Evaluating the impact of standards and fiscal policies on CO_2 emissions of cars in Europe

Amela Ajanovic, Vienna University of Technology, Affiliation, Vienna, Austria
Reinhard Haas, Vienna University of Technology, Vienna, Austria

Abstract

The already applied measures such as voluntary agreements between car manufactures and energy labeling for a new cars have not shown sufficient reduction of greenhouse gas emissions. More rigorous options are mandatory standards and taxes. Standards should reduce the average fuel intensity of a car fleet. Fiscal policy measures like taxes can force car users to change behavior – to reduce travel activity, to buy smaller cars with higher energy efficiency or to switch to other transport modes if possible.

The core objectives of this paper are: (i) to provide surveys on standards and fiscal policies for car passenger transport in EU countries; (ii) to provide a formal framework that links consumers decision making processes with technical and economic aspects of service demand (this framework allows analysis of the impact of standards and fiscal policies on energy consumption and CO_2 emissions); (iii) to identify the crucial impact parameters in this formal framework; and (iv) to discuss and interpret the magnitude of these impact parameters on the effectiveness of policies.

The major conclusions from this analysis are: (i) The intended introduction of standards as announced by the EU will not lead to the theoretically possible energy savings and CO_2-reduction due to the rebound effect; (ii) The standards and fuel taxes are linked via the service price elasticity. The magnitude of the service price elasticity defines which instrument is more effective; (iii) A combined tax-standard policy could lead to a win-win situation from which the environment benefits and car drivers are not hurt; (iv) Another finding is that the introduction of a registration tax is in principle the same as the introduction of a standard and leads to the same rebound problems.

Introduction

Road transport which is primarily based on fossil energy is after power generation, the second biggest source of greenhouse gas emissions (GHG) in the EU. It contributes about one-fifth of the EU's total emissions of carbon dioxide (CO_2). Emissions from road transport were continuously increasing over the last twenty years (EU, 2014), see Figure 1.

The largest part of the total GHG emissions of road transport is caused by passenger cars. Although fuel efficiency of passenger cars has been significantly improved in the last decade, trends toward more powerful vehicles and additional services in cars have reduced impact of fuel efficiency improvements. At the same time vehicle ownership level is continuously increasing in all EU countries.

In the past the emission reduction policy in the EU was mostly based on CO_2 emissions standards and fiscal policy measures. However, the applied policy measures - in the first line voluntary agreements between car manufactures and energy labeling for a new cars - have not stopped increase in GHG emissions in road transport, see Figure 1. Since targets for the emission reduction were not achieved on time more rigorous options - mandatory standards and higher taxes – have been implemented in the last years. Standards could reduce the average fuel intensity of a car fleet. Fiscal policy measures like taxes can encourage car users to change behavior – to reduce travel activity, to buy smaller cars with higher energy efficiency or to switch to other transport modes if possible.

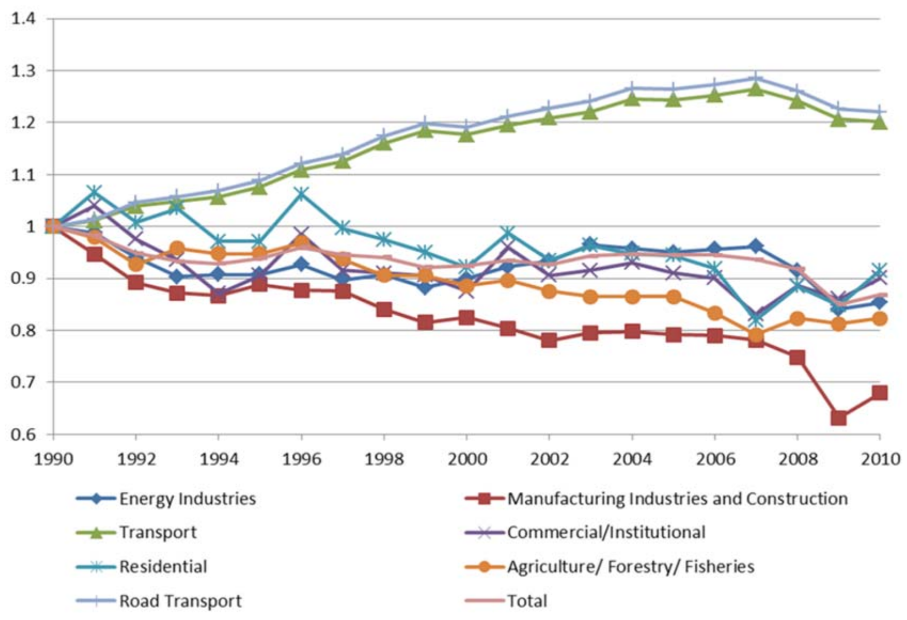

Figure 1. GHG emissions (1990=1) (Eurostat, 2013)

The core objectives of this paper are: (i) to provide surveys on standards and fiscal policies for car passenger transport in EU countries; (ii) to provide a formal framework that links consumers decision making processes with technical and economic aspects of service demand (this framework allows analyze of the impact of standards and fiscal policies on energy consumption and CO_2 emissions); (iii) to identify the crucial impact parameters in this formal framework; and (iv) to discuss and interpret the magnitude of these impact parameters on the effectiveness of policies.

