Distortionary Taxation in General Equilibrium Climate Modeling *

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I. Introduction

The meeting of economists and modelers at the Fourth Annual Conference on Global Economic Analysis indicates the importance of global modeling and, consequently, global datasets. The GTAP data base has become a leading dataset used by researchers worldwide for a large number of important issues.

In this paper, we discuss the importance of distortionary taxation in general equilibrium climate modeling. Towards that end, we'd like to do the following. First, we discuss how distortionary taxation affects our policy choices in the area of environmental policymaking in general and global climate change in particular. Then, we discuss how GTAP could be expanded to incorporate distortionary factor taxes (as well as consumption taxes) so that researchers can carry out applied research in a second best world with distortionary taxation. Finally, we also demonstrate its use with the MIT Joint Program on the Science and Policy of Global Change's CGE model known as EPPA.

II. Distortionary Taxation and Global Climate Change Modeling

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. Some of the modeling has been analytical and some computational and we present a few key results here. No attempt has been made to be exhaustive but we do try to highlight some important themes.

A popular but often ill-defined concept is the "double dividend." This is the concept that an environmental tax provides one benefit in the form of an improved environment and a second benefit in the form of revenues with which other distorting taxes can be reduced.[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. 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 (net of any improvement in environmental quality) is increased in response to an environmental tax regardless of the disposition of the revenue. 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. As we discuss below, a strong double dividend does not in general hold. 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

[1] Much of this subsequent discussion draws on Fullerton and Metcalf (1998).
[2] See Bovenberg (1999) for an update to that literature.

taxes with less distorting taxes are, in general, good ideas. See Bovenberg and Goulder (forthcoming) for further discussion of this point.

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. Models typically show the existence of a weak double dividend; in fact, if there is only one distorting tax in the economy, then a weak double dividend must occur. We show below, however, that in an economy with multiple distortions, a weak double dividend need not occur.

We mention in passing four other issues that have been fruitfully analyzed with general equilibrium models:

- *optimal environmental tax rates and marginal environmental damages*: in a first best world, the optimal environmental tax rate is set equal to marginal environmental damages. Early partial equilibrium analysis incorporating pre-existing distortionary taxation suggested that optimal environmental tax rates should be larger than marginal environmental damages if the environmental tax revenue elasticity was positive at the Pigouvian tax rate (where the rate equaled marginal environmental damages).[3] In other words, at the Pigouvian tax rate, a marginal increment in the environmental tax would have benefits in an improved environment exactly offsetting

[3] See, for example, Lee and Misiolek (1986).

the private costs of the additional tax. But the incremental funds could be used to lower other distorting taxes for which distortions are of first order importance.

The problem with this argument is that it ignores the efficiency costs of the environmental tax itself. In a partial equilibrium world, there would be no other distortions (and so no additional efficiency cost); but in a general equilibrium world with other distorting taxes, there would be first order costs. Bovenberg and de Mooij (1994) show this in a simple one factor analytical general equilibrium model. A simple way to think about their result is to imagine a tax on labor income and the resulting Harberger deadweight loss triangle. An environmental tax levied on a polluting commodity raises the general price level (to the extent that the tax is passed forward) and so reduces the real net wage. The reduction in the real net wage is tantamount to an increase in the wage tax and the increase in deadweight loss is of first order importance. In effect we are adding on to the wide end of a Harberger triangle. This efficiency loss must be balanced against the environmental benefits of the tax.

- *government revenue needs and environmental quality*: the Bovenberg and de Mooij finding that optimal environmental tax rates fall short of marginal environmental damages in the presence of distortionary taxation suggests that environmental quality suffers as tax distortions rise in the economy. Metcalf (2001) points out that one needs to disentangle "price" questions (e.g., optimal tax rates) and "quantity" questions (e.g. optimal environmental quality) in this second best world.

Using an analytic general equilibrium model, he shows that an increase in government revenue needs (and thus distortionary taxation) can both reduce the optimal tax on pollution while improving environmental quality. The key insight is that higher prices (cum taxes) can induce substitution into untaxed activities that may be non-polluting.

