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Reducing transport's impact on climate change and energy consumption - the role of the EU's vehicle CO_2 emissions regulations

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ABSTRACT

Road transport accounts for around 25% of energy consumption and over 20% of greenhouse gas (GHG) emissions across Europe. The EU has regulated CO_2 emissions from new cars since 2009 and from new vans since 2011, and these Regulations have been the flagship policy measures for addressing transport-related GHG emissions. We carried out an evaluation of the first phase of these Regulations, to assess their effectiveness, efficiency and ongoing relevance. Using regression analysis to help control for the role of other relevant factors and policy measures, we found that the adoption of mandatory CO_2 targets was likely to have accounted for 65-85% of the actual reductions in emissions achieved. The Regulations were more successful in reducing CO_2 emissions than the voluntary agreements in place between the automotive industry and the European Commission between 1998 and 2009. The analysis showed that the Regulations achieved vehicle emissions reductions in a cost-effective manner, delivering a significant reduction in fuel costs for consumers while costs to manufacturers were found to be much lower than originally anticipated. However, the analysis also pointed to certain limitations and weaknesses. The increasing discrepancy between real-world and the test-cycle emissions eroded the potential benefits of the Regulations. The more demanding CO_2 standards probably contributed to increased sales of diesel cars that have had adverse side-effects on air pollution. Finally, the annual rate of improvement in fuel efficiency and CO_2 emissions must increase, along with the proportion of alternative-fuel vehicles sold, to meet more ambitious climate and energy policy targets.

Introduction

Purpose and scope of the evaluation

To address the GHG emissions associated with light duty vehicles (LDVs[1]), the EU implemented two tailored Regulations to encourage emissions reduction in passenger cars and light commercial vehicles (LCVs), respectively. Ricardo Energy & Environment carried out an evaluation of the first phase of these Regulations, commissioned by DG Climate Action:

- **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 Union's integrated approach to reduce CO2 emissions from light-duty vehicles;
- **Regulation (EU) No 510/2011** of the European Parliament and of the Council of 11 May 2011, setting emission performance standards for new light commercial vehicles as part of the Union's integrated approach to reduce CO_2 emissions from light-duty vehicles.

These Regulations represented the cornerstones of the EU's strategy to improve the CO_2 emissions performance of new LDVs sold on the EU market. The Regulations are also referred to, respectively, as the

[1] Passenger cars and light commercial vehicles.

passenger car CO_2 Regulation and the LCV CO_2 Regulation, and collectively as the LDV CO_2 Regulations. The purpose of the evaluation was to provide insights into the performance of the Regulations and the associated societal, economic and environmental impacts (both intended and unintended). Therefore, the evaluation highlighted the achievements and challenges of the Regulations, indicated the factors that may have resulted in the interventions being more or less successful than anticipated, and provided recommendations to help inform the design of any future Regulations.

While the original passenger car CO_2 Regulation came into force in 2009, it was preceded by voluntary agreements with various vehicle manufacturers' associations, which were first mentioned in a Commission strategy in 1995. Therefore, the timescale of the evaluation covered the entire period from 1995 to 2014 for passenger cars. There were no equivalent voluntary agreements for LCVs, so the timescales for which an evaluation for LCVs was possible was shorter than that for cars. While much of the evaluation was backward looking, there was also a forward-looking element that aimed to identify whether the Regulations were fit for purpose for the period beyond 2020. It was appropriate to raise this question, due to the range of emerging issues that were impacting the effectiveness of the Regulations. Geographically, the focus of the evaluation was on the implementation of the Regulations in the EU. However, the EU automotive sector is not an isolated sector, and many of its manufacturers and suppliers operate globally. In addition, similar requirements in terms of improved fuel efficiency and CO_2 reductions were being placed on manufacturers in many other major global vehicle markets. The evaluation accounted for these issues, where relevant.

Background to the Regulations

Purpose of the Regulations

The primary aim of the Regulations was to contribute to reductions in actual, or real-world, CO_2 emissions from passenger cars and LCVs, primary sources of transport emissions. Beyond environmental impacts, LDVs also play an important role in supporting societal needs and economic growth. Cars enable people to access employment, education, goods and services. LCVs play an important role in the freight distribution network, particularly at the local level. Manufacturers of cars and LCVs in the EU also contribute to EU employment and GDP growth. Therefore, the Regulations aimed to achieve a balance between their overall environmental objectives and societal and economic needs.

History and evolution of measures

Passenger cars

The origins of the Regulations date back to 1995, when the Commission published a strategy on passenger car CO_2. This responded to requests from the Council and the European Parliament for EU-level action to reduce car CO_2 emissions; these requests had suggested that an appropriate target would be to reduce average CO_2 emissions from new passenger cars to 120 gCO_2/km, relative to average CO_2 emissions of 186 g/km in 1995 (ICCT, 2018). The strategy to achieve this target was based on three pillars, covering supply and demand measures (European Commission, 1995): voluntary commitments from automobile manufacturers; promotion of fuel-efficient vehicles through fiscal measures (i.e. taxation); and the introduction of fuel economy labelling. The strategy's intention was to meet the 120 gCO_2/km target by 2012.