Survey on currently implemented policies

For the reduction of CO_2 emissions from passenger cars a very broad portfolio of policy measures have been implemented across EU countries. Currently mostly used policy measures are standards and fiscal policies. Standards for CO_2 emissions of new cars are set on the EU level and are same for all Member States, fiscal policy measures are determined at the national level, and they are very different across the EU. Mostly used fiscal measures are fuel tax, car registration tax and car annual ownership tax.

In this paper special focus is put on fuel taxes, registration taxes and CO_2 standards.

Fiscal policy measures

Due to different national goals, implemented fiscal policy measures are very different across the EU. The most common taxes are fuel tax, Value Added Tax (VAT), registration taxes and annual ownership taxes. However, the criteria for these taxes are very different.

Figure 2 shows composition of gasoline prices including taxes for different EU countries in 2013. In the shown countries the VAT is in the range from 19% (Germany) to 25% (Sweden and Denmark), and total tax on gasoline is in the range from 47% (Spain) to 61% (Finland). A similar situation is with diesel, but the tax on diesel is slightly lower, in range between 42% and 57%.

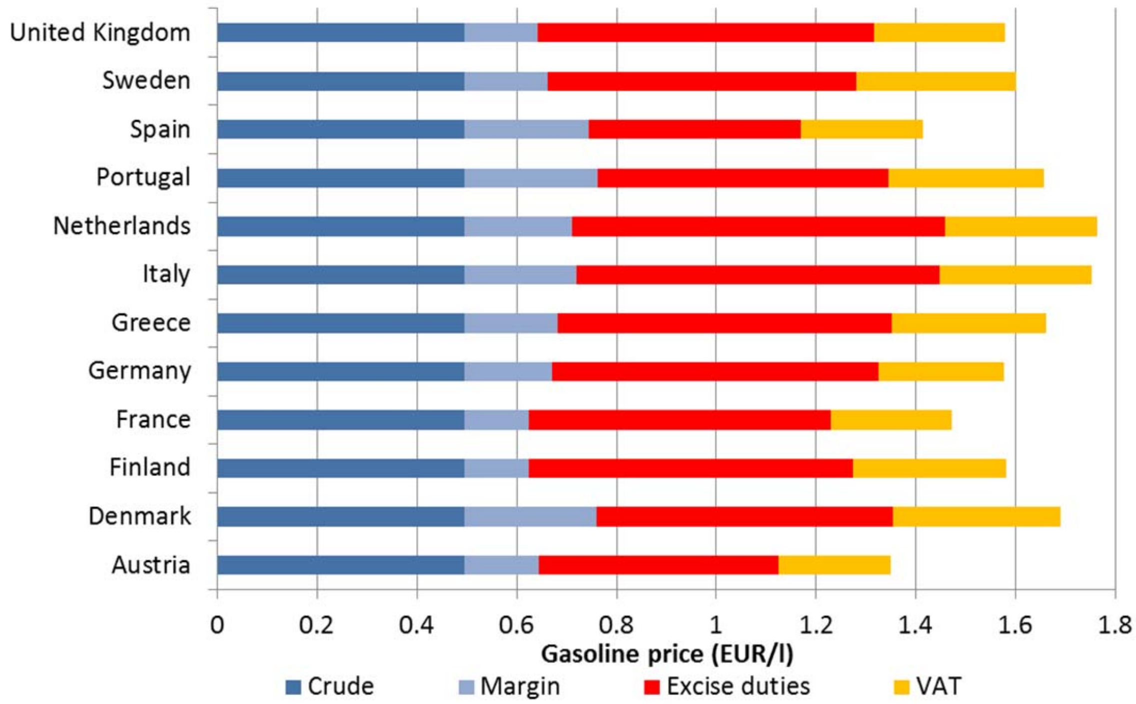

Figure 2. Composition of gasoline prices including taxes in 2013 (EEP, 2013)

Different criteria for registration- and ownership tax in EU countries are shown in Table 1. A registration tax is tax paid once, by each vehicle owner, for each vehicle purchased and entered into service. It is usually based on CO_2 emissions, cylinder capacity, car price, fuel consumption and power or weight of car. In the most of countries two different criteria are combined. However, there are also countries without registration taxes such as Germany, Sweden and United Kingdom. Annual ownership tax is paid annually, regardless of how often the vehicle is used. In the case of passenger cars this tax is mostly based on CO_2 emissions, weight, cylinder capacity, power and fuel consumption. Also this tax is not applied in all countries (e.g. France).

