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Full Account of the Costs and Benefits of Reducing CO_2 Emissions in Transport

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1. INTRODUCTION

Among economists and policy makers more general, the fuel efficiency standard for cars and the fuel tax have been the subject of extensive debate. The major benefits of stricter fuel efficiency standards and higher fuel taxes are the reduction of Greenhouse gas emissions and the reduced oil dependence. The major costs are the increased production cost, the reduced comfort and the negative impact on mileage related externalities (congestion, accidents) due to the rebound effect.

In this contribution we use a wider framework than Harrington (2008), Plotkin (2008) and Raux (2008) to discuss the CO_2[1] emission reduction in transport. In section 2 we analyze, for the EU, the effects on welfare and CO_2 emissions of pricing all transport activities according to their full social costs. In section 3, we go beyond the transport sector and compare the options to reduce emissions in the transport sector with the possibilities and costs to reduce emissions in other sectors of the economy. In section 4 we take a world view and analyze the impact of two types of international climate negotiations on the emission reduction strategy in the transport sector.

The GHG reduction ambitions differ strongly in the world. It is normal that this translates into different CO_2 reduction policies in the transport sector. This is the first reason why this contribution focuses more on EU policies than on American policies. A second reason is that the EU has been a forerunner on high fuel taxes for cars and ambitious CO_2 reduction targets.

The EU has high fuel taxes and considers strong fuel efficiency standards. The EU has very ambitious overall GHG emission targets (up to -50% in 2030) but considers at the same time a strong reform of its transport policies, possibly moving away from fuel taxes. This raises several policy questions. First, what are the impacts of a strong reform of the transport pricing policy on overall welfare and how will this affect the overall CO_2 emission reductions? Second, if one gives up the principle of high fuel taxes in the transport sector, how will one be able to meet ambitious GHG emission targets in the economy? The first question will be dealt with by considering the transport sector globally, trading off the different modes and the different types of externalities. For the second question we put the emissions of all sectors in a country on the same basis and assess the role of the transport sector in reaching the national GHG emission target in the most efficient way.

In the second part of this contribution, we take an international cooperation view to the policies to reduce CO_2 emissions. As climate change is a world issue, the costs and benefits for any region to reduce emissions in the transport sector or in other sectors, depend in the end on whether one's effort is part of an international agreement or not. At present the EU developed a double strategy of cooperation ("tit for tat ": deep cuts in emissions if the world joins them, small efforts if they are the only ones). We look at the implications of the two scenarios for the costs and benefits of CO_2 emission reductions in the transport sector. In the same section we also pay attention to the potential of technological cooperation.

[1] We use CO2 and GHG (Greenhouse gasses) as synonyms in this text. In the transport sector, CO2 is by far the most important greenhouse gas.

In this contribution we use three types of numerical model analysis that are very different. In order not to confuse the reader, we define them briefly in Table I. The three types of modeling exercises are internally consistent. First they all use similar exogenous assumptions on economic growth and oil prices. Second, the carbon values that result from the exercise at world level and the exercise at energy sector level are of the same order of magnitude as the exogenous carbon value used in the model for the transport sector.

Table 1. Frameworks of analysis used in this contribution

Research Question	Scope	Model used
Effect on CO_2 emissions of pricing all modes of transport in function of their external costs.	Transport sector with its different modes in 2020 Carbon price is exogenous	TREMOVE-II Partial equilibrium model of the transport sector applied to EU-27+ 4 countries
What is the potential contribution of the transport sector to a cost efficient reduction of CO2 emissions in a country	All energy use in a country 2005 – 2050 Carbon price is endogenous	MARKAL-TIMES Partial equilibrium model of the energy sector , applied to Belgium
What is the expected price of CO2 emissions in different types of international agreements	World economy 2005-2050 Carbon price is endogenous	GEM-E3 General equilibrium model of the world economy

2. WHERE DOES EUROPE GO IN TERMS OF PRICING AND REGULATING EMISSIONS: MOVING FROM FUEL TAXES TO KM CHARGES

There is a long standing debate in Europe on the need to introduce new policy instruments in the transport domain. Starting with the Fair and Efficient transport pricing doctrine launched in 1998, there has been an emphasis on pricing reform that makes all modes pay their full external costs. External costs include here climate change damage, other air pollution and noise damage, accidents and external congestion costs.