In 1998, a voluntary agreement was reached with the European automobile manufacturers' association (ACEA) to reduce the average CO_2 emissions of new cars to 140 gCO_2/km by 2008. However, this was not met, and in 2008, the average CO_2 emissions of new cars were 152.3 gCO_2/km (European Commission, 2010). The taxation measure was expected to be delivered primarily by action at the national level, although few Member States had taken action by 2005. This led the Commission to publish a proposal for coordinated action (European Commission, 2005), which faced opposition from some Member States and subsequently, was not enshrined in law. Directive 1999/94/EC, which requires new cars to display a label showing fuel consumption and CO_2

emissions, implemented the third pillar of the strategy. Additionally, a monitoring mechanism, Decision No 1753/2000/EC, was put in place so that the necessary data could be collated and analysed, to assess manufacturers' progress in meeting the targets that they had committed to in the voluntary agreements (European Commission, 2000). This Decision was repealed by Regulation 443/2009, which included the necessary monitoring requirements.

The Commission published a review of the strategy in 2007, which concluded that manufacturers' progress in reducing the CO_2 emissions of the new EU car fleet was insufficient to meet the targets set by the voluntary agreements, or to meet the EU target for 2012. This Communication set out an 'integrated approach' within which a target of 130 gCO_2/km would be delivered by mandatory requirements on manufacturers, while the additional 10 gCO_2/km would be delivered by other technological improvements and by an increased used of biofuels. In this way, the Regulation remained part of a wider package of measures that would work together to reduce the CO_2 emissions from passenger cars. The proposal that eventually led to the passenger car CO_2 Regulation that was published at the end of 2007 and set a target for 2015. The Regulation contained an indicative target for 2020, which was subsequently confirmed by Regulation (EU) No 333/2014, although it is to be achieved in 2021, through a phase-in approach. A 2010 report on the implementation of the integrated approach concluded that it was unlikely that the target of the Community's strategy, to reduce average CO_2 emissions of new cars to 120 gCO_2/km by 2012, would be met, although it expected the Regulation to achieve its target (European Commission, 2010).

Light commercial vehicles

LCVs were not mentioned in the Commission's original 1995 strategy. In the early 2000s, the European Parliament and the Council asked the Commission to assess possible approaches to extending the 1995 strategy to LCVs (TNO, LAT and IEEP, 2004). As part of the preparation of the 2007 review of the strategy, the Commission held a public consultation, which expressed strong support for the extension of the strategy to LCVs (European Commission, 2007a). Mandatory requirements on LCV manufacturers, similar to those being proposed for cars, were included in the 2007 strategy. Further consultations and meetings with key stakeholders were held in the following years, before the proposal for a Regulation was published in 2009 (European Commission, 2009a). This took a similar approach to the passenger car CO_2 Regulation and contained many of the same elements. This eventually led to the publication of the LCV CO_2 Regulation in 2011, which set a target for 2017 and also included an indicative target for LCVs for 2020. This target was subsequently confirmed by Regulation (EU) No 253/2014.

Expected outcomes

The Impact Assessment accompanying the original proposal for the passenger car CO_2 Regulation estimated that the implementation of the preferred option (i.e. the option that was proposed and subsequently implemented by the Regulation) would deliver well-to-wheel (WTW) CO_2 emissions reductions, between 634 and 638 Megatonnes (Mt) of CO_2eq by 2020 at a cost of between €32.4 and €39.8 per tonne of CO_2 abated (European Commission, 2007b). It was expected that costs to manufacturers would increase by between €620 and €1,670 per vehicle (in 2006 prices) and that the retail price of cars would increase by around 5% as a result of the Regulation. The net present value (NPV) of costs to society were estimated at between €20.5 billion and €21.7 billion for the period 2006 to 2020. In its Impact Assessment, the LCV CO_2 Regulation was estimated to deliver emissions reductions of around 60 $MtCO_2$ between 2010 and 2020, with costs to manufacturers of €1,798 per vehicle (in 2007 prices) and retail price increases per vehicle of between 5.4% and 9.9% depending on assumptions about mass increases. Other anticipated benefits included net economic benefits to vehicle operators and increases in employment as a result of the higher added value on the vehicle (European Commission, 2009b).

Trends relevant to the CO_2 emissions of LDVs

The ultimate aim of the Regulations was to deliver CO_2 emission reductions in the real world. While CO_2 emissions performance, as measured on the laboratory test cycle, is one element of this, there are other external trends that influence CO_2 emissions from the transport sector. This includes the decline in the amount of both passenger and freight transport that was being undertaken, the potential reasons for this and the level and composition of fuel use by transport mode. In recent years, there has been a decline in GHG emissions from all transport modes, including road transport where emissions decreased by 9% between 2007 and 2012 (European Commission, 2014a). There is some debate as to the extent to which the observed reductions in GHGs are solely the result of the economic crisis or whether they represent a fundamental change to trends in the transport sector. The EU is becoming increasingly dependent on imports for diesel, i.e. it uses more diesel than is being refined in the EU and so needs to import the remainder (although recent trends are less clear), while the EU has a surplus of petrol that it can export. In relation to other types of fuel and energy used by the transport sector, the main change in recent years has been a small increase in the use of biofuels for road transport. Even though transport's fuel use and GHG emissions have begun to decline, the sector is still a major consumer of energy. In 2012, transport consumed 32% of the EU's final energy consumption, which was up from 28% in 1995, to make transport the largest final consumer of energy by sector (European Commission, 2014a).