Table 1. Criteria for a taxes on acquisition and ownership (data source: ACEA, 2013) Status: 1 January 2013

Registration tax based on:		**Ownership tax based on:**	
Fuel consumption	AT	**Fuel consumption**	DK
Car price	FI,NL	**Weight**	DK,FI,NL,SE
CO_2 emissions	FI,FR,NL,PT,ES	**CO_2 emissions**	FI,DE,GR,NL,PT,SE,UK
Cylinder capacity	GR,PT	**Cylinder capacity**	GR,PT,UK
Kilowatt/weight/seats	IT	**Kilowatt**	AT,IT
None	DE,SE,UK	**None**	FR

Contrary to a fuel tax which could have an impact on the short-term driving behavior (e.g. travel activity), registration tax can impact the choice of cars.

Standards

Important measures for the reduction of emissions in the EU are standards for CO_2 emissions from new passenger cars. The EU Regulation (EC, 2009) on passenger cars is directly applicable in all Member States and does not need to be transposed into national law through national legal instruments. According to the Regulation average CO_2 emissions from cars should not exceed 130 grams CO_2 per km by 2015 and should drop further to 95g/km by 2020. The 130 grams target will be phased in between 2012 and 2015 (EU, 2014). The evaluation of CO_2 emissions from new passenger cars by association is shown in Figure 3 as well as the commitments undertaken by the European (ACEA), Japanese (JAMA) and Korean (KAMA) car manufacturer associations related to the average new car emission targets.

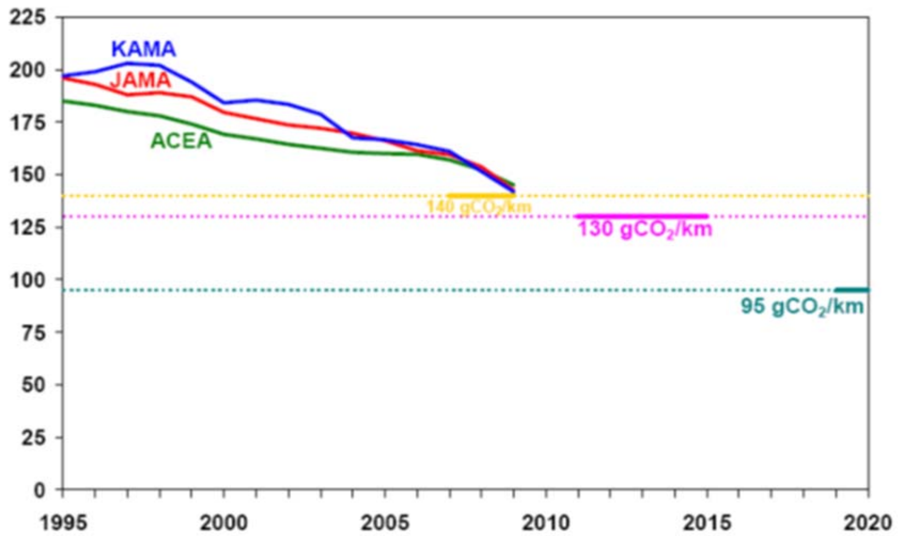

Figure 3. Evolution of CO_2 emissions from new passenger cars by association

The first agreements with car manufactures have been voluntary agreements. Since the target of 140 gCO_2/km for 2008 was not met on time (the average for the whole car market for 2008 was 153.7 g/km (Wikipedia, 2014), in 2009 the first mandatory CO_2 emission standards for cars were adopted in the EU (de Wilde/Kroon, 2013).

In practice this means that each manufacturer gets an individual annual target based on the average mass of all its new cars registered in the EU in a given year. Since only the fleet average is regulated, manufacturers are able to produce cars with emissions above their indicative targets if these are offset by other cars which are below their indicative targets. Indicative emissions are established for each car according to its mass on the basis of the emissions limit value curve. This curve is set in a way that a fleet average of 130 grams of CO_2 per km is achieved for the EU as a whole (EU, 2014). The limit value curve for the 2015 target is calculated using following equation:

$$CO_{2\_SP} = 130 + \alpha \cdot (M - M_0) \quad (1)$$

Where CO_{2_SP} are permitted specific emissions, M is a mass of car in kg, M_0 is 1289 kg, and α is the slope of the LVC (0.0457). This curve is set in a way that emissions from heavier cars have to be reduced more than those from lighter cars.

Since targets for 2015 and 2020 are mandatory, manufacturer will have to pay penalties if their average emission levels are above the target set by the limit value curve. The penalties will be based on the calculation of number of grams per kilometre (g/km) that an average vehicle registered by the manufacturer is above the target, multiplied by the number of cars registered by the manufacturer. A premium of 5 EUR per car registered will apply to the first g/km above the target, 15 EUR for the second g/km, 25 EUR for the third g/km, and 95 EUR for each further g/km. From 2019 every g/km of excess will cost 95 EUR (EU, 2014).

