

EMF Working Group 18

Preliminary Results of Sensitivity Analysis on Leakage with GEMINI-E3/*GemWTraP*

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Abstract

The paper presents the results of a sensitivity analysis on leakage performed with GEMINI-E3/*GemWTraP*. They show that, the bigger the substitutability of energy intensive goods in world markets, the bigger the “delocalisation” of production from Annex I countries and the bigger the welfare cost of committing to the Kyoto Protocol for them. On the contrary, non-Annex I countries benefit from a higher substitutability in markets of energy intensive goods. These results are corroborated by the simulation of “Enlarged Kyoto” scenarios, i. e. scenarios in which CO₂ emissions of non-Annex I countries are hypothetically stabilized or constrained to a given rate of abatement. Detailed analysis shows that the main effects on welfare are channeled through international markets, and in particular gains and losses from terms of trade.

Keywords : Leakage, Carbon Tax, Welfare Cost, Terms of Trade, Deadweight Loss of Taxation

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Preliminary Results of Sensitivity Analysis on Leakage with GEMINI-E3/*GemWTraP*¹

Alain L. Bernard and Marc Vielle

The present paper yields the preliminary results of a sensitivity analysis on leakage, decided upon at the kick-off meeting of EMF 18, and implemented with the model GEMINI-E3/*GemWTraP*. It consists in comparing scenarios of Kyoto Protocol corresponding to different values of the elasticity of substitution between imports and domestic production. This elasticity is representative of the “Armington assumption”, and will be labeled thereafter “Armington elasticity” (AE in short).

In fact, two elasticities of substitution intervene in the Armington mechanism: i) the elasticity between domestic production and the nest representing imports from all other countries, and ii) the elasticity between imports from various countries in the nest. We will term the latter “inter-country elasticity of substitution”.

Initial runs of sensitivity analysis considered independent changes of the two elasticities. However the role of the inter-country elasticity of substitution did not appear visible enough to maintain this complication. Moreover it is very likely that the inter-country elasticity is equal to or bigger than the Armington elasticity, as imports from other countries appear more substitutable between them than to domestic production. For the sake of simplicity, we then assumed in all scenarios that the two elasticities were equal.

Sensitivity analysis is not applied to the whole economy but to a specific sector or group of sectors, the “Energy Intensive Sectors”, which are the most sensitive to distortions of concurrence and then transfer of production from Annex I toward non-Annex I countries, and in particular toward developing countries. In GEMINI-E3/*GemWTraP*, these E.I.S. are represented by a single sector, which is the sector of intermediate goods.

In the standard version of GEMINI-E3/*GemWTraP*, the value retained for both elasticities in E.I.S. is, for all countries, equal to 3. Sensitivity analysis was then performed by varying this parameter from 0 (i. e. total complementarity) to 9, with an intermediate value of 6. As for the types of scenarios, “No Trade” assumption was first retained but it appeared interesting to check if the main results would be modified by the existence of a market of tradable permits between Annex I countries.

Finally the fundamental question raised by leakage is “what if” without leakage, and in particular whether and in which proportion Annex I countries are penalized by this phenomenon. A way to answer this question is to compare the present Kyoto Protocol to a scenario in which non Annex I countries would be committed to their Business as Usual CO₂ emissions. This can be obtained through imposition of a carbon tax in the concerned countries. A simulation with a more stringent commitment from non-Annex I countries (Business as Usual less 10%) has also been implemented to better assess their potential role in world climate change policies.

¹ We are indebted to Tom Rutherford for comments on an earlier version of the paper.

On the whole, nine sensitivity scenarios have been simulated beside the central scenario (*Sct3*) and are listed below:

- *Sct0*: Domestic taxes and AE in E.I.S. equal to 0;
- *Sct6*: Domestic taxes and AE in E.I.S. equal to 6;
- *Sct9*: Domestic taxes and AE in E.I.S. equal to 9;
- *Scp0*: Tradable permits and AE in E.I.S. equal to 0;
- *Scp3*: Tradable permits and AE in E.I.S. equal to 3;
- *Scp6*: Tradable permits and AE in E.I.S. equal to 6;
- *Scp9*: Tradable permits and AE in E.I.S. equal to 9;
- *Scpworld*: Like scenario *Scp3* and commitment by non Annex I countries to BaU CO2 emissions;
- *Scpworldm10*: Like scenario *Scp3* and commitment by non Annex I countries to 10% below BaU CO2 emissions.

The simulation is over the period 2000-2040, and is based on an assumption of “Kyoto forever” for Annex I countries². Note that, for each scenario, the model has to be re-calibrated with respect to the new elasticities of substitution. Calibration has been performed in order to adjust to the same evolution of CO2 emissions by each country/region on the whole period. But differences between BaU scenarios are inescapable because they result from the working of the model. In particular, rates of growth of production in E.I.S. differ from one to the other, as given by the table below.

Table 1 : E.I.S. growth of production in BaU scenarios according to Armington elasticity
(Average rate 1990-2040)

	AE = 0	AE = 3	AE = 6	AE = 9
USA	2.4%	2.1%	1.8%	1.6%
EU11	2.4%	2.0%	1.7%	1.4%
France	2.3%	1.7%	1.2%	0.8%
Japan	2.1%	1.7%	1.5%	1.2%
FSU	2.6%	2.7%	2.7%	2.7%
EEC	3.9%	4.7%	5.1%	5.4%
ROW	3.8%	4.0%	4.2%	4.3%

Sections 1 and 2 review the results of the pure sensitivity exercise (scenarios *Sct0* to *Sct9* and *Scp0* to *Scp9*), respectively macro-economic and sectoral aspects. Section 3 analyzes the effect on Annex I countries of a progressive commitment to maintain or reduce CO2 emissions by non-Annex I countries (Scenarios *Scpworld* and *Scpworldm10*). Section 4 concludes and suggests further analysis.

² Main features of the model and characterization of the BaU scenario were presented in the first meeting of WP 18. Let us only recall that the model includes 7 countries/regions : USA, France, Other European Countries (EU11), Japan, Former Soviet Union (FSU), Energy Exporting Countries (EEC) and Rest of the World (ROW). The first four are representative of OECD, the first five of Annex I.

I Macro-economic aspects of leakage : increased emissions of CO2 by non Annex I countries and change in welfare cost

Leakage, at the macro-economic level, can be appreciated through two main indicators: the increased emissions of CO2 by non-Annex I countries and the effects on welfare cost borne by each country, belonging or not to Annex I. Change in emissions by non-Annex I countries is normally equal to total world change, as Annex I countries are constrained to their commitments of the Kyoto Protocol. However this is not true for FSU, in the “No Trade” case: at least during the first two decades, the Kyoto commitment is not binding.