The need for evaluation

Following agreement on the original Regulations, various issues came to light, in relation to whether the Regulations were as cost-effective as they could be and whether they breached the principle of technological neutrality. The issue of technological neutrality was increasingly recognised as being important in the context of the LDV CO_2 Regulations. In the Impact Assessments that accompanied the original Regulations, there was no mention of the need to ensure technological neutrality. However, in the Impact Assessment accompanying the proposal to confirm the 2020 targets, 'technological neutrality' was one of the criteria that was used to assess whether options for changing modalities should be considered in the context of achieving the 2020 targets (European Commission, 2012). Evidence also arose which suggested that different types of vehicles travel different distances to those assumed in the Regulations. If these differences were taken account of in the passenger car CO_2 Regulation, the fleet-wide cost of achieving the same CO_2 reduction could be reduced, and so improve the cost-effectiveness and efficiency of that Regulation (Ricardo-AEA and TEPR, 2014). Finally, there are incentives in the Regulations for the introduction of vehicles with alternative powertrains, e.g. battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs), that means that these vehicles are incentivised more by the Regulations than would be justified on the basis of their WTW CO_2 emissions. This is due to the fact that BEVs and FCEVs have zero tailpipe CO_2 emissions, as measured on the test cycle and can also benefit from super-credits[2]. Therefore, a clear need for an evaluation arose following the emergence of issues ex-post the policy implementation. The evaluation also provided insights into the extent to which the Regulations were fit for purpose beyond 2020. The evaluation was a precursor to development of post-2020 targets for CO_2 emissions reductions from LDVs, as the European Commission requires evaluations of existing policies to take place prior to any legislative changes. The original Regulations set emission reduction targets in relation to cars for 2015 and to LCVs for 2017. Both of these Regulations were amended, by Regulation (EU) No 333/2014 and Regulation (EU) No 253/2014 respectively, in order to set additional targets for 2021 for cars and for 2020 for LCVs (European Commission, 2014b; 2014c). These Regulations were repealed by Regulation (EU) 2019/631, which sets revised CO_2 emission performance standards for new passenger cars and LCVs. This Regulation came into force in January 2020, following the evaluation. The Regulation sets fleet-wide emission targets for 2025 and 2030 for new passenger cars and LCVs, relative to 2021.

[2] Credits which give manufacturers additional incentives to produce vehicles with low emissions by counting these as additional vehicles against their targets.

Methodology

Introduction to evaluation questions

The primary objective was to conduct a formal evaluation of the passenger car CO_2 Regulation and the LCV CO_2 Regulation. With this in mind, the priorities of the study were used to formulate a list of evaluation questions, covering the whole range of evaluation topics. These questions were developed in the context of a conventional and well-established evaluation framework that is regularly used by the European Commission. Table 1 presents the evaluation criteria and their associated evaluation questions.

Table 1. Evaluation criteria and associated evaluation questions

Evaluation criteria	Question(s)
Relevance	To what extent do the objectives of the Regulations still respond to the needs?
Effectiveness	To what degree have the Regulations contributed to achieving their targets and what are their weaknesses? To what extent have the Regulations been more successful in achieving their objectives compared to the voluntary agreement on car CO2 emissions? How do the effects of the Regulations correspond to the objectives?
Efficiency	Are the costs resulting from the implementation of the Regulations proportional to the results that have been achieved? What are the major sources of inefficiencies? What steps could be taken to improve the efficiency of the Regulations? Are there missing tools and/or actions to implement the Regulations more efficiently?
Coherence	How coherent are the Regulations' modalities with their objectives? How well do the Regulations fit with other EU policy objectives?
EU added value	What is the EU added value of the Regulations? To what extent could the changes brought by the Regulations have been achieved by national or individuals' measures only? Are there other technological, economic or administrative issues that are not covered by the existing Regulations and that could be introduced in view of their potential added value?

Methods and processes used

Desk and field research

The first stage of the evaluation was to collect data, which comprised desk research, analysis of official data sources and stakeholder engagement through interviews and online surveys. The literature review covered various relevant reports, policy documents, academic and scientific articles, databases, as well as European Commission consultations and work performed previously by the evaluation study team. The sources were primarily selected by the study team, and were supplemented by suggestions from stakeholders. Over 230 pieces of literature were used in total, and conclusions emerging from the literature review were supplemented by information collected through other means. Desk research was supported by field research activities, which involved the use of online surveys and interviews. The survey responses were complemented by the telephone interviews, to improve response rates and to enrich questionnaire responses. Two survey questionnaires were developed and used for the consultation process; the main questionnaire focused on the EU car and LCV CO_2 Regulations and was used to gather information from all actors apart from international (non-EU) government organisations. The main questionnaire included a range of open and closed questions on the following themes:

- The relevance of the Regulations, at the time and in 2030.
- The effectiveness of the Regulations, considering their impacts on CO_2 emissions both during the test cycle and in real world conditions.
- Suggestions on how the effectiveness and efficiency of the Regulations could be improved.
- Identifying and providing data on cost factors such as costs to industry, public authorities or consumers.

- Identifying aspects within and between the Regulations that are not considered coherent and seeking suggestions on how this could be improved.

