CO_2 Emissions, Energy, and Economic Impacts of CO_2 Mandates for New Cars in Europe

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Abstract

CO_2 emissions mandates for new light-duty passenger vehicles have recently been adopted in the European Union (EU), which require steady reductions to 95 g CO_2/km in 2021. Using a computable general equilibrium (CGE) model, we analyze the impact of the mandates on oil demand, CO_2 emissions, and economic welfare, and compare the results to an emission trading scenario that achieves identical emissions reductions. We find that while the mandates reduce the CO_2 emissions from transportation by about 50 $MtCO_2$ in 2020 and reduce oil expenditures by about 4.7-6.2 billion Euro in 2020, the net cost of the mandates is 12 billion Euro/year in 2020. Tightening CO_2 standards increases the welfare cost for the EU. In 2015 the policy costs are estimated at 0.7 billion Euro/year, in 2020 the cost increases to about 12 billion Euro/year, and keeping the 2021 target unchanged leads to a consumption loss of about 24 billion Euro/year in 2025. Increasing the stringency of CO_2 emissions targets further leads to a consumption loss of 40-63 billion Euro/year in 2025. CO_2 mandates are less cost effective than an emission trading scheme, with year-on-year consumption loss rising to 0.69% in 2025 under the proposed emission standard, compared to 0.08% under an emission trading system that achieves an equivalent reduction in CO_2 emissions.

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1. Introduction

European Union legislation sets mandatory CO_2 emissions reduction targets for new cars (EC, 2009). The legislation is based on the EU strategy for passenger cars and light commercial vehicles that is at once aimed at fighting climate change, reducing the EU reliance on imported fuels, and improving air quality (EC, 2007). Currently, for cars it sets targets for the fleet average that are reduced from 130 grams of CO_2 per kilometer (g/km) by 2015 (phased in from 2012) to 95 g/km by 2021 (phased in from 2020). These targets represent substantial reductions from the 2007 fleet average of about 159 g/km (EC, 2014).

The goal of this paper is to assess the resulting CO_2 emissions, energy, and economic impacts of the EU CO_2 legislation for new cars. Most of the analyses to date have been based on simplified benefit-cost calculations that estimate fuel savings and additional costs of introducing new technology deployment driven by the targets (e.g., TNO, 2011; Ricardo-AEA, 2014; ICCT, 2014a). Here we employ an economy-wide tool to assess the full economic impact of the emission reduction targets. Assessment of the performance of the EU targets and alternatives needs to account for the interactions of the transport sector with other energy sectors and with other parts of the economy. For this purpose we apply the MIT Economic Projection and Policy Analysis (EPPA) model (Paltsev et al., 2005) modified to represent a technology-rich representation of the passenger vehicle transport sector and its substitution with purchased modes, as documented in Karplus et al. (2013a).

Tailpipe CO_2 emissions standards are similar to fuel economy standards to the extent that they are based on a conversion between fuel use and energy-related CO_2 emissions per distance travelled. For example, 95 g/km is equivalent to 4.1 liters of gasoline per 100 kilometers (l/km) or 57.4 miles per gallon (mpg). However, the actual performance of the U.S. and EU standards differs from this direct conversion due to a different car mix in a fleet (gasoline versus diesel), different test cycle settings and different driving habits and conditions. ICCT (2014a) estimates that the 95 g/km target for the EU is equivalent to 3.8 l/km (considering a mix of gasoline and diesel cars) and to about 62 mpg (considering the differences between the EU and U.S. test standards). Currently, real world fuel consumption exceeds the test results by about 20% in the U.S. (EPA, 2014) and about 30% in the EU (ICCT, 2014b). In addition, car air conditioners use hydrofluorocarbons (HFCs) as refrigerants, which are also greenhouse gases (GHG). Reduction of refrigerants in air conditioners can count toward GHG reduction, therefore the CO_2 standard and their equivalent fuel standards end up being less stringent.

Since fuel economy and CO_2 emissions standards are implemented at the national or regional level and focus on the transportation sector only, their economy-wide effect and impacts on global fuel markets are often overlooked. Policies that target CO_2 emissions (or fuel economy) standards reduce fuel use or emissions per unit of distance traveled, but do not constrain the total quantity of fuel use or total CO_2 emissions. These standards apply only to new vehicles, and not on opportunities to reduce fuel use in the existing fleet—for instance, through low carbon fuel substitution or mileage conservation. Our analysis is able to capture the impacts of CO_2 standards as they propagate across linked markets for fuels and other inputs and affect incentives to invest in efficiency-improving technologies as well as demand response to price changes.

This paper is organized as follows. In Section 2 we review the fuel economy policies enacted in different parts of the world. In Section 3 we describe the model used for the analysis. In Section 4 we implement a scenario analysis to study the effects of the EU CO_2 standards. In Section 5 we discuss interaction of regulatory approach and emission trading. Section 6 summarizes the results and conclusions.

2. Policy Status

Many nations have increased the stringency of vehicle fuel economy standards to unprecedented levels within the last decade. The European Union and the United States have enacted some of the toughest standards globally. The latest U.S. fuel economy standards would raise the combined city-highway test-cycle fuel economy from around 27.5 mpg in 2007 to around 54.5 mpg in 2025 (combined for cars and light trucks). China, South Korea, Canada, India, Japan, and Mexico also have fuel economy standards in place (ICCT, 2014a). These standards raise the overall fuel economy of the vehicle fleet gradually as new vehicles are introduced and old vehicles are retired.