Due to the implementation of mandatory CO_2 emissions standards, cars are expected to become more energy efficient – to consume less fuel per km driven.

Formal framework

To analyse the impact of various policies on overall CO_2 emissions we create in the following a formal framework. This framework is based on technical relations between CO_2 emissions, energy and service demand. It builds on works provided by Wirl (1992), Walker/Wirl (1993) and Haas (2009). It furthermore considers consumers' decision making processes and their sensitivity to technical standards and taxes.

How service is produced – basic technical framework

The basic presumption is that consumers do not demand energy or technology per se, but energy services (S), in this case mobility – vehicle kilometres driven (vkm).

Total energy for mobility used, which is mostly dependent on fuel intensity (FI) of cars and number of kilometres driven per year (vkm), can be written as:

$$E = vkm \cdot FI \qquad (2)$$

Emissions from passenger car depend in principle on total energy used in cars as well as on the type of energy used. Different fuels (e.g. gasoline, diesel, biofuels, etc.) have different specific CO_2 emissions coefficient. The average specific CO_2 emissions coefficient (f_{CO2}) can be improved with better quality of fossil fuels, higher share of biofuels with better ecological performance, more electricity from renewable energy sources, etc.

CO_2 emissions (CO_2) from passenger cars can be described as:

$$CO_2 = E \cdot f_{CO_2} = vkm \cdot FI \cdot f_{CO_2} = vkm \cdot CO_{2\_SP} \qquad (3)$$

with

CO_2…….total CO_2 emissions [ton CO_2/yr]
f_{CO2}…….CO_2 emission factor of fuel [kg CO_2/litre]
FI ……...fuel intensity [litre/100 km]
CO_{2_SP}…specific CO_2 emissions [kg CO_2/km]

Consumers' decision-making model

To find out how policies work we have to know how consumers make decisions. In principle consumers try to maximize the benefits they enjoy from the consumption of a specific service or a good and to minimize the monetary and other efforts related to the consumption of this good or service, see Wirl (1992) and Walker/Wirl (1993).

If we look at the service vkm consumers will maximize the utility they obtain from consuming this service minus the disutilities, (see Wirl (1992)). Disutilities in this context are fuel costs (P_f E), the capital costs (ρ I(η)), transaction costs and the possible damage for the environment. In the following we neglect the last two parts and obtain:

$$\max_{E,\eta} u(vkm) - p_f \cdot E(\eta) - \rho I(\eta) \qquad (4)$$

P_f………fuel price including tax
ρ …. ….Annuity factor
I(η)……Investment costs

The first-order condition with respect to energy leads to:

$$u' = \frac{\partial u}{\partial E} = \frac{P_f}{\eta(T)} = P_f \cdot FI \qquad (5)$$

In principle, better efficiency η(T) lowers the marginal costs of a particular service and thus raises the demand for this service. For example, a more fuel efficient car implies that one can afford higher mobility. Figure 4 provides a graphical representation of this effect for two different levels of marginal service costs P_S.

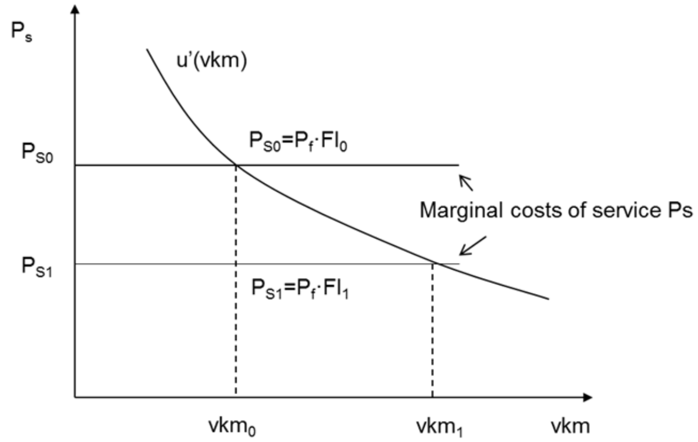

Figure 4. Choice of service level for vkm driven for different fuel intensities of a car (based on Wirl 1992)

The two marginal cost curves correspond to two different equipments, $FI_1<FI_0$, where the technology 1 is more efficient. The downward sloping curve represents marginal willingness to pay for the service, u'(vkm). The optimum is given where marginal benefits equal marginal costs. Thus, the cars with FI_0 implies the service demand vkm_0 while the more efficient cars with FI_1 implies a higher service level vkm_1.

Consumer decision can be affected with policy measures, e.g. fuel tax (τ_f), efficiency standards (η^*) and registration tax (τ_R). Including this policies in Eq. (4) we obtain:

$$\max_{E,\eta} u(vkm) - (p_f + \tau_f) \cdot E(\eta^*) - \rho(I(\eta^*) + \tau_R) \qquad (6)$$

Modelling the demand for service

Based on the above derived model for consumer decision making we summarize that consumers strive for service demand, and service demand depends on energy service price (Ps), income (Y), investment costs (IC) and quality (q) from other possible attributes (x).