A separate questionnaire was developed for international government organisations that focused on gathering information on legislative measures introduced in their respective countries for regulating CO_2 emissions and/or the fuel economy of light duty vehicles. This second questionnaire was sent to the relevant government representatives in the USA, Canada, Mexico, South Korea and Switzerland, to source views on whether there is a case for greater levels of international harmonisation of vehicle CO/fuel economy standards. A summary of the stakeholder engagement is provided in Table 2.

Table 2. Summary of stakeholder engagement

Type of stakeholder	Approached	Responded	Response rate
Interviews			
Commission officials	2	2	100%
Industry associations	8	6	75%
Manufacturers/suppliers	9	7	78%
Vehicle user/consumer groups (including safety, business workers)	5	2	40%
NGOs/research	5	4	80%
Other (safety, business, workers)	5	0	0%
Total (interviews)	**34**	**21**	**62%**
Surveys			
Industry associations	25	3	12%
Manufacturers/suppliers	8	5	63%
Public authority/ administration	28	14 (12)*	50% (43%)
Vehicle user/consumer groups	2	1	50%
NGOs	22	6	27%
Fuels/energy	7	5	71%
Non-EU international governments	5	3	60%
Other	2	2	100%
Total (survey)	**99**	**39**	**39%**

**Although there were 14 completed responses for Member States, in two countries a couple of ministry departments completed the survey. Therefore, only 12 Member States are represented in the responses.*

Comparative analysis against a counterfactual scenario

An important aspect of any evaluation is to compare the outcomes of the intervention with what would have occurred in the absence of the intervention. To carry out analysis of this nature, a baseline counterfactual scenario is required. The baseline represents the starting point for analysis of ex-post impacts and can be used for quantifying the effects of the intervention on costs and other key outcome indicators. It is important to stress that the presence of differences between the baseline scenario and the actual outcomes, do not, on their own, indicate direct causal relationships between the intervention and the actual outcomes. Two baselines were required: one for evaluating the passenger car CO_2 Regulation and one for the LCV CO_2 Regulation.

For passenger cars (see Figure 1), the baseline scenario takes actual CO_2 emissions achieved in 2006 and assumes that, in the absence of the Regulation, there would have been annual improvements of 0.5 gCO_2/km per year until 2013. This assumption of autonomous improvement is based on the average rate of gCO_2/km reduction between 1990 and 1996. Historical evidence indicates that, in the absence of regulatory measures, vehicle fuel economy remains static or can worsen (National Research Council of the National Academies, 2014). In the case of passenger cars in the EU, the existence of the ACEA voluntary agreement on car CO_2 emissions

immediately prior to the introduction of the Regulation adds some complication. It was assumed that investments made by manufacturers in CO_2 abatement technologies for meeting the voluntary agreement targets continued to have some limited impacts up to 2013. The baseline counterfactual scenario used in the evaluation was not the same as the one used in the original Impact Assessment. This was because the original Impact Assessment was based on assessing the impacts of achieving the 130 gCO_2/km target by 2012, and it assumed that car manufacturers would achieve the ACEA voluntary agreement target of 140 gCO_2/km by 2008, and that there would be no change in fleet-average emissions between 2008 and 2012. In practice, the Regulation required full achievement of the target by 2015, and the voluntary agreement target was not achieved in 2008, but it is likely that it will have continued to have had impacts on fleet-average emissions beyond 2008.

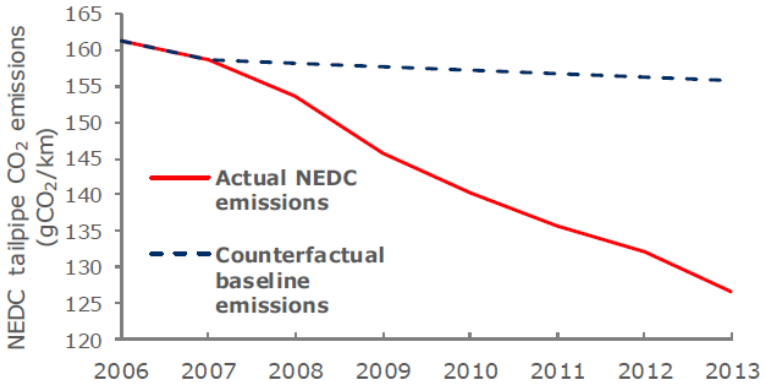

Figure 1. Baseline counterfactual scenario for passenger cars.

For LCVs (see Figure 2), there was no voluntary agreement in place prior to the introduction of the Regulation and hence it was assumed for the baseline scenario that fleet-average emissions performance (in gCO_2/km) remained static from 2009 (the year the Regulation was announced) onwards. The baseline scenario used for LCVs was different to that used in the original Impact Assessment, due to the fact that the available data on the pre-Regulation emissions performance of LCVs has improved over the last few years. Prior to 2009, the quality and availability of data on CO_2 emissions from LCVs was poor. Unlike for cars, there was no requirement to gather and publish data on the CO_2 emissions performance of LCVs at the time. The only data available was an estimate for new LCVs registered in 2007 of 203 gCO_2/km. No data was available for 2008 and better quality estimates are now available for 2009, 2010 and 2011. The available data appeared to indicate that even before the Regulations were announced, LCV emissions declined from 203 gCO_2/km in 2007 to 185 gCO_2/km in 2009 (9% reduction). Whilst it is possible that a reduction of this level actually occurred, it is likely that improvements in the robustness and availability of data on LCV CO_2 emissions performance account for much of the apparent improvement. The 2007 figure of 203 gCO_2/km is important, as it was used to underpin much of the analysis of the costs and benefits of setting a regulatory target of 175 gCO_2/km undertaken as part of the original Impact Assessment. If average LCV emissions performance in 2009 was actually 185 gCO_2/km, then it is likely that the original Impact Assessment from 2009 overestimated the amount of effort required to achieve the 175 gCO_2/km target.

