Multigas Greenhouse Gases Emissions in a Computable General Equilibrium Model

Elisa Lanzi
School of Advanced Studies in Venice
Italy

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Abstract

This paper attempts to include multigas greenhouse gases emissions in the Computable General Equilibrium framework of the GTAP model. This is done by including data on emissions of non-CO_2 gases in the model database and then by changing the emissions proportionally to changes in output and income. The modified GTAP framework is then used to simulate a carbon tax, an international emission trading scheme for CO_2 and the combination of the latter with regulations on non-CO_2 greenhouse gases. The results confirm the importance of setting a multigas framework when attempting to study the effects of climate change policies in a computable general equilibrium model.

1 Introduction

Carbon dioxide (CO_2) originating from fossil fuel combustion and human land use is considered to be the main cause of climate change. In fact, although percentages of emissions of each greenhouse gas depend on the country and the sector considered, CO_2 accounts for the highest percentage in most countries. In the European Union CO_2 corresponds to 82% of total greenhouse gases emissions, whereas methane (CH_4) and nitrous oxide (N_2O) account for 8% each; perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF6) account for the rest (EEA, 2003). Emissions in other industrialized countries present similar percentages, whereas in developing countries N_2O and CH_4 represent a higher share of the overall greenhouse gases emissions.

As a consequence of the high percentage of carbon dioxide, policies to reduce climate change mainly address this gas instead of the whole range of greenhouse gases (GHG). The EU, the leading promoter of environmental policies to address climate change at the moment, has in fact established a European Emission Trading Scheme for CO_2 only. However, emissions of non-CO_2 greenhouse gases also have a critical impact on global warming. This is also due to the fact that, although CO_2 is more diffused, it is the greenhouse gas with the lowest Global Warming Potential (IPCC, 2001). Hence, reducing other greenhouse gases could be more efficient and less costly than reducing CO_2; this idea was the start point of investigations on non-CO_2 climate change policies.

Several studies have focused on stabilization of climate targets and have shown that it is important to take into account the full range of greenhouse gases including, but not limited to, the six greenhouse gases and gas groups controlled by the Kyoto Protocol, both for economic cost-effectiveness and climatic reasons (Reilly et al., 1999; Manne and

Richels, 2001; Eickhout et al., 2003; van Vuuren et al., 2003). These studies suggest that any policy measure that does not take into account all greenhouse gases is expected to be worse in terms of costs and environmental effectiveness. However, until recently, most studies have focused on CO_2-only, thereby obtaining results showing that the cost implications of climate stabilization could be lower than usually expected. Including all GHG in the studies could therefore show higher costs of stabilization targets. However, it is also necessary to consider that the portfolio of policies and measures to achieve stabilization goals is much broader and more flexible if multi-gas reduction options are included.

These studies underline the importance of implementing multigas climate change policies as a more cost-effective and efficient way to reduce the impact of climate change. It is therefore important that economic studies also take into consideration non-CO_2 greenhouse gases, in order to assess the possible increase in efficiency in multigas policies, as well as spillover and interaction effects that may arise from single-gas regulations.

Previous work has been done to explore this issue by considering abatement opportunities for non-CO_2 greenhouse gases together with the related costs of abatement. Results show that non-CO_2 abatement policies could reduce GHG emissions and could diminish the costs of achieving GHG emission targets. Reilly et al. (1999) use results on emissions of fossil carbon including exogenous marginal abatement curves (MAC) in an economic analytical model. Another type of approach is taken by Hyman et al. (2002) who aim at endogenizing emissions of all GHG in a computable general equilibrium (CGE) framework. This is done by adding GHG directly as inputs in the production function and it allows to introduce GHG control measures by including such an input for each gas and for each sector that causes emissions. They find that non-CO_2 GHG can contribute to a relevant share of emissions reduction varying from around 20% in Japan and the EU to higher shares in developing countries. Furthermore, the paper achieves its purpose to include non-CO_2 GHG in a CGE framework. This is important as it allows to study synergism between CO_2 and non-CO_2 GHG policies and cost accounting. The same approach is also used by Paltsev et. al. (2005) in the fourth version of the MIT Emissions Prediction and Policy Analysis (EPPA) model.

This paper also tries to include multigas emissions in a CGE framework, although taking a different approach. It builds on the Energy-Environmental version of the GTAP model (GTAP-E) designed by Burniaux and Truong and follows their procedure to include emissions of CH_4 and N_2O. These are added to the database of the GTAP6 model and increased proportionally to production in related sectors. Contrarily to the previous approach, emissions of GHG are derived as output from production processes and not as inputs. This still allows for studying synergies between single-gas environmental policies, but it does not require assumptions on the substitutability between gases and other productive inputs.

