a green tax reform if the environmental tax revenues are used to lower a particularly egregious distorting tax. This simply points out the obvious fact that tax reforms to replace highly distorting taxes with less distorting taxes are, in general, good ideas. See Bovenberg and Goulder (forthcoming) for further discussion of this point. We find, as discussed below, that a strong double dividend is unlikely for the climate policy targets in the Kyoto Protocol.

A "weak" double dividend occurs when the welfare improvement from a tax reform where environmental taxes are used to lower distorting taxes is greater than the welfare improvement from a reform where the environmental taxes are returned in a lump sum fashion. A general consensus has emerged that the weak double dividend is an uncontroversial idea. We show below, however, that in an economy with multiple distortions, a weak double dividend need not occur. Moreover, we argue that climate policies under consideration in response to global warming will likely not provide a weak double dividend in a number of European countries.

We proceed as follows. In the next section, we provide a simple analytic general equilibrium model to show why a weak double dividend need not hold. We then turn to computable general equilibrium (CGE) modeling. Most general equilibrium models typically focus on a single country. The ability to carry out cross country comparisons as well as analyses that evaluate international policy schemes (*e.g.*, Kyoto) in a world with pre-existing taxation cannot be done until datasets used to calibrate international CGE models include a comprehensive set of taxes across countries that are constructed in a consistent fashion. The third section illustrates how this could be done. Section 4 provides results from the MIT EPPA model. Section 5 concludes.

2. MUST A WEAK DOUBLE DIVIDEND OCCUR?

A weak double dividend arises when welfare is increased by using environmental tax revenues to lower distorting taxes as opposed to returning the revenues in a lump-sum fashion. Economists view this as an uncontroversial proposition.[3] In this section, we present a simple analytic general equilibrium model to show that the weak double dividend need not hold. While the weak double dividend will hold true in a world with only one (non-environmental) distorting tax, it will not necessarily be true in a more general economy.

Our model is particularly simple. There are two goods, both of which are produced with labor (L) and one of which creates pollution (Z) as a by-product of the production process. As noted elsewhere (see Fullerton and Metcalf, 2001), we can model pollution as an input into the

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[2] See Bovenberg (1999) for an update to that literature.

[3] Starrett (1999) notes, for example, that "this result is quite general and reflects the fact that we are always better off using the green tax revenue to reduce some other distorting tax rather then [sic] (for example) returning it in a lump sum manner." (p. 36) See also the discussion in Goulder (1995) on pages 159-161.

production process. Without loss of generality, we can also associate some labor with pollution. This simply assures an interior solution to the model:

$$X = L_X \tag{1}$$

$$Y = F(L_Y, Z) \tag{2}$$

where F is a constant returns to scale production function. We assume that one unit of labor is associated with each unit of pollution so that the resource constraint is

$$L = L_X + L_Y + Z \tag{3}$$

Utility of a representative agent is a function of consumption of the two goods, leisure (V) and environmental quality (E):

$$U(X,Y,V;E)\ E = e(Z),\ e' < 0. \tag{4}$$

Consumers maximize utility subject to the budget constraint

$$p_X X + p_Y Y = L + T \tag{5}$$

where p_X and p_Y are the consumer prices for X and Y, the gross wage rate equals 1 (labor is taken as the numeraire good) and T is a lump-sum transfer. Leisure and labor sum to a fixed time endowment. Consumer prices are related to producer prices as follows:

$$p_X = 1 + t_X \tag{6a}$$

$$p_Y = q_Y(1 + t_Y) \tag{6b}$$

$$p_Z = 1 + t_Z \tag{6c}$$

where t_X and t_Z are commodity taxes levied on goods X and Y, respectively, to raise revenue, and t_Z is an environmental tax, levied on Z. Given the technology, the producer prices of X and Z always equal 1 and we normalize the producer price of Y so that it equals 1 prior to the imposition of an environmental tax. The environmental tax is equal to zero initially. Consumer behavior can be represented by the following two equations under the assumption that L and E are weakly separable from each other and from (X,Y) and that utility over (X,Y) is homothetic:[4]

$$\hat{X} - \hat{Y} = \sigma_C\,(\hat{p}_Y - \hat{p}_X) \tag{7}$$

$$\hat{L} = -\varepsilon\,\left(\phi\ \hat{p}_X + (1-\phi)\hat{p}_Y\right) \tag{8}$$

where σ_C is the elasticity of substitution between X and Y in consumption, ε is the uncompensated labor supply elasticity and ϕ is the share of consumer expenditure on X. A hat over a variable indicates a percentage change. In other words, $\hat{X} = dX/X$. (For taxes and transfers below, we will define $\hat{t} = dt/(1+t)$ and $\hat{T} = dT$.) Equation (7) says that substitution between X and Y depends on relative prices for X and Y and σ_C, while equation (8) relates labor supply to the real net wage. The nominal wage is 1 and the real wage equals the nominal wage divided by a price index based on the consumer prices of X and Y.

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[4] These assumptions are commonly made as a "neutral" stance assumption.

The government budget constraint is given by

$$t_X X + t_Y q_Y Y + t_Z Z = T, \tag{9}$$

again noting that t_Z initially equals zero. Below, we discuss how taxes and transfers adjust to maintain equation (9) as the environmental tax is levied.

Finally, pollution abatement can be captured in the production function for Y by

$$\hat{L}_Y - \hat{Z} = \sigma_Y \hat{t}_Z . \tag{10}$$

We consider three different experiments. In each, we introduce a small environmental tax ($\hat{t}_Z > 0$) and let one of the three following variables adjust endogenously: $\hat{T}$, $\hat{t}_X$, $\hat{t}_Y$. We can then compare the change in utility across policy changes. The change in utility in general is given by:

$$\frac{dU}{\lambda L} = \left(\frac{t_X X}{L}\right)\hat{X} + \left(\frac{t_Y Y}{L}\right)\hat{Y} - \mu\left(\frac{Z}{L}\right)\hat{Z}, \tag{11}$$

where λ is the private marginal utility of income and $\mu \equiv -\frac{\partial U}{\partial E}\frac{e'(Z)}{\lambda}$ is the social marginal damages of pollution. The left hand side of equation (11) gives the change in utility in dollar terms $\left(\frac{dU}{\lambda}\right)$ as a percentage of the value of resources used in production. In other words, it expresses the dollar value of the utility change as a percentage of GNP.