- *use of environmental tax revenue*: another strand of the double dividend literature that has led to careful general equilibrium modeling focuses on the ability of environmental policy instruments to raise revenue. Recall that the entire double dividend literature has focused on revenue with which other distorting taxes could be lowered as the source of the second dividend. Goulder, Parry and Burtraw (1997) made the important point that raising revenue *per se* is not the source of a potential efficiency gain as the revenue could be returned in a lump sum fashion. The logic of the weak double dividend is that it is preferable to return the revenue by reducing a distorting tax rather than a lump sum tax. Thus, this paper made the important point that raising revenue is not sufficient for an efficiency gain. In the context of the SO_2 trading scheme implemented in the Clean Air Act Amendments of 1990, giving away the permits to electric utilities is equivalent (from an efficiency point of view) to levying a tax on SO_2 emissions sufficient to lower emissions to the same level as would occur under the permit scheme and returning the tax revenue in a lump sum fashion. Fullerton and Metcalf (2001), on the other hand, showed that raising revenue is neither necessary nor sufficient. This latter paper showed the equivalence of a class of models that either raised revenue, lost revenue, or had no revenue impact at all.[4]

- *mixed instruments*: the topic of instrument choice in a second-best world typically focuses on extreme policy choices. In the context of tradable permit schemes, for example, the debate is typically framed as a choice between the government selling permits or giving them away for free. A richer set of instrument choices are possible if one allows for the possibility of mixed instruments. Bovenberg and Goulder (2001), for example, carry out an exercise in which they consider a policy that involves giving a fraction of permits to industry (grandfathered permits) and selling them the remainder. They calculate the minimum fraction of permits that need be grandfathered to ensure that equity values of industry are not reduced. The question is an interesting one since it is more likely that industry buy-in for a carbon trading permit scheme could be generated if equity values were not adversely affected by the program. They find that only a small fraction of permits need be grandfathered to preserve equity values. The small amount of grandfathering required follows from the fact that much of the cost of permits is passed forward to consumers in the form of higher product prices.

These various studies are but a small slice of the many studies of environmental policy in a world with pre-existing tax distortions where general equilibrium modeling has proven to be essential for a complete analysis. The general

[4] See Fullerton and Metcalf (1998) for further discussion of this point.

equilibrium models briefly described (as well as many others that have not been mentioned) 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 next section illustrates how this could be done.

III. Modeling Taxes in GTAP

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. The latest version of the GTAP data base covers 65 regions. One of the major contributions of this data project is to construct data so as to compare "apples to apples" across countries and time.

It turns out that a group of economists have already tackled the problem of constructing consistent international tax data. Mendoza, Razin and Tesar (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.

The basic methodology is quite simple and we illustrate it for consumption taxes[5]. If p is the consumer price for a good and q the producer price, then p and q are linked by the relation

(1) $$p = q + t$$

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):

(2) $$\tau = t/q$$

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

(3) $$\tau = \frac{pC - qC}{qC},$$

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).

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

[5] 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.

government and also subtracting compensation of government workers (GW) which is included in G. Thus the tax rate on consumption is given by

(4) $$\tau_c = \frac{T_G + T_S}{C + G - GW - T_G - T_S}$$

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:

(5) $$\tau_h = \frac{T_P}{W + K_P}$$

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):

(6)
$$\tau_L = \frac{\tau_h W + PT}{W + SS_E}.$$

Finally, the tax on capital income (τ_k) is corporate and non-corporate tax payments divided by total surplus.[6] 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):

(7)
$$\tau_k = \frac{\tau_h K_D + T_C + T_{PF}}{OS}.$$

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 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 1 reports our calculations of tax rates for a number of OECD countries for 1995. Consumption 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

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

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 1 lends support to that argument.

Table 1. 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.

IV. An Example From EPPA

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, Reilly and Ellerman (2000c), Babiker, Reilly and Jacoby (2000d), 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[7]) 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, Reilly, Eckaus and Sue Wing (2000b). 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, Babiker and Reilly (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 is higher in the EPPA model with taxes than in the model without taxes (see Table 2).

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

Table 2. 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 A-1 for country codes.						

Carbon emissions are 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. Table 3 reports changes in welfare relative to reference scenarios.

Table 3. 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).

There are two important forces at work that drive these welfare results. First, the greater measured productivity of factors in the EPPA model with taxes explicitly modeled leads to greater growth over time. This makes achieving the reductions in carbon emissions required under Kyoto more costly than in the model without taxes explicitly modeled. Second, the use of fewer factors for a given level of production makes it easier for firms to shift out of carbon intensive production in response to Kyoto. In other words, fewer resources need to be shifted across sectors for a given reduction in carbon use. This reduces the welfare cost of achieving Kyoto, holding other things constant. The first effect dominates for the United States while the second effect dominates for Germany.

