



Working Paper

Closing the Emission Gap: EU CO2 Standards and Plug-in Hybrid Vehicles

Ariane Bousquet ¹, Quentin Hoarau ², Maria-Eugenia Sanin ³

Octobre 2026

¹ LAET-ENTPE

² EconomiX, Université Paris Nanterre

³ ERUDITE, Université Paris-Est Créteil (UPEC), Centre for Economics at Paris-Saclay (CEPS)

La Chaire Energie et Prospérité

La chaire Energie et Prospérité a été créée en 2015 pour éclairer les décisions des acteurs publics et privés dans le pilotage de la transition énergétique. Les travaux de recherche conduits s'attachent aux impacts de la transition énergétique sur les économies (croissance, emploi, dette), sur les secteurs d'activité (transport, construction, production d'énergie, finance), aux modes de financement associés ainsi qu'aux problématiques d'accès à l'énergie. Hébergée par la Fondation du Risque, la chaire bénéficie du soutien de l'ADEME, de la Caisse des Dépôts, d'Engie et du groupe Renault.

Les opinions exprimées dans ce papier sont celles de son (ses) auteur(s) et ne reflètent pas nécessairement celles de la Chaire Energie et Prospérité. Ce document est publié sous l'entière responsabilité de son (ses) auteur(s).

Les Working paper de la Chaire Energie et Prospérité sont téléchargeables ici :

<http://www.chair-energy-prosperity.org/category/publications/>

Chair Energy and Prosperity

The Energy and Prosperity Chair was created in 2015 to inform decisions of public and private actors in managing the energy transition. The Chair research deals with the impacts of energy transition on national economies (growth, employment, debt...), on specific sectors (transportation, construction, energy, finance), on access to energy and with the associated financing issues. Hosted by the Fondation du Risque, the chair has the support of ADEME, the Caisse des Dépôts, Engie and the Groupe Renault.

The opinions expressed in this paper are those of the author(s) and do not necessarily reflect the position of Chair Energy and Prosperity. It is therefore published under the sole responsibility of its author(s).

Chair energy and Prosperity working paper can be downloaded here:

<http://www.chair-energy-prosperity.org/en/category/publications-2/>

Closing the Emission Gap: EU CO₂ Standards and Plug-in Hybrid Vehicles

Ariane Bousquet^a, Quentin Hoarau^b, Maria-Eugenia Sanin^c

^a*LAET-ENTPE*

^b*EconomiX, Université Paris Nanterre*

^c*ERUDITE, Université Paris-Est Créteil (UPEC) and Centre for Economics at Paris-Saclay (CEPS)*

Abstract

Plug-in hybrid electric vehicles (PHEVs) occupy a particular position in European CO₂ regulation. Their certified emissions depend on a regulatory Utility Factor (UF), which determines the assumed share of driving performed in electric mode. Evidence from real-world driving has shown that this share was substantially overestimated, leading European regulators to revise the UF from 2025 onward. This reform changes the compliance role of PHEV for car manufacturers facing the EU emission standards. This paper quantifies the market, environmental and welfare consequences of this reform.

We estimate a structural model of demand and multi-product supply for the French and German new-car markets over 2020–2024, incorporating manufacturer-specific CO₂ standards and regulatory pooling. We use the model to distinguish the effect of correcting PHEV emissions accounting from that of tightening the fleet-wide CO₂ target.

Correcting the UF alone increases the regulatory cost of PHEVs, lowers BEV prices, and shifts demand from PHEVs toward BEV. The reform reduces CO₂ emissions and generates positive welfare effects. Its effects become much larger when combined with the tighter 2025 fleet target: the stricter target increases the incentive to sell low-emission vehicles, while the UF reform changes which technologies provide compliance value. Welfare costs under a fixed product set are substantial, but fall sharply when additional BEV models are available. Finally, the pooling arrangements observed in 2025 significantly reduce manufacturers' statutory penalties, at the cost of a reduction in emissions abatement.

JEL classifications— H22, H23, Q52, Q58, L62

Keywords: Environmental Policy, Automobile, Standards, PHEV

[Preliminary version, do not circulate without authorization](#)

1. Introduction

Decarbonizing passenger transport requires a profound transformation of the technological composition of the automobile market. In the European Union, the main instrument driving this transition is the fleet-average CO₂ standard imposed on car manufacturers. Because compliance is assessed on the sales-weighted emissions of the vehicles sold by each manufacturer, the regulation directly affects firms' incentives to sell different powertrain technologies. Low-emission vehicles create compliance capacity that allows manufacturers to continue selling more emitting models. The effectiveness and incidence of the standard therefore depend not only on how stringent the emission target is, but also on which technologies are treated as low-emission for regulatory purposes.

Plug-in hybrid electric vehicles (PHEVs) are particularly important in this respect. Combining an electric drivetrain with an internal combustion engine, PHEVs have played the role of a transition technology in the European decarbonization strategy. Their low certified CO₂ emissions have made them valuable for manufacturer compliance while preserving part of the industrial and technological infrastructure associated with combustion engines. Yet their environmental performance depends critically on actual usage. In particular, it depends on how frequently vehicles are charged and on the share of kilometres effectively driven in electric mode.

European regulation accounts for this through the Utility Factor (UF), which determines the assumed share of electric driving used to compute the certified CO₂ emissions of PHEVs. Evidence from real-world driving shows that this share has historically been overestimated, implying substantially higher real-world emissions than certified emissions ([Dornoff et al., 2024](#); [Transport & Environment, 2025](#); [Joint Research Centre \(JRC\), 2025](#)). In response, the European Commission revised the UF, with successive adjustments taking effect in 2025 and 2027.¹ For a given vehicle, the reform reduces the assumed share of electric driving and therefore raises the CO₂ emissions attributed to PHEVs for regulatory compliance.