However, in the short-term service demand – in this case vkm - can be written as:

$$vkm = f(P_S, Y) \qquad (7)$$

With

$$P_s = P_f \cdot FI \qquad (8)$$

This service price can be changed with policies:

- Rising the fuel tax τ_f which increases P_f and consequently Ps or
- Reducing fuel intensity by a standard (FI^*) which decreases Ps

The level of short-term service demand with respect to kilometre driven depends on available income (Y)[1] and the service price of a km driven (P_S). In other words we assume that once a car is purchased there are no other attributes for driving more or less than lower or higher energy service prices. The impacts on vkm driven is analysed in Ajanovic/Haas (2012) by applying a cointegration approach to the following model:

$$vkm = C \cdot P_S^{\alpha_s} Y^{\beta} \qquad (9)$$

Where:

C	Intercept
vkm	Demand for service, vehicle km driven in year t in a country
Ps	Weighted average price of service vkm driven (calculated by means of weighted fuel prices)
Y	Real private final consumption expenditures

The most interesting numbers of this analysis are the energy service price elasticities α_S because they contain information for both - price and efficiency impact. It is the crucial parameter for our further analysis.

Empirical analyses of the magnitude of price elasticities have been conducted in many papers, e.g. Dahl (2012), Dargay (1993) and Goodwin et al. (2004). Investigations conducted by the authors of this paper – see e.g. Ajanovic/Haas 2010, 2011 and 2012 – have resulted in long-term service price elasticities of about (-0.4) to (-0.45). Related to the above reflections this leads to the following interpretations: the increase in fuel prices due to a fuel tax of 1% would result in energy savings of about 0.4% to 0.45%. With a standard which decreases CO_2 emissions by 1% the savings would be between 0.55% and 0.6%. About the same effect would result from a CO_2-dependent registration tax.

Interaction of policies

The principle of how changes in efficiency due to standards and in prices due to taxes affect energy consumption is depicted in Figure 5. For a fuel tax the reduction in energy consumption ΔE results from higher service price Ps_τ remaining on the same curve η_0. When a standard is implemented we switch from η_0 to η_1 leading to a reduction ΔE of energy consumption. However, due to a lower service price Ps_η this saving effect is lower than the theoretical effect which is ΔE_η.

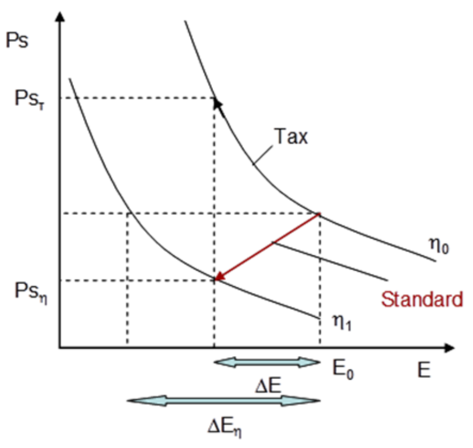

Figure 5. How a tax vs a standard works

1 Note, that further on in the empirical analyses of this paper we use Private Consumption Expenditures (PCE) as a proxy for income

In this section we analyze the impacts of changes in fuel intensity due to standards vs changes in fuel prices due to taxes on energy consumption. This is important to derive conclusions with respect to the effect of the implementation of standards for fuel intensity vs the effect of the introduction of fuel taxes leading to increasing fuel prices.

The rebound effect

One of the most critically discussed issues with respect to the implementation of standards for fuel intensity or corresponding CO_2 emissions is the rebound effect. The service cost savings for car users usually lead to the change in driving behavior. The behavioral response to the introduction of a new more efficient technology or other measures implemented to reduce energy use is called direct rebound effect.

The basic principle of a rebound effect is shown in Figure 6. Point 1 shows the initial situation (E_1 –energy consumption, η_1 –fuel efficiency, S_1 – service, in this case vehicle kilometer driven vkm_1). With the increasing energy efficiency from η_1 to η_2 theoretically energy consumption could be reduced from E_1 to E_2^{th}. Due to the higher efficiency, service price is lower, which causes increase in service demand. Due to the increase in energy efficiency from η_1 to η_2 and the resulting rebound effect energy consumption will be reduced to E_2^{pr} instead to E_2^{th} (Ajanovic/Haas, 2010a).