We next report on simulations in which carbon taxes are used to achieve Kyoto with tax recycling of the proceeds a possibility. We consider the following possible uses of carbon tax revenues.

Table 4. 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 5. presents results.

Table 5. 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 Kyoto accord and 2) emissions growth in those countries since 1990 has been more rapid than in other European countries.[8]

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. 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

[8] 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.

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 6 provides results.

Table 6. 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%

This table reports welfare changes 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).

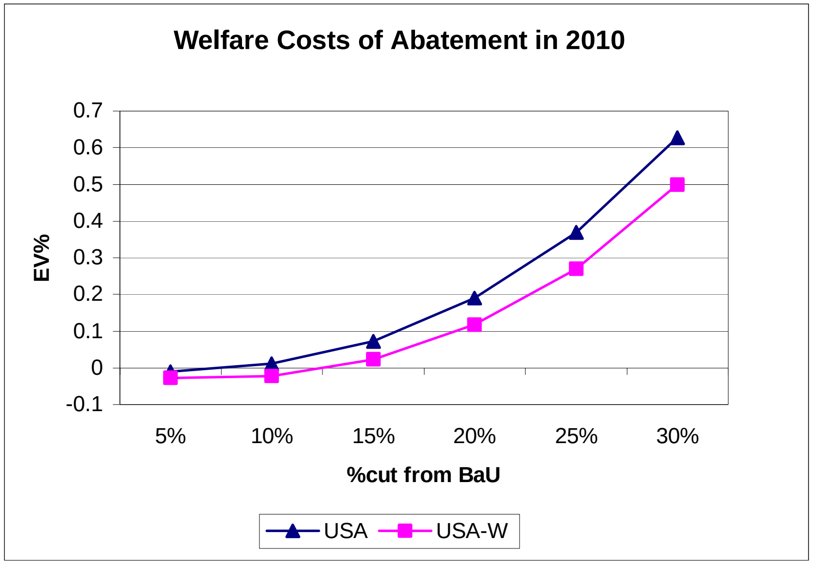
Our second scenario keeps the compensated labor supply elasticity at 0.25 and measures the marginal welfare costs of carbon abatement for various levels of reductions. The point of this scenario is to examine whether smaller reductions in emissions with tax replacement might achieve a strong double dividend. Figures 1a-d graph the marginal welfare costs of carbon abatement against percentage reductions in emissions relative to the reference scenario. Two graphs are shown. The graph with triangles measure the welfare loss when carbon taxes are returned lump sum while the graph 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.

V. Conclusion

General equilibrium modeling has been an important tool for carrying out policy analysis related to global climate change. Systematically incorporating distortionary taxes in international models has the potential to increase the payoff from these models for, at least, three reasons. First, the welfare impacts of carbon policies are strongly influenced by interactions with pre-existing tax distortions. Second, the use of revenues from carbon taxes (or wealth taxes on carbon permits) can have important efficiency impacts in a second-best world in addition to distributional impacts. Both the efficiency and distributional effects contribute to our understanding of the international political economy of carbon policies. Finally, 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.