This is exactly what many economists have been advocating for years and also what has been at the core of the fuel efficiency standard debate. In the fuel efficiency debate, the effects of stronger standards on the CO2 emissions but also on the mileage related externalities (accidents, congestion) were an important consideration. An important drawback of a stricter fuel efficiency standard is the rebound effect that increases congestion costs and accident costs and this is an economic efficiency loss when transport taxes do not internalize these mileage related externalities. Abolishing the fuel efficiency standard and the high fuel price and replacing them with better targeted instruments looks like the obvious way forward.

What can we expect in the larger EU, if there is a full internalization of all the external effects as economics prescribes? A recent exercise by the GRACE research consortium is probably one of the most

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complete analyses of the effects of such a policy change[2]. For 2020, the TREMOVE model was used to examine what the effects would be on emissions (CO2 and conventional) of a drastic change in pricing policy. The alternative pricing scenario is defined in Table II. The analysis is done for 31 countries (the EU – 27 + Switzerland, Norway, Turkey and Croatia).

The TREMOVE model represents the transport activities in a country as an aggregate of the activities in three types of zones: metropolitan, urban and non urban. For each zone, one represents all modes of passenger transport and freight transport. Road freight and passenger transport interact via congestion and a distinction is made between peak and off peak traffic. The preferences of passengers differ in function of the motive (professional, commuting, leisure) and choices are made taking into account preferences, money and time costs. For freight, different types of transport (unitized, bulk..) are distinguished and modal choice is a function of the time and money cost of the different alternatives. The private cost of transport consists of the price set by the suppliers (equal to the marginal resource cost if not subsidized) plus all the taxes, charges and tolls. Urban public transport supply is characterized by a Mohring effect: an increase in demand allows to improve frequencies and to reduce waiting times. The capacity of the infrastructure is represented via aggregated speed flow functions.

The model computes equilibrium on each transport market (this means for each zone) via iterations on the time costs and the demand levels. The model is calibrated such as to match an exogenous unchanged policy or “reference” scenario. Of interest is that the model computes, for a given transport equilibrium, all the external costs and all tax and charge revenues. Welfare is defined as the sum of consumer surplus, producer surplus minus total external costs plus the value of tax revenue[3]. In our case the model is used for counterfactual analysis: what is the effect on welfare of modifying taxes, charges or regulations such that they better match the different external costs?

Table 2. Scenario Description

	Cars	Trucks	Other modes
reference	Current tax system+ regulation for conventional emissions	Current fuel taxes + regulation for conventional emissions + Eurovignet	Unchanged policies
CO2 tax + km charge	Fuel tax= CO2 tax + flat km tax that covers all other externalities and that is differentiated by country and type of vehicle	CO2 tax on fuel + flat km tax that covers all other externalities and that is differentiated by country and type of vehicle	Prices cover variable costs

[2] Earlier exercises of this nature can be found in Proost, Van Dender *et al.* (2001) and ECMT –OECD (2004).

[3] The value of extra tax revenue is parameterised and depends on who pays taxes and how it is used.

In the reference scenario the main instruments to price transport are all kind of vehicle taxes, a high fuel tax plus a km charge for trucks. The investment and operation costs of public transport are heavily subsidized in some of the countries. Conventional emissions are controlled by the different EURO regulations for cars and trucks. The CO2 emissions are controlled by a "voluntary" fuel efficiency standard and it is assumed that technological progress continues to reduce average fuel consumption slightly. Most of the taxes are not connected at all to the different types of external costs. There is one exception: the fuel tax (in fact a CO2 tax) is twice as large as the climate change damage (by assumption equal to 80 Euro/ ton of CO2). Overall user prices for most modes are too low, even the variable public transport prices are heavily subsidized.

Figures 1 and 2 show the mismatch between current taxes and external costs for passengers and for freight transport by mode. Both figures represent averages for the EU-27+4 in the reference scenario. Figure 1 shows that air transport does not pay its marginal external costs (noise, air pollution): the left column is larger than the right column (here 0). The high fuel tax and other car taxes are on average insufficient to cover the marginal external costs of car use. Passenger rail generates also external costs but its variable costs are subsidized so that the tax column becomes negative. Figure 2 gives a general picture of the external costs and current taxes for different freight transport modes. On average the charges and taxes for IWW (inland waterways), large trucks and rail freight do not cover their marginal external costs.