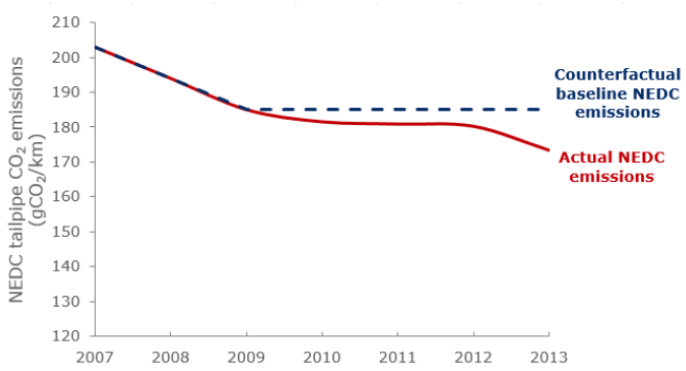

Figure 2. Baseline counterfactual scenario for LCVs.

Regression analysis

The quantitative analysis conducted using the baseline was supplemented by further quantitative analysis using an empirical approach. Data from the European Environment Agency (EEA) passenger car and van CO_2 monitoring databases (EEA, 2019a; EEA, 2019b), which are published each year, were analysed using a regression model that attempted to quantify the impact of the Regulation, while controlling for other factors that may have had an impact on new car emissions. Regression analysis is a statistical technique that provides a measure of the relationship among variables. Specifically, it aims to quantify how a dependent variable changes when one of the independent variables (i.e. explanatory variable) is varied, while the other independent variables are held fixed.

Research limitations

There are a number of limitations that restricted the extent to which the evaluation of the car and LCV CO_2 Regulations could be fully comprehensive. Of particular importance was the timing of the evaluation. The car CO_2 Regulation was introduced in 2009 and the LCV CO_2 Regulation was introduced in 2011. Whilst in both cases, their initial emissions reductions targets for 2015 (cars) and 2017 (LCVs) were already met (early, in both cases), the amount of data available on actual outcomes was limited. For example, in the case of LCVs, there were only two years of official monitoring data available (i.e. for 2012 and 2013) and this made a full assessment of effectiveness and efficiency more complex. Robust data on LCV CO_2 emissions prior to 2012 was not readily available. However, the study team supplemented the available data with estimates available from the literature for the years 2007, 2009 and 2010. The data used represented the best available estimates and could be considered to be sufficiently representative for the purposes of ascertaining trends.

For assessing costs, emissions benefits and cost-effectiveness, it was necessary to construct a baseline scenario. This was made more complex by the fact that for passenger cars, a voluntary agreement on reducing CO_2 emissions was in place immediately prior to the introduction of the car CO_2 Regulation. The voluntary agreement led to reductions in passenger car CO_2 emissions between 1998 and 2007, but it was not clear whether reductions would have continued beyond this time in the absence of a Regulation, and if so, what level of annual emissions reduction would have been achieved between 2007 and 2013. For LCVs, there was a lack of high-quality data on emissions performance prior to 2012 and consequently, there are limitations on how robust the baseline scenario can be. For the empirical research, based on regression analysis of the official monitoring data, there are several limitations. Ideally, data would be available to allow comparisons of observations with and without treatment. This would allow the use of “difference in difference” estimation, which attempts to mimic an experimental setting by estimating the difference in the differences between treatment groups and non-treatment groups over time. There was no control group because the Regulation was implemented in all Member States and therefore the analysis relied on the variation in the data before and after the Regulation. As a result, the selection of appropriate control variables was important, and great care was taken when specifying the model. Secondly, it was not possible to include year fixed effects because the treatment (i.e. Regulation) is

determined in time. Inclusion of year fixed effects would not allow the estimation of the impacts of all fixed effects as well as the Regulation. Instead, a time trend was introduced to control for changes in CO_2 emissions in time not explained by the control variables. Thirdly, omitted variables that are correlated both with the Regulation and the CO_2 emissions can introduce bias to the estimated effect of the Regulation. For example, consumers' environmental preferences and technological development are potentially omitted variables. The trend variable likely captures the technological development to an extent, although it is not a perfect proxy. Due to these limitations, the results of the regression analysis were cross-checked with other literature sources, in order to determine whether the findings were in line with other analysis.