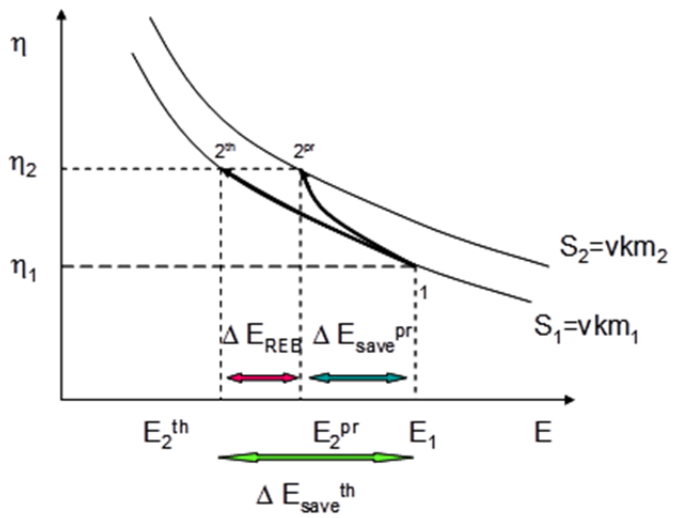

Figure 6. The rebound effect (Ajanovic/Haas, 2010a)

Using the definition of the service price elasticity, the difference in vkm driven caused by the rebound effect is calculated as:

$$\Delta vkm_{REB} = \alpha_{vkm,P_s} vkm_1 \frac{\Delta(P_f FI)}{P_f FI_1} \qquad (10)$$

Where $\alpha_{vkm,Ps}$ is the elasticity of vehicle kilometres driven with respect to service price P_S.

Using previous equations and the fundamental definition described in Greene (1997), the elasticity of energy consumption with respect to a change in fuel intensity is derived, (for detail see Ajanovic/Haas, 2012):

$$\gamma_{E,FI} = 1 + \alpha_{vkm,P_S} \qquad (11)$$

From the Eq. 11 it can be seen that the elasticity of energy consumption with respect to a change in fuel intensity ($\gamma_{E,FI}$) is one plus the elasticity of energy service (in our case vkm) with respect to service price (Ps).

Figure 7 depicts the effect of a fuel tax versus a standard depending on the service price elasticity. For example, if a tax in the magnitude of 100% is introduced and the price elasticity is (-0.3) then the energy saving effect is 30%. If a standard in the magnitude of 100% is introduced and the price elasticity is e.g. (-0.3) then the energy saving effect is 70% and the rebound effect due to more km driven is 30%.

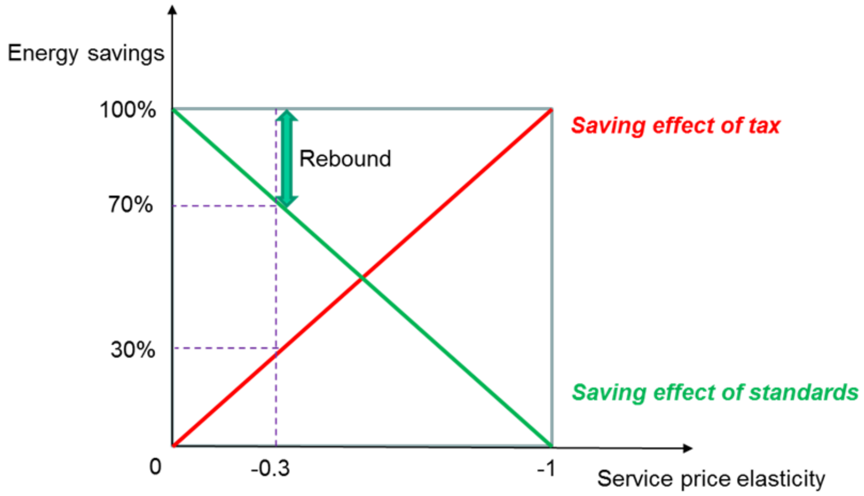

Figure 7. Effect of a tax versus standard depending on service price elasticity

A CO_2 emission standard should lead to increasing fuel efficiency of new cars. This could reduce energy service price for car drivers and lead to change of the behaviour, e.g. cars are used more frequently and/or on longer distances.

A first major conclusion of this paper is that the preference for taxes versus standards depends solely on the magnitude of the service price elasticity α_{vkm}.

If this α_S is small (e.g. -0.1) the fuel tax effect is almost neglectable. In this case a standard is clearly preferable with an empirical saving effect of about 90% of theoretically calculated 100%. If at other hands α_{vkm} is high it is vice versa and the tax is preferable. As mentioned before α_{vkm} is in the range of -0.4 to -0.45. This leads to an ambiguous situation and it is likely that a combined introduction of standards and fuel taxes depending on the service price elasticity will lead to the most beneficial solution for society, see Figure 8.