Figure 1. Marginal external costs compared to taxes for 2020 – passenger transportation in Reference scenario

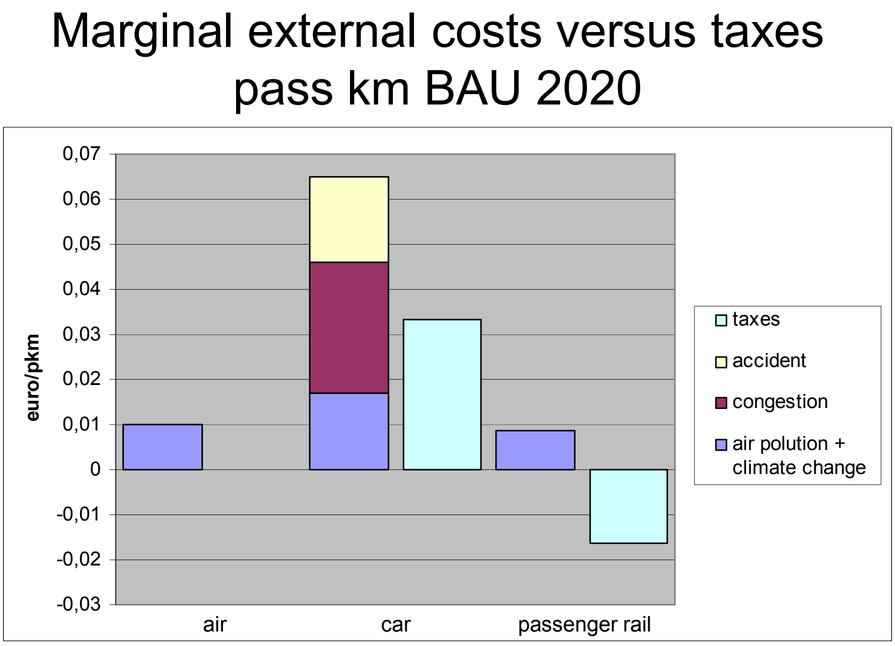
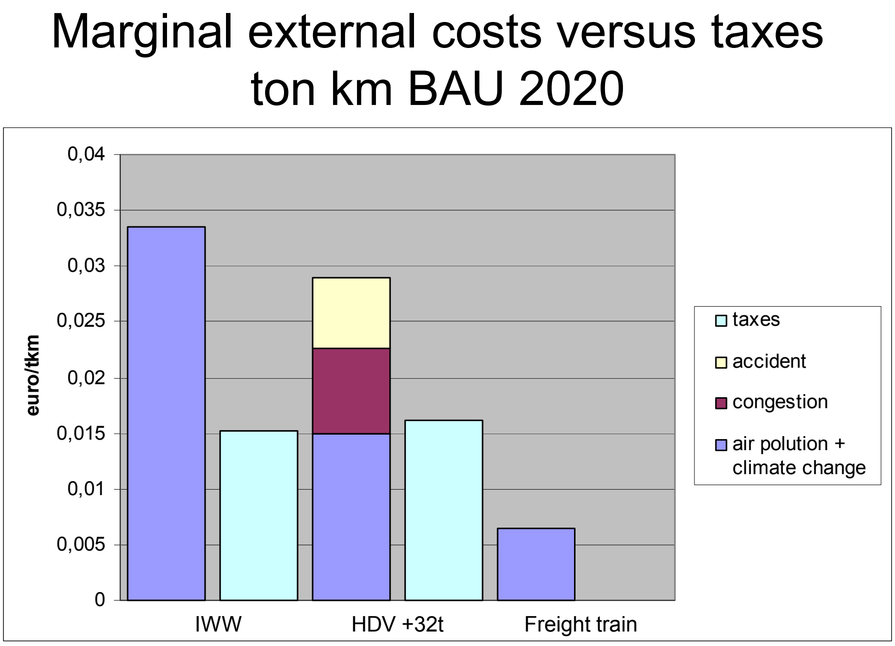


Figure 2. Marginal external costs compared to taxes for 2020 – freight transportation in Reference scenario



In the alternative scenario (CO_2 tax+flat km charge), the effects of a combination of lower fuel taxes and km charges (differentiated by type of vehicle and country) are simulated such that all modes pay approximately their marginal social cost. This implies a fuel tax that is only half of that in the reference scenario but a flat high km-charge that is differentiated by country and by type of vehicle[4].

The results are summarized in Table III. A reform of the price system away from the current high fuel charges to more targeted taxes per mile with country and vehicle differentiation generates important extra revenues and an important gain in welfare. Fuel taxes decrease but the km charges for car use are strongly increased to match the congestion, accident and air pollution costs. For public transport, subsidies on operation costs are abolished and this leads to an overall price increase that can be strong in some countries. The final result is a decrease of the volume of passenger transportation of 11.5% compared to the reference. The decrease of the volume of car transport is even lower because public transport increases in price. The type of car also changes: away from large and medium diesel cars who had an unjustified fuel cost advantage due to the high fuel prices in the reference to medium to large gasoline cars. For freight transport, similar decreases are expected.