This reform takes place at a particularly important moment for European automotive policy. Regulation (EU) 2023/851 established increasingly stringent fleet targets culminating in a 100% reduction in tailpipe CO₂ emissions from new cars in 2035. In December 2025, however, the European Commission proposed replacing the 2035 target by a 90% reduction requirement, with the remaining emissions compensated through other mechanisms. If adopted, this revision would preserve a potential role for PHEVs and other combustion-engine technologies beyond 2035. The current policy debate therefore concerns two distinct dimensions of the regulation at the same time: *how stringent* the fleet standard should be, and *which technologies count as low-carbon* when manufacturers comply with it.

Distinguishing these two margins is important. Tightening the fleet target increases the scarcity and hence the value of compliance. Correcting the measurement of PHEV emissions instead changes

¹Regulation (EU) 2023/443.

the relative compliance value of technologies. A stringent standard combined with favorable PHEV accounting may encourage manufacturers to rely on PHEVs to meet their targets, whereas the same standard under a corrected Utility Factor may redirect sales toward BEVs. Measurement rules can therefore affect not only short-run emissions and compliance costs, but also firms’ technological incentives and the longer-run direction of the automotive transition. These effects have important environmental consequences and potentially large implications for consumers, manufacturers, and an industry undergoing rapid technological transformation.

This paper studies how correcting the regulatory emissions of PHEVs affects the European automobile market and how this effect interacts with the stringency of fleet CO₂ standards. We make several contributions to the existing literature.

First, we construct a harmonized product-level dataset covering the French and German new-car markets between 2020 and 2024. The dataset combines publicly available vehicle registrations and regulatory emissions with prices, technical characteristics, operating costs and manufacturer information, and reconstructs the variables needed to evaluate compliance with European CO₂ standards.

Second, we develop and estimate a structural model of differentiated-product demand and oligopolistic supply that incorporates a central feature of the European regulation: compliance pooling among manufacturers. Existing theoretical work shows that pooling can affect the incidence of fleet regulation ([Dertwinkel-Kalt and Wey, 2025](#)), but this mechanism has not, to our knowledge, been quantified in an estimated structural model of the European car market. We extend the framework of [Durrmeyer and Samano \(2018\)](#) by representing compliance allocation within observed pools through an internal credit market. Manufacturers remain independent competitors in vehicle prices, while the marginal value of compliance is determined at the pool level and bounded by the statutory excess-emissions premium.

Third, we provide the first structural evaluation, to our knowledge, of the PHEV Utility Factor reform. The reform provides a useful setting to distinguish between two margins of fleet regulation: tightening the aggregate emissions target and changing the regulatory measurement of a particular technology. We first isolate the effect of correcting PHEV emissions measurement while holding the fleet target, product set and pooling structure fixed. We then combine the UF reform with the tighter 2025–2029 target and examine how its effects depend on two additional margins of adjustment: the availability of BEV models and manufacturers’ pooling arrangements. This allows us to study not only the direct effect of the reform, but also the mechanisms through which regulatory measurement, technological availability and compliance flexibility jointly shape market outcomes and welfare.

Our results highlight the importance of distinguishing target stringency from technology measurement. Correcting the Utility Factor reduces the compliance advantage of PHEVs and redirects the technological response toward BEVs, with larger effects when the underlying fleet standard is tighter. We further show that the welfare cost of a stringent standard depends importantly on the available product set: expanding

the BEV choice set provides an additional margin of substitution and substantially mitigates the cost of compliance. Finally, pooling changes both the distribution and the aggregate cost of compliance across manufacturers, showing that the organization of regulatory flexibility matters for the incidence of the standard.

Our analysis relates to the structural literature on fuel-economy and fleet-emission regulation (Goldberg, 2003; Anderson, 2010; Jacobsen, 2013; Durrmeyer and Samano, 2018; Reynaert, 2021; Reynaert and Sallee, 2021). We complement this literature by studying a reform of the regulatory metric itself, rather than only a change in the stringency of the standard, and by explicitly incorporating European compliance pools into the equilibrium model.

The remainder of the paper is organized as follows. Section 2 describes the institutional background. Section 3 presents the data and descriptive evidence. Section 4 develops the structural model. Section 5 discusses identification and estimation results. Section 6 presents the policy counterfactuals, and Section 7 concludes.

2. Institutional and technical background

2.1. The evolution of EU CO₂ standards

CO₂ emission standards for new passenger cars constitute one of the main instruments used by the European Union to reduce emissions from road transport. The regulation does not impose an emission ceiling on each individual vehicle. Instead, manufacturers must comply with a target defined over the average CO₂ emissions of their newly registered fleet. This fleet-averaging structure gives manufacturers flexibility over the technological composition of their sales: vehicles with low certified emissions can compensate for the sale of more emitting models.

The current regulatory framework is primarily defined by Regulation (EU) 2019/631.² A key feature of the system is that manufacturer-specific targets are attribute-based and depend on the average mass of the registered fleet. This feature has received particular attention in the economic literature because it affects the effective stringency of the standard and firms' incentives over vehicle characteristics (Reynaert, 2021).

The regulatory trajectory has progressively tightened. Regulation (EU) 2023/851, adopted as part of the *Fit for 55* package, strengthened the post-2025 targets and established a 55% reduction in fleet-average CO₂ emissions for new passenger cars from 2030, followed by a 100% reduction from 2035.³ The previously adopted 15% reduction applies over 2025–2029. Table 1 summarizes the legally adopted trajectory.

²Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 setting CO₂ emission performance standards for new passenger cars and for new light commercial vehicles.

³Regulation (EU) 2023/851 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2019/631 as regards strengthening the CO₂ emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition.

Table 1: EU passenger-car CO₂ reduction targets

Period	Reduction relative to 2021
2025–2029	15%
2030–2034	55%
2035 onwards	100%

Several flexibility mechanisms operate around this trajectory. During 2020–2022, very-low-emission vehicles benefited from a declining “super-credit” multiplier, which increased their weight in the calculation of fleet-average emissions. The regulation also allows manufacturers to form compliance pools, discussed below, and imposes an excess-emissions premium when the applicable target is exceeded.

More recently, the long-run trajectory has again become politically contested. In December 2025, the European Commission proposed replacing the 100% reduction requirement from 2035 by a 90% tailpipe-emissions reduction, with the remaining emissions offset through additional mechanisms (COM(2025) 995 final). This proposal would preserve a potential role for PHEVs and other combustion-engine technologies beyond 2035. It has not, however, replaced the legislation currently in force.

2.2. PHEV emissions and the Utility Factor reform

PHEVs occupy a particular position within the European regulatory framework because their certified CO₂ emissions depend not only on vehicle technology, but also on assumptions about how the vehicle is used. A PHEV can operate in charge-depleting mode, relying primarily on electricity stored in the battery, and in charge-sustaining mode, in which the combustion engine provides a much larger share of propulsion. Its official fuel consumption and CO₂ emissions therefore depend on the assumed fraction of driving performed in each mode.

Under the WLTP type-approval procedure, this fraction is summarized by the Utility Factor (UF). The UF is an increasing function of the vehicle’s all-electric range and determines the relative weight assigned to charge-depleting and charge-sustaining operation when certified emissions are calculated. In simplified form,

$$e_j = UF_j e_j^{CD} + (1 - UF_j) e_j^{CS}, \quad (1)$$

where e_j^{CD} and e_j^{CS} denote emissions in charge-depleting and charge-sustaining operation, respectively. A higher Utility Factor therefore reduces the regulatory CO₂ emissions attributed to a PHEV, all else equal.

This assumption has become increasingly important as evidence on real-world PHEV use has accumulated. A number of studies show that PHEVs are driven electrically less often than assumed under the type-approval procedure and therefore consume substantially more fuel and emit more CO₂ in actual use than suggested by certified values (Plötz et al., 2018, 2021; Tansini et al., 2022). The discrepancy is

particularly pronounced when vehicles are infrequently charged, as is often observed for company cars.

The European Commission explicitly responded to this evidence in Commission Regulation (EU) 2023/443, which revised the Utility Factor calibration used for PHEV type approval.⁴ The reform is introduced in two steps. The pre-reform calibration uses a normalized distance of 800 km. This parameter increases to 2,200 km from 2025 and to 4,260 km from 2027. For a given all-electric range, these changes reduce the Utility Factor and therefore increase the regulatory emissions assigned to PHEVs.

Table 2: Evolution of the PHEV Utility Factor calibration

Calibration	Application	Normalized distance (km)
Pre-reform UF	Before 2025	800
Step 1	From 2025	2,200
Step 2	From 2027	4,260

Figure 1 illustrates how these successive calibrations modify the Utility Factor as a function of the vehicle's all-electric range. For any given electric range, the 2025 and especially the 2027 calibration assign a lower share of electric driving than the pre-reform procedure. The reform therefore reduces the regulatory advantage previously associated with PHEVs without changing their underlying technical characteristics.

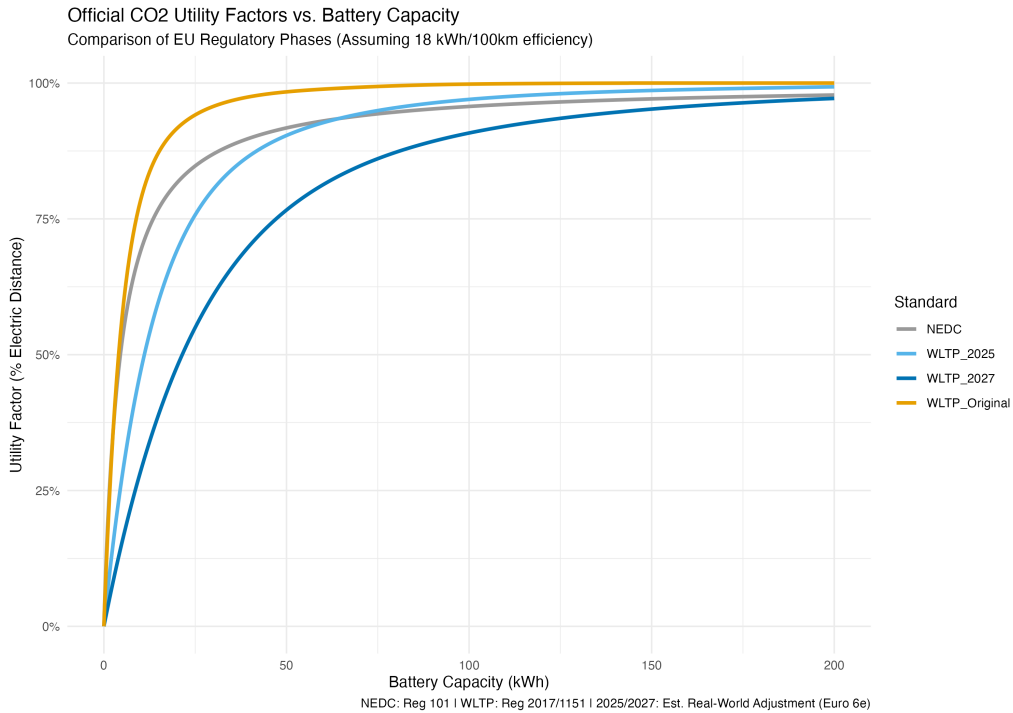


Figure 1: Utility Factor curves under alternative regulatory calibrations

This change has a direct implication for manufacturer compliance. A lower Utility Factor raises the