CO_2 and fuel economy standards have proven more politically feasible relative to other policy options, although the economics literature has found such approaches to be relatively costly.[2] New gasoline or diesel taxes, widely considered to be the most cost-effective option for displacing petroleum-based fuel use, have failed to gain political traction in the United States (Knittel, 2012). Even in Europe, where taxes on refined oil (diesel and gasoline) used in vehicles are among the world's highest, opposition to increasing the gasoline tax has been strong, particularly given the recent economic slowdown (Sterner, 2012). Higher fuel prices have been shown to incentivize consumer purchases of more efficient vehicles, although consumer responses have been shown to vary across regions (Klier and Linn, 2011).

The first fuel economy standard was introduced in the United States in 1978 after being established by the Energy Policy and Conservation Act of 1975 (US EPCA, 1975) following the

[2] There is wide variation in the estimated costs of fuel economy standards. Studies that assume automakers actually realize improvements in fleet-wide fuel efficiency find high costs (Goldberg, 1998). In many cases automakers may exploit sources of compliance flexibility or pay non-compliance penalties. For instance, Anderson and Sallee (2010) find much lower costs of compliance when automakers exploit flex-fuel vehicle credits.

1973 oil crisis. In Europe, the response to oil crises largely involved taxation of petroleum-based fuels. More recently, voluntary or mandatory fuel economy standards have been implemented in several nations, including Canada, Japan, Korea, Australia, and China (ICCT, 2014a). The European Union has started with voluntary agreements with car manufacturers set for 2008-2009 at 140 g/km. Later, based on the EC proposal (EC, 2007), the European Parliament and Council reached an agreement on the details of the CO_2 legislation for passenger cars (EC, 2009) that include setting the fleet average to be achieved by all new passenger cars registered in the EU at 130 g/km. A so-called limit value curve was introduced to allow heavier cars to have higher emissions than lighter cars while preserving the overall fleet average. A target of 95 g/km was specified for the year 2020, which was later phased in from 2020 to 2021. In 2013 the European Parliament issued a report calling for a 2025 target in the range of 68 to 78 g/km (EPRS, 2014).

A summary of historic, enacted and proposed CO_2 emission reductions through 2025 for new cars in the EU and USA is shown in Figure 1. Historically, the average EU cars are more fuel efficient (and produce less tailpipe CO_2 emissions per kilometer) than the U.S. cars due to higher fuel taxes in the EU and larger penetration of diesel cars, which are more fuel efficient than their gasoline counterparts. The U.S. standards are specified through 2025, but they are enacted only up through the 2021 model year, because the U.S. Energy Independence and Security Act of 2007 states that a fuel efficiency rulemaking may only cover at most five model years. To establish final standards for the 2022 model year and beyond, a revision by the U.S. Department of Transportation and U.S. EPA must be undertaken. A mid-term review of the standards is scheduled to take place in 2017.

As already mentioned above, the EU currently sets two targets for new cars: for 2015 at 130 g/km and for 2021 at 95 g/km. Both of these targets are phased in, so that a certain percentage of new cars have to comply during the phase-in period. In 2020, 95% of new cars have to comply with 95 g/km target, which, according to ICCT (2014a), makes it effectively a 98 g/km target for 2020. The targets for the years between 2015 and 2020 are not specified explicitly; therefore, in Figure 1 we provide a linear approximation between these two targets. For 2025 a range of 68 to 78 g/km is suggested for the EU (EPRS, 2014; ICCT, 2014a).