Tax revenues (including all subsidies to public transport) increase strongly (by 3.1% of GDP) and welfare increases by some 1.2% of GDP[5]. The major benefits come from a reduction of accident

[4] We presents here results for a flat km charge. A better policy would be to differentiate the km charge in some countries by region, time of day and type of road. This gives higher welfare results but average tax levels that are similar and CO2 emissions that are of the same order.

[5] Welfare is here a simple sum of gains and losses for all groups in society. If one wants to pay attention to the distribution of income aspects, it is best to do this via the use of revenues and not by interfering in the efficient pricing. See Proost &Van Regemorter (1995) and Mayeres & Proost (2001) for illustrations on carbon policies and transport pricing.

externalities and congestion. The total emissions of CO2 decrease by 12.2% and this despite the strong reduction of the fuel excises. This is due to two effects. First there is the overall reduction in volume of transportation. Second there is the small effect of lower fuel taxes on the types of cars that are bought. In the model there is a strong technological lock-in and although people would buy larger cars, the European car stock does not start to look like the US fleet. The model may underestimate this effect in purchasing behavior.

Table 3. Effects of pricing the transport modes more correctly

2020 – difference with Reference	Revenue	Overall welfare	Total Environmental damage	GHG emission damage
Difference in % of GDP	+3.1%	+1.2%	-0.22%	- 0.054%
	Passenger km on road	Total pass km	Ton km on road	Total ton km
% difference	-8.6%	-11.5%	-10.1%	-11.0%

In conclusion, pricing all externalities in the transport sector can be done more efficiently by using a combination of low fuel taxes and km charges where the latter charges can be differentiated by vehicle type and country. This allows important welfare gains and does lead to a small "no regret" reduction of CO2 emissions compared to the reference.

3. THE CONTRIBUTION OF THE TRANSPORT SECTOR IN REACHING THE NATIONAL EMISSION CAP: AN ENERGY TECHNOLOGY APPROACH

How far one should push the GHG reduction efforts in the transport sector can be analyzed in two ways. One can take an exogenous national benchmark marginal cost level in Euro per ton of CO2 and check what policies have a lower cost per ton of CO2 reduction. This gives a potential of CO2 emissions that can be reduced at a cost lower than the threshold value. In section 1 this procedure was used to judge the effects of alternative pricing policies in the transport sector: all measures that generate CO2 emissions at a cost below the threshold are in principle taken and increase the welfare level.

The national benchmark cost level is ideally the result of a broader analysis comparing the possibilities to reduce the emissions in all sectors including transportation. The outcome is then an efficient allocation of emissions over sectors like the transport sector, the residential sector, the electricity generation sector etc.. In this section we take this broader view, analyzing all sources of CO2 emissions in an economy and comparing them on the same basis.

We use the MARKAL-TIMES model[6] for this analysis. This model describes all energy transformation and use in an economy, from the import of fuel to the delivery of energy services (car km, heated homes etc.). The demand functions for energy services are given by expected sector activity growth rates (say steel production or passenger car km) and household incomes. The energy services (passenger car km or process heat for steel making) are then produced in the most cost effective way, combining demand side technologies (more energy efficient light bulbs, more efficient car engines etc.) and supply side technologies (better power stations or refineries). In this way one is able to simulate the potential role of new technologies in the energy supply and demand in a sector. This can be seen as a two step procedure. In the first step one minimizes the total system cost of satisfying a given demand for energy services. In the second step, one compares the marginal cost of satisfying this level of energy services with the willingness to pay of the user (household or firm) for the energy services. When the marginal cost of supplying a given level of energy services becomes very high, it is cheaper for the household or firm to reduce their demand for services by foregoing the trip or by substituting the energy services by other production factors.

One useful feature of the model is that one can add a national emission cap[7]. The model generates then the most cost efficient way of satisfying the national emission cap. This means specifying what combination of technologies and activity levels for energy use minimizes the overall system cost of satisfying this absolute cap.

Important inputs in any model exercise of this type are the expected growth rate of economic activities and their translation into energy service levels. A GDP growth rate of some 2% is used and crude oil prices double between 2000 and 2020. Also transport demand is assumed to increase at some 2% per year. Important assumptions for the transport sector are that fuel efficiency of new traditional gasoline and diesel cars is assumed to improve by 15% in 2030 compared to 2005. Also all new technologies (hybrid, electric, hydrogen) can be chosen from 2010 onwards except the hydrogen fuel cell that is only made available from 2030 onwards.