Main findings

Relevance

The evaluation of the 'relevance' of the Regulations aimed to identify the extent to which the objectives of the intervention remain pertinent to the needs, problems and issues that needed to be addressed. The original Commission proposals and their associated Impact Assessments defined the rationale for the Regulations consisting of four 'needs' (European Commission, 2007b; 2009b). The evaluation concluded that the Regulations were still valid, as follows:

- All sectors still needed to contribute to the fight against climate change: international scientific bodies, the European Commission and stakeholders generally agree that there is a need to fight climate change.
- The CO_2 performance of new vehicles needs to improve at a faster rate: since LDVs account for the majority of CO_2 emissions from transport, reductions in their emissions are required in order to contribute to overall GHG reductions.
- Road transport needs to use less oil. Even if the trends towards the increasing diversification of the fuels and energy sources used by transport continued, it would still be prudent to improve the security of energy supply since the vast majority of oil used in the EU is imported.
- CO_2 reductions must be delivered cost-effectively without undermining either sustainable mobility or the competitiveness of the automotive industry. The importance of maintaining sustainable mobility was emphasised in the 2011 Transport White Paper.

Effectiveness

The analysis suggested that the car CO_2 Regulation was likely to have accounted for 65-85% of the reductions in tailpipe emissions achieved following the introduction of the Regulation. The Regulations were found to have been more successful in reducing CO_2 emissions compared to voluntary agreements from industry, which achieved an estimated rate of annual improvement in CO_2 of 1.1 to 1.9 gCO_2/km compared to the annual improvement rate achieved by the Regulations of 3.4 to 4.8 gCO_2/km. For LCVs, the fleet wide average emissions exceeded the required target for 2017, and the rapid rate of CO_2 emission reductions suggested that the Regulations played an important role in speeding up specific emission reductions. The analysis highlighted some key weaknesses for consideration in future policy proposals:

- **Test cycle**: The lab-based emissions test cycle used at the time for certifying the emissions performance of new cars and LCVs did not provide an accurate reflection of real-world emissions. This was a significant concern, as the increasing discrepancy between test cycle and real-world emissions performance has eroded the benefits of the Regulations. We note that the test-cycle used at the time (known as the New European Driving Cycle (NEDC)) has subsequently been replaced by an improved emissions certification test cycle (known as the Worldwide harmonized Light vehicle Test Procedure (WLTP)).
- **Well-to-tank (WTT) emissions**: The Regulations incentivise the use of powertrains that have "zero" tailpipe CO_2 emissions as measured on the test cycle, but which have higher indirect emissions associated with their production than fossil fuels. These indirect, non-tailpipe emissions are not considered within the Regulations. Although indirect emissions were not taken into account, WTW emissions were

reviewed, and the Regulations still led to a reduction in overall WTW emissions associated with LDVs. Figure 3 presents the lifetime CO_2 emissions associated with cars with different technologies.

- **Embedded emissions**: The Regulations incentivise the use of vehicles that have higher GHG emissions associated with their production and disposal than more conventional vehicles, which are also not considered within the Regulations.

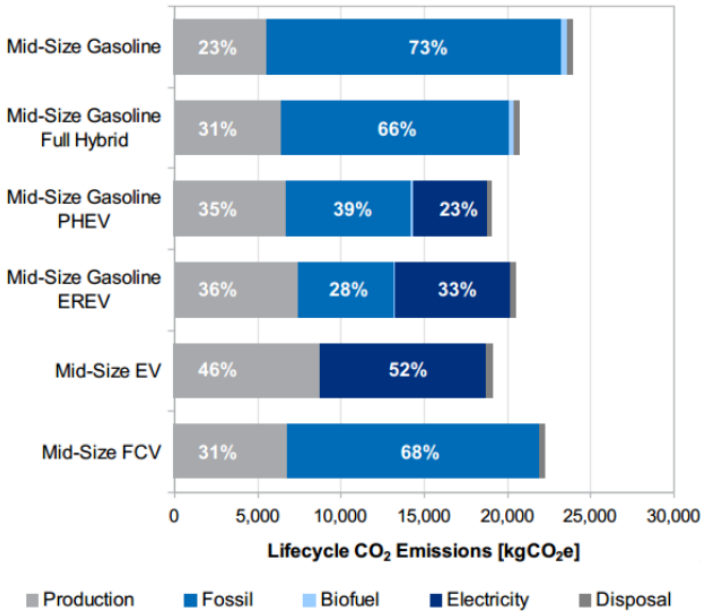

Figure 3. Lifetime CO_2 emission associated with production, fuel and energy use and disposal for mid-size cars with different technologies.

Other potential measures (super-credits and phasing in of the targets) did not appear to have significantly weakened the targets in practice. The impact of derogations for small volume and niche manufacturers were relatively small. In terms of the impact on life cycle emissions, the analysis did not indicate that there were environmental trade-offs between types of pollutants or life cycle stages. In the longer term, the potential for burden-shifting was expected to be much greater, particularly considering batteries in hybrid and electric vehicles. At the same time, technological developments in production processes, battery lifetimes and the decarbonisation of the electricity sector mean that the overall impact is still likely to be positive. Impacts on competitiveness and innovation also appeared to be positive. There were promising signs that research and development of fuel-efficient technologies had ramped up. On the basis of the available information, there did not appear to be any signs of significant competitive distortion. However, data availability did not allow for a thorough analysis that could rule it out entirely. The analysis was mainly based on retail price changes, which were used as a proxy for technology costs faced by vehicle manufacturers. The evaluation also considered the potential impact of the 'rebound effect', which refers to the fact that improvements in fuel efficiency can make driving the same distance cheaper, and hence stimulate additional demand which offsets (at least partially) the increased efficiency. While it is difficult to quantify the magnitude of this effect, the evaluation estimated that there could be a small negative impact on the effectiveness of the Regulation.