Differentiating equation (5), we can obtain:

$$\phi(\hat{p}_X + \hat{X}) + (1-\phi)(\hat{p}_Y + \hat{Y}) = S_L \hat{L} + \frac{\hat{T}}{L+T} \tag{12}$$

where $S_L \equiv \frac{L}{L+T}$. Differentiating equation (9) yields

$$\phi(\hat{t}_X + \theta_X \hat{X}) + (1-\phi)(\hat{t}_Y + \theta_Y (\hat{Y} + \hat{q}_Y)) + \left(\frac{Z}{T+L}\right)\hat{t}_Z = \frac{\hat{T}}{L+T} \tag{13}$$

where $\theta_i = \frac{t_i}{1+t_i}, i = X, Y$. Next, we can differentiate the three price expressions in equation (6) to obtain

$$\hat{p}_X = \hat{t}_X \tag{14}$$

$$\hat{p}_Y = \hat{q}_Y + \hat{t}_Y \tag{15}$$

and

$$\hat{p}_Z = \hat{t}_Z . \tag{16}$$

Assuming firms set producer price equal to marginal cost, $q_Y = MC = C(t_Z, Y=1) \equiv \left(\frac{L_Z^*}{Y}\right) + p_Z\left(\frac{Z^*}{Y}\right)$ where L_Z^* and Z^* are the optimal (and observed) levels of labor input and pollution used in the production of Y. These equalities follow since the production function is constant returns to scale. Differentiating this equation and invoking the Envelope Theorem, we obtain

$$\hat{p}_Y = \hat{t}_Y + \left(\frac{Z}{Y}\right)\hat{t}_Z \,. \tag{15'}$$

Finally, we can differentiate the resource constraint (equation (3)) to obtain

$$\hat{L} = \left(\frac{L_Y}{L}\right)\hat{L}_Y + \left(\frac{X}{L}\right)\hat{X} + \left(\frac{Z}{L}\right)\hat{Z} \,. \tag{17}$$

If we substitute equations (14), (15'), and (16) into equations (7), (8), (12), and (13), we can express the general equilibrium response in terms of tax changes rather than price changes:

$$\hat{X} - \hat{Y} = \sigma_C\left(\hat{t}_Y + \left(\frac{Z}{Y}\right)\hat{t}_Z - \hat{t}_X\right) \tag{18}$$

$$\hat{L} = -\varepsilon\phi\,\hat{t}_X - \varepsilon(1-\phi)\left(\hat{t}_Y + \left(\frac{Z}{Y}\right)\hat{t}_Z\right) \tag{19}$$

$$\phi(\hat{t}_X + \hat{X}) + (1-\phi)\left(\hat{t}_Y + \left(\frac{Z}{Y}\right)\hat{t}_Z + \hat{Y}\right) = S_L\,\hat{L} + \frac{\hat{T}}{L+T} \tag{20}$$

and

$$\phi(\hat{t}_X + \theta_X\,\hat{X}) + (1-\phi)\left(\hat{t}_Y + \theta_Y\left(\hat{Y} + \left(\frac{Z}{Y}\right)\hat{t}_Z\right)\right) + \left(\frac{Z}{T+L}\right)\hat{t}_Z = \frac{\hat{T}}{L+T} \,. \tag{21}$$

Equations (18) through (21) along with (10) and (17) are a system of six linear equations in six unknowns. The endogenous variables are $\hat{X}, \hat{Y}, \hat{L}, \hat{L}_Y, \hat{Z}$, and one of the following three variables $\hat{T}, \hat{t}_X, \hat{t}_Y$ while $\hat{t}_Z$ is the exogenous variable.

As we consider implementing a small tax on pollution ($\hat{t}_Z > 0$), we have a number of possible uses of revenues. **Table 1** outlines the three policies we consider:

Table 1. Policy Scenarios

Policy	Hold Fixed	Adjust
1	t_X, t_Y	T
2	t_Y, T	t_X
3	t_X, T	t_Y

A weak double dividend occurs when the welfare gains from policies 2 or 3 are greater than the welfare gains from policy 1. We next show that the weak double dividend need not hold.

We impose a small environmental tax (starting at a zero tax rate) and solve the general equilibrium model described above and use equation (11) to measure the welfare impact of the policy. We note our parameter assumptions in **Table 2**. These parameter assumptions are based on Fullerton and Metcalf (2001).

Table 2. Model Assumptions

σ_c		1.0
σ_Y		1.0
ε		0.4
μ		0.1
Initial Allocation	L_X	40
	L_Y	30
	L_Z	30
	Y	30

Table 3 reports the welfare gains (or losses) for a small environmental tax with proceeds returned lump sum for various configurations of initial tax rates. We simulate an environmental tax rate equal to ten percent of the producer price of pollution $\left(\hat{t}_Z = 0.1\right)$. In general the tax is welfare enhancing unless the commodity tax on the polluting good is disproportionately larger than the tax on the non-polluting good. This follows since the pollution tax increases the cost of the polluting good and so increases the intercommodity distortion between goods *X* and *Y* that exists initially because of the commodity tax.

Table 3. Lump Sum Return of Tax

		t_X				
		0	0.1	0.2	0.3	0.4
t_Y	0	0.25%	0.32%	0.39%	0.47%	0.56%
	0.1	0.05%	0.13%	0.20%	0.28%	0.36%
	0.2	–0.15%	–0.07%	0.01%	0.09%	0.17%
	0.3	–0.35%	–0.27%	–0.19%	–0.11%	–0.03%
	0.4	–0.55%	–0.48%	–0.40%	–0.32%	–0.23%

Welfare impact of a new environmental tax for different initial tax rates on *X* and *Y*.

Table 4 conducts a similar simulation in which the environmental taxes are used to lower taxes on *X*.