Then in “No Trade” scenarios, it is relevant to consider leakage by both FSU and non Annex I countries. In scenarios of tradable permits, there is no leakage attributable to FSU as pollution rights available in excess can be sold to other Annex I countries. Leakage is only from non-Annex I countries.

1.2. Global emissions of CO2

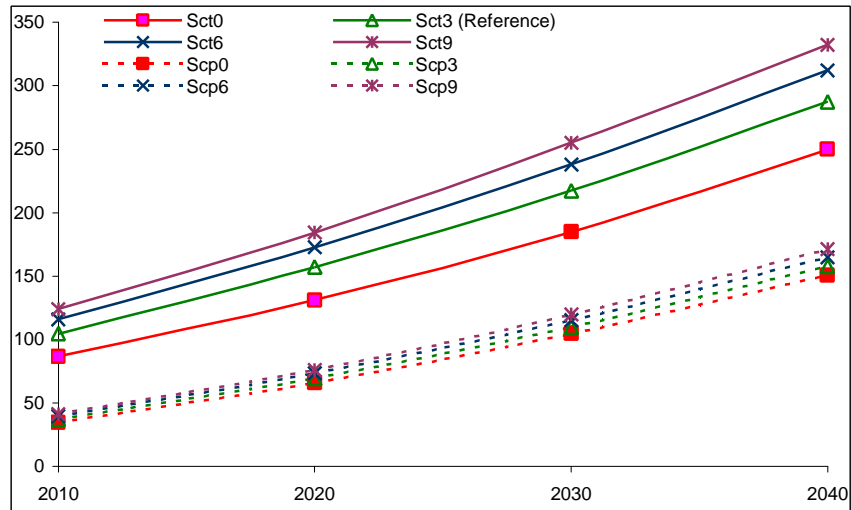
Increased emissions by non-Annex I countries (and eventually FSU), i. e. the difference with respect to the BaU scenario, result from the reduced demand of fossil fuels by Annex I countries, and the correlative decrease of prices in international markets. Elasticity of supply by exporting countries, and elasticity of demand by non-Annex I countries are the main parameters determining the importance of this effect.

Results obtained with the model are given in Table 2 below, and represented in Figure 1. They exhibit an effect which is small compared to total world emissions by the considered countries but not compared to the abatement required from Annex I countries in the Kyoto Protocol.

Table 2
Additional emissions of CO2 by non-Annex I countries and FSU
(millions metric tons of carbon)

	2010	2020	2030	2040
Sct0	87	131	185	250
Sct3 (Reference)	105	157	217	287
Sct6	116	173	238	312
Sct9	124	184	255	332
Scp0	35	66	105	151
Scp3	37	70	110	158
Scp6	40	73	115	165
Scp9	41	76	120	171
Total corresponding emissions in the baseline scenario (incl. FSU)	5270	6846	8535	9814
Total abatement by OECD countries	829	1065	1235	1416

Figure 1
Additional emissions by non-Annex I countries and FSU according to scenarios
(millions metric tons of carbon)



In the “No Trade” case, leakage increases with the Armington elasticity, representing roughly from 2% (AE = 0) to 3% (AE = 9) of total emissions by Non-Annex I countries and FSU. The level of leakage and the sensitivity with respect to AE are much smaller in the case of “Tradable Permits” and this is easily understandable as, owing to “Hot Air” and additional abatement by FSU induced by taxation, the carbon constraint for Annex I countries is less stringent.

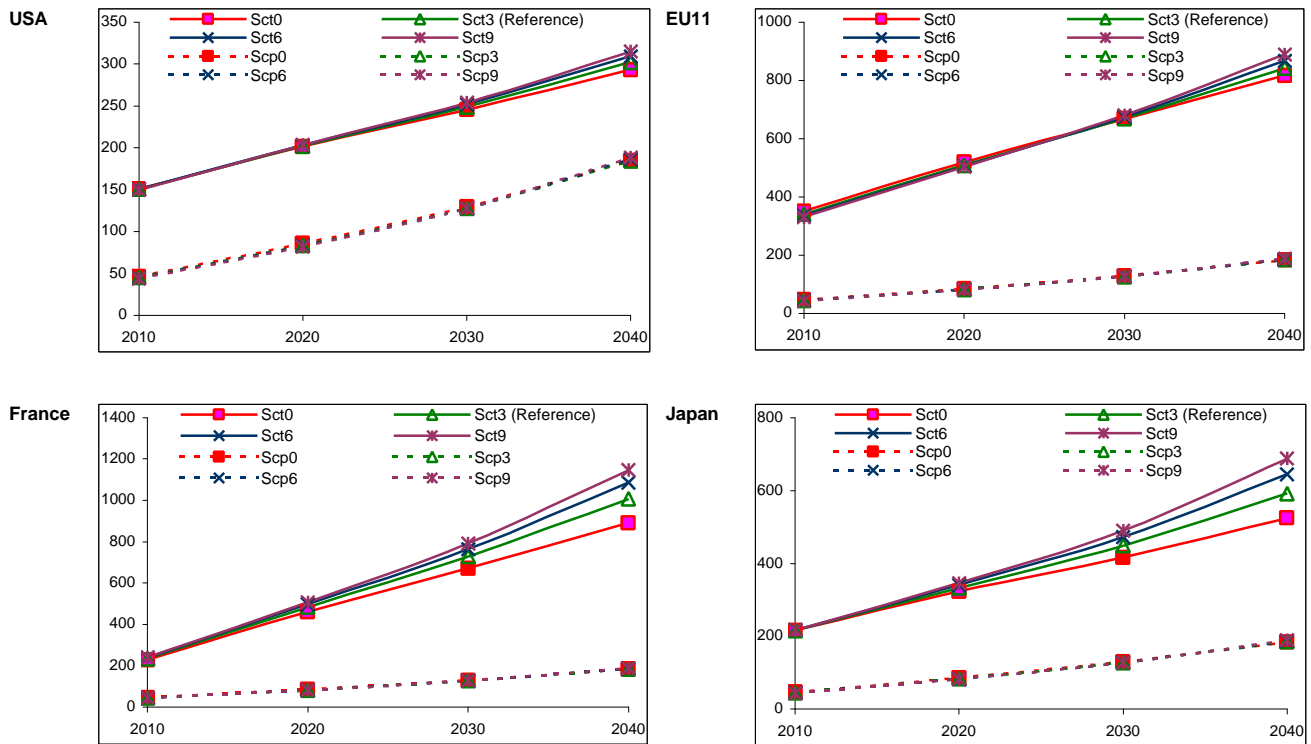
Compared to the committed abatement from other countries (Annex I less FSU, i. e. “OECD” in the model terminology), leakage is not a negligible phenomenon, particularly in the long run (around 20% in 2030 and 2040 in the “No trade” case, around 10% in the “Tradable Permits” case).