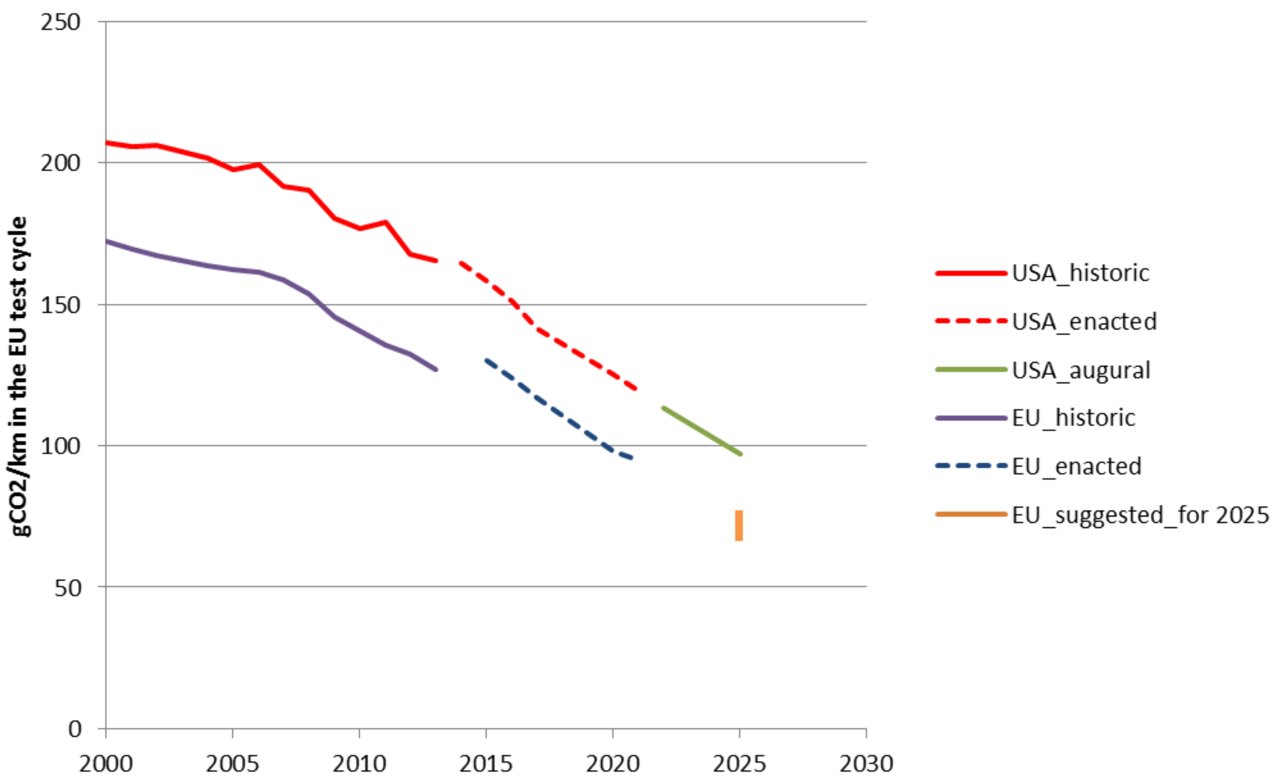

Figure 1. CO_2 regulations for cars in USA and EU normalized to the EU NEDC test cycle. Data source: ICCT (2014a), EPRS (2014).

The EU target for 2015 has been reached ahead of time. Based on the official EU data reported by European Environment Agency (EEA, 2014), in 2013 the fleet average for new cars was 127 g/km, while according to the phase-in schedule only 75% of newly-registered cars in

2013 were required to meet the 130 g/km target. At the same time, the EU system of testing cars to measure fuel economy and CO_2 emissions shows a growing gap between the test results and real-world on-road performance of cars. ICCT (2014b) reports that a divergence has grown from 8% in 2001 to 31% in 2013 and Transport & Environment (2014) estimates that without action the divergence is likely to grow to over 50% by 2020. Applying the 31% difference to the 2013 test results leads to about 166 g/km for real-life performance of new cars. A difference between the test results and on-road performance is a concern both in the EU and U.S., and changes have been proposed to the testing and labelling of cars to better represent the information about fuel economy (EPA, 2014). Using new procedures will make the standards more stringent and increase the cost of compliance.

Another aspect of the fuel and emission standards is that national or regional government regulatory processes typically estimate the fuel use or emissions impacts at the regional or sector level and do not consider the aggregate effects of adopting standards within and across adopting markets in response to changes in relative fuel prices. These effects include both changes in passenger vehicle travel demand as well as demand for petroleum-based fuels in other sectors, such as electric power, petrochemicals, or heavy industry. The first response is often called the rebound effect, as it refers to an increase in travel demand in response to an efficiency-induced reduction in the marginal cost of driving (Small and Van Dender, 2007). The second response is the leakage effect, which occurs when a drop in fuel prices stimulates demand for the targeted fuel in sectors unconstrained by the policy.

However, regulatory processes that assess the energy, emissions, and economic impacts of these fuel economy programs typically rely on vehicle fleet and technology models that do not capture broader macroeconomic and global impacts. Regulatory impact assessments in the

United States (EPA, 2012a, 2012b) focus on the new vehicle fleet and do not assess impacts on fleet turnover, on non-transport sectors, or on global oil price and quantity demanded. In the European Union, EUCLIMIT, an economy-wide model for Europe is used with broad sectoral coverage and fleet dynamics, however, international variables are still assumed to be exogenous (Eur-Lex, 2012). Given the scale of vehicle energy use and the stringency of announced fuel economy standards, estimating the magnitude of the impacts requires a carefully parameterized global energy-economic model. Here, based on careful parameterization of the passenger vehicle sector, we use a computable general equilibrium (CGE) framework that can capture both the rebound effect and the leakage effect in its many manifestations. In our model we are able to capture leakage that occurs across sectors within economies, across regions, and even between new and used passenger vehicles. The rebound effect is also captured, and based on parameterization of the costs associated with vehicle efficiency improvements, the contribution of resulting fuel savings given diverse taxation regimes for motor vehicle fuel, and heterogeneity in vehicle ownership and travel demand patterns. The model further captures how these two effects interact with each other.

3. Model and Scenarios

3.1 Model Description

We use the MIT Economic Projection and Policy Analysis (EPPA) model (Paltsev et al., 2005; Karplus et al., 2013a) for the analysis. The EPPA model is developed by the Joint Program on the Science and Policy of Global Change at the Massachusetts Institute of Technology. It provides a multi-region, multi-sector recursive dynamic representation of the global economy.

For the underlying data on the initial economic flows of production, consumption, intermediate inputs, international trade and taxes, the model is parameterized using the Global Trade Analysis Project (GTAP) dataset, which records national energy and economic (input-output) flows in 113 regions for the year 2004 (Narayanan and Walmsley, 2008). For use in the EPPA model, the GTAP dataset is aggregated into 16 regions (Table 1) and 24 sectors with several advanced technology sectors that are not explicitly represented in the GTAP data. The model includes representation of CO_2 and non-CO_2 (methane, CH_4; nitrous oxide, N_2O; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulphur hexafluoride, SF_6) greenhouse gas emissions abatement, and calculates reductions from gas-specific control measures as well as those occurring as a byproduct of actions directed at CO_2. The model also tracks major air pollutants (sulfates SOx, nitrogen oxides NOx, black carbon BC, organic carbon OC, carbon monoxide CO, ammonia NH3, and non-methane volatile organic compounds VOCs). The data on GHG and air pollutants are documented in Waugh et al (2011).