Table 4. Reduction in Tax on *X*

		t_X				
		0	0.1	0.2	0.3	0.4
t_Y	0	0.30%	0.60%	0.91%	1.24%	1.57%
	0.1	0.00%	0.30%	0.61%	0.94%	1.27%
	0.2	–0.32%	–0.01%	0.30%	0.62%	0.96%
	0.3	–0.64%	–0.34%	–0.02%	0.30%	0.63%
	0.4	–0.97%	–0.67%	–0.35%	–0.03%	0.30%

Welfare impact of a new environmental tax for different initial tax rates on *X* and *Y*.

Again, the environmental tax raises welfare unless the polluting good is taxed more heavily than the non-polluting good. Note that the welfare change is constant so long as the two goods are taxed at the same rate. This follows because of our assumption of weak separability from leisure along with homotheticity. In such a case, the optimal tax is a uniform tax on commodities or equivalently a tax on labor in this model (see Deaton, 1979). Given the optimal construction of the tax system, the change in the tax on pollution has first order welfare effects through changes in environmental quality.

Next we compare the welfare gains from returning the environmental tax by lowering the tax on *X* versus increasing the lump-sum transfer.

Table 5. Weak Double Dividend Calculation

		t_X				
		0	0.1	0.2	0.3	0.4
t_Y	0	0.054%	0.283%	0.520%	0.764%	1.019%
	0.1	–0.056%	0.174%	0.411%	0.655%	0.909%
	0.2	–0.172%	0.058%	0.294%	0.538%	0.790%
	0.3	–0.293%	–0.064%	0.172%	0.414%	0.664%
	0.4	–0.415%	–0.188%	0.046%	0.286%	0.534%

Welfare gain in case where environmental tax used to lower tax on *X* less welfare gain in case where environmental tax used to increase lump-sum transfer.

A weak double dividend occurs in cases where entries in **Table 5** are positive. The first row is the usual case considered in the literature when there is only one distortionary tax. In this case, the weak double dividend holds. When the initial tax on the polluting good is sufficiently higher than the tax on the non-polluting good, however, a weak double dividend will not hold. In other words, it will be better to return the environmental proceeds lump-sum rather than use them to reduce distorting taxes.

Table 6 shows that this result is not due to the particular commodity tax chosen to be lowered in response to the environmental levy. Now we use the proceeds to lower the commodity tax on the polluting good.

Table 6. Alternative Weak Double Dividend Calculation

		t_X				
		0	0.1	0.2	0.3	0.4
t_Y	0	–0.096%	–0.168%	–0.244%	–0.324%	–0.406%
	0.1	0.097%	0.024%	–0.053%	–0.132%	–0.214%
	0.2	0.296%	0.221%	0.144%	0.064%	–0.019%
	0.3	0.498%	0.423%	0.345%	0.264%	0.181%
	0.4	0.705%	0.628%	0.549%	0.468%	0.384%

Welfare gain in case where environmental tax used to lower tax on *Y* less welfare gain in case where environmental tax used to increase lump-sum transfer.

Again, the weak double dividend fails if the good whose commodity tax is not adjusted is taxed at a higher rate than the other good.[5] Interestingly, if there are no distortionary taxes in place then the weak double dividend still does not hold if revenues are used to reduce taxes on *Y*. This result, that lowering a commodity tax on a good that contributes to the pollution problem that one is solving with the environmental tax, might seem peculiar at first. There are two reasons for this result that are quite intuitive. One is that if an existing commodity tax already disproportionately reduces consumption of a good that produces pollution, then one does not want to 'double-up' on that good with the environmental tax. Essentially this leads to over control of pollution if we assume that environmental tax is set to equal marginal damage. The second reason is that one

[5] These qualitative results hold over any reasonable range of estimates for parameter values in Table 2.

prefers a tax on the pollution itself rather than on the commodity itself as one then can take advantage of the ability to substitute away from the pollution input in the production process.

The general result is that if the environmental tax revenue is used to reduce the differential between two distorting taxes then a weak double dividend occurs. If the recycling increases the difference between existing distortions then recycling is welfare worsening compared with lump sum recycling *even if it reduces an existing distortion*. In other words, in an economy with multiple distortions one must choose carefully which distortions to reduce, or one can do worse than a lump sum redistribution. Put simply, there is no theoretical basis to conclude that a weak double dividend must exist. Later, we show that the pattern of taxes in many European countries match the conditions identified in this section and that a weak double dividend is unlikely to occur in practice in these countries.

3. MODELING TAXES IN GTAP

We next turn to a computational general equilibrium model to consider climate change policy proposals for a number of developed countries. Incorporating taxes will be important to consider the interaction between environmental policy and pre-existing tax distortions. Adding taxes to the dataset used to calibrate a CGE model for any particular country is not particularly difficult. What is more challenging is to construct a methodology that is consistent across countries and relies on readily available data. Mendoza *et al.* (1994) sets out a method by which effective tax rates on labor and capital income as well as consumption can be calculated from National Accounts data from OECD for different countries. By using OECD data, the constructed rates are consistent across countries and time and so might be amenable for inclusion in the GTAP data base. We follow this approach in our work.

The basic methodology is quite simple and we illustrate it for consumption taxes.[6] If p is the consumer price for a good and q the producer price, then p and q are linked by the relation

$$p = q + t \tag{22}$$

where t is a unit tax on the consumption good. We can re-express the unit tax as a tax exclusive ad valorem tax (τ):

$$\tau = \frac{t}{q} \tag{23}$$

We'd like to calculate τ using observable data and so Mendoza *et al.* suggest the following:

$$\tau = \frac{pC - qC}{qC}, \tag{24}$$

where C represents aggregate consumption. The tax rate is the difference between the value of consumption in consumer prices and its value in producer prices divided by the latter. In other words, it is the tax revenue divided by the tax base (producer receipts).

[6] Mendoza *et al.* note that Razin and Sadka (1993) develop these tax rates from specific tax rates faced by a representative agent in a general equilibrium model.