We consider national CO2 reduction scenarios for Belgium that aim to reduce emissions drastically in the long term as shown in Table IV. Compared to emissions of 1990[8], a reduction of emissions with 20% (in 2020) up to 52.5% (in 2050) is required. These reductions are even more impressive when they are compared with a reference case where, in the absence of climate policy, emissions would have grown by some 15% in 2020 compared to 1990 and by some 50% in 2050. Moreover we assume that the nuclear power stations (that still produce more than 50% of electricity production in Belgium in 2005) are all phased out in 2030 and that no international permit trade is possible. This is the most stringent scenario in terms of CO2 reductions and it is chosen precisely to examine the role of the transport sector in overall emission reductions in the most demanding case.

[6] MARKAL-TIMES is a model that has initially been developed within an IEA implementing agreement since 1981. The Belgian version has been developed by CES-KULeuven and VITO with funding of the Belgian Science Policy Office. We use here the results of Nijs and Van Regemorter (2007).

[7] This cap can be combined with an international emission price.

[8] 1990 is used as reference year in most Climate Change negotiations.

Table 4. Cap on national CO2 emissions

	2010	2020	2030	2050
% reduction required compared to 1990 emissions	- 7.5%	-20%	-30%	-52.5%
% reduction compared to reference scenario without climate policy	-18%	-30%	-59 %	-76%

The point of this modeling exercise is to know what is the cost effective use of different technologies and activity reductions that achieves the CO2 emission objective at the lowest cost for the national economy. More specifically what is the role of the transport sector in this cost effective strategy?

Table V reports on the role of the transport sector in the reduction of CO2 emissions given the climate objectives of Table IV. The first line of Table V reports the marginal cost of CO2 reductions in this ambitious emission reduction scenario. The marginal cost is the shadow price of the maximum emission constraint and tells us what is the marginal welfare cost[9] for the Belgian energy system of having to reduce emissions by one more ton. This marginal cost can be the basis to consider international trading of emission rights. The marginal costs obtained are reasonable up to the period 2020–2030 but are clearly very high in 2050 and this despite all new energy saving and renewable technologies foreseen beyond 2030. The main reason why this scenario is very demanding for Belgium is the simultaneous strong reduction of total CO2 emission reductions and the nuclear phase out in the absence of carbon trading.

The second line reports the ideal reduction of the CO2 emissions in the transport sector that is expected when all sectors are treated on the same least cost basis. The expected reduction from the transport sector is very moderate (-1 % in 2010 to -17% in 2020) and much smaller than the overall reduction needed for the country (-18% in 2010 to -59% in 2020). This shows that the same proportional reduction of emissions over all sectors is not at all cost minimizing. In addition this scenario shows that a strong reduction of emissions is technologically and economically feasible without requiring large efforts from the transport sector. In 2050 one attains a limiting case where the reduction of emissions is pushed to its extremes. In this case the emissions of the transport sector have to be reduced by 48% compared to an overall effort of 76%. In the latter case one has to resort to really new technologies.

Emission reductions usually require a combination of a reduction of specific emissions by using better technologies and a reduction of the level of activity (vkm, tkm in transport sector). The two last lines of Table V show that the major reduction effort comes via adaptation of fuels and technologies rather than via a reduction of activity. The volume of car traffic and truck traffic are hardly affected.

[9] The avoided climate change damage is not counted in the welfare cost.

Table 5. Role of transport sector in reduction of CO2 emissions in Belgium

Years	2010	2020	2050
Marginal cost of CO2 reduction (Euro/ton)	31	68	531
% reduction of emissions in transport sector compared to reference scenario	-1%	-17%	-48%
% reduction of emissions for the country	-18%	-59%	-76%
% reduction of activity for car transport	0%	0%	0%
% reduction of activity for truck transport	-2%	-5%	-5%

It is interesting to see what technologies are used in the transport sector to respond to very strong CO2 emission reductions targets. We find that, starting in 2020, the major change is the use of alternative fuels in conventional engines: CNG (compressed natural gas) in conventional combustion engines, ethanol and biodiesel. Many technologies are not cost effective when they are placed in a fair comparison with traditional technologies. The gasoline and diesel parallel hybrid sytems are higher fuel efficient but this fuel efficiency comes at a very high cost. The same holds for electric technologies: they never penetrate because the electricity needs to be produced using conventional gas power stations because the nuclear power option is excluded and renewables reach quickly their potential. Table VI reports the percentage decrease in investment cost that is needed for the penetration of some of the new car technologies in the strong emission reduction scenario that is simulated here. As an example, take the hydrogen combustion car: its investment cost needs to decrease by 56 to 59% to make this technology viable as a carbon emission saving technology.