⁴Commission Regulation (EU) 2023/443 of 8 February 2023 amending Regulation (EU) 2017/1151 as regards the emission type-approval procedures for light passenger and commercial vehicles.

certified CO₂ emissions of a PHEV and therefore reduces the contribution of its sale to meeting the fleet-average standard. The reform is thus fundamentally different from a tightening of the CO₂ target itself: it changes the regulatory treatment of one technology rather than the overall level of the standard. This distinction is central to the counterfactual analysis developed below.

2.3. Compliance flexibility and pooling

Fleet averaging is not the only source of flexibility available to manufacturers. Regulation (EU) 2019/631 allows manufacturers to form regulatory pools for the purpose of meeting their CO₂ obligations jointly. A pool is treated as a single manufacturer for compliance purposes, so that the low emissions of one member can compensate for higher emissions of another. Pooling agreements may cover several calendar years, subject to the conditions specified in the Regulation.

Pooling can therefore be particularly valuable when manufacturers have different technology portfolios. A manufacturer with a large BEV share may generate substantial regulatory surplus, while a manufacturer specialized in heavier or more combustion-intensive vehicles may face a deficit. Pooling allows these positions to be combined rather than requiring each manufacturer to meet its target independently.

At the same time, pooling does not merge manufacturers commercially. For pools formed by independent firms, Regulation (EU) 2019/631 requires pooling arrangements to comply with EU competition law and limits the information that can be exchanged between pool members. The institutional framework therefore separates joint regulatory compliance from competition in vehicle markets.

A final source of flexibility is the excess-emissions premium: a manufacturer or pool whose average emissions exceed its applicable target pays €95 for each gram of excess CO₂/km multiplied by the number of newly registered vehicles. Consequently, manufacturers are not required to achieve the regulatory target at any economic cost: paying the premium remains an alternative when additional compliance is sufficiently expensive.

These different mechanisms—fleet averaging, attribute-based targets, intertemporal averaging, pooling, and the excess-emissions premium—create several margins through which manufacturers can respond to increasingly stringent CO₂ standards. The structural model developed below focuses on the interaction between pricing, PHEV emissions measurement and pooling.

3. Data

3.1. Data construction and estimation sample

Our empirical analysis focuses on the French and German new-car markets over the period 2020–2024. France and Germany are two of the largest passenger-car markets in the European Union and differ substantially in both market structure and the diffusion of electrified powertrains, providing useful variation for the analysis.

Our main source is the European Environment Agency (EEA) monitoring database on CO₂ emissions from newly registered passenger cars.⁵ The EEA data provide vehicle registrations together with information on the manufacturer, commercial model, powertrain and technical characteristics, including vehicle mass and certified WLTP CO₂ emissions. We distinguish five main powertrain technologies: gasoline, diesel, non-plug-in hybrid (HEV), plug-in hybrid (PHEV), and battery electric vehicles (BEV).

The EEA data do not contain vehicle prices. We therefore complement them with model-level information collected from the ADAC and Caradisiac websites.^{6 7} These data provide list prices and vehicle segments, which we match to the EEA records using manufacturer and commercial model information.

We aggregate registration records to the manufacturer–model–powertrain level within each country and year. A product j is therefore defined by a manufacturer, commercial model and powertrain, and a market is defined as a country–year pair. With two countries observed over five years, the data contain ten markets.

We additionally construct an expected operating cost per kilometre for each vehicle. For gasoline and diesel vehicles, fuel cost combine fuel consumption with country- and year-specific fuel prices. For BEVs, we combine electricity consumption with residential electricity prices. For PHEVs, fuel cost depend on both electricity and fuel use. We use the regulatory Utility Factor to construct the share of driving attributed to electric operation:

$$FC_{PHEV} = UF \times FC_{elec} + (1 - UF) \times FC_{fuel}, \quad (2)$$

where FC_{elec} is the cost per kilometre in electric operation and FC_{fuel} is the corresponding cost in combustion-engine operation.

The model also controls for vehicle size and body type. We distinguish compact SUVs, large SUVs, midsize vehicles, large vehicles, and an omitted compact category. Finally, we construct an indicator for domestic brands, equal to one when the historical nationality of the brand corresponds to the country in which the vehicle is sold.

To construct market shares, vehicle registrations are divided by the market size used in the demand estimation. In the current specification, market size is set to 1/6 of national population.

The matched product dataset contains 8,740 product–market observations over the ten country–year markets. After constructing the instruments and retaining observations with complete information for the preferred demand specification, the final estimation sample contains 8,340 product–market observations and 42 brands.

⁵<https://co2cars.apps.eea.europa.eu/>

⁶ADAC (*Allgemeiner Deutscher Automobil-Club*) is the German automobile club. See <https://www.adac.de/>.

⁷Caradisiac is a French specialized automotive website. See <https://www.caradisiac.com/>.