Efficiency

Both of the Regulations generated net economic benefits to society. The car CO_2 Regulation generated abatement costs of -€46.4 per tonne of CO_2 abated, compared to central ex-ante estimates of +€32.4/tCO_2 to +€38.7/tCO_2. The LCV CO_2 Regulation also generated net economic benefits and emissions savings, although these were smaller than anticipated in the ex-ante Impact Assessment, primarily because the baseline emissions

estimates used were likely to have been overestimated. The overall cost effectiveness (which is measured in terms of the abatement costs per tonne of CO_2 emissions avoided) of the LCV Regulations was estimated at -€173/tCO_2, which compares favourably with the ex-ante estimates of -€38.9/tCO_2 to €32.6/tCO_2. Costs to manufacturers were much lower than originally anticipated, as emissions abatement technologies have generally proved to be less costly than expected. For passenger cars, the ex-post average unit costs associated with meeting the fleet-average 130 gCO_2/km target were estimated at €183 per car. By contrast, the ex-ante estimates of average costs to manufacturers prior to the introduction of the Regulation ranged from €430 to €984 per car. For LCVs, the average costs to manufacturers were lower than originally anticipated; average ex-post costs for meeting the 175 gCO_2/km target were estimated at €115 per vehicle, as opposed to the ex-ante estimate of €1,037 per vehicle.

Lifetime fuel expenditure savings for cars were lower than originally anticipated in the Impact Assessment, primarily because of the increasing divergence between test cycle and real-world emissions performance. Similarly, for LCVs, the fuel lifetime expenditure savings were also significantly affected by this divergence from test cycle performance. Linked to these fuel expenditure savings were losses in fuel tax revenues. For passenger cars, fuel tax revenues were estimated to have reduced by €22 billion over the time period 2006 to 2013, whilst for LCVs, the reduction in fuel tax revenue over the period 2010 to 2013 was estimated to be €1 billion. Whilst overall, the Regulations were cost efficient in achieving CO_2 emissions reductions, a key weakness relates to the NEDC test cycle not being representative of real-world emissions. The analysis carried out for this evaluation displayed that the increasing discrepancy between test cycle and real-world emissions performance eroded the expected emissions benefits and fuel expenditure savings of both the car and LCV CO_2 Regulations. The analysis suggested that some design elements (modalities) of the Regulations were likely to have had an impact on the efficiency of the Regulations. In particular, the use of mass as the utility parameter penalises vehicle mass reduction as an emissions abatement option. The analysis suggested that for mass reduction options, having 'mass' as the utility parameter was less than half as efficient as using 'footprint'.

Coherence

The two Regulations were considered to be largely coherent internally and with each other, with some important caveats:

- The derogation for niche manufacturers potentially weakened the delivery of CO_2 emissions reductions. Less than one third of the manufacturers eligible benefited from a derogation. If all of the other manufacturers that were eligible for a niche derogation applied for it, the numbers of cars covered could have increased by five times, which could have impacted the level of CO_2 emissions reductions achieved.
- Super-credits provide an incentive for manufacturers to develop and market low CO_2 emitting cars. The application of super-credits effectively increases the number of vehicles that are used to calculate the average CO_2 emissions of a manufacturer, or of the entire fleet, allowing the real average CO_2 emissions of a manufacturer to be higher than the target would otherwise imply. Due to this, there is the potential for super-credits to undermine the targets. In 2013, super-credits did not appear to have weakened the targets.
- The phase-in period covering 2020-21 for the second car CO_2 target potentially weakened the Regulation and delivered little with respect to any other objective, as manufacturers would have had sufficient time to develop their cars in order to deliver the targets. This highlighted the importance of setting a post-2020 target as soon as possible, to give manufacturers sufficient time to plan to meet this target.

In relation to the coherence between the two Regulations, the main issue identified was the different level of stringency between the targets. As 'car-derived' goods vehicles, which are constructed or adapted as a derivative of passenger vehicles, can be certified as LCVs, they are able to align with the less stringent LCV Regulation. If the targets in the respective Regulations were set to be equivalent, including a recognition that some LCVs are car-derived, and therefore could benefit from technologies applied to deliver the targets in the passenger car CO_2 Regulation, the Regulations would be far more coherent with each other. The objectives of

the LDV CO_2 Regulations were generally coherent with objectives of other GHG reduction policies and overarching EU policies. The potential conflicts with other legislation were found at the interface with non-GHG polices. The issues mainly related to specific technology choices that may have trade-offs between CO_2 and air pollutant emissions, noise or recyclability. In addition, the means of improving safety may have led to increased fuel consumption in some cases. These trade-offs do not currently appear to compromise compliance with multiple Regulations at the same time.

EU added value

The harmonisation of the market is the most crucial aspect of added-value and it is unlikely that uncoordinated action would have been as efficient. The Regulations ensure common requirements across the EU and thus minimise costs for manufacturers, whereas Member States would represent too small a market to achieve the same level of results and therefore an EU-wide approach is needed to drive industry level changes. The automotive industry requires as much regulatory certainty as possible, if it is to make the large capital investments necessary to maximise the fuel economy of new vehicles, and even more so for shifting to new primary energy sources. Performance standards can provide this certainty over a long planning horizon. In addition, there do not appear to be any plausible alternatives to achieving the same level of CO_2 emission reductions in a more cost-effective manner compared to the LDV CO_2 Regulations.