1.2. Welfare Cost and Components

The first indicator –or proxy³– of cost is the equilibrium carbon tax, or the price of permits in the “Tradable Permits” case. Results presented in the graphs below show that the sensitivity to the Armington elasticity is fairly low, and this is particularly verified in the case of “Tradable Permits”. Sensitivity appears bigger for France and Japan than for US and EU11.

³ A better indicator is the marginal abatement cost. Calculations have not been performed for this preliminary paper but obviously variations of MAC are correlated to changes in carbon taxes.

Figure 2 : carbon tax or price of permits according to Armington elasticity
(In Dollars of 1990 by metric ton of carbon)



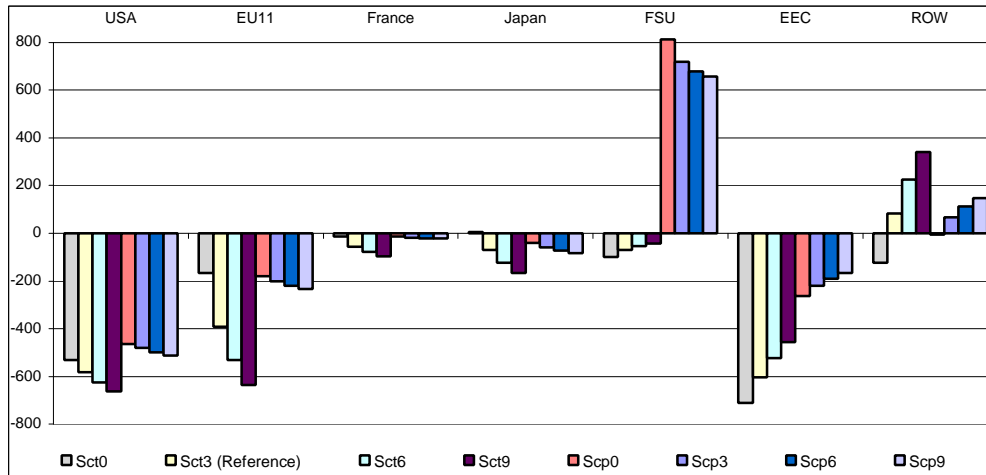
Concerning welfare cost of climate change policies, the fundamental result obtained in the simulations is that higher Armington elasticity benefits to non-Annex I countries and penalizes “OECD” countries. Numerical results of scenarios are given in Table 3, and represented in the graphs of Figure 3.

The case of FSU is intermediate: its welfare cost decreases with AE in the “No Trade” case but increases in the case of “Tradable Permits” (more precisely, the welfare gain decreases).

Table 3 : Welfare Cost of the Kyoto Protocol according to Armington elasticity
(Present Discounted Value at 5% discount rate, in billions of 1990 US \$s)

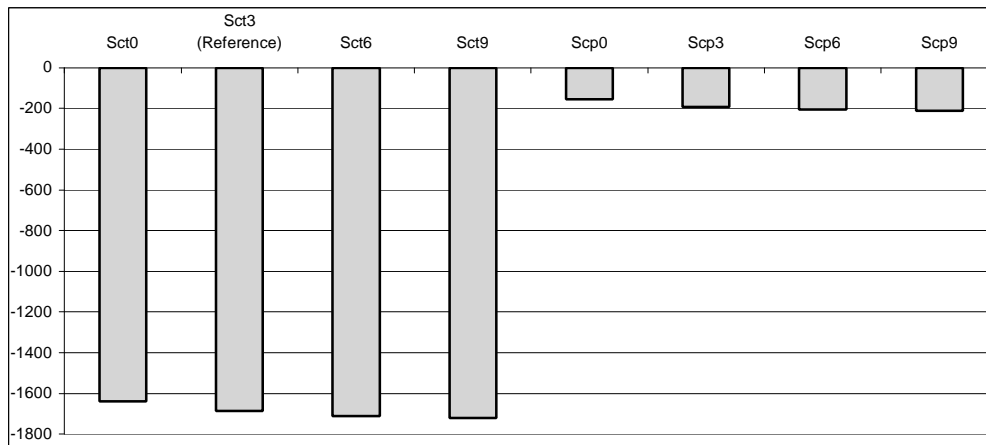
	Sc t0	Sc t3	Sc t6	Sc t9	Sc p0	Sc p3	Sc p6	Sc p9
USA	-531	-583	-625	-662	-464	-481	-498	-513
EU11	-165	-391	-532	-636	-180	-201	-219	-233
France	-13	-55	-79	-96	-15	-18	-21	-23
Japan	6	-68	-123	-167	-40	-58	-71	-82
FSU	-100	-70	-54	-44	813	718	680	658
EEC	-711	-603	-523	-455	-263	-219	-190	-166
ROW	-123	84	226	340	-6	68	114	148
Total "OECD"	-704	-1098	-1359	-1561	-698	-759	-809	-851
Total World	-1638	-1687	-1710	-1720	-154	-191	-206	-212

Figure 3 : Welfare cost by country/region according to scenarios
(Present Discounted Value at 5% discount rate, in billions of 1990 US \$s)



Aggregation⁴ over all countries/regions leads to the result that total world welfare cost increases with the Armington elasticity, both in the “No Trade” and “Tradable Permits” cases, though the differences are quite small. Numerical results are represented in Figure 4 below.

Figure 4 : Total world welfare cost according to scenarios
(Present Discounted Value at 5% discount rate, in billions of 1990 US \$s)



In terms of efficiency, leakage becomes a problem all the more serious that the Armington elasticity is high, as it induces more CO2 emissions and a bigger aggregate welfare cost. *In terms of equity*, leakage is favorable to non-Annex I countries and in particular to developing countries.

As usual in simulations of the Kyoto Protocol, unequal allocation of global welfare change between countries/regions can be attributed to the incidence of terms of trade, and the associated gains and losses. Effectively, Table 5 shows that gains accruing to the “OECD” countries

⁴ Households’ surpluses aggregated at 1990 exchange rates. This implicit summation of surpluses is evidently questionable (see Bernard, 1999. “The Pure Economics of Tradable Pollution Permits,” communication to the Joint Energy Meeting organized by the International Energy Agency, the Energy Modeling Forum and the International Energy Workshop, Paris June 16–18).

decrease with higher Armington substitutability and, correlatively, gains for non-Annex I countries increase or losses decrease. As previously noted, FSU is in an intermediate situation, according to the type of scenario (“No Trade” or “Tradable Permits”).