The base year for the model is 2005, based on the calibration of the GTAP data for 2004, and from 2005 the model solves at 5-year intervals. We also further calibrate the data for 2010-2015 based on the data from the IMF and IEA. The model includes a technology-rich representation of the passenger vehicle transport sector and its substitution with purchased modes, which include aviation, rail, and marine transport (Paltsev et al., 2004). Several features were incorporated into the EPPA model to explicitly represent passenger vehicle transport sector detail (Karplus et al., 2013). These features include an empirically-based parameterization of the relationship between income growth and demand for vehicle miles traveled (VMT), a representation of fleet turnover, and opportunities for fuel use and emissions abatement, including representation of the electrified vehicles. The opportunities for fuel efficiency improvement are parameterized to the U.S Environmental Protection Agency data (EPA, 2010; EPA, 2012b) as described in Karplus (2011) and Karplus and Paltsev (2012), and Karplus et al (2013a).

Table 1. Sectors and regions in the EPPA model.

Sectors	***Regions***
Non-Energy	***Developed***
Agriculture	United States (USA)
Forestry	Canada (CAN)
Energy-Intensive Products	Japan (JPN)
Other Industries Products	Europe (EUR)
Industrial Transportation	Australia & Oceania (ANZ)
Household Transportation	Russia (RUS)
Food	Eastern Europe (EUR)
Services	***Developing***
Energy	India (IND)
Coal	China (CHN)
Crude Oil	Indonesia (IND)
Refined Oil	Rest of East Asia (REA)
Natural Gas	Mexico (MEX)
Electricity Generation Technologies	Central & South America (LAM)
Fossil	Middle East (MES)
Hydro	Africa (AFR)
Nuclear	Rest of Europe and Central Asia (ROE)
Solar and Wind	Dynamic Asia (ASI)
Biomass	
Natural Gas Combined Cycle	
Natural Gas with CO_2 Capture and Storage (CCS)	
Advanced Coal with CCS	
Synthetic Gas from Coal	
Hydrogen from Coal	
Hydrogen from Gas	
Oil from Shale	
Liquid Fuel from Biomass	

Note: Detail on aggregation of GTAP sectors and the addition of advanced technologies are provided in Paltsev *et al.* (2005). Details on the disaggregation of industrial and household transportation sectors are documented in Paltsev *et al.* (2004).

Given that the CO_2 standards apply only to new model-year vehicles sold, it is essential to differentiate between the new and used vehicle fleets because the total energy and emissions depend on characteristics of the total fleet and turnover dynamics. In our analysis we include a parameterization of the total miles traveled in both new (0 to 5-year-old) and used (6 years and older) vehicles and track changes in travel demand in response to changes in income as well as cost-per-mile. The EPPA model represents substitution between new and used vehicles, which captures an additional way in which consumers respond to changes in relative prices, including those changes that result from the introduction of CO_2 standards or an increase in the price of fuel given a carbon price. For more details on technology and price responses in the MIT EPPA model, please see Karplus et al. (2015).

Our representation of vehicle efficiency options is based on the detailed study on the costs of fuel efficiency improvements performed by the U.S. EPA for the U.S. (EPA, 2010; EPA, 2012b). We are not aware of any comparable study done by the EU. The evaluation done by TNO (2011) is not as comprehensive as the data for costs are mostly derived from the existing literature and TNO's in-house expertise rather than from the car manufacturers. The budget of the EPA studies was around an order of magnitude higher than that of the TNO work for the EU, so there are limitations in the scope and accuracy (TNO, 2011).

Our results in this paper should also be treated with a caution as they are not based on the EU data for efficiency improvements. One might argue that the EU costs are higher than the U.S. costs because the fuels in the EU have been taxed at a higher rate, which in turn resulted in a more efficient EU car fleet. As a result, we expect that many options for further efficiency improvements are already implemented there.

The fuel economy standards are implemented in the EPPA model as constraints on the fuel allowed per kilometer of household travel. They are converted to CO_2 standards based on characteristics of the fleet (composition of diesel and gasoline vehicles). The standards are imposed at their values based on *ex ante* usage assumptions (i.e., before any change in miles traveled due to the higher efficiency). It forces the model to simulate adoption of vehicle technologies that achieve the imposed standard at least cost. Opportunities to improve fuel economy and reduce CO_2 emissions from cars in each region are described by a response function that relates cost of technology and abatement potential, which is used to parameterize the elasticity of substitution between fuel and powertrain capital as an input to household vehicle transport (Karplus et al., 2013a). The model then captures how total vehicles-miles traveled respond when CO_2 standards have been forced to higher levels. The form of the utility function, the input shares, and the substitution elasticity between vehicle and powertrain capital determines how much the cost of travel changes in response to changes in the underlying CO_2 requirement and vehicle characteristics, which in turn determines the magnitude of the rebound effect.