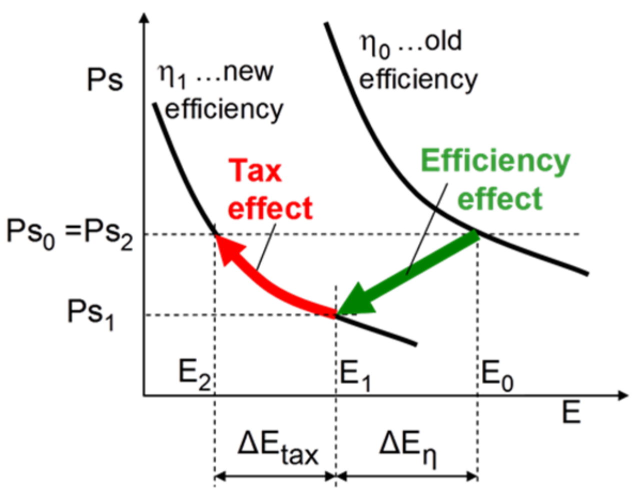

Figure 8. How taxes and standards interact and how a win-win situation is derived for society

How registration taxes work

As shown in Table 1 in some EU countries registration tax is based on the specific CO_2 emissions (CO_{2_SP}) of a car. The relation between specific CO_2 emissions and fuel intensity is given in Eq. (3). Corresponding to this equation, specific CO_2 emissions set by standards (*) are:

$$CO^*_{2\_SP} = f_{CO_2} \cdot FI^*$$

where FI^* is to the standard related fuel intensity.

A CO_2 based registration tax leads to purchase of cars with lower specific CO_2 emissions per km driven. Figure 9 depicts the relation between a registration tax based on CO_2 emissions and the specific CO_2 emissions of cars chosen. The higher the registration tax is the lower are the specific CO_2 emissions of the average sold cars. For every required emission standard ($CO_{2\_SP}^*$) a corresponding registration tax ($\tau_{R\_CO2}^*$) could be implemented to meet this standard and vice versa, see example in Figure 9.

$$CO^*_{2\_SP} = f(\tau^*_{R\_CO_2}) \qquad (13)$$

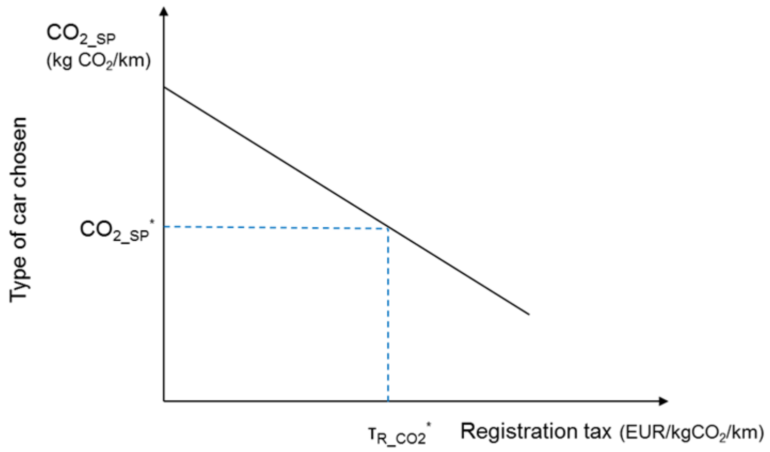

Figure 9. Relation between a registration tax (τ_{R_CO2}) and the specific CO_2 emissions (CO_{2_SP}) of cars

It should be noted that the relationship between a registration tax and the specific CO_2 emissions will also depend on the elasticity of investment costs (γ).

A high registration tax will lead to the purchase of cars with lower specific CO_2 emissions. Cars with lower specific CO_2 emissions have lower fuel intensity. If we introduce specific CO_2 emissions the corresponding fuel intensity (FI^*) will affect service price Ps:

$$P_S^* = (P_f + \tau_f) \cdot FI^* \qquad (14)$$

Where FI^* is a function of specific CO_2 emissions: $FI^*=f(CO_{2\_SP}^*)$

Since $FI^*=f(CO_{2\_SP}^*)$ and $CO_{2\_SP}^*=f(\tau_{R\_CO2}^*)$ this leads to the following reflections: from Eq. (13) follows

$$P_S^* = P_S(\tau_f, \tau^*_{R\_CO_2}) \qquad (15)$$

This means that the service price does not just depend on the fuel tax τ_f but also from registration tax τ_{R_CO2}.

Finally, from Eq. (7) we obtain:

$$vkm^* = f(P_S^*) = f(\tau_f, \tau^*_{R\_CO_2}) \qquad (16)$$

From this equation is clear that a registration tax based on CO_2 emissions will also have an impact on service demand - vehicle kilometer driven. In principle a CO_2 based registration tax works like a standard and leads to the same effect. With a higher CO_2 based registration tax demand for cheaper and more energy efficient vehicles rise. Due to the better efficiency of cars, service price decreases and leads to a direct rebound effect caused by more km driven, see Figure 10.