For this consumption tax measure to be comprehensive, we need to capture both general and specific taxes. The tax on consumption (τ_c) is the sum of general (T_G) and specific (T_S) taxes divided by private consumption (C) and government consumption (G) after subtracting consumption taxes paid by consumers and government and also subtracting compensation of government workers (GW) which is included in G. Thus the tax rate on consumption is given by

$$\tau_c = \frac{T_G + T_S}{C + G - GW - T_G - T_S} \tag{25}$$

For OECD countries, collecting the required tax data is relatively straightforward as it is published annually in their *Revenue Statistics* series. The other required data are published for OECD countries in the *National Accounts* series. Obviously, OECD data can not be relied on for the 65 regions contained in the GTAP data base. United Nations National Accounts data can substitute for the OECD National Accounts. A challenge for GTAP will be to assemble the tax data across countries beyond the OECD countries. We hope to show below that the effort will have substantial payoff. Even if it is not possible to extend the tax data beyond OECD countries, it would be useful to offer an OECD module with taxes broken out.

The tax on labor income (τ_L) requires an estimate of the individual income tax on wages. Since this is not broken out in the tax data set, Mendoza *et al.* begin by calculating the average tax on household income (τ_h). This is individual income tax collections (T_P) divided by wage (W) and capital income (K_P) subject to the individual income tax:

$$\tau_h = \frac{T_P}{W + K_P} \tag{26}$$

They then assume that the marginal tax rate on all sources of income is the same. This is clearly a restrictive assumption but it is not clear a priori what sort of bias this imparts to the labor income tax rate. The tax on labor income is then the sum of taxes on wage income plus payroll taxes (PT) divided by total compensation (including the employer contribution for Social Security (SS_E):

$$\tau_L = \frac{\tau_h W + PT}{W + SS_E}. \tag{27}$$

Finally, the tax on capital income (τ_k) is corporate and non-corporate tax payments divided by total surplus.[7] All capital income distributed to individuals (K_D) is assumed taxed at rate τ_h. In addition, corporate tax payments (T_C), as well as taxes on real property and financial transactions (T_{PF}) must be included in the numerator of the tax rate expression. The base is total operating surplus in the economy (OS):

$$\tau_k = \frac{\tau_h K_D + T_C + T_{PF}}{OS}. \tag{28}$$

Mendoza *et al.* compare their estimates of tax rates to aggregate marginal tax rates as constructed by Joines (1981), Seater (1985), and Barro and Sahasakul (1986) and find that the

[7] This tax rate assumes a constant returns to scale aggregate production function and thus the absence of economic rents.

levels are different but that they move similarly over time. The MRT estimates are close to those of Joines, lower than Barro-Sahasakul and higher than Seater's.

Table 7 reports our calculations of tax rates for a number of OECD countries for 1995. Consumption taxes, reported here inclusive of energy taxes, are high in Europe relative to Japan and the United States. The United States does not rely on a Value Added Tax as do the other countries and Japan's VAT is both a low tax VAT and subject to a relatively narrow base. The countries included in Table 1 differ in their relative taxation of capital and labor. It has long been argued that the double taxation of corporate capital income unfairly burdens capital income. The relative taxation of capital and labor in the United States in Table 7 lends support to that argument.

Table 7. Tax Rates for 1995

Country	Consumption	Labor	Capital
Denmark	33.2%	49.8%	41.5%
Finland	26.0%	48.4%	35.0%
France	19.7%	49.3%	24.7%
Germany	16.7%	43.5%	24.7%
Great Britain	17.3%	25.0%	46.3%
Italy	15.8%	47.0%	32.6%
Japan	6.0%	27.8%	44.3%
Netherlands	18.5%	51.2%	28.4%
Spain	13.7%	36.4%	19.9%
Sweden	22.8%	52.2%	41.6%
United States	5.6%	27.2%	39.9%

Source: Authors' calculations; see text for description of methodology and sources.

4. KYOTO POLICY IN A WORLD WITH TAX DISTORTIONS

The Emissions Prediction and Policy Analysis (EPPA) model is a recursive dynamic multi-regional general equilibrium model of the world economy that has been developed for analysis of climate change policy (see, for example, Babiker *et al.*, 2001, 2000; Ellerman and Sue Wing, 2000; and Babiker and Jacoby, 1999). The current version of EPPA is built on a comprehensive energy-economy data set (GTAP4-E[8]) that accommodates a consistent representation of energy markets in physical units as well as detailed accounts of regional production and bilateral trade flows. The base year for the model is 1995 and it is solved recursively at 5-year intervals. A full documentation of EPPA is provided in Babiker *et al.* (2001). In this paper, we use a new version of the model (EPPA-EU) including a breakdown for the European Union. The reference case for Europe in EPPA-EU is presented and compared with other economic models in Viguier *et al.* (2001). See the appendix to this paper for a brief description of the model.

In order to calibrate the EPPA model, social accounting matrices are constructed from the GTAP data base for 1995. These are used to benchmark the starting point for the calculations. Factor payments in GTAP are gross (of tax) payments and so overestimate the amount of capital and labor used in production. Once we break out factor taxes, we obtain the same amount of output with fewer inputs. One implication of the higher productivity of factors is that welfare in the reference scenarios was initially higher in the EPPA model with taxes than in the model without taxes, but for comparability purposes the model was rebenchmarked by lowering exogenous growth in labor productivity so that growth in welfare was nearly identical (see **Table 8**).

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[8] For description of the GTAP database see Hertel (1997).

Table 8. Reference Welfare in EPPA

	Taxes Included			Taxes Excluded		
	2000	2005	2010	2000	2005	2010
USA	1.253	1.500	1.785	1.222	1.447	1.705
JPN	1.102	1.321	1.530	1.090	1.256	1.435
GBR	1.233	1.451	1.693	1.209	1.418	1.648
DEU	1.172	1.379	1.589	1.159	1.370	1.579
DNK	1.334	1.616	1.938	1.294	1.588	1.916
SWE	1.342	1.695	2.087	1.292	1.626	2.006
FIN	1.366	1.768	2.252	1.352	1.749	2.227
FRA	1.175	1.333	1.508	1.157	1.300	1.455
ITA	1.140	1.295	1.453	1.118	1.259	1.399
NLD	1.207	1.416	1.642	1.186	1.373	1.572
ESP	1.228	1.484	1.791	1.205	1.433	1.693
REU	1.214	1.415	1.650	1.188	1.362	1.556
OOE	1.196	1.398	1.619	1.181	1.370	1.579
EEX	1.157	1.314	1.490	1.159	1.316	1.492
CHN	1.362	1.793	2.363	1.364	1.794	2.364
FSU	1.048	1.220	1.465	1.050	1.221	1.466
IND	1.335	1.757	2.307	1.336	1.758	2.307
EET	1.041	1.134	1.315	1.041	1.135	1.315
DAE	1.058	1.276	1.523	1.182	1.388	1.634
BRA	1.177	1.365	1.581	1.178	1.365	1.581
ROW	1.154	1.325	1.521	1.155	1.326	1.522

Welfare is indexed at 1.000 in 1995. All calculations from EPPA model. See Table A1 for country codes. Labor and capital taxes were not introduced for non-OECD countries. Changes in welfare for these regions are small and due to trade effects resulting from the changes in OECD countries.