3.2 Scenarios

In this analysis we consider several scenarios regarding the EU CO_2 emissions targets. Our "*No Policy*" scenario considers no GHG reduction targets and no mandatory CO_2 emissions reduction targets for new cars. It provides the basis against which we compare the outcomes of the other scenarios. We then consider the EU GHG reduction targets (20% reduction by 2020 and 40% reduction by 2030 relative to 1990 levels) achieved by an economy-wide emission trading system (denoted as "*Emissions Trading*"). In the emission trading scenario, permit trading is allowed across all sectors within the EU. We then include a current policy scenario (denoted as "*Current ES*") that imposes CO_2 mandates at 130 g/km in 2015 improving to 98 g/km in 2020 and keeping in 2025 the 2021 target of 95 g/km. To explore the proposals for 2025, we add two scenarios that increase the targets for 2025 to 78 g/km ("*ES_ 2025_low*") and to 68 g/km ("*ES_2025_high*"). In all these scenarios we assume that a difference between the test values and real-life performance of new cars is kept at 2013 levels of 30%. Table 2 summarizes the scenarios, which we run for 2010 to 2025.

Table 2. List of Scenarios.

Name	Description
No Policy	No GHG reductions and no mandatory CO_2 reduction targets for new cars
Emission Trading	Economy-wide emission trading to achieve the EU goals (20% reduction in 2020, 40% reduction in 2030 relative to 1990 levels)
Current ES	Current policy for Emission Standards (ES) in cars: 130 g/km in 2015, 98 g/km in 2020, 95 g/km in 2025
ES_2025_low	Same as Current ES for 2015-2020, 78 g/km in 2025
ES_2025_high	Same as Current ES for 2015-2020, 68 g/km in 2025

In our scenarios we do not model several policy design features that could loosen stringency in practice, for example, super-credits for extremely low emission vehicles and eco-innovations. We also assume that car manufacturers meet the standards rather than paying penalty for excess emissions (set at 95 Euro for a g/km of exceedance).

In addition to the scenarios listed in Table 2, we also explored an alternative setting for a comparison of policies. Following Karplus et al. (2015), we first imposed CO_2 mandates on new cars without imposing additional GHG reductions committed by the EU. Based on the resulting CO_2 profiles, we then include scenarios where the same emissions reduction targets are achieved by an emissions trading scheme. As the difference in the costs between standards and emission trading scenarios in this alternative comparison is similar to the setting described in Table 2, in this paper we focus on the cases where the EU GHG targets are met with or without emission standards for new cars.

4. Results

In interpreting the results of the scenarios, we focus on several outcomes. First, we are interested in quantifying the impacts of the current EU CO_2 mandates on energy, CO_2 emissions, and economy. Second, we are interested in the effects of the proposed mandates for 2025, and in understanding how these paths compare to an emission trading system that achieves the same CO_2 reduction in the EU as the CO_2 mandates.

4.1. Impact of the current policies on new cars and total fleet

To illustrate how the CO_2 mandate acts upon fuel use, we show the resulting imputed on-road fuel consumption (fuel used divided by distance traveled, in liters per 100 km) of an average on-road vehicle in the new and total vehicle fleet. As anticipated, we observe a declining trend in imputed fuel consumption through 2025, as shown in Figure 2. The trajectories shown are the VMT-weighted (on-road) fuel consumption realized for the new vehicles sold in the most recent five years as well as for the entire fleet (both newly sold and pre-existing vehicles considered together), and includes any response in distance traveled associated with changes in the fuel- and vehicle-related cost of driving. The model solves every 5-year time step so the lines on the figures are linearly interpolated between 5-year intervals.

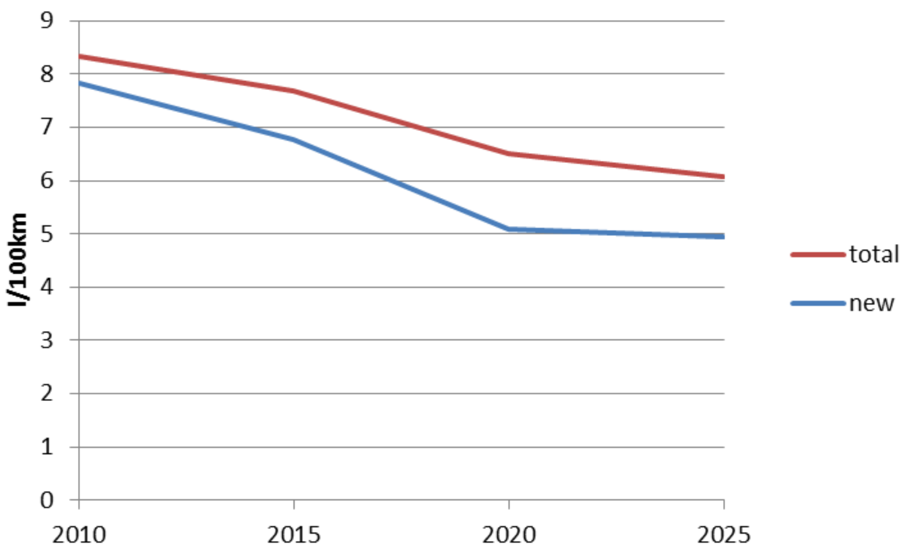

Figure 2. On-road fuel consumption for an average new car and total fleet in the *Current ES* Scenario.

On-road CO_2 emissions for new cars and the total fleet in the *Current ES* Scenario are presented in Figure 3. They follow the fuel consumption trajectory closely. The figure also presents a difference between the targets set for new cars based on the test results and estimated on-road performance of new cars and the total fleet. In the *Current ES* Scenario, the mandates for new cars are set to be tightened from 130 g/km in 2015 to 95 g/km in 2025 (assuming no further tightening of the 2021 target—we change this assumption in later analysis), while the total fleet performance improves from 192 g/km in 2015 to 152 g/km in 2025.