Table 5 : Net gains from terms of trade according to Armington elasticity
(Present Discounted Value at 5% discount rate, in billions of 1990 US \$s)

	Sc t0	Sc t3	Sc t6	Sc t9	Sc p0	Sc p3	Sc p6	Sc p9
USA	105	58	18	-17	1	-19	-35	-50
EU11	548	337	213	122	96	76	62	51
France	86	56	40	28	23	20	18	16
Japan	195	132	86	48	56	40	28	19
FSU	-77	-52	-39	-30	150	51	11	-13
EEC	-690	-586	-511	-446	-256	-214	-186	-163
ROW	-192	16	155	265	-43	36	82	117
Total "OECD"	934	584	357	181	176	118	73	35

The difference between welfare cost and gains from terms of trade is the deadweight loss of taxation in the “No Trade” case, and the sum of DWL and net purchases of permits in the case of “Tradable Permits”. This sum represents, in particular for Annex I countries, the cost of committing to the Kyoto Protocol, with domestic policies and/or trade of permits, net of the effect of international trade. The corresponding figures, given in Table 6, show that this cost increases with Armington elasticity for each country/region of “OECD” in the “No Trade” case and are approximately constant in the case of “Tradable Permits”.

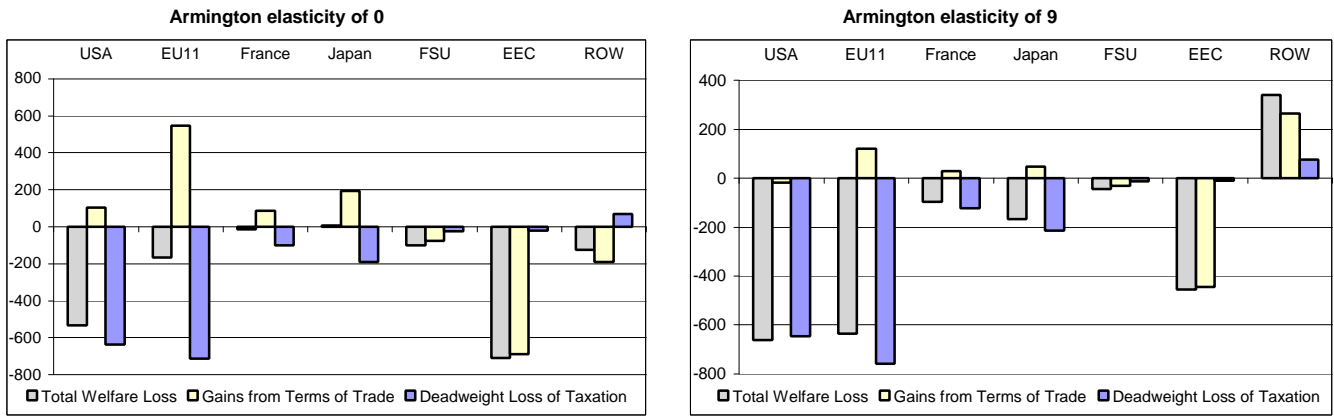
Table 6 : Deadweight Loss of Taxation plus net purchases of permits according to Armington elasticity
(Present Discounted Value at 5% discount rate, in billions of 1990 US \$s)

	Sc t0	Sc t3	Sc t6	Sc t9	Sc p0	Sc p3	Sc p6	Sc p9
USA	-636	-641	-644	-645	-465	-463	-463	-463
EU11	-713	-728	-745	-758	-275	-278	-281	-284
France	-100	-112	-119	-124	-38	-38	-38	-39
Japan	-189	-200	-209	-216	-96	-98	-100	-101
Total "OECD"	-1638	-1681	-1716	-1742	-874	-876	-882	-887

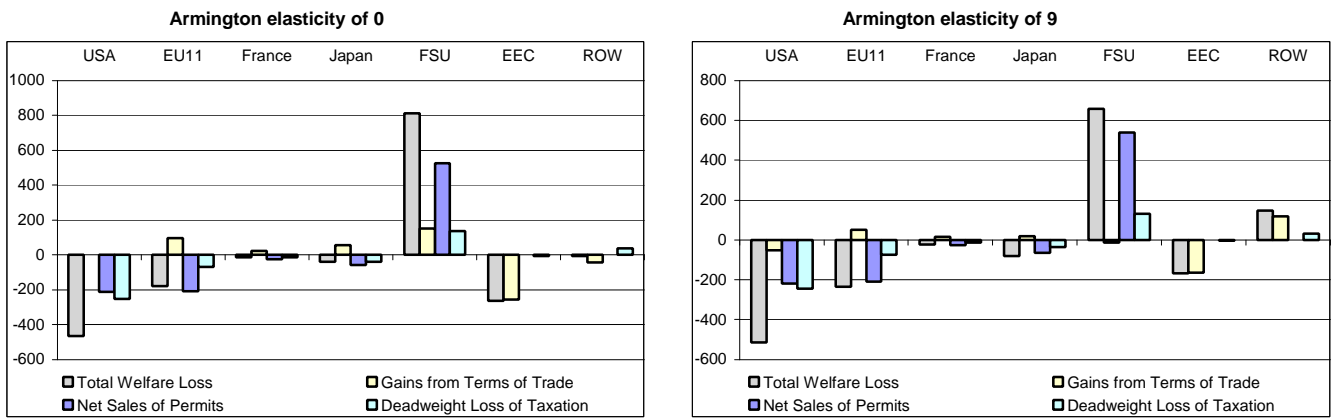
Welfare cost and components can be visualized in the two graphs below, corresponding to extreme retained values of the Armington substitutability, 0 and 9.