The rebenchmarking of the model also assured that carbon emissions were not appreciably changed in the reference scenario with taxes explicitly incorporated. We next report results from the EPPA model of caps on carbon emissions to achieve the carbon reductions set forth in the Kyoto Protocol, including the United States. We consider carbon emissions from energy only, ignoring forest sinks for carbon and other greenhouse gases (GHGs) and in all cases here we assume that the caps are met domestically without emissions trading among countries. These assumptions require fairly sizable reductions in emissions from reference so the welfare effects are evident. This differs considerably from all that is included in the Protocol but serves as a convenient scenario against which to evaluate the double dividend issue.[9] The caps for individual

[9] As finally negotiated in Marrakech with the U.S. not participating, allowances for extra forest sinks for carbon, other GHG abatement potential, and with full emissions trading among the countries that remained parties to the Protocol, it turns out that the Kyoto cap is only marginally binding. Excess allocation of permits to Russia, Ukraine, and other transition countries in Europe (*i.e.* an allocation beyond their projected emissions) means that virtually no actual reductions in any country are required if these credits can be applied in other countries as allowed under the Protocol (Babiker *et al.*, 2002). While that result is an important policy conclusion in itself, it means the permit price is near zero, there is little possibility for revenue generation, negligible welfare effects of the policy, and little scope for revenue recycling making it an uninteresting case for the questions we consider here. Many European countries may choose to meet their targets mainly through domestic action as the EC originally objected to full emissions trading and nothing in the Protocol requires that they use international credits to the full extent they are available.

EC countries are individual caps agreed to in the EU burden-sharing plan (see Viguier *et al.*, 2001). **Table 9** reports changes in welfare relative to reference scenarios.

Table 9. Welfare Costs of Kyoto (No Trading)

	Taxes Excluded			Taxes Included		
	2010	**2015**	**2020**	**2010**	**2015**	**2020**
USA	–0.61	–0.82	–1.27	–0.65	–0.86	–1.27
JPN	–0.63	–0.81	–1.11	–0.62	–0.80	–1.08
GBR	–1.23	–1.44	–1.99	–1.05	–1.22	–1.69
DEU	–0.87	–0.90	–1.24	–0.77	–0.79	–1.09
DNK	–4.26	–4.21	–4.63	–3.82	–3.77	–4.05
SWE	–3.63	–4.24	–4.91	–3.46	–3.98	–4.56
FIN	–2.26	–2.84	–3.56	–1.86	–2.34	–2.93
FRA	–0.71	–0.95	–1.42	–0.70	–0.93	–1.36
ITA	–1.14	–1.55	–3.30	–1.26	–1.70	–3.30
NLD	–5.08	–5.42	–5.98	–4.67	–5.11	–5.72
ESP	–3.34	–4.40	–6.11	–3.13	–4.17	–5.83
REU	–1.29	–2.06	–3.33	–1.27	–2.03	–3.28
OOE	–2.27	–2.67	–2.57	–1.96	–2.30	–2.20
EEX	–3.54	–4.08	–3.18	–3.62	–4.16	–3.29
CHN	0.27	0.29	–0.14	0.26	0.27	–0.16
FSU	–2.22	–2.54	–1.19	–2.27	–2.59	–1.23
IND	1.10	1.24	0.23	1.11	1.25	0.24
EET	0.75	0.80	0.10	0.74	0.78	0.07
DAE	0.53	0.53	–0.17	0.53	0.51	–0.20
BRA	0.45	0.46	0.09	0.45	0.46	0.08
ROW	0.13	0.10	–0.22	0.12	0.07	–0.24

This table reports percentage changes in EV relative to the reference scenarios (either with or without taxes). Labor and capital taxes were not introduced for non–OECD countries. Changes in welfare for these regions are small and due to trade effects resulting from the changes in OECD countries.

Given the improvement in welfare in the reference we observed before rebenchmarking, we thought it possible that simply including the tax wedges might change the costs of meeting a target. We hypothesized that resource substitutions might be less costly, thus making it easier for firms to shift out of carbon intensive production in response to Kyoto. In other words, fewer resources would need to be shifted across sectors for a given reduction in carbon use.[10] As can be seen from Table 9, there was little difference in the cost of Kyoto when simulated using the standard EPPA version and the tax version of EPPA. For the most part, the remaining differences appear due to the fact that even after rebenchmarking there remained some minor differences between the two reference scenarios. The inclusion of taxes did not by itself change estimates of the cost of Kyoto policy when the carbon taxes are recycled in a lump sum, nor do the differences in tax rates for capital, labor, and consumption taxes appear to explain differences in estimates of the costs among countries. The standard version of EPPA includes distorting energy taxes and, elsewhere, it has been shown that the presence or absence of these does affect the cost of Kyoto substantially (Babiker *et al.*, 2000).

[10] Without rebenchmarking the results would have been convoluted with the fact that the required reductions would have been larger in the tax version of EPPA.

We next report on simulations in which carbon taxes are used to achieve Kyoto with tax recycling of the proceeds a possibility, here focusing on only the tax version of EPPA where the results across scenarios are strictly comparable. We consider the following possible uses of carbon tax revenues.

Table 10. Tax Recycling Scenarios

NRP	Lump Sum Recycling
LRP	Labor Tax Recycling
CRP	Non–Energy Consumer Tax Recycling
LCRP	50% Labor and 50% Consumer Tax Recycling

All scenarios levy a carbon tax sufficiently high to achieve Kyoto reductions.