Section 2 will explain in more detail how the GTAP model has been modified to include emissions of CH_4 and N_2O. In Section 3 this framework will be used to simulate different climate policies and the related results will be presented. Finally, Section 4 will conclude and introduce some ideas for future developments of this work.

2 Including non-CO_2 Greenhouse Gases in the GTAP Model

Non-CO_2 greenhouse gases originate from industrial processes as well as agriculture and other anthropogenic activities. Methane emissions are due to the agricultural sector, waste management and energy use; nitrous oxide emissions are caused by the agricultural sector, by the use of fertilizers in agriculture, by the management of animal waste, energy use and street transport; whereas the rest of the greenhouse gases, $PFCs$, $HFCs$ and SF_6, are mainly industrial gases.

Because of the different origin of these gases, data on emissions are not easy to find. In this paper the database by Lee (2003), that includes data on emissions of CH_4 and N_2O, will be used to account for non-CO_2 GHG. This limits the dataset to only three of the six greenhouse gases, but it accounts for majority of emissions and it is an improvement on the CO_2-only version.

The data on CH_4 and N_2O emissions is disaggregated by sector and by region and it allows to include such emissions in the database of the extended version of the GTAP-E model with augmented sectoral disaggregation (GTAP-EXB, Roson (2003)). Emissions of methane are caused by agricultural activities (cultivation of rice, wheat, cereal, crops, vegetables and fruit), animal livestock, energy use (coal, oil, gas) and human activities such as waste disposal and heating. These correspond to the non-market services and to a new sector (denoted HH in the database) that corresponds to the activities of households that cause emissions of GHG. Emissions of N_2O are caused by agricultural activities (cultivation of rice, wheat, cereal, crops, vegetables and fruit), animal livestock, industrial production (energy intensive industries), market and non-market services and household activities.

Once changed the database, the model is modified to include CH_4 and N_2O proportionally to production and household activities in the same form as it is done for CO_2 in the GTAP-E model. Emissions from households are assumed to be proportional to regional income, hence the richer a country is, the more its households will emit GHG.

This modification to the GTAP-EXB model allows to study the effects of a carbon tax and of a CO_2 emissions trading scheme not only on the economy but also on the emissions of CH_4 and N_2O. By further modifying the model it will also be possible to apply environmental regulations or extend the emission trading scheme to non-CO_2 GHG.

3 Simulations and Results

This sections presents the results from simulations corresponding to three different hypothetical types of climate change policies. The first one will consider an international market for CO_2 emissions where countries are allowed to trade permits of CO_2 and an overall emission cap is given to the participants. In the second, a tax on CO_2 emissions will be simulated in order to compare relative costs and efficiency of Permit Trading and Pigouvian taxes. Finally, a combination of regulations on the three GHG will be considered.

All simulations are related to the Business as Usual (BAU) scenario at year 2030. The year 2030 baseline is achieved by shocking the main structural parameters and input variables (population, GDP, CO_2 emissions, labor, capital, natural resources, energy, electricity, water, services, some industrial production sectors). The used aggregation is that of the GTAP-EXB version of the GTAP model, which includes 18 sectors and 8 regions (USA, EU, EEFSU, JPN, RoA1, EEx, CHIND and RoW). The shocks and the aggregation are set following Roson (2003).

3.1 Emission Trading

This section reproduces a Kyoto-like agreement in order to consider the equilibrium price for permits of carbon dioxide, spillover effects on other greenhouse gases and an eventual carbon leakage effect. The international emission trading scheme is simulated by introducing a market for carbon and an exogenous reduction of the emission quotas available. The emission cap is therefore exogenous, whereas countries are free to trade between each other so that marginal costs are equalized to the permit price. The shock on quotas imposed is chosen arbitrarily (-22%) in order to compare a BAU scenario with that in which an Emission Trading Scheme is implemented. This shock is not aimed at the achievement of Kyoto targets, but it is only meant to allow for comparisons between the two scenarios. The countries participating to the emission trading are the same as the countries in the Annex I of the Kyoto Protocol, as those who ethically should bare most emissions reductions. By setting a negative shock on the available quotas, regions are allowed to trade at a permit price that leads to equalization of marginal costs. With the shock imposed the permit price obtained is 57,8 $ per ton of C that is equivalent to 15,8$ per ton of CO_2 (1g C=3.664 g CO_2). The results of the simulation on the emissions of CO_2 are as follows:

Table 1: CO_2 Emissions (in M tons C eq.)