Table 6. Reduction in investment costs needed to make a particular technology cost effective in a CO2 reduction scenario.

	2020	2030	2040
Biodiesel	21%	13%	0%
Hydrogen.Combustion	56%	59%	45%
Diesel.EURO4	1%	1%	7%
Electric.Battery	41%	146%	163%
Hydrogen.FuelCell	58%	29%	20%
Hydrogen.Hybrid.FuelCell	59%	34%	25%
Gasoline.CNG	3%	0%	0%
Gasoline.EURO4	0%	0%	7%
Diesel .EURO4.parallelhybrid	18%	17%	20%
Gasoline.CNG.parallelhybrid	13%	8%	4%
Gasoline.EURO4.parallelhybrid	6%	3%	1%
Hydrogen.Hybrid.Combustion	57%	63%	49%

In conclusion we find that the share of the transport sector in reducing the CO2 emissions is small in a cost effective reduction scenario. It is technologically feasible and cost effective to reach strong emission reductions (-30 to -50%) by reducing emissions strongly in other sectors than transport. When one focuses really on CO2 emissions, technologies like CNG may be more promising than fuel efficiency standards, hybrid cars or electric cars.

4. ROLE OF CO_2 EMISSION REGULATION IN THE TRANSPORT SECTOR: A WORLD VIEW

As climate change is a world issue, the costs and benefits for any region depend in the end on whether one's effort is part of an international agreement or not. CO2 emissions of one country generate climate damage (or benefits) in the whole world. Whenever one considers the benefits of emission reductions, the benefits for the EU or the USA are only a fraction (20 or 30%) of the world benefits of an emission reduction.

The reduction of emissions in the transport sector in any country is motivated by the position that country takes in the international climate negotiations. If the country only takes into account the damage avoided in its own country (a non cooperative attitude) it will make a much smaller effort than when its efforts are part of a larger international agreement (the cooperative attitude).

We know from economics that reaching a large stable coalition to reduce emissions is very difficult. Barrett (1994) showed with a simple model that the equilibrium number of signatories of an international agreement for a problem of the climate change category is small. In some of his stylized examples only 3 out of 100 equal countries would sign. The main problem is that international agreements have to be self enforcing: a country signing a climate treaty should be as well as off as when it would not sign the treaty because no international law can force a country to observe a signed international agreement. More favorable outcomes are possible when one takes into account that countries play this game repeatedly and when countries are of unequal size

Given our interest in the CO2 emissions in the transport sector, there are two international cooperation issues that need our attention. The first is the possibility of an international agreement to reduce emissions and the associated word wide trading of emissions that limits the costs of emission reductions. What are the likely impacts on carbon prices and what implications does this have on carbon policies in the transport sector? The second issue is the option to have international cooperation focusing on the development and adoption of breakthrough technologies in the car sector that limit drastically emissions and fuel use.

4.1. International climate negotiations and its impact on transport emission reduction strategy

The EU has decided to reduce emissions of GHG by 20% in 2020 and even by 30% in 2030 (compared to 1990) if the other big emitters of GHG join them. The EU starts with a cooperative attitude in the hope that the other important players realize that this is also in their interest. It is difficult to assess the chances of success for this strategy. It is important to also assess the fallback strategy of the EU. If other big players do not follow, the EU wants to go, unilaterally, for smaller emission reductions.

The effects of both strategies on total emissions, economic costs, trade in emissions and price of carbon have been assessed using the GEM-E3 model (Capros et al, 1997,[10]). GEM-E3 is a world general

[10] Model results of D.Van Regemorter obtained in May 2007.

equilibrium model that represents the economic activity in the world using a disaggregation in 18 groups of countries and 18 sectors. There is trade in products but also trade in emission rights.

The “cooperative” scenario (with efforts by all important players) and the unilateral EU scenario (only efforts by the EU) are compared with the reference scenario where the world economy grows by some 2.5 to 3% per year and where there are no specific CO2 emission reduction efforts.