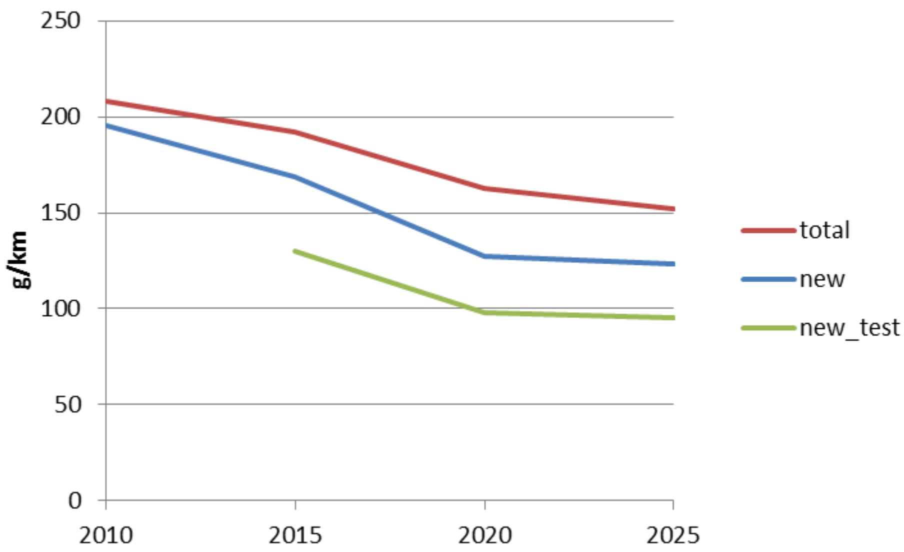

Figure 3. CO_2 mandates for new cars based on the test cycle (“new_test”) and on-road CO_2 emissions for an average new car (“new”) and total fleet (“total”) in the *Current ES* Scenario.

4.2. Energy and environmental impacts of the current policies

We now consider the net effect of the current EU CO_2 emission mandates on energy and environmental outcomes. We first focus on the change in the EU total oil consumption shown in Figure 4. The *No Policy* scenario results in a slight decrease in oil use over the 2010-2025 period. The *Emission Trading* scenario further reduces the total EU year-on-year oil use by 23 million tonnes of oil (mtoe) in 2020 and by 55 mtoe in 2025, which results in about 4.1% and 10% reductions relative to the *No Policy* scenario in 2020 and 2025, respectively. Building on the *Emissions Trading* scenario, the *Current ES* scenario imposes emission standards for cars, which forces an additional reduction in the EU oil consumption by 12 mtoe/year in 2020 and 14 mtoe/year in 2025. With the steeper 2025 targets, the corresponding declines in the

ES_2025_low and *ES_2025_high* scenarios are 18 and 20 mtoe/year in 2025 (in contrast with 14 mtoe/year when current standards are extended from 2021 to 2025).

Based on the oil price range of $60-80/barrel, we can estimate fuel expenditure savings in the *Current ES* scenario, which we find to be about $5.4-7.2 billion (4.7-6.2 billion Euro at the current exchange rates) in 2020 and about $6.1-8.2 billion (5.4-7.1 billion Euro) in 2025. Higher emission targets in 2025 would save more in reduced oil payments (6.9-10.4 billion Euro), but as we show later, they would also cost more.

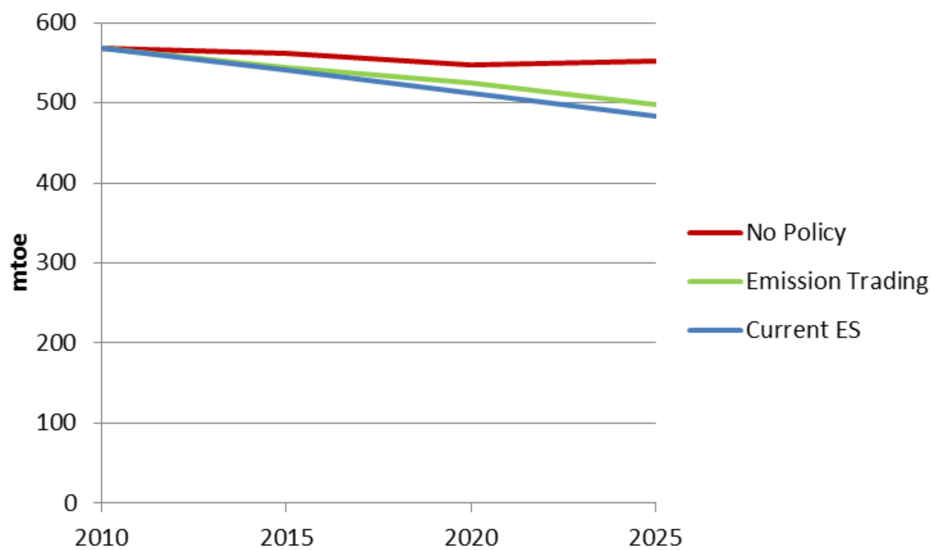

Figure 4. Total oil consumption in the EU in the *No Policy, Emission Trading,* and *Current ES* Scenarios.

Turning to the *Emission Trading* scenario, our design of the policy ensures that CO_2 emissions reach a consistent EU-wide emissions target in both the *Emission Trading* and *Current_ES* scenarios. However, the resulting CO_2 emissions from private vehicles are different. In this scenario, private vehicles' emissions are reduced by 18 million tonnes of CO_2 ($MtCO_2$) in 2020, while the *Current_ES* scenario forces an additional 47 $MtCO_2$ to be reduced from private cars, illustrating the fact that cost-effective allocation seeks reductions elsewhere. We also observe that emission reductions from private cars are relatively modest compared to the total EU CO_2 emissions of about 3,100-3,400 $MtCO_2$ in 2020-2025. (A similar result is obtained when we consider an alternative setting based on the *No Policy* case, where we only impose CO_2 emission standards for private cars. In this case, the reductions are about 67 $MtCO_2$ in 2020).