Table 3 describes the underlying product market before the final estimation restrictions. Germany offers substantially more vehicle alternatives than France. The German choice set contains between 1,118 and 1,172 products per year, compared with between 583 and 638 products in France. New-car registrations are also larger in Germany, ranging between 2.39 and 2.70 million vehicles annually, compared with 1.45–1.67 million in France.

Table 3: New-car market structure, 2020–2024

Country	Year	Products	Brands	Sales	Inside share (%)	Outside share (%)
Germany	2020	1,118	42	2,695,017	38.3	61.7
Germany	2021	1,152	48	2,386,243	33.9	66.1
Germany	2022	1,122	48	2,453,721	34.9	65.1
Germany	2023	1,166	48	2,680,687	38.1	61.9
Germany	2024	1,172	48	2,674,108	38.0	62.0
France	2020	638	35	1,671,157	29.4	70.6
France	2021	590	37	1,612,140	28.4	71.6
France	2022	583	39	1,452,113	25.6	74.4
France	2023	596	40	1,642,495	28.9	71.1
France	2024	603	44	1,612,727	28.4	71.6

Notes: A market is defined as a country–year. The table is computed on the 8,740-observation matched product sample before the final restrictions associated with the preferred estimation specification. The outside option corresponds to consumers who do not purchase a new vehicle.

3.2. Product characteristics

Table 4 reports descriptive statistics for the main product characteristics entering the demand equation. The average list price in the estimation sample is approximately €51,800, with substantial dispersion across vehicles: the interquartile range extends from €32,100 to €62,600. The average vehicle weighs 1.75 tons and has an estimated operating cost of 9.14 cents per kilometre.

Approximately half of the product–market observations correspond to a domestic brand. Compact and large SUVs each represent around 21% of the product observations, while midsize vehicles account for 24%.

The differences across powertrains are particularly relevant for our application. Table 5 reports sales-weighted average characteristics by technology.

PHEVs are the most expensive and heaviest vehicles in the sample. Their average price is approximately €60,400 and their average mass is close to two tons. BEVs are less expensive on average, at about €46,300, while gasoline vehicles are substantially lighter and cheaper. Electrified vehicles also have lower fuel cost than gasoline vehicles.

The most striking difference concerns regulatory CO₂ emissions. BEVs are assigned zero tailpipe emissions, while PHEVs emit only 51.8 g/km on average under the regulatory metric used over our estimation period. By comparison, average certified emissions are between 134 and 139 g/km for HEVs,

Table 4: Descriptive statistics of demand covariates

Variable	Mean	Std. dev.	P25	Median	P75	Min.	Max.
Price (€)	51,835	29,635	32,100	43,990	62,600	11,090	178,000
Weight (tons)	1.75	0.37	1.49	1.69	2.00	0.89	2.87
Operating cost (cents/km)	9.14	3.45	6.98	8.74	10.86	0.06	28.90
Domestic	0.499						
Compact SUV	0.206						
Large SUV	0.206						
Large	0.066						
Midsized	0.239						

Notes: Statistics are computed on the 8,340 product–market observations of the final estimation sample. Indicator-variable means correspond to the share of product–market observations belonging to each category. The omitted vehicle-segment category is Compact.

gasoline and diesel vehicles. The relatively low regulatory emission content of PHEVs, despite their high mass and price, is particularly important for their compliance value under the European fleet standard.

Table 5: Vehicle characteristics by powertrain

Powertrain	Product-market obs.	Sales	Sales share (%)	Price (€)	Weight (kg)	Fuel cost (cents/km)	CO ₂ (g/km)
BEV	1,083	2,589,153	12.6	46,267	1,788	5.52	0.0
PHEV	848	1,251,961	6.1	60,361	1,969	6.16	51.8
HEV	1,952	4,331,660	21.1	41,944	1,542	8.32	133.9
Diesel	1,757	3,863,964	18.9	34,643	1,603	7.85	139.0
Gasoline	2,700	8,453,900	41.3	25,692	1,304	9.73	135.8

Notes: Product–market observations correspond to the estimation sample. Prices, weight, fuel costs and CO₂ emissions are sales-weighted averages. Sales are aggregated over France and Germany and over the 2020–2024 period.

3.3. Technology adoption in France and Germany

Although both countries experienced rapid electrification over the sample period, the composition of this transition differs significantly between France and Germany. Figure 2 reports the evolution of new-car sales shares by powertrain.

Germany experienced a particularly rapid expansion of PHEVs during the first part of the period. Their market share increased from 7.4% in 2020 to 13.9% in 2022, before falling sharply to 6.1% in 2023 and 7.0% in 2024. BEV adoption also increased substantially, from 5.1% in 2020 to 18.1% in 2023, before declining to 13.6% in 2024. At the same time, non-plug-in hybrids expanded from 11.9% to 28.2% of German sales.