Table 7. Costs and emission reductions of two EU climate change negotiation strategies

	Cooperative scenario				Unilateral EU scenario	
	2020		2030		2020	
% change compared to baseline with no reduction efforts	Economic cost	Emission GHG	Economic cost	Emission GHG	Economic cost	Emission GHG
USA	-1.4%	-39.5%	-3.4%	-52.4%	0.0%	0.0%
EU27	-2.3%	-28.1%	-5.7%	-41.6%	-0.2%	-5.8%
Brezil	-0.3%	-4,8%	-1.5%	-15.0%	0.0%	0.1%
India	-0.9%	-0.6%	-1.6%	-23.3%	0.0%	0.0%
China	+0.3%	-25.9%	-0.8%	-32.8%	0.1%	-15.2%
World total	-1.2%	-25.9%	-3.4%	-37.2%	0.0%	-3.6%
Price of carbon (US$/ton CO2eq)		45		93		6

In the cooperative scenario it is assumed that the EU and the US promise each a reduction of 30% in 2020 with respect to 1990, in 2030 the reduction effort would reach -55%. The emission reduction can also be achieved by buying emission reductions in other countries that participate in the agreement. These other countries are China, India and Latin-America. These countries commit themselves in this scenario to limit the emissions per unit of output. Independently of the trade in emissions, China promises to limit its emissions by 12.5% compared to the reference emission levels. Because China can reduce emissions more cheaply than the EU and the US, this is an important component of a cooperative agreement. It is mainly China and India that sell emission rights to the US and EU. The EU27 reduce their emissions by only 41.6% in 2030 but buy the remaining emission reductions in China and India (13.6% = 55% total effort for EU -41.6% effort internal in the EU). With efficient trading all over the world, this scenario will, in 2020, only cost 1.2% of economic welfare for the world (before counting the benefits of reduced climate change). Costs for the EU (-2.3%) are larger because they start from a lower level of emissions than the US and the rest of the world (except Japan).

The climate change benefits of this scenario are more uncertain than the costs but the objective is to limit global warming to 2 C° (CEC 2007, IPCC, Stern Report). This is achieved with the worldwide reduction of emissions of 37.5% in 2030 (see last line of Table VII).

Important for the emission reduction strategy in the transport sector, is the marginal cost of CO2 reduction at world level. This carbon price would grow from 45 US$/ton of carbon in 2020 to 93 US$/ton in 2030 (last line of Table VII). These are the orders of magnitude used in section 1 and section 2 (Table VI) to assess the cost efficiency of emission reduction efforts in the transport sector. Given the results of the TREMOVE modeling exercise, this suggests that, taking a world point of view, there is no need to push the saving of CO2 emissions in the transport sector.

Whenever the rest of the world does not follow the initiative of the EU to join them in an agreement that reduces emissions strongly, we end up in the unilateral EU scenario[11]. In this scenario, the EU is the only one to make strong reduction commitments. It promises a reduction at 20% in 2020. Because the other big players do not commit to any effort, it is in the interest of the EU to make an agreement with China to buy cheap emission reductions. The result is that the 20% reduction of emissions is mainly achieved by efforts in China. Table VII (last column), shows how the -20% reduction in the EU means a reduction of emissions at home of 5.8% compared to the baseline and a reduction in China of 15.2%. The overall emission reduction in the world is limited to 3.6% only - a tiny result compared to the 25.9% reduction achieved in 2020 in the cooperative scenario. In this case the carbon price drops to 6 $/ ton of CO2 because the required emission reduction is low.

The implication for transport emission reductions of this unilateral scenario is that despite the cut in emissions proposed by the EU, the efforts expected from the transport sector in the EU are almost nil.

Only the future can tell whether the world will ever cooperate seriously to reduce CO2 emissions. Even if it goes for very ambitious reductions, the role for the transport sector in achieving cost-effective emission reduction will be very limited in the next 20 to 30 years, certainly if international trading of emissions is in place.

Theoretically the EU is faced with an emission reduction target that is uncertain: the value of an emission reduction varies between 6 $ and 45 $ (2020) to 93 $ (2030) per ton of CO2. Only when the EU learns more about the attitude of the other players can it determine definitely its policy. The general information about the climate change puzzle will also be updated regularly. This type of uncertainty together with the rather flat shape of the damage function for CO2 emissions pleads for the use of a flexible price instrument rather than for a more rigid quantity based instrument: CO2 taxes under the form of fuel taxes would therefore be preferred to fuel efficiency standards.

4.2. International agreements on fuel efficiency standards

One alternative approach to an international agreement that puts caps on the emissions of different countries is an agreement where a number of countries promise to cooperate in the development of a new very carbon efficient sectoral technology and promise to use it once it is there. This could be a car technology (hydrogen, breakthrough in traditional engine technology).