Region	Participant ETS	BAU (M ton C)	ETS (M ton C)	Percentage change	Emissions change	Costs of reduction
USA	$\surd$	3915.3	2867.6	-26.80	-1047.7	60557.06
EU	$\surd$	2116.9	1829.8	-13.64	-287.1	16594.38
EEFSU	$\surd$	2100.8	1599.1	-24.68	-501.7	28998.26
JPN	$\surd$	834.8	700.1	-16.18	-134.7	7745.20
RoA1	$\surd$	646.1	511.8	-20.96	-269.0	15548.20
EEx	×	2313.9	2350.4	0.80	36.5	-
CHIND	×	4298.9	4273.0	-1.11	-25.9	-
RoW	×	2062.4	2133.4	3.18	71.0	-

From the table we notice that the greatest emissions reduction is achieved by the United States, both in terms of absolute reductions and relatively to their initial level. A great part of the reduction is also achieved by Eastern European countries and the former Soviet Union, whereas Japan and the EU limit their reduction to respectively 16.18% and 13.64% of their initial level, which is inferior to the imposed shock. Hence, it appears that emission trading favors these countries in the achievement of the emissions reduction, although it will be shown later exactly which of these countries is a buyer and seller in the market. Note that the extent of emissions reduction of the USA is so large that by implementing emission trading without them would lead to much higher costs. Simulating another emissions trading scheme that excludes the USA and leaves each of the other countries to reduce emissions of the same amount (what they were reducing without considering the emissions cut within the US) the permit price is much higher and it amounts to 102$ per ton of C.

From the table we can also notice that there is a certain amount of carbon leakage. Whereas emissions in China and India are reduced, probably as an effect of trade with neighboring countries, emissions in the rest of the excluded countries from the ETS grow slightly from their initial level.

The cost of reducing emissions is calculated as the change in emissions multiplied by the price of permits. This shows that the CO_2 market causes very high costs especially to the United States. These costs will be compared to the costs of an carbon tax in the next section.

For what regards sectoral changes in emissions, the main reductions take place in the coal sector and in general in the non-electric energy sectors. However, emissions grow in non-Annex I countries, especially in the oil sector, showing that there is a problem of carbon leakage also in the exploitation of natural resources in non-participant countries.

We can also gain some more information on the behavior of the carbon market by studying the change in quotas:

Table 2: CO_2 Emission quotas (in M tons C eq.)

Region	Participant ETS	Initial quotas	Final quotas	Change in quotas
USA	✓	3915.3	2523.2	-1392.1
EU	✓	2116.9	1644.1	-472.8
EEFSU	✓	2100.8	2396.3	295.5
JPN	✓	834.8	569.6	-265.2
RoA1	✓	646.1	416.3	-229.8
EEx	×	2313.9	2350.4	-
CHIND	×	4298.9	4273.0	-
RoW	×	2062.4	2133.4	-
Total	-	18362.9	16306.4	-2056.5

Most quotas traded in the market are bought by Eastern European and former Soviet Union countries. This could correspond to the fact that the countries still have to undergo a process of industrialization and hence need to buy quotas to be able to develop their industrial systems.

Having introduced non-CO_2 gases in the model, it also possible to check for spillover effects, that is reduction or growth in emissions of other gases caused by a policy addressing CO_2. The following table shows emissions reduction of the other gases:

Table 3: CO_2 Emissions of CH_4 and N_2O (in M tons C eq.)

Region	CH_4 emission growth	N_2O emission growth ETS
USA	-13.20	-0.91
EU	-5.49	-0.10
EEFSU	-15.45	-2.79
JPN	-4.22	-0.37
RoA1	-7.86	0.18
EEx	0.24	0.59
CHIND	-0.29	0.05
RoW	0.21	0.09

The table shows that there are quite strong spillover effects. For what regards changes in these gases by sector, the main reductions in emissions are in the energy sector. However, there are some reduction also in the agricultural and animal livestock sector, showing also intra-sectoral effects. Spillover effects between gases are very important as they show that the actual reduction in GHG is not just the one achieved with the set cut in the GHG targeted but that there are synergies between the gases that need to be taken into account when designing policies. In this case the reduction in CO_2 amounts to 2098 M Tons of Carbon equivalent, whereas the overall GHG reduction amounts to 2244 M Tons of Carbon equivalent. This confirms the importance of using a multigas framework when studying policies addressing climate change.