Figure 5 : Components of welfare costs for the two extreme values of elasticity
(Present Discounted Value at 5% discount rate, in billions of 1990 US \$s)

Case of “No Trade”

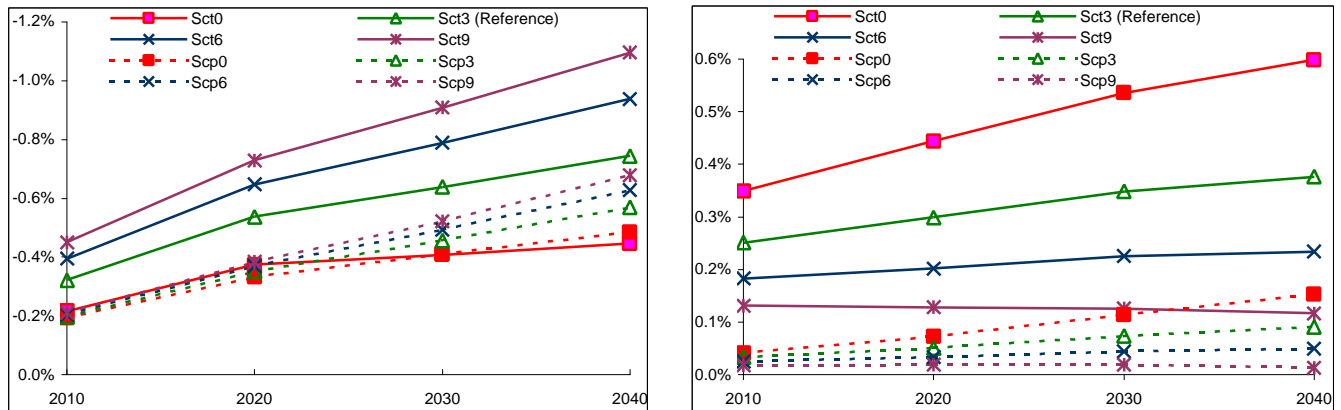


Case of “Tradable Permits”



Evolution during the period 2010-2040 is also illustrative. For total “OECD”, the graphs below represent the comparative evolution of net gains from terms of trade and deadweight loss of taxation in the different scenarios.

Figure 6 : Evolution of welfare cost (left) and net gains from terms of trade (right) for total “OECD”
(in percentage of Households’ Final Consumption)



Similar evolutions are obtained for each country/region of the zone.

II Sectoral effects

Effects of leakage are channeled through domestic sectors in competition in world markets, and in particular (though obviously not exclusively) through Energy Intensive Sectors. As recalled above, E.I.S. are represented in GEMINI-E3/*GemWTraP* by a single sector, which is the sector of Intermediate Goods. It is then an aggregate, with a cluster of goods obviously different from one country to the other. Considering it as an homogenous good is not really legitimate but allows to illustrate the mechanisms at work in the phenomenon of leakage.

II.2. Effects on the allocation of production between countries

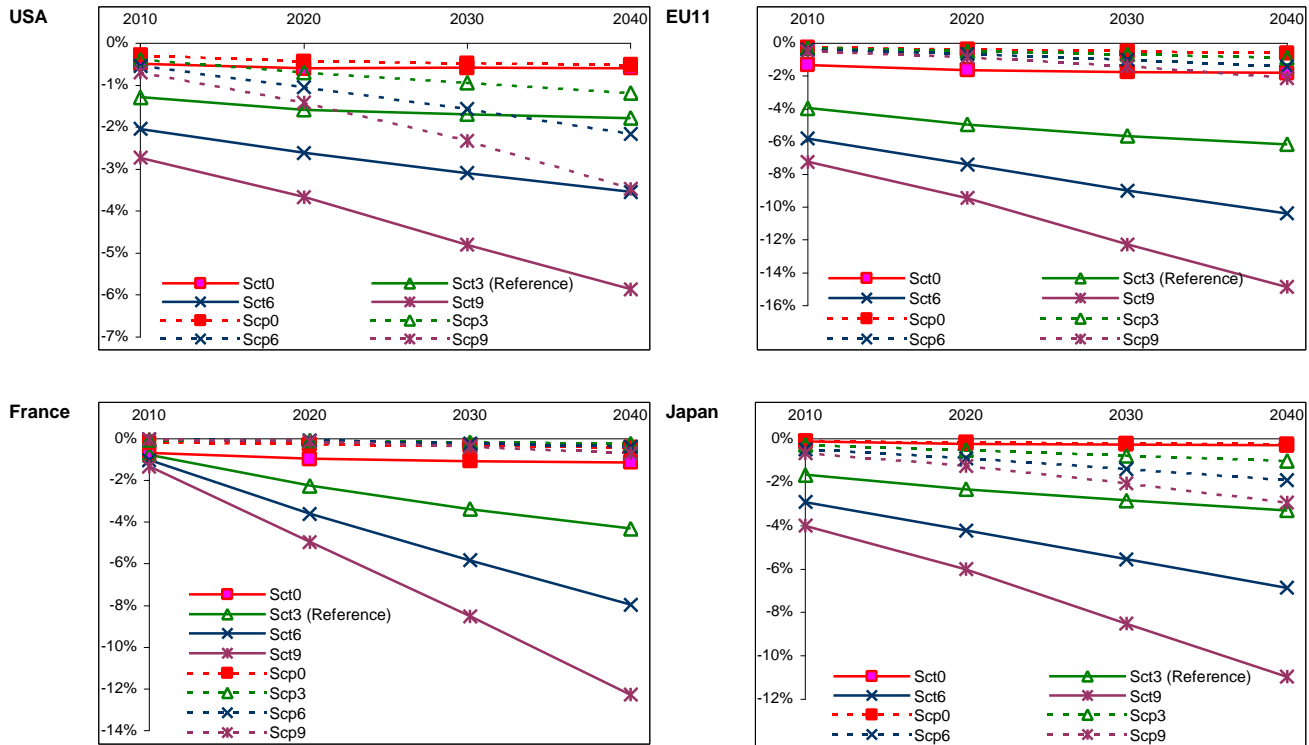
The general result which is obtained –and it is not a surprise– is that “*delocalisation*” of E.I.S. from Annex 1 to non-Annex 1 countries increases with Armington elasticity⁵. This is represented in the graphs of Figure 7.

With a zero Armington elasticity, the loss of production is negligible, for the whole period and in all “OECD” countries (smaller than 1%, except for other European countries where it reaches 2%), both in the “No Trade” and “Tradable Permits” scenarios. When AE increases, the loss remains very limited in the “Tradable Permits” case but reaches 12 to 15% in the “No Trade” case, except for the US where it is much smaller.

Differences between the “No Trade” and “Tradable Permits” scenarios can be explained by the compared stringency of the “carbon constraint”, which is much bigger in the former than in the latter. The same reasoning can be applied to the comparison between countries in the “No Trade” case: the carbon tax is significantly higher in European Countries (including France) and Japan than in the US, particularly in the long run.

⁵ Note that this “delocalisation” starts before implementation of any climate change policy, as mentioned in the introduction.