The first scenario returns carbon tax revenues to the representative agent in a lump sum fashion. The other three scenarios use proceeds to lower some distorting tax (or set of taxes). **Table 11** reports the change in welfare in 2010 relative to the reference scenario for the various proposals.

Table 11. Welfare Changes with Recycling

	NRP	LRP	CRP	LCRP
USA	–0.65%	–0.49%	–0.57%	–0.53%
JPN	–0.62%	–0.56%	–0.54%	–0.54%
GBR	–1.05%	–0.97%	–0.91%	–0.94%
DEU	–0.77%	–0.69%	–0.55%	–0.62%
DNK	–3.82%	–3.54%	–3.23%	–3.38%
SWE	–3.46%	–3.27%	–3.03%	–3.14%
FIN	–1.86%	–1.67%	–1.45%	–1.55%
FRA	–0.70%	–0.64%	–0.76%	–0.70%
ITA	–1.26%	–1.08%	–1.22%	–1.14%
NLD	–4.67%	–4.45%	–4.87%	–4.65%
ESP	–3.13%	–3.01%	–3.32%	–3.16%
REU	–1.27%	–1.17%	–1.44%	–1.31%
OOE	–1.96%	–1.88%	–1.84%	–1.85%

Welfare changes are relative to the reference scenario.

Not surprisingly, carbon reductions to achieve Kyoto with lump sum recycling reduce welfare relative to the reference scenario. Welfare losses range from a low of 0.6 percent in the United States and Japan to over 4 percent for the Netherlands. The Netherlands, Denmark, and Sweden suffer large losses because 1) they agreed to large cuts in emissions as part of the European burden sharing agreement by which the EC intends to meet its target under the Kyoto accord, and 2) emissions growth in those countries since 1990 has been more rapid than in other European countries.[11]

The next three columns provide results for various tax reductions. In no case does welfare rise relative to the reference scenario. In other words, a strong double dividend is not possible in any of the EU countries or the United States and Japan as a result of a carbon tax to achieve Kyoto.

[11] Sweden actually was allowed a four percent growth in emissions for 2010 relative to 1990. Its emissions in the reference scenario grow by 44 percent however. Germany and the UK agreed to very large cuts in emissions from 1990 (*i.e.* ~20 percent) but there emissions fell by large amounts between 1990 and 1995 so that these cuts do not involve as large a cut from their projected reference emissions in 2010.

The use of carbon taxes to reduce labor taxes does give rise to a weak double dividend. Welfare losses under the LRP scenario are always lower than under the NRP scenario.

Interestingly, the weak double dividend does not hold in all cases when carbon tax revenues are used to lower non-energy consumption taxes (CRP). France, the Netherlands, and Spain are all better off with lump-sum recycling of the carbon tax revenues than if the alternative is to reduce non-energy consumption taxes. The failure of the weak double dividend to hold simply reflects the existence of distorting energy consumption taxes that have not been reduced in this policy experiment. Intercommodity distortions are increased by a selective reduction in consumption taxation; second best considerations mean that the weak double dividend is not a universal phenomenon.

We next turn to the question of whether a strong double dividend is possible? We consider two scenarios. First, we investigate how an increase in the labor supply elasticity affects the possibility of a strong double dividend. Increasing factor supply elasticities will increase the distortions from pre-existing taxes and so increase the probability of a strong double dividend. **Table 12** reports welfare changes in 2010 relative to the reference scenario for differing labor supply elasticities.

Table 12. LRP Scenario: Higher Labor Supply Elasticity

	Elasticity	
	0.5	**1.0**
USA	–0.27%	0.01%
JPN	–0.37%	–0.12%
GBR	–0.63%	–0.04%
DEU	–0.61%	–0.43%
DNK	–3.30%	–2.60%
SWE	–2.76%	–1.78%
FIN	–1.25%	–0.53%
FRA	–0.33%	0.22%
ITA	–0.57%	0.14%
NLD	–3.82%	–2.27%
ESP	–1.87%	0.01%
REU	–0.67%	0.15%
OOE	–1.41%	–0.64%

Welfare changes are relative to the reference scenario.

We draw a couple of conclusions from this analysis. First, an increase of the labor supply elasticity to 0.5 is insufficient to achieve a strong double dividend under the Kyoto Protocol. Moreover, an increase to 1.0 is required before we begin to see a possible strong double dividend. Such an estimate of the labor supply elasticity is so far out of the bounds of reasonable estimates as to preclude the existence of a strong double dividend. Second, Table 6 illustrates sharp welfare differences between the United States and many EU countries. This illustrates the important point that policy conclusions drawn from studies of the United States may not be transferable to EU countries (and vice versa). Clearly, tax rates (and relative tax rates among commodities) differ among countries and the relative tax distortions among goods were shown in Section 2 to be the key factor determining whether a double dividend exists.

Our second scenario keeps the compensated labor supply elasticity at 0.25 and measures the marginal welfare costs of carbon abatement for various levels of reductions. The point of this scenario is to examine whether smaller reductions in emissions with tax replacement might achieve a strong double dividend. **Figures 1a-d** graph the marginal welfare costs of carbon abatement against percentage reductions in emissions relative to the reference scenario. Two sets of plots are shown. The plots with triangles measure the welfare loss when carbon taxes are returned lump sum, while the plots with squares measures the loss when carbon taxes are used to reduce labor taxes. Figure 1a indicates the possibility of a small strong double dividend for modest carbon reductions relative to the reference scenario when tax recycling occurs. Note that Kyoto represents roughly a 30 percent cut from the reference scenario. None of the other countries in our model benefit from any reductions in carbon emissions relative to the reference scenario in the recycling case. Again this reiterates the point that policy conclusions drawn from the U.S. experience may not be appropriate for Europe (and vice versa).

Figures 1a-d illustrate a second point. The shift in the curves between the NRP and the LRP scenarios indicates an ability to achieve greater reductions in carbon emissions for given welfare loss. As the figures indicate, greater carbon reductions can be achieved in the United States for a given welfare loss than can be achieved in France, Germany, and the United Kingdom. This pattern holds true for other EU countries.