Can this type of agreement work and what are the implications for current policy? Barrett (2006) used a small theoretical model with identical countries to give some intuition for this problem. Because the benefit of R&D funding depends on the number of adopters, one needs to solve first the question of the adopters before the R&D funding problem.

Countries would only adopt a breakthrough technology if the country's own extra benefit of adopting the new technology outweighs the extra operation and investment cost of the new technology. The development costs are considered as sunk costs once the technology is there. The net benefit is mainly the reduction in climate change damage for the country itself and this depends on the number of adopters. The

[11] In fact, in a non-cooperative scenario, every country will make small efforts until its marginal costs equal the marginal damage in their own country. This gives rise to emission reductions that are anyway small (less than 20% of the cooperative level). See Eyckmans et al (1993).

final result is that the equilibrium number of adopters will be limited when the gains of cooperation are largest. There is one exception however. If there are increasing returns of adoption (learning by doing), the equilibrium number of signatories may be much higher.

Let us turn to the R&D funding part of the international agreement. The benefit for a country of investing in R&D equals the expected avoided climate change damage. This avoided climate damage increases with the number of adopters. As long as the number of adopters is small, the national gains of an R&D funding agreement will be small. Only when there are important economics of scale in adoption can these technological treaties be successful.

Returning to the transport sector, is international R&D cooperation on the development of super fuel efficient vehicles a priority? Two reasons mitigating our entousiasm are that first, present car companies are already integrated world wide and make use of possible returns to scale and second, carbon is already highly taxed in the case of car fuel. A reason in favour of this cooperation is the existence of important economics of scale in adoption.

4.3. Spillovers of national fuel efficiency standards

Harrington et al.(1998) explored the economics of emission standards in a federal setting where California would set stricter standards for conventional pollutants than the rest of the US. They find that extending the stricter standard to the rest of the US would clearly benefit California via economies of scale in car production. The benefits in terms of pollution reduction outside California would probably be too small to make this generalization cost efficient. In the case of CO2, it is in the interest of a single country or region to lobby even more for a national adoption because every region benefits from the reduced climate damage.

More limited spillovers of national fuel efficiency standards are possible in the absence of international agreements. Barla & Proost (2007) show that fuel efficiency standards can have a role in parallel with fuel taxes when the car producing country (or dominant consuming country) is concerned with the damage of fuel use and when there is only one type of car on the market. The car producing country can control emissions at home via a fuel tax but can only control emissions abroad via the car design. This type of indirect policy to limit emissions abroad will only give rise to an important reduction of emissions abroad if the production country is relatively large because then it will reap a large share of the benefits.

5. CONCLUSIONS AND CAVEATS

This paper has analyzed the role of emission reductions in the transport sector sing a wider framework. First, it was shown how a global reform of transport pricing geared to internalizing all external costs of transport leads to lower fuel taxes but higher km charges. The final result is a reduction of transport volumes and emissions of CO2 in the transport sector as an important byproduct.

Second, it was demonstrated that an industrialized economy that wants to reduce its emissions of GHG at lowest cost, has more cost efficient options to reduce CO2 emissions in other sectors than the

transport sector. This holds even for very ambitious national targets (30 to 50%), reduction of emissions in the transport sector is almost never a cost effective option.
Thirdly, the main advantage of reducing GHG emissions is the reduced damage worldwide. If countries are not able to make a self enforcing climate change agreement, the benefit for each country to reduce emissions in the transport sector (or in any other sector) becomes very small.

International cooperation to adopt and to develop a super fuel efficient car technology has some appeal because there are economies of scale in adoption. On the other hand one starts with carbon that is already very highly taxed in the transport sector and the production of cars benefits already from strong economics of scale internationally.

This is an analysis far in the future on a very global scale requiring many assumptions. One underdeveloped aspect in our analysis is oil market uncertainty. This raises two issues: first the level of the oil price, second the gains of cooperation for oil importing countries. The oil price scenario that has been used is one of moderate increase. A much higher oil price (beyond 100 $/bbl would at first sight reduce the need for specific GHG reduction policies. When one takes into account the potential substitution by more CO2 intensive substitutes like synfuels based on coal, high oil prices do not necessarily solve the climate change issues. When we discussed the gains of a reduction of fuel use in the transport sector we did not consider the monopsony gains of the oil importers. They exist but are less important than the GHG reduction benefits, their magnitude will depend on the precise fuel reduction policy that is adopted as this is a repeated game with the oil exporters (Liski and Tahvonen (2004)).

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