Figure 7 : Loss of production in E.I.S. for « OECD » countries according to Armington elasticity
(in % of production in volume)



II.2. Effects on CO2 emissions

Change in the localisation of E.I.S. has a direct incidence on the emissions of CO2 generated by these activities, both the total level of emissions and the sharing among countries and in particular between “OECD” and non-“OECD” countries.

Total world abatement in E.I.S. decreases rapidly with higher Armington elasticity, as shown in the Table 7 below.

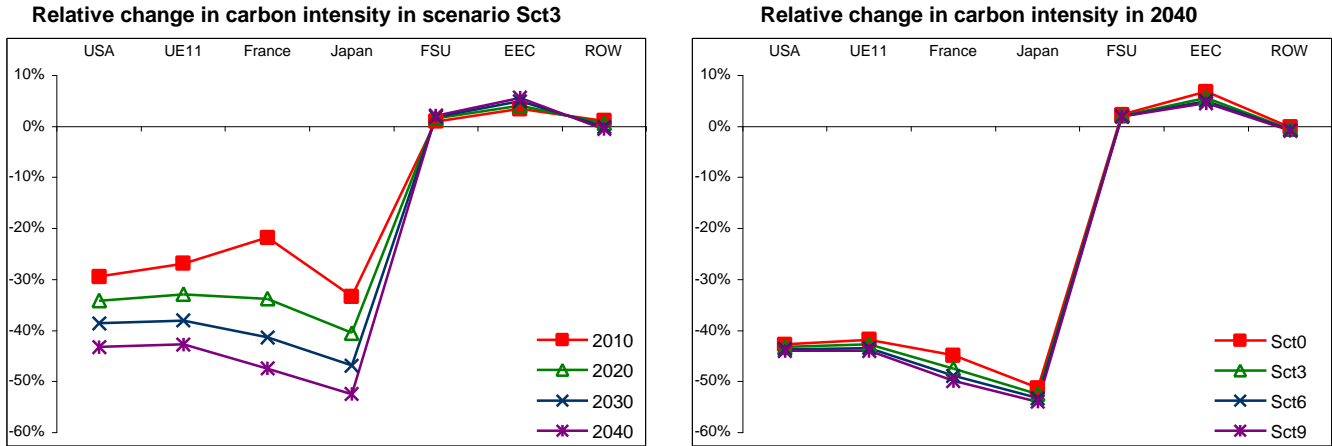
Table 7 : Total world reduction of CO2 emissions in E.I.S. according to Armington elasticity
(in millions of metric tons of carbon)

	Sc t0	Sc t3	Sc t6	Sc t9	Sc p0	Sc p3	Sc p6	Sc p9
2010	119	100	88	79	62	60	58	56
2020	166	132	109	93	110	102	96	91
2030	220	168	132	103	171	151	138	127
2040	281	209	158	117	246	213	190	172

Comparing change in emissions for a given country or region is not significant at the aggregate level because, as mentioned in the introduction, production in E.I.S. and correlatively CO2 emissions differ in the BaU scenarios corresponding to the various values of AE. What appears more significant is the change in carbon intensity, i. e. the ratio of carbon emissions to production in volume.

Graphs below represent the evolution of the relative change of carbon intensity during the period 2010-2040 in the Reference scenario (Sct3), and for the terminal year (2040) the comparative evolution of “No Trade” scenarios.

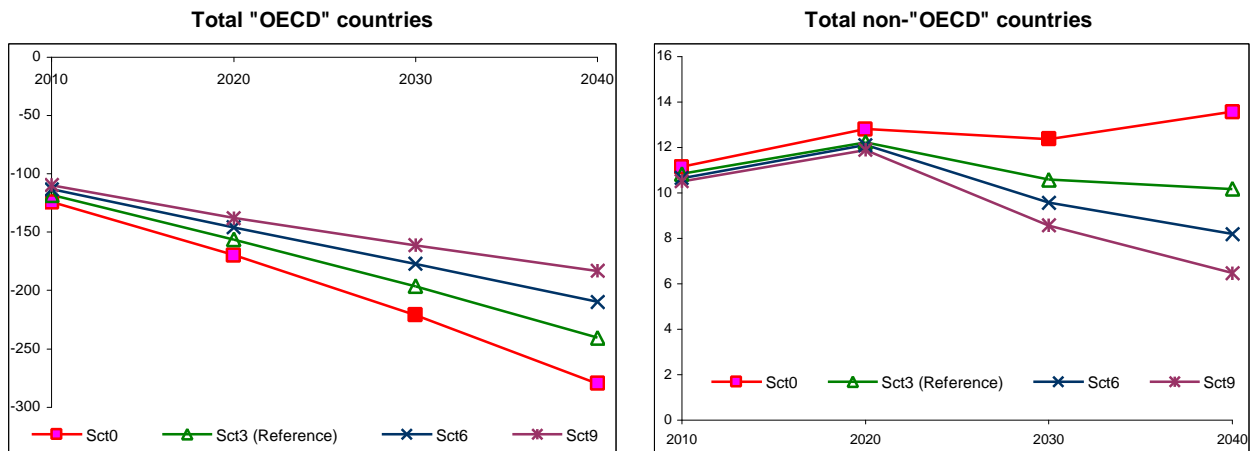
Figure 8 : Evolution of the carbon intensity in E.I.S.



Carbon intensity decreases in “OECD” countries from around 30% in 2010 to around 50% in 2040, while it slightly increases in FSU and EEC (left graph). Reduction in carbon intensity increases with AE, but differences are fairly small (right graph).

Effects of change in carbon intensity on emissions can be visualized in the graphs below, concerning respectively “OECD” and non-“OECD” countries.

Figure 9 : Reduction in carbon emissions attributable to change in carbon intensity
(in millions of metric tons of carbon)



Concerning “OECD” countries, differences between scenarios are explained not by carbon intensity, which is very close from one scenario to the other, but by the levels of production in the initial situation.

III Stabilization or abatement of CO2 emissions in non-Annex I countries

Would commitment by non-Annex I countries to limit or, a fortiori, to reduce CO2 emissions be profitable to Annex I countries? On the one hand, total world emissions of CO2 would be smaller, which is of course an environmental benefit; on the other hand, delocalisation of production in E.I.S. should presumably be reduced or even cancelled, and this, according to the previous analysis, would be profitable to Annex I countries.

A precise scrutiny has been performed by comparing, for a given set of values of Armington elasticity (those of the Reference case), the corresponding Kyoto scenario to “Enlarged Kyoto” scenarios, i. e. scenarios in which non-Annex I countries would commit to stabilization of CO2 emissions (same level than in BaU) or to a 10% abatement (10% below BaU each year).