The French market followed a different technological trajectory. BEV penetration increased relatively steadily, from 6.3% of sales in 2020 to 17.5% in 2024. The strongest expansion, however, occurred among non-plug-in hybrids, whose market share increased from 9.8% to 35.9%. PHEVs remained a much smaller segment throughout the period, accounting for only 1.2% of sales in 2020 and 1.9% in 2024, with

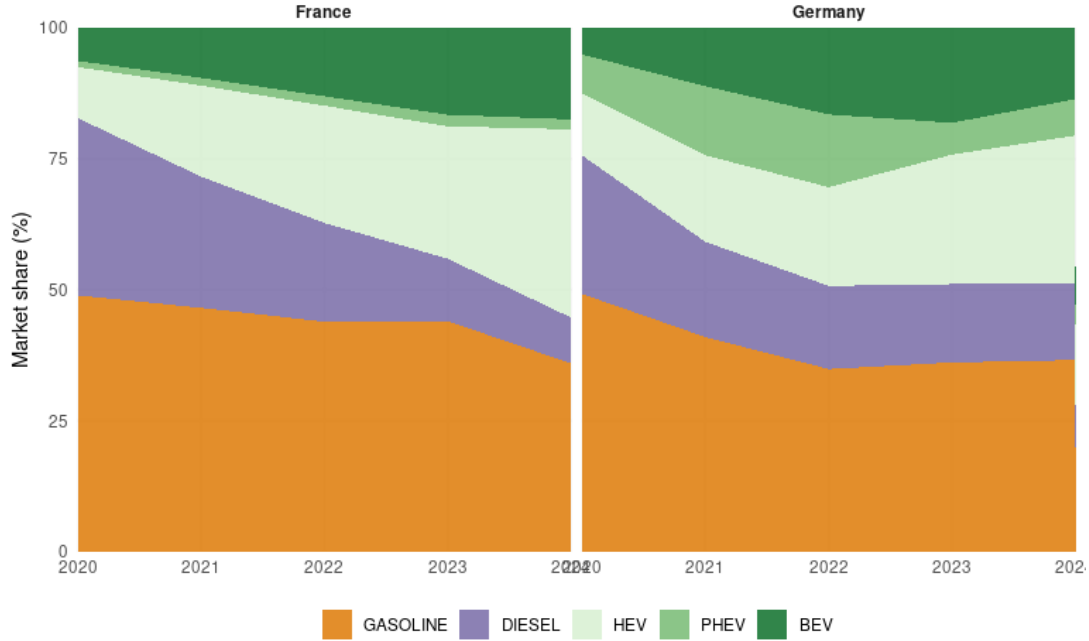


Figure 2: Powertrain composition of new-car sales in France and Germany, 2020–2024

Notes: Shares are computed from new registrations in the matched EEA product data. Source: EEA, own calculations.

a maximum of 2.2% in 2023.

These differences are useful for our analysis. In particular, German manufacturers and consumers were substantially more exposed to PHEVs during the estimation period, whereas the French electrification path relied much more heavily on BEVs and non-plug-in hybrids. The two markets therefore provide distinct initial conditions from which to evaluate a reform that specifically changes the regulatory treatment of PHEVs.

3.4. Regulatory pools

The final dimension of the data concerns the organization of manufacturers into regulatory pools. This information is central to the supply side of the model because manufacturers belonging to the same pool can jointly satisfy the fleet CO₂ standard.

Tables 6 and 7 describe the pooling structure used for the 2024 reference equilibrium. Pool membership is constructed at the brand level and corresponds to the regulatory arrangements prevailing in the baseline year.

Pooling concerns a large fraction of the market. The Volkswagen pool, composed of Audi, Cupra, Porsche, Seat, Skoda and Volkswagen, represents 31.1% of sales in the French and German markets in 2024. Stellantis accounts for another 17.9%, while the Renault–Nissan–Mitsubishi pool represents 15.3%. Together, these three pools account for almost two thirds of the market.

The technological composition of pools also differs considerably. BEVs represent more than 20%

of BMW’s sales, while PHEVs account for 17.0% of Mercedes sales and 25.1% of Volvo-pool sales. Conversely, BEVs and PHEVs represent only a small share of the Toyota pool in the 2024 sample. Pure or almost pure electric manufacturers such as Tesla, BYD and XPeng naturally have very different compliance positions.

Table 6: Composition and market position of regulatory pools, 2024

Pool	Brands	Sales	Market share (%)	BEV share (%)	PHEV share (%)	No. brands
Volkswagen	Audi, Cupra, Porsche, Seat, Skoda, Volkswagen	1,319,394	31.1	12.1	4.3	6
Stellantis	Abarth, Alfa Romeo, Citroën, DS, Fiat, Jeep, Maserati, Opel, Peugeot	760,955	17.9	15.2	1.4	9
RNM	Dacia, Mitsubishi, Nissan, Renault	651,560	15.3	10.6	0.9	4
BMW	BMW, Mini	345,970	8.1	21.9	10.2	2
Mercedes	Mercedes-Benz, Smart	281,504	6.6	15.2	17.0	2
Toyota	Lexus, Mazda, Subaru, Toyota	279,086	6.6	1.5	1.5	4
Volvo	Suzuki, Volvo	133,099	3.1	16.3	25.1	2
Hyundai	Hyundai	132,525	3.1	17.2	0.6	1
Ford	Ford	111,739	2.6	3.7	10.0	1
Kia	Kia	110,929	2.6	15.1	3.9	1
Tesla	Tesla	78,665	1.9	100.0	0.0	1
JLR	Jaguar, Land Rover	14,662	0.3	0.7	22.7	2
Honda	Honda	11,728	0.3	10.6	2.3	1
BYD	BYD	6,683	0.2	98.4	1.6	1
MG	MG	6,651	0.2	21.0	0.0	1
XPeng	XPeng	901	0.0	100.0	0.0	1

Notes: Sales and market shares are computed over the French and German new-car markets in 2024. BEV and PHEV shares refer to the composition of each pool’s sales in these two markets.

Table 7 describes the corresponding regulatory position of each pool in the 2024 baseline of the model. Because the EU target is mass-adjusted, differences in average fleet mass generate different pool-specific targets. We separately report this mass-based target and the additional relaxation associated with eco-innovation credits.