Cross-cutting issues

Since the Regulations were published, a number of issues have emerged that have the potential to affect their effectiveness. Some of these were already recognised when the Regulations were originally developed, but have become more of an issue as a result of subsequent developments and a better understanding of the relevant issues. Issues affecting the real-world CO_2 reductions of LDVs. The Regulations focus on reducing the specific CO_2 emissions of vehicles, as measured on the NEDC test cycle, as this was considered to be a suitable proxy for real-world emissions. Reductions in emissions according to this measure will deliver emissions reductions in the real-world if a number of conditions hold (i.e. the CO_2 emissions per kilometre as measured on the test cycle are an accurate reflection of real-world emissions per kilometre). At least for cars, there is evidence that these conditions are not met in practice. While the literature has paid less attention to LCVs, there are issues for these vehicles as well, or at least there was the potential for such issues to exist after 2020. There was evidence of an increasing divergence between real-world CO_2 emissions and those emissions measured on the NEDC. While the methods for collecting these data differ, in all cases the discrepancy over time was increasing and the discrepancy appeared to be increasing at similar rates. As a result, only a proportion of the emissions reductions that have been achieved on the test cycle may have been delivered in the real-world, meaning that vehicle drivers would not have received the anticipated benefit (e.g. as communicated on the label required under Directive 1999/94/EC). This would also mean that the Regulations were not delivering the real-world reductions that they appear to be if the test cycle figures were accurate.

Secondly, there is increasing evidence to suggest that there is variation in the mileages that different vehicles travel. A report for the Commission showed that on average, diesel cars are driven nearly 50% further than petrol cars over their lifetime (Ricardo-AEA and TEPR, 2014). While there was no significant difference between the way in which different masses and sizes (measured in terms of their respective footprints) of diesel cars and LCVs are driven, larger and heavier petrol cars are driven further than smaller petrol cars over their lifetime. For vehicles using alternative powertrains, indirect, well-to-tank CO_2 emissions associated with the production of electricity (and hydrogen) are a significant proportion of total lifecycle emissions. This is important, as it suggests that some of the reductions that were achieved according to the specific CO_2 emissions as measured on the test cycle will have been replaced by increased emissions elsewhere. Finally, embedded CO_2 emissions associated with electric vehicles are typically higher than the equivalent internal combustion engine (ICE) emissions, largely as a result of emissions associated with the production of the battery (Ricardo-AEA, 2014). These emissions were not taken account of in the Regulations, and so some (but by no means all) of the apparent CO_2 reductions that were achieved will have been offset by increases in production emissions.

In addition, there were also a number of issues relating to the design of the Regulations. The issue of technological neutrality has been increasingly recognised as being important in the context of the LDV CO_2 Regulations. In the Impact Assessment accompanying the proposal to confirm the 2020 targets, 'technological neutrality' was one of the criteria that was used to assess whether options for changing modalities should be considered in the context of achieving the 2020 targets (European Commission, 2012). In relation to the design of the Regulations, the choice of utility parameter for the passenger car CO_2 Regulation has been the subject of much debate (e.g. ICCT (2011)). In the original impact assessment, 'mass' (defined as the mass in running order and measured in kg) and 'footprint' (defined as 'wheelbase' multiplied by 'track width' and is measured in m^2) were the two alternative utility parameters considered for use in the passenger car CO_2 Regulation. Two of the original arguments in favour of the use of 'mass' over 'footprint', that there was a lack of data to enable the calculation of 'footprint' and that using 'footprint' would not be compatible with utility parameters used in other countries around the world, are no longer valid.

Conclusions

Although the assessment of the Regulations was largely positive, a few areas of improvement were identified, to enable the Regulations to remain relevant, coherent, effective and efficient. In regard to relevance, the need to encourage a reduction in energy use was highlighted, to account for the increasing range of fuels and energy sources that the transport modes are likely to use. Therefore, the evaluation indicated that energy efficiency would become a more important metric, as the LDV fleet moves to a more diverse mix of powertrains. Concerning effectiveness, the Regulations were successful in improving the specific CO_2 emissions of cars and LDVs. The increasing discrepancy between real-world and test cycle emissions is a key issue, which has been recognised by policy-makers and is partially addressed by the development of the revised test procedure, part of the WLTP. A lack of consideration of lifecycle and embedded emissions is a minor issue, due to the low penetration of electric and plug-in hybrid vehicles. However, as the proportion of electric vehicles is expected to rise, this will become more significant. With respect to efficiency, whilst the Regulations generated net economic benefits to society and have provided consumers with savings in fuel expenditure, both of these metrics have been adversely affected by problems with the test cycle. It was expected that the WLTP test cycle would address this issue, but the importance of sufficient checks was noted, to ensure that the test did not become subject to the problems experienced with the NEDC. It became clear from the evaluation that the costs to manufacturers assumed prior to the introduction of the Regulations were much higher than those in reality. Concerning internal coherence, the use of super-credits in future periods was presented as a consideration, as their use was not necessarily needed to incentivise the uptake of low-emission vehicles. In regard to external coherence, trade-offs did not appear to compromise compliance with multiple Regulations at the time of the evaluation.

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