Stabilization or abatement taxation in non-Annex I countries are assumed to be obtained by domestic taxation. Concerning Annex I countries, we referred to the case of “Tradable Permits”, which appears more likely than “No Trade” in the long run⁶. The new scenarios, *Scpworld* and *Scpworldm10*, are then compared to *Scp3*.

III.2. Sectoral effects

In *Scp3* the loss of production in E.I.S. by Annex I countries is, as was noted in the previous section, quite small. Carbon taxation in non-Annex I countries reduces the shifting of production, as shown in the graphs of Figure 10.

Concerning CO2 emissions, constraint on non-Annex I countries has a very sensitive effect on E.I.S. Graphs of Figure 11 represent the reduction of CO2 emissions in EEC and in ROW. In particular in the latter region, a major share of total abatement would rest on these industries: though they represent less than 20% of emissions in the present -and expected future - situation, from 40% (in 2010) to nearly 60% (in 2040) of total abatement would be realized by them, mainly by reducing carbon intensity.

⁶ Scenarios of world market of tradable permits have been implemented but they don't allow to capture the phenomenon of leakage, as their main effect is to alleviate the carbon constraint for Annex I countries and then reduce substantially the welfare cost of the Kyoto Protocol.

Figure 10 : Loss of production in E.I.S. for « OECD » countries according to scenarios
(in % of production in volume)

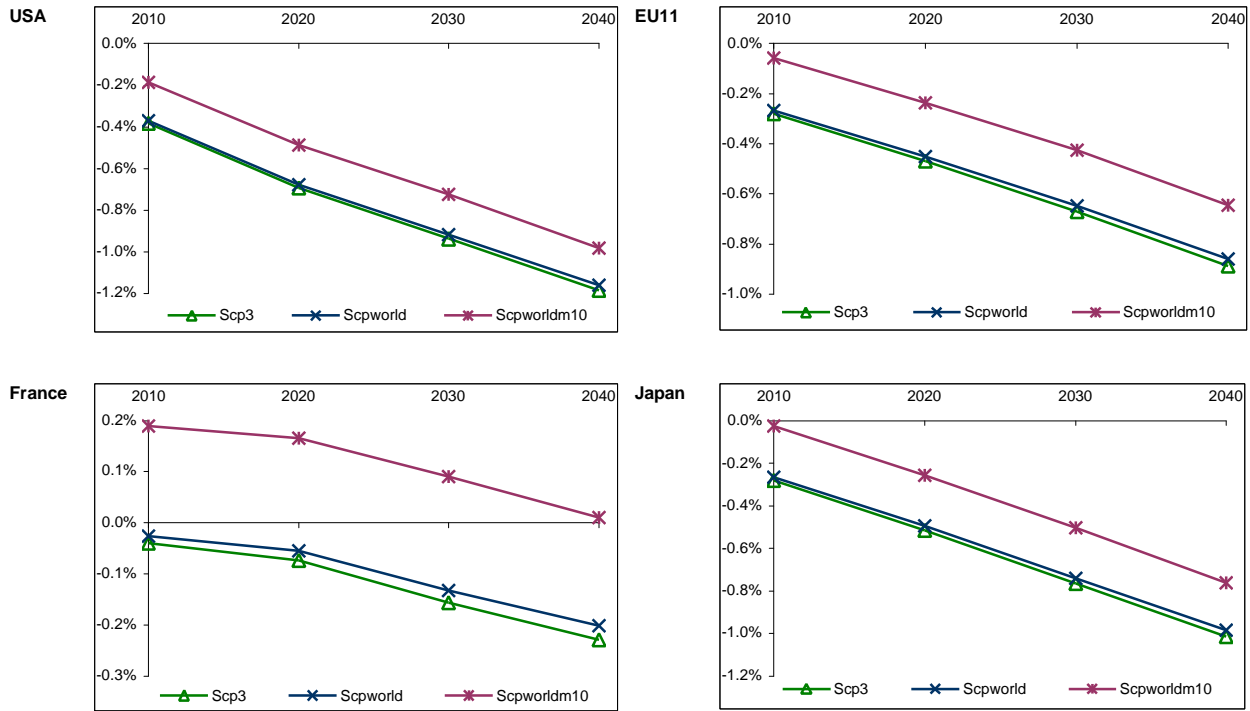
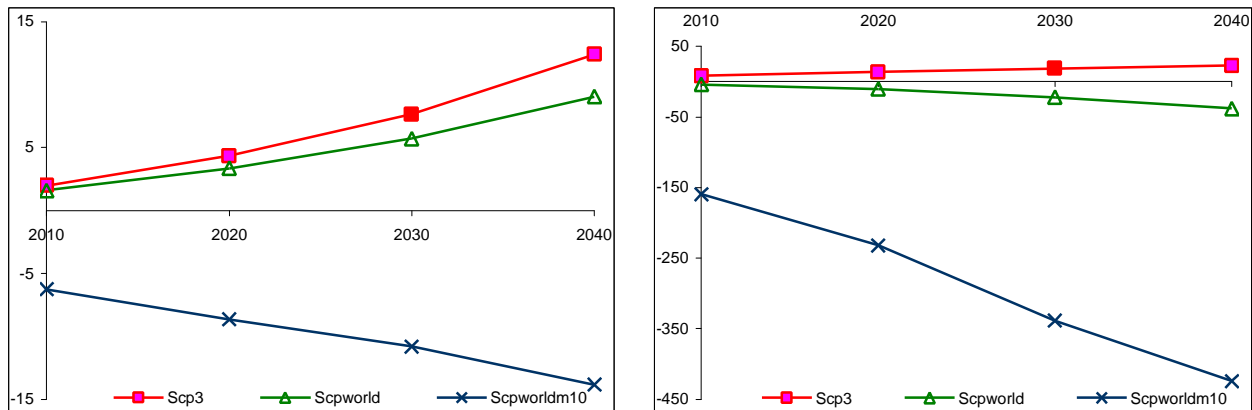