There is substantial heterogeneity in the distance to the regulatory constraint. In the baseline, Volkswagen is almost exactly at its effective target, with average regulatory emissions only 0.34 g/km below the standard. Stellantis, RNM, BMW, Mercedes, Toyota, Hyundai and Kia have larger compliance surpluses. Ford and JLR are above their effective targets and therefore pay the excess-emissions premium in the baseline equilibrium. BEV-intensive manufacturers such as Tesla, BYD and XPeng are far below their targets.

This heterogeneity is important for the counterfactual analysis. A change in the regulatory emissions assigned to PHEVs has little direct pricing effect for a pool with abundant compliance capacity, but can generate substantial adjustments for a pool initially close to its regulatory constraint.

4. Structural model

In this section we develop a structural model of demand and supply for the European new-car markets. The model is then estimated with French and German data to recover consumer preferences and manufacturers’ marginal costs, and to characterize how changes in the European CO₂ regulation affect manufacturers’ strategy, emissions and welfare.

Table 7: Baseline regulatory position of compliance pools, 2024

Pool	Mass (kg)	Eco. (g/km)	Reg. CO ₂ (g/km)	Mass target (g/km)	Effective target (g/km)	Gap excl. eco. (g/km)	Gap (g/km)	Gap (%)	Status
Volkswagen	1,583.91	0.60	121.54	121.27	121.87	0.26	-0.34	-0.3	Compliant
Stellantis	1,370.68	1.30	103.25	114.17	115.47	-10.93	-12.23	-10.6	Compliant
RNM	1,383.38	1.20	110.48	114.60	115.80	-4.12	-5.32	-4.6	Compliant
BMW	1,838.94	1.00	112.49	129.77	130.77	-17.27	-18.27	-14.0	Compliant
Mercedes	1,981.87	0.20	118.34	134.53	134.73	-16.19	-16.39	-12.2	Compliant
Toyota	1,367.57	0.50	110.88	114.07	114.57	-3.19	-3.69	-3.2	Compliant
Volvo	1,666.27	0.60	85.61	124.02	124.62	-38.40	-39.00	-31.3	Compliant
Hyundai	1,471.97	0.00	109.83	117.55	117.55	-7.72	-7.72	-6.6	Compliant
Ford	1,619.05	0.00	132.03	122.44	122.44	9.58	9.58	7.8	Paying
Kia	1,482.64	0.00	108.99	117.90	117.90	-8.91	-8.91	-7.6	Compliant
Tesla	1,980.12	0.00	0.00	134.47	134.47	-134.47	-134.47	-100.0	Compliant
JLR	2,328.01	0.00	177.28	146.05	146.05	31.23	31.23	21.4	Paying
Honda	1,567.13	0.00	109.66	120.72	120.72	-11.06	-11.06	-9.2	Compliant
BYD	1,982.80	0.00	0.74	134.56	134.56	-133.82	-133.82	-99.5	Compliant
MG	1,481.95	0.00	101.50	117.88	117.88	-16.38	-16.38	-13.9	Compliant
XPeng	2,264.23	0.00	0.00	143.93	143.93	-143.93	-143.93	-100.0	Compliant

Notes: The table reports the baseline compliance position used in the two-country structural model. Regulatory CO₂ is the sales-weighted average certified emission rate. The mass target is the pool-specific target before eco-innovation credits; the effective target additionally includes eco-innovation credits. The gap is regulatory CO₂ minus the effective target, so that a positive value indicates emissions above the target.

On the demand side, we describe a nested-logit model in which vehicles are grouped according to their powertrain technology. On the supply side, multi-product manufacturers compete in prices while facing the European fleet CO₂ standard. Our supply model builds on the literature on fuel-economy and CO₂ standards in the automobile market. Specifically, we follow [Reynaert \(2021\)](#) in accounting for the mass-based structure of manufacturer-specific targets under the European CO₂ regulation. We also adapt the competitive credit-market framework of [Durrmeyer and Samano \(2018\)](#) that studies the US car market and CAFE regulation, to the European pooling system. In contrast to CAFE credit market that applies to all manufacturers on the US market, European compliance is organized through regulatory pools where each pool can be modeled as a separate compliance-credit market, with a common credit price within the pool but potentially different compliance prices across pools. Note that we do not model the pooling decision of manufacturers and take observed pools as exogenous. Importantly, in the model pooling affects regulatory compliance but not competition: manufacturers belonging to the same pool remain competitors in the car market.

4.1. Demand

The demand model is a nested logit model in line with previous literature on the new car market ([Berry, 1994](#); [Verboven, 1996](#)). A market t is defined as a country–year pair. Consumers in each market choose among J_t new cars and an outside option, indexed by 0. The outside option captures the decision to not purchase a new vehicle, including retaining an existing vehicle or purchasing a used vehicle.

New cars belong to one of two nests. The first contains electrified powertrains (BEV, PHEV and HEV), while the second contains conventional powertrains (gasoline and diesel). This nesting structure captures stronger substitution between vehicles using similar powertrain technologies.

Mean utility from vehicle j in market t is

$$\delta_{jt} = x'_{jt}\beta - \alpha \log p_{jt} + \eta_{b(j)} + \tau_t + \xi_{jt}, \quad \alpha > 0, \quad (3)$$

where p_{jt} is price, x_{jt} contains observed vehicle characteristics, $\eta_{b(j)}$ denotes brand fixed effects, τ_t market fixed effects, and ξ_{jt} unobserved product quality.