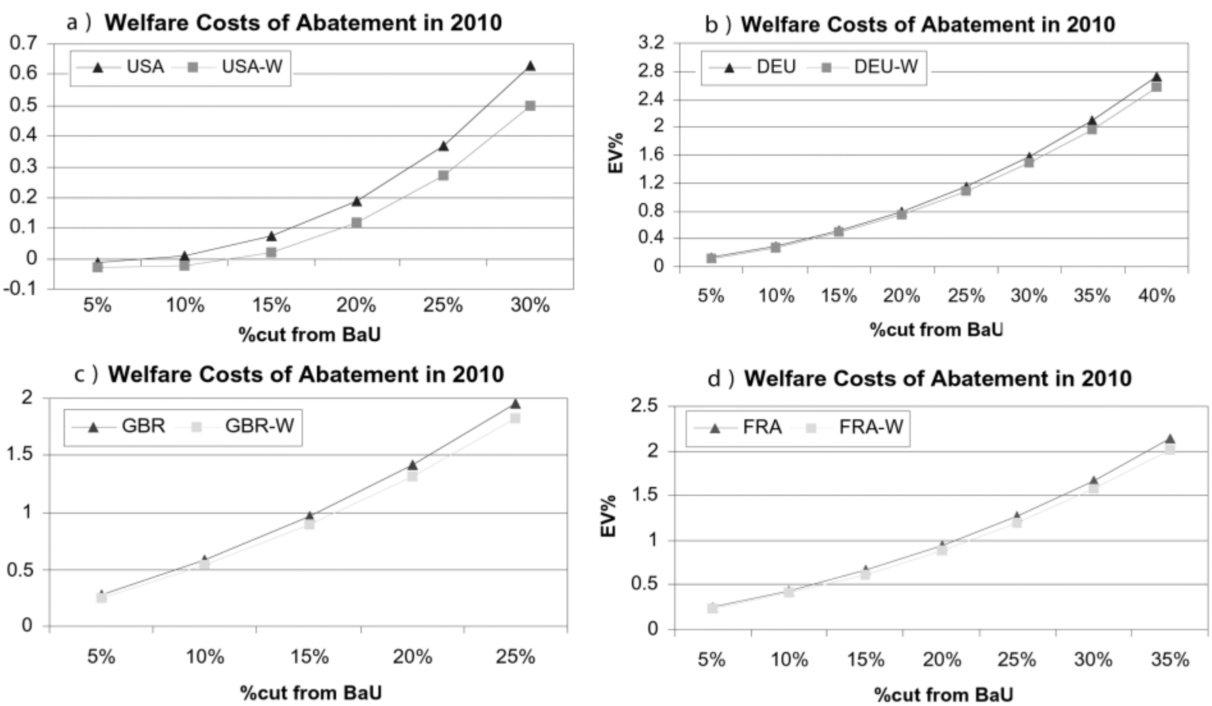

Figure 1. Marginal welfare costs of carbon abatement against percentage reductions in emissions relative to the reference scenario. The lines with triangles plot the welfare loss when carbon taxes are returned lump sum; the lines with squares graph the loss when carbon taxes are used to reduce labor taxes.

5. CONCLUSION

We began by showing in a simple analytic general equilibrium model that the weak double dividend does not hold unambiguously. Relative tax distortions play an important role in this result. Revenue recycling can be welfare worsening if it increases the relative distortion among goods *even if it reduces an existing distortion*. This suggests that a careful assessment of just which distortions to reduce is necessary or one can do worse than lump sum recycling. While this result is of theoretical interest, it turns out also to be of important practical interest. As the results from the EPPA model demonstrate, the weak double dividend is unlikely to hold for a number of European countries when policies are considered to reduce carbon emissions. Finally, and of equal importance, this paper has shown that the interplay between carbon policies and pre-existing taxes can differ markedly across countries. Thus one must be cautious in extrapolating the results from a country specific analysis to other countries.

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APPENDIX: EPPA-EU MODEL

A.1. EU Disaggregation

EPPA-EU extended the current version of EPPA by bringing in a detailed breakdown of the EU and incorporating an industry and a household transport sectors for each region. The regional, sectoral, and factors aggregation shown in Table A1, together with the substitution elasticities in Table A2 completely specify the benchmark equilibrium.

The European Union is disaggregated into 9 countries and 1 region representing the Rest of Europe (REU). Four out of the 9 EU countries (France, Spain, Italy, and the Netherlands) were aggregated together with REU in the GTAP4-E database. We disaggregated this region using data from the GTAP-5 Pre-release that provides a complete disaggregation of the EU.[12] To accomplish this task we developed an optimization algorithm that uses the economic structure of these 4 countries in GTAP-5 Pre-release while imposing the output, demand, and trade balances for their corresponding aggregate region in GTAP4-E. This allowed us to leave unchanged all other regions of the standard EPPA based on GTAP4-E.

A.2. Transportation Sector Disaggregation

The other change in this version of the model is the disaggregation of the transportation sector. With transportation disaggregated, there are now nine output sectors for each of the 22 regions in EPPA-EU, as shown in the left-hand column of **Table A1**. The EPPA model also includes future or “backstop” sources of fuels and electricity, but they do not play a significant role in this analysis which looks only out to 2010. Eight of the production sectors follow the standard EPPA definitions. The GTAP database does not include a separate transportation sector within industry, nor does it contain a separate category for private automobile services in the household sector. We followed the methodology developed by Babiker *et al.* (2000) for the United States to break out transportation from EPPA’s OTHERIND sector and to create a household supplied transportation sector (*i.e.* private automobiles) in the EU.

The basic approach for the TRANS sectors is to use GTAP’s trade and transport sector that combines transport with trade margins in combination with data from Input-Output tables produced by the European statistical office (Eurostat). These tables provide the data to disaggregate trade margins from transportation for each European country. For the other regions in the model, we used the U.S. input-output coefficients from Babiker *et al.* (2001). The TRANS industry supplies transportation services (both passenger and freight) to other sectors and to households.