It is also interesting to check for changes in prices and output in the energy sector consequent to the environmental policy imposed. The following tables illustrate results for changes in prices and output in the energy-related sectors:

Table 4: Percentage Change in Prices per Energy-Related Sector

Region	Coal	Oil	Gas	Oil Pcts	Electricity	En Int Ind
USA	-12.39	1.58	-0.03	0.39	13.58	2.21
EU	-21.18	-1.84	-3.17	-0.75	14.60	2.35
EEFSU	-20.98	-1.72	-7.01	-1.92	31.04	3.12
JPN	-13.53	-4.45	5.98	-0.09	7.72	2.57
RoA1	-12.01	-0.63	-4.60	-0.47	9.57	1.87
EEx	-8.74	-0.71	-0.78	-0.59	-0.56	0.41
CHIND	-1.91	0.27	1.11	-0.29	0.49	1.12
RoW	-6.53	-0.06	0.87	-0.15	0.18	1.09

From the table it is possible to see that prices changes uniformly across countries. The main changes in prices correspond to an increase in the prices of electricity and a decrease in the prices of coal. This may be due to a change in energy use from coal to electricity, which produces less GHGs emissions. Note that the trend in price changes shows a negative change in non-electric energy sources, contrarily to a positive change in electricity. Also note that this change in energy use takes place despite the low elasticity of substitution between electric and non-electric energy sector, that is $\sigma_{elec,non-elec} = .1$. Furthermore, such changes in energy use also correspond to an increase in prices of the energy intensive industries. The changes in prices also correspond to sizes of changes in output per sector:

Table 5: Percentage Change in Output per Energy-Related Sector

Region	Coal	Oil	Gas	Oil Pcts	Electricity	En Int Ind
USA	-32.69	-17.86	-19.19	-15.15	-3.75	-1.13
EU	-37.84	-5.41	-27.05	-9.06	-5.73	-1.45
EEFSU	-31.35	-9.17	-14.63	-10.59	-17.77	-3.17
JPN	-17.30	-1.97	-33.90	-10.80	-1.90	-1.49
RoA1	-24.72	-10.36	-19.19	-10.60	0.33	-0.43
EEx	-12.64	-4.83	-7.20	-0.47	1.54	1.87
CHIND	-3.43	-1.39	-0.73	0.39	0.48	0.51
RoW	-7.86	-1.72	0.16	0.56	3.37	0.96

The trend shows a general decline in production, although there is an increase in production in non Annex I countries, coherently with the previous findings of carbon leakage. The main production cuts are in the coal sector and generally in the non-electric energy sector, whereas electricity is the least affected. This supports once again the hypothesis of a change in energy use towards the electric sector.

The next section will consider the imposition of a carbon tax instead of a system of tradable permits, and this will also allow to gain more information on the trading system itself.

3.2 Carbon Tax vs. Emission Trading

This section considers the same reduction in emissions but distributed equally across regions, which can be achieved by imposing a carbon tax. Hence, whereas before the permit price was equal in all countries, the carbon tax needed to achieve a reduction of 22% of CO_2 emissions is different across regions. Results from this simulations are presented below:

Table 6: CO_2 Emissions (in M tons C eq.) with tax and with ETS

Region	Value of TAX	Emissions (ETS) (M ton C)	Emissions (TAX) (M ton C)	Net Export	Net value of trade
USA	44.2	2867.6	3050.8	-183.2	-11028.24
EU	110.0	1829.8	1649.8	+180.0	10404.00
EEFSU	50.7	1599.1	1653.2	-54.1	-3126.98
JPN	90.1	700.1	650.4	+49.7	2872.66
RoA1	63.3	511.8	504.2	+7.6	439.28

From the table it is possible to see that the countries that are net sellers of permits are the European union, Japan and the countries included in the RoA1 region, that is countries such as Australia, Canada or New Zealand that have smaller emissions reduction requirement in the Kyoto Protocol, whereas the net buyers are the US, possibly due to the huge reduction requirement imposed, and the Eastern European and former Soviet Union countries, which is coherent with the previous result that underlined the need for an industrial expansion of this region. It is also possible to notice that the value of the taxes in each region are very different from those in the Emission Trading case. We can combine the information to compare the costs of the two policies:

Table 7: Costs of Policies

Region	Value of TAX	Change in Emissions (BAU-CTAX)	Cost of Carbon Tax	Costs of ETS	Gains from ETS
USA	44.2	864.5	38210.9	60557.06	-22346.16
EU	110.0	467.1	51381.0	16594.38	34786.62
EEFSU	50.7	447.6	22693.3	28998.26	-6304.96
JPN	90.1	284.4	25624.4	7745.20	17879.20
RoA1	63.3	141.9	8982.3	15548.20	-6565.90
Total	-	2205.5	146891.9	129443.10	17448.80