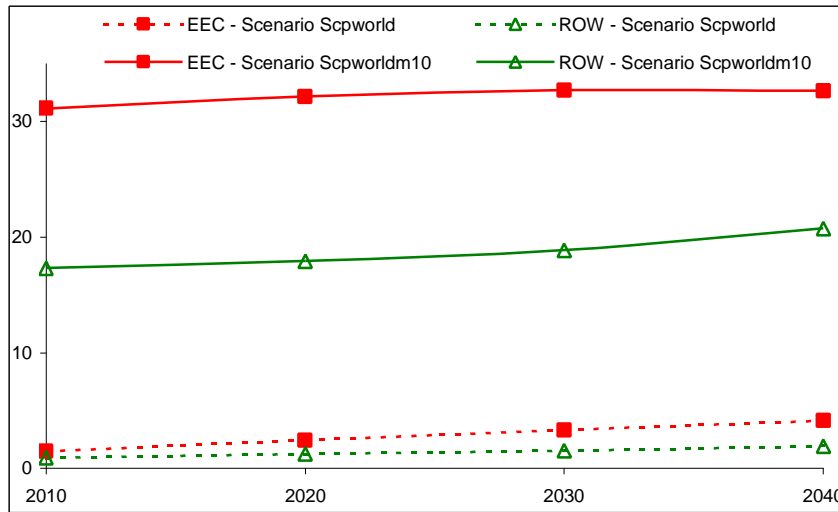
Figure 11 : Reduction of carbon emissions in E.I.S. of EEC (left) and ROW (right)
(in millions of metric tons of carbon)



III.2. Welfare cost for Annex I and non-Annex I countries

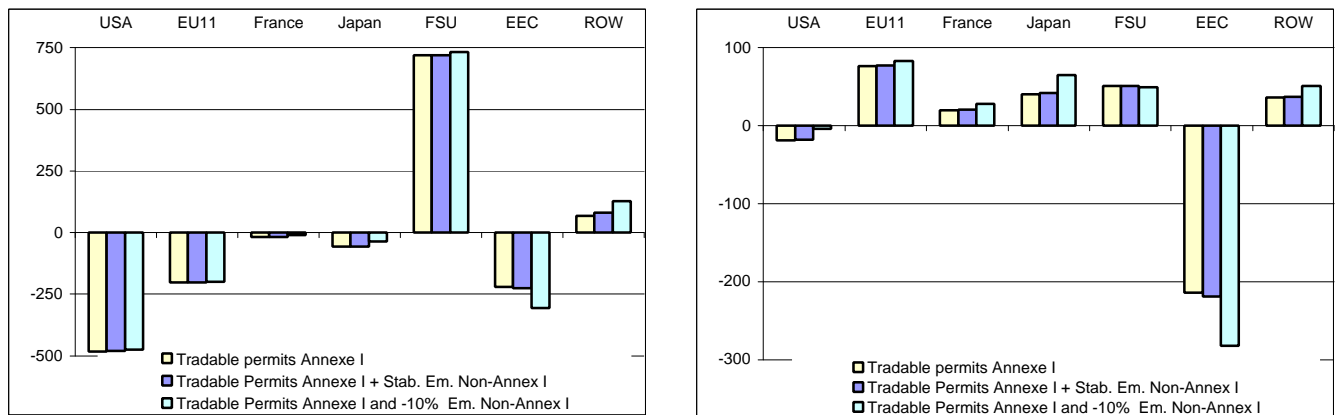
Stabilization of emissions, and even 10% abatement, do not change significantly the equilibrium price of permits for Annex I countries. Compared to it, the carbon tax applying to non-Annex I countries is small, only of a few dollars by ton of carbon in the stabilization scenario. Evolution of carbon tax is represented in the graph below.

Figure 12
Carbon tax in non-Annex I countries
(In Dollars of 1990 by metric ton of carbon)



Total welfare cost for Annex I and non-Annex I countries are represented in Figure 13. Differences from scenario *Scp3* are small, but conform to expectations: all countries/regions benefit from stabilization or abatement in non-Annex I countries, except Energy Exporting Countries which bear an additional welfare loss. The reason is terms of trade, and increased gains for energy importing countries and correlatively increased losses for exporting countries⁷.

Figure 13 : Welfare cost (left) and gains and losses from terms of trade (right)
(Present Discounted Value at 5% discount rate, in billions of 1990 US \$s)



As it already appeared in the scenarios of the previous section, the sharing of total welfare cost of climate change policies between countries is very sensitive to foreign trade and to change in

⁷ FSU, which is also a net exporter of energy, supports a decrease of gains from terms of trade, but it is compensated by in additional receipts from sales of permits.

prices of international markets. Accruing gains and losses are often much bigger than the direct welfare cost of taxation, and this explains why leakage may represent an important issue.

IV. Concluding comments and further work

Leakage, i. e. the distortion of concurrence between Annex I and non-Annex I countries underlying the Kyoto Protocol, is often presented as an important issue because it is considered as potentially responsible of significant output and employment reductions in Energy Intensive Sectors of developed countries. Moreover, some point out that the General Equilibrium Models, commonly used for assessing the Kyoto Protocol, and incorporating the so-called “Armington assumption”, underestimate the phenomenon⁸.

Sensitivity scenarios on the Armington elasticity confirm that leakage increases with substitutability in international markets of energy intensive goods, but remains of a limited extend when implementation of the Kyoto Protocol incorporates trade of permits between Annex I countries. Total world emissions of CO₂ also increase, mainly through the shifting of production in energy intensive industries from countries induced to reduce the carbon intensity of their products toward countries which do not have the same incentive.

In a long run and full employment perspective, leakage should not be an issue in itself: loss of production in energy intensive sectors would normally be compensated by gains in other sectors, and the speed of adjustment does not appear unbearable. Real issues are: on the one hand increased emissions of CO₂, which can reach 10% (in the “Tradable Permits” case) to 20% (in the “No Trade” case) and then question the political relevance of costly policies of abatement in industrialized countries; on the second hand the increased cost for Annex I countries, though the latter does not result from the distortion of concurrence or change in the structure of production but plainly from the change in the terms of trade. Effectively, higher demand for energy by non-Annex I countries gives rise to increased prices of energy in international markets and “penalizes” Annex I countries which are net importers (in fact reduces their gains from terms of trade).

Simulation of “Enlarged Kyoto” scenarios corroborate the previous results: Annex I countries would benefit –and not suffer- from a commitment by non-Annex I countries to stabilize, and a fortiori, abate their emissions. Losers would then be energy exporting countries, but this already appears in simulation of Kyoto scenarios.

Going further in the analysis would require first to consider more detailed models, with a higher disaggregation by sector, then representation of production functions which do not require to resort to the Armington assumption. Vintage production functions appear promising candidates. The challenge is not the size of such models, manageable with existing computers and software, but the availability of information and reliable statistical data

⁸ See in particular A. S. Manne and R. Richels “The Kyoto Protocol: A Cost Effective Strategy for Meeting Environmental Objectives,” *The Energy Journal*, Special Issue May 1999.