Potential reductions due to the displacement of petroleum-based fuels are partially offset by increases in vehicle travel due to the reduced cost per mile (a result of both higher vehicle efficiency and reduced fuel cost), and the adoption of plug-in hybrid electric vehicles (which run on electricity and therefore displace refined oil but not necessarily CO_2). In short, total CO_2 emissions suggest that when viewed in the EU-wide perspective, the net effect of current mandates on total EU CO_2 emissions is fairly modest. We consider the cost effectiveness of achieving these reductions relative to an efficient instrument targeting CO_2 in the next section.

4.3. Economic impacts

We also report the predicted consumption loss due to the current CO_2 mandates for new cars. While on aggregate consumers face lower fuel payments as discussed above, we find that on balance the aggregate EU consumption is reduced in every year in comparison to the *No Policy* and *Emission Trading* scenarios. The CO_2 mandate's net costs are 0.7 billion Euro in 2015, and rise to 12 billion Euro in 2020. The consumption losses are measured as equivalent variation and they are roughly comparable with GDP losses relative to the *No Policy* scenario (for a discussion of cost measures of climate policy, see Paltsev and Capros, 2013). The losses occur due to increased costs for the automotive industry to introduce more efficient vehicles, changes in the price of capital due to new investments, changes in allocative efficiency, and a reduction in fuel tax revenue. As the economy grows and the number of cars that need to meet new requirements are increasing over time, the costs of meeting the standards are rising over time even when CO_2 mandates are not tightening substantially. We find an increased CO_2 target from 98 g/km in 2020 to 95 g/km in 2025 changes consumption losses from 12 billion Euro/year in 2020 to 24 billion Euro/year in 2025, mostly because of the dynamic effect of increased capital expenditures and slowing down economic growth due to re-allocation of payments. Projecting the new car sales in the EU at about 13 million per year, the 2020 CO_2 standards result in about 925 Euro of additional cost per new car sold.

4.4. Assessing the proposed targets for 2025

As mentioned above, the current EU legislation enacts the targets up to 2021. More stringent CO_2 targets for new cars for 2025 have been proposed. In 2013 the European Parliament's Environment Committee issued a report calling for a target for 2025 in the range of 68 to 78 g/km (EPRS, 2014). Here we assess how these proposed mandates affect the results of the *Current ES* scenario reported above. The results are presented in Table 3. More stringent targets would improve CO_2 performance of the fleet while reducing oil use and total EU CO_2 emissions, but targets would be reached at a higher net cost of 42 billion Euro for the 78 g/km target (*2025_ES_low*) and 63 billion Euro for the 68 g/km target (*2025_ES_high*). Note that even though the costs in Table 3 are reported for a given year (2025), they represent the consumption impacts that are affected by choices that consumers make for a life of the vehicle for a given model year.

Table 3. Impacts of alternative targets for 2025.

Scenario	test target g/km	on-road CO2 for new cars g/km	on-road CO2 for total fleet g/km	additional reduction in oil use mtoe	additional reduction in CO2 emissions from private cars Mt CO2	net cost of policy billion Euro
Current_ES	95	124	152	14	58	24
2025_ES_low	78	101	137	18	74	42
2025_ES_high	68	88	127	20	84	63

As the stated goal for CO_2 mandates is a reduction in the total EU CO_2 emissions (EC, 2009), policy makers should be aware of the net costs of achieving emission reduction when considering new targets. In principle the public should equate their willingness to pay with the cost of the policy. Indeed, the EU issued a regulation (EU, 2014) that the CO_2 target should be achieved "in a cost-effective manner." Below we consider a system that achieves the same emission reduction trajectory at a lower cost.

4.5. Comparing CO_2 mandates for new cars with an emission trading system

Today, many countries have implemented emissions and fuel economy standards in transportation, while market-based instruments for addressing energy and climate challenges (for example a carbon tax or emissions trading system) have proven to hold far less political appeal. An important question is how CO_2 mandates for cars compare to market-based instruments in terms of their ability to address energy- and climate-related goals, and at what cost they do so. We now consider how achieving CO_2 emissions reductions through a mandate compares to an alternative market-based policy instrument.

For our market-based policy, we consider a trading system for CO_2 emissions that targets a reduction equivalent to that achieved when the CO_2 mandates for new cars are implemented. The emission trading policy does not explicitly constrain motor vehicle fuel use, but instead requires that reductions be met with the least cost solutions available, which are deployed over time in order of increasing cost to comply with the emissions cap. The sectoral contribution to total reductions will differ because of differences in resource costs, household consumption patterns, and production technology.

How much does achieving an identical emissions target through these two alternative policies cost? In 2020, the aggregate EU consumption loss is four times higher with vehicle efficiency (CO_2 emissions) mandates in comparison to emission trading scheme, as shown in Table 4. The cost differences are increasing with an increase in the stringency of the mandate because of the higher and steeper abatement cost curve in transportation. Karplus and Paltsev (2012) found a similar result for the U.S. fuel efficiency standards, where fuel standards were increasing linearly and it lead to an approximately quadratic increase in costs due to the shape of marginal abatement cost curve.