We have also made adjustments directly to the Household (H) sector to represent own-supplied transportation services, primarily that provided by personal automobiles. Households produce transportation services for their own consumption using inputs from the Other Industry Products (OIND) and Refined Oil sectors. Consumption expenditure of private households reported by Eurostat (1999) and energy statistics from the International Energy Agency (1998, 2000) along with the coefficients reported in Babiker *et al.* (2001) were used to separate the household purchases that are part of household production of transportation from other household purchases.

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[12] Though GTAP-5 Pre-release has all 9 of these countries broken out we chose to focus on disaggregating only the 4 largest of these countries.

Table A1. Dimensions of the EPPA-EU Model

Production Sectors	Name	Countries and Regions	Name
Non–Energy		***Annex B***	
1. Agriculture	AGRI	United States	USA
2. Energy-Intensive Industries	EINT	Japan	JPN
3. Other Industries and Services	OIND	Europe	EEC
4. Transportation	TRAN	Denmark	DNK
Energy		Finland	FIN
5. Crude Oil	OIL	France	FR
6. Natural Gas	GAS	Germany	DEU
7. Refined Oil	REFOIL	Italy	ITA
8. Coal	COAL	Netherlands	NLD
9. Electricity	ELEC	Spain	ESP
Future Energy Supply		Sweden	SWE
10. Carbon Liquids		United Kingdom	GBR
11. Carbon-Free Electric		Rest of EU[a]	ROE
		Other OECD	OOE
Households (Consumers) Sector	H	Former Soviet Union	FSU
		Central European Associates	EET
Primary Factors		***Non–Annex B***	
1. Labor	L	Brazil	BRA
2. Capital	K	China	CHN
3. Fixed Factors for Fuel and Agriculture		India	IND
		Energy Exporting Countries	EEX
		Dynamic Asian Economies	DAE
		Rest of World	ROW

[a] Includes Austria, Belgium, Greece, Ireland, Luxembourg, and Portugal

The new breakout yields a sector of own-supplied personal transportation (private automobiles) separate from other household activities, and a separate transportation sector in industry that supplies transport services to both industry (*i.e.*, freight transportation and any passenger transportation purchased by business) and households (purchased transportation service, mainly passenger transportation services such as air and rail service). Services from private automobiles involve inputs from OIND that include the automobile itself, repairs, insurance, parking, and vehicle fuel from the REFOIL sector. The procedure involves allocating OIND and REFOILS output between direct uses in the household.

A.3. Incorporating Labor Leisure Choice

We have adjusted the Social Accounting Matrices for OECD regions in the database to account for the leisure component in the utility function. Based on the literature we have assumed a leisure-labor ratio of 0.25, and a compensated labor supply elasticity of 0.25.

A.4. Incorporating factor taxes and non-energy consumption taxes

We have treated factor earnings in the GTAP database as gross earnings. Accordingly, we use the factor taxes schedule in Table 1 to compute the net factor flow services and maintain the income-expenditure balance in the database by transferring the tax revenues to the consumer as lump sum. The consumer expenditure on non-energy goods gross of tax has been adjusted to reflect the tax in Table 1 and the income-expenditure balance is maintained as in the factor tax case by lump sum transfer of the tax revenues to the consumer.

Table A2. Model Parameters

Parameter	Description	Value
σ_{ERVA}	Elasticity of substitution between energy resource composite and value-added (agriculture only)	0.6
σ_{ER}	Substitution between land and energy-material bundle (agriculture only)	0.6
σ_{AE}	Substitution between energy and material composite (agriculture only)	0.3
σ_{VA}	Substitution between labor and capital[a]	1
σ_{ENOE}	Substitution between electric and non-electric energy	0.5
σ_{EN}	Substitution among non-electric energy[b]	1
σ_{GR}	Substitution between fixed factor and the rest of inputs	0.6
σ_{EVA}	Substitution between energy and value added composite[c]	0.4
σ_{DM}	Armington substitution between domestic and imports[d]	3
σ_{MM}	Armington substitution across imports: Non-energy goods Energy goods[e]	5.0 4.0
σ_{CS}	Temporal substitution between consumption and saving	1
σ_{C}	Substitution across consumption goods[f]	
G0	Labor supply annual growth rate in efficiency units: Developed countries Developing countries	1–3% 2.5–6%

[a] Except nuclear in which it is 0.5.
[b] Except for electricity where coal and oil generation substitute at 0.3 among themselves and at 1.0 with gas.
[c] Except energy intensive and other industry where it is 0.5.
[d] Except Electricity where it is 0.3.
[e] Except refined oil (6) and electricity (0.5).
[f] Varies across countries and is updated with income recursively to reflect income elasticities based on an econometrically estimated equation. See Babiker *et al*. (2001) for details.

At the Third Conference of the Parties (COP-3) to the United Nations Framework Convention on Climate Change (UNFCCC), Annex B[13] Parties committed to reducing, either individually or jointly, their total emissions of six greenhouse gases (GHGs) by at least 5 percent within the period 2008 to 2012, relative to these gases' 1990 levels.

The European Union (EU) is a full Party to the UNFCCC and a signatory of the Kyoto Protocol, and has accepted a quantitative absolute reduction of 8 percent of its GHG emissions. Article 4 of the Protocol allows the EU to allocate its target among the Member States. A political agreement on that redistribution was reached at the environmental Council meeting in June 1998, and is referred to as the "Burden Sharing" Agreement (BSA). **Table A3** shows the BSA adopted at the environmental Council meeting by Member States on June 1998. The sharing scheme specifies emissions targets for each member country with the objective to reflect opportunities and constraints that vary from one country to another, and to share "equitably" the economic burden of climate protection.

[13] Annex B refers to the group of developed countries comprising of OECD (as defined in 1990), Russia and the East European Associates.

Table A3. Burden Sharing Agreement for 2010

Country	Base 1990 = 100
Austria	87.0
Belgium	92.5
Germany	79.0
Denmark	79.0
Spain	115.0
Finland	100.0
France	100.0
United Kingdom	87.5
Greece	125.0
Ireland	113.0
Italy	93.5
Luxembourg	72.0
Netherlands	94.0
Portugal	127.0
Sweden	104.0
Total European Union	92.0

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