The table above shows that the overall costs of the emissions trading scheme are lower than the costs of a carbon tax. Nonetheless, they involve very high costs of emission trading for the US. The RoA1 region is also disadvantaged from the implementation of emission trading. On the other hand, the gains from implementing emission trading for the European Union and Japan are very high. This scenery is coherent with the actual situation of the Kyoto Protocol that sees the EU and Japan as the main leaders in the implementation of the international emission trading and the US and some of the countries included in the RoA1 region not willing to take part to it. Despite the lack of flexibility of this trading scheme that does not allow for carbon sinks, for other flexible mechanisms or for trading with non-Annex I countries, the costs of the ETS are lower.

The impact of the two policies can also be compared using changes in GDP. These are shown in the table below:

Table 8: Changes in GDP

Region	Change in GDP (ETS)	Change in GDP (TAX)
USA	0.47	0.77
EU	0.75	0.67
EEFSU	1.64	-2.56
JPN	0.64	0.87
RoA1	-0.19	-0.13
EEx	-0.11	0.11
CHIND	0.82	1.16
RoW	0.76	1.13

The changes in GDP reflect the same situation as those depicted in the previous table in the comparison of the costs of reduction. Whereas for the EU and the Eastern European and former Soviet Union countries it appears to be convenient to implement emission trading, a carbon tax leads to higher GDP increase in the rest of Annex I countries. For what concerns the rest of the world, whereas a carbon tax does not influence negatively the growth of countries in which the tax is not applied, the emission trading scheme seems to have a negative impact on the economy of some of the non-Annex I regions.

3.3 Multigas Environmental Policies

The last simulation includes a multigas policy, achieved by imposing an exogenous reduction in emissions of CH_4 and N_2O in specified sectors of production. This simulates a target-based policy that aims at reducing emissions of these GHG in certain productive sectors. The targeted sectors are the animal livestock sector for the emissions of methane, and the fruits and vegetable sector for the emissions of N_2O. These have been chosen as for each of the two GHG they are the sectors that cause most emissions. Furthermore, these sectors have also been addressed many times in environmental policies, especially in the EU, as they represent a relevant problem in the context of climate change. By imposing a .1% reduction in emissions of methane in the animal sector and a .05% reduction in emissions of N_2O in the fruits and vegetables sector, the result is a decrease in emissions of all three GHG. Emissions are reduced in these two GHG not only in the sectors in which a shock is imposed, but also in other sectors, as the production is related between sectors. Thus, as a consequence, energy use diminishes, and hence also emissions of CO_2 decrease. The consequent overall decrease in GHG is of 300 M tons of C equivalent.

Applying now an emission trading system with less stringent reduction in order to obtain a similar final result to the one in Section 3.1, combines the two climate policies. By imposing a decrease of the 18% in the market of quotas (on the baseline obtained after the taxes) the final overall emissions reduction is now of 2214 M tons C equivalent but this time the price of permits is lower than it was in the previous simulation with ETS. In fact, it is now 42.2$ per ton of C or 11.5$ per ton of CO_2, which lowers the costs of reduction of CO_2.

This shows that implementing non-CO_2 policies could lead to lower costs of reduction of GHG. However, this analysis does not take into consideration the costs of imposing a reduction to the emissions of CH_4 and N_2O, nor it considers the intra-sectoral and intra-regional distribution of reductions and the related changes in prices, output and GDP. This preliminary paper will in fact be extended to include a more detailed analysis and more precise taxation system for non-CO_2 GHG as well as more flexibility in emissions trading that allows to trade not only CO_2 but all the greenhouse gases.

4 Conclusions

This paper modifies the GTAP-EXB framework to include multigas emissions of GHG. In this new setting different simulations address the problem of climate policies. The multigas framework allows to gather information of synergic effects between GHG. Results show that policies targeting CO_2 also lead to a reduction in the other GHG included in the model. Furthermore, multigas policies are simulated imposing an exogenous reduction in emissions of CH_4 and N_2O combined with international emission trading of CO_2. This shows that when obtaining reduction in GHG by cutting non-CO_2 emissions, it is possible to diminish the permit price and therefore to achieve emission targets in a less costly manner.

However, these results are very preliminary as an exogenous reduction does not supply any information on the costs of this policy. It will be necessary to extend this framework to be able to analyze more precisely multigas policies. The next steps of this work will be to combine the CO_2 policies already used with Pigouvian taxes on the other pollutants and consider a trading scheme in which all GHG can be traded. This will then allow to compare costs of multigas and CO_2-only climate policies.

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