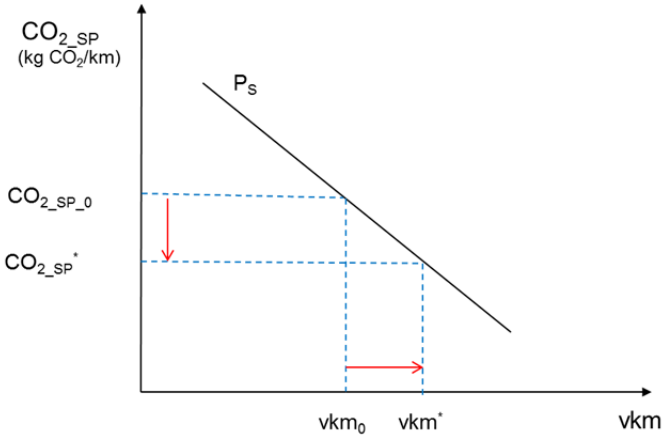

Figure 10. Relation between specific CO_2 emissions and the vehicle km driven

Conclusions

The major conclusions from this analysis are:

1. The intended introduction of standards as announced by the EU will not lead to the theoretically possible energy savings and CO_2-reduction. The major reason is that the rebound effect due to more km driven and larger cars will eat up a part of the theoretically calculated savings.
2. Despite the fact that there are a numerous parameters that constitute a formal framework, to explain energy consumption and CO_2 emissions, there is only one important parameter which influences the final CO_2 emissions and this is the service price elasticity.
3. In addition standards and fuel taxes are linked via the service price elasticity and are not independent! The magnitude of the service price elasticity defines which instrument is more effective – the tax or standard. Another finding is that the introduction of a registration tax is in principle the same as the introduction of a standard and leads to the same rebound problems. The registration taxes may cover a specific part of the standards' component.
4. Our results for the service price elasticity are about -0.4 to -0.45. This result leads to the situation that a mix of policies is preferable. A simultaneously introduced tax will compensate for the rebound effect without hurting car drivers due to service vkm driven remaining at same service price. A combined tax-standard policy will lead to a win-win situation for the environment and car drivers. Figure 8 describes how the policy designs should look like in principle. The fuel tax should compensate the standard to an extent so that finally the service price before and after policy introduction remains the same.

References

ACEA. 2013. Tax Guide 2013. www.acea.be

Ajanovic A., R. Haas, 2012. "The role of efficiency improvements vs. price effects for modeling passenger car transport demand and energy demand — Lessons from European countries". *Energy Policy* 41 36-46.

Ajanovic A, R. Haas. 2011.“ On the effectiveness of standards vs. taxes for reducing CO2 emissions in passenger car transport Europe”. *Proceedings,* Risø International Energy Conference (RIEC).

Ajanovic A., R. Haas. 2010. “The impact of fiscal policies on passenger car transport energy demand in OECD countries”. *Proceedings,* 29th USAEE/IAEE Annual North American Conference in Calgary. Canada.

Ajanovic A., R. Haas. 2010a.”On extracting the impact of consumer behaviour and the rebound effect in passenger car transport in selected EU countries”. *Proceedings,,* 8th BIEE Academic Conference, Oxford.

Dahl C.A. 2012. “Measuring global gasoline and diesel price and income elasticities”. *Energy Policy* 41.

Dargay, J.M., 1993. “Are price and income elasticities of demand constant? The UK Experience” EE16. Oxford Institute for Energy Studies.

EC. 2009. European Commission. Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community’s integrated approach to reduce CO2 emissions from light-duty vehicles. June 2009.

EEP. 2013. Europe’s Energy Portal. http://www.energy.eu/ accessed on 1.10. 2013.

EU. 2014. website on Climate action in the transport sector: http://ec.europa.eu/clima/policies/transport/vehicles/cars/faq_en.htm accessed on 4.4.2014

Eurostat. 2013. http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home accessed on 30.1. 2013.

Goodwin, P.B., Dargay, J.M., Hanly, M., 2004. “Elasticities of road traffic and fuel consumption with respect to price and income: a review”. *Transport Reviews* 24 (3), 292–375.

Greene D.L. 1997.”Theory and Empirical Estimates of the Rebound Effect for the U.S. Transportation Sector.” ORNL.

Haas, R., Nakicenovic, N., Ajanovic, A., Faber, T., Kranzl, L., Mueller, A., Resch, G., 2009. „Towards sustainability of energy systems: a primer on how to apply the concept of energy services to identify necessary trends and policies”. *Energy Policy* 36, 4012–4021.

Walker, I.O., Wirl, F., 1993. “Irreversible price-induced efficiency improvements: theory and empirical application to road transportation”. *The Energy Journal* 14 (4), 183–205.

Wikipedia. 2014. http://en.wikipedia.org/wiki/ACEA_agreement accessed on 4.4.2014.

de Wilde H.P.J. , P. Kroon. 2013. “Policy options to reduce passenger cars CO2 emissions after 2020” ECN-E-13-005.

Wirl F. 1992. “The impact of conservation, technology and the new registration tax on automobiles on energy consumption”. *Empirica – Austrian economic paper*. Vol.19, No. 1.