Table 4. Policy costs (in billion Euro/year) of reaching the same CO_2 targets with alternative policy instruments.

	Emission Mandate	Emission Trading
2015	2.7	2.0
2020	17.2	4.9
2025_Current_ES	32.3	8.2
2025_low	50.7	8.2
2025_high	70.9	8.2

These results illustrate a difference in cost of reaching emissions reduction in different sectors of the economy. It may seem “fair” to require same percentage reduction from all sectors, but it turns out that at least for transportation sector this equal reduction design leads to severe distortions in terms of the total economic cost of policy. At the same time CO_2 mandates and fuel standards are effective at reducing fuel use. Table 5 shows that oil use in the EU drops more under the vehicle emissions mandates than in the emissions trading that achieves the same CO_2 emission reductions, because trading substantially affects other sectors and fuels.

Table 5. Reduction in oil use (mtoe) with alternative policy instruments.

	Emission Mandate	Emission Trading
	mtoe	mtoe
2015	20.8	17.2
2020	34.9	22.7
2025	69.1	55.1
2025_low	73.0	55.1
2025_high	75.4	55.1

5. Transportation in an Emission Trading Scheme

A reason frequently given for implementing or tightening new vehicle fuel economy standards is that consumers overly discount the recurring cost of fueling at the time of vehicle purchase, requiring correction through policy (Greene et al., 2005). Recent work has tested this hypothesis. One study suggests that consumers that are indifferent between one dollar in fuel costs and 76 cents in vehicle purchase price (Allcott and Wozny, 2012), suggesting mild undervaluation, while other empirical work finds scant evidence of consumer myopia (Goldberg, 1998; Knittel et al., 2013). Their work suggests that consumers respond rationally to price mechanisms like carbon taxes or gasoline taxes, leaving little need for additional policy intervention as prices influence both what cars people buy and how much people drive.

Rausch and Karplus (2014) use a model of the U.S. and find that cap-and-trade system is more efficient than fuel standards, and combination of cap-and-trade and fuel stands reduces inefficiencies but this combination is still less cost-effective in comparison to an economy-wide emission trading. Paltsev et al. (2014) considered a sequential policy design, when global emissions are first regulated in electricity and private transportation, but then later they are combined with economy-wide emissions trading and it reduces the cost of mitigation.

Ellerman et al. (2006) considered an example of the U.S. to illustrate the ways for avoiding inefficiency of fuel standards in transportation. They concluded that in the presence of an overall carbon cap, CAFE (U.S. fuel standard for cars and light trucks) is a poor regulatory policy for dealing with carbon emissions, whether or not it is integrated with the cap-and-trade system. They discuss the practical steps of how to bring transportation under emissions trading and design a cost-effective system that engages both upstream (level of fuel provider) and downstream (level of car owner).

6. Conclusions

Although CO_2 mandates are implemented at the sectoral level, this analysis illustrates the importance of an economy-wide analysis. Capturing both the rebound and the leakage effects, our model results suggest that at the EU level a CO_2 mandate serves energy policy goals (i.e., a reduction in oil use) far better than long-term global climate change mitigation objectives. Reductions in demand for petroleum as well as other fuels are further facilitated by the costs that a CO_2 mandate places on the economy, as capital costs rise to achieve vehicle efficiency improvements or accommodate the production of alternative fuel vehicles.

We find that while the mandates reduce the CO_2 emissions from transportation by about 50 $MtCO_2$ in 2020 and reduce oil expenditures by about 4.7-6.2 billion Euro in 2020, the net cost of the mandates is 12 billion Euro/year in 2020. Tightening CO_2 standards increases the welfare cost for the EU. In 2015 the policy costs are estimated at 0.7 billion Euro/year, in 2020 the cost increases to about 12 billion Euro/year, and keeping the 2021 targets unchanged leads to a consumption loss of about 24 billion Euro/year in 2025. Increasing the emission targets further lead to a consumption loss of 40-63 billion Euro/year in 2025. CO_2 mandates are less cost effective than an emission trading scheme, with year-on-year consumption loss rising to 0.69% in 2025 under the proposed high emission standard, compared to 0.08% under an emission trading system that reaches the same target for emissions reduction.

Our analysis suggests that policies that appear "fair" by requiring equal emissions reductions from all sectors may incur a hefty toll. By contrast, market-based instruments that achieve an equivalent overall reduction shrink the economic pie by a substantially smaller margin. The emission trading system results in modest reductions in refined oil use in passenger vehicle transportation, while standards would require large reductions from the transportation sector. We stress the need and importance of the detailed studies on additional costs for meeting CO_2 standards in the EU. We base our results on the U.S. studies as we are not aware of the comparable EU exercises. Such study requires an involvement of the industry and transportation research centers. The existing TNO (2011) report needs to be expanded to include the latest car industry data.

Our results suggest that bringing transportation under the EU Emission Trading Scheme (ETS) is an alternative to the CO_2 standards that is worth considering. It may seem fair to require same percentage reduction from all sectors, but it turns out that at least for transportation sector this equal reduction design leads to severe distortions in terms of the total economic cost of a policy. The advantage of an emissions trading system is that it searches out the cheapest way to reduce emissions. If it is more expensive to reduce emissions from cars, it can reduce emissions elsewhere. While the current EU ETS is mostly related to electricity and energy-intensive industries, it would be feasible to extend it to transportation fuels. With emissions trading that covered transportation fuels, the currently targeted EU-wide emission reductions would be achieved at a lower cost.

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