We hope that the brief discussion and examples contained in this paper may whet modelers' appetites and that we will see a greater integration of existing tax policies in international general equilibrium models. We believe that the costs of undertaking this integration are low relative to the potential benefits.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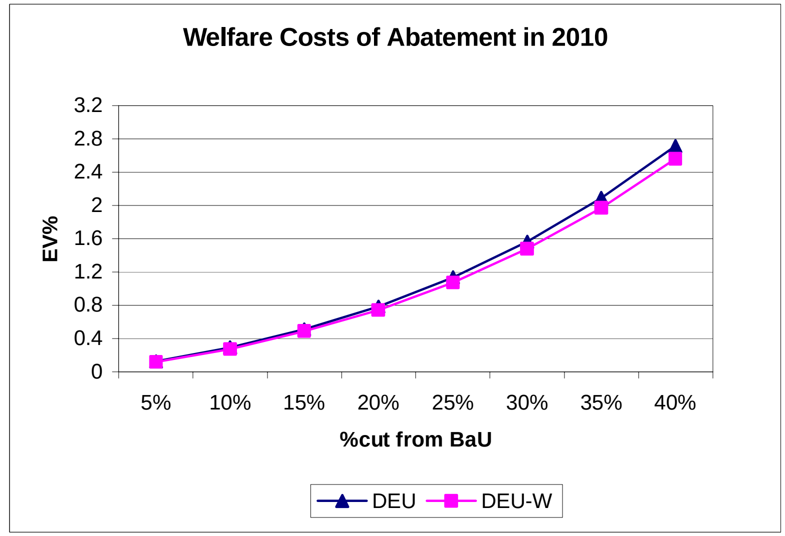
Welfare Costs of Abatement in 2010
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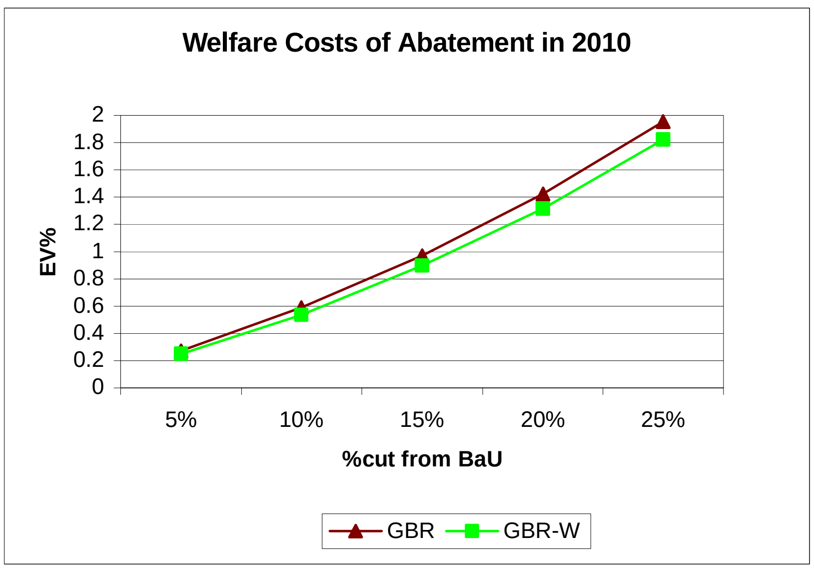
Welfare Costs of Abatement in 2010
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5%
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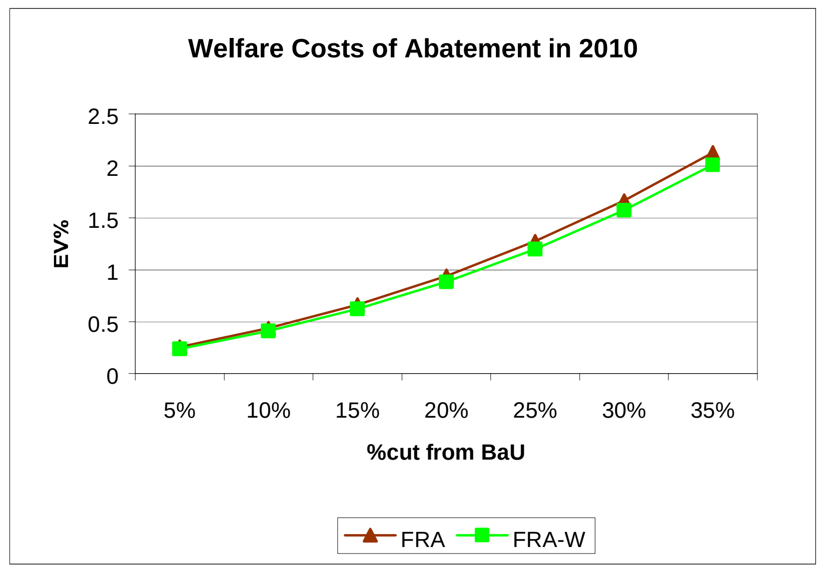
%cut from BaU
GBR
GBR-W


Welfare Costs of Abatement in 2010
2.5
2
1.5
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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 A-1, together with the substitution elasticities in Table A-2 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.[9] 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

[9] 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.

sectors for each of the 22 regions in EPPA-EU, as shown in the left-hand column of Table A-1. 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, Bautista, Jacoby and Reilly (2000a) 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.

Table A-1. 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		India	IND
and Agriculture		Energy Exporting Countries	EEX
		Dynamic Asian Economies	DAE
		Rest of World	ROW

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

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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 US input-output coefficients from Babiker, et al. (2000a). 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. (2000a) were used to separate the household purchases that are part of household production of transportation from other household purchases.

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 A-2. 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 & 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[10] 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

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

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 A-3 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.

Table A-3. 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
Luxemburg	72.0
Netherlands	94.0
Portugal	127.0
Sweden	104.0
Total European Union	92.0

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