The vector of characteristics includes vehicle weight, fuel costs, body type and size controls, as well as an indicator for domestic brands in each market. We use log price rather than price in levels, which provides more plausible price elasticities and implied markups across vehicle price segments compared to a utility specification linear in price (Birchall et al. (2024)).

Let s_{jt} denote the market share of vehicle j , s_{0t} the outside share, and $s_{j|g,t}$ the share of vehicle j conditional on choosing its nest. The nested-logit inversion is

$$\log s_{jt} - \log s_{0t} = x'_{jt}\beta - \alpha \log p_{jt} + \sigma \log s_{j|g,t} + \eta_{b(j)} + \tau_t + \xi_{jt}, \quad (4)$$

with $0 \leq \sigma < 1$.

Price and within-nest market shares are potentially correlated with unobserved product quality. We therefore estimate equation (4) using instrumental variables. we use differentiation instruments *à la* Gandhi and Houde (2019) based on the number and characteristics of competing vehicles. The model is estimated jointly for France and Germany, with country-year fixed effects.

The estimation results provides the own- and cross-price derivatives used in the supply model. Since price enters utility in logarithms,

$$\frac{\partial \delta_{jt}}{\partial p_{jt}} = -\frac{\alpha}{p_{jt}}. \quad (5)$$

4.2. Supply

4.2.1. Pricing

Let $\mathcal{J}_f$ denote the set of vehicles sold by manufacturer f . For a given market, sales of vehicle j are

$$q_j = M s_j(\mathbf{p}), \quad (6)$$

where M denotes market size and $s_j(\mathbf{p})$ is the market share implied by the demand system.

Absent regulation, manufacturer f chooses the prices of its products to maximize

$$\Pi_f = \sum_{j \in \mathcal{J}_f} (p_j - c_j) q_j(\mathbf{p}), \quad (7)$$

where c_j denotes technological marginal cost. The first-order condition for product $k \in \mathcal{J}_f$ is

$$q_k + \sum_{j \in \mathcal{J}_f} (p_j - c_j) \frac{\partial q_j}{\partial p_k} = 0. \quad (8)$$

4.2.2. The European CO₂ standard

European regulation imposes a fleet-average CO₂ target that manufacturers must not exceed. The regulatory design provides several margins of flexibility. Two of them have already received substantial attention in the literature: emissions are averaged across all vehicles sold by a manufacturer, and the target is attribute-based, with heavier fleets facing a higher CO₂ threshold (Reynaert, 2021).

Let

$$Q_f = \sum_{j \in \mathcal{J}_f} q_j \quad (9)$$

denote manufacturer f 's total sales and

$$\bar{m}_f = \frac{\sum_{j \in \mathcal{J}_f} m_j q_j}{Q_f} \quad (10)$$

its sales-weighted average vehicle mass. The manufacturer-specific target is

$$T_f = T_0 + a \frac{\bar{m}_f - M_0}{1000} + \kappa_f, \quad (11)$$

where T_0 is the reference CO₂ target, a is the mass-adjustment coefficient, M_0 is the reference mass and κ_f captures the applicable eco-innovation adjustment.

Let e_j denote the regulatory emissions attributed to vehicle j . Manufacturer f 's sales-weighted average regulatory emissions are

$$\bar{e}_f = \frac{\sum_{j \in \mathcal{J}_f} q_j e_j}{Q_f}. \quad (12)$$

Considering this simple specification, compliance therefore requires

$$\bar{e}_f - T_f \leq 0. \quad (13)$$

Because both emissions and the mass-based target are linear in sales, this condition can also be written as

$$\frac{1}{Q_f} \sum_{j \in \mathcal{J}_f} q_j \left[e_j - T_0 - a \frac{m_j - M_0}{1000} - \kappa_f \right] \leq 0. \quad (14)$$

Equation (14) makes the compliance contribution of each vehicle transparent. Vehicles for which the term in brackets is positive push the fleet toward non-compliance, whereas vehicles for which it is

negative create regulatory room for more emitting vehicles.

Regulatory emissions need not coincide with physical emissions. This distinction is central for PHEVs, since e_j depends on the Utility Factor used to combine electric and combustion-engine operation.

4.2.3. Pooling and compliance credits

A further flexibility mechanism since 2020 is regulatory pooling. Firms can form a pool and satisfy the CO₂ standard jointly. If $\mathcal{F}_r$ denotes the manufacturers belonging to pool r , joint compliance requires

$$\sum_{f \in \mathcal{F}_r} Q_f(\bar{e}_f - T_f) \leq 0. \quad (15)$$

One possibility would be to introduce equation (15) directly as a common constraint in the pricing problem of every manufacturer in the pool. Such a formulation, however, would generate a shared-constraint game in which each manufacturer internalizes how its pricing decisions affect the compliance position of all other pool members. This would impose a strong form of coordination across firms and substantially complicate the equilibrium problem. This is particularly unattractive in the European setting, where pool members remain independent competitors and pooling agreements remain subject to competition law.

We instead extend the competitive credit-market approach used by [Durmeyer and Samano \(2018\)](#) to describe the CAFE efficiency standard. We represent the allocation of the joint compliance obligation as an implicit market for compliance within each pool. This should not be interpreted as a formal credit market created by the European regulation. Rather, it represents the commercial allocation of the costs and benefits of joint compliance among independent pool members.

Following [Durmeyer and Samano \(2018\)](#), let η_f denote manufacturer f 's net supply of compliance credits per vehicle sold. A positive η_f means that the manufacturer supplies credits to the pool, whereas a negative value means that it demands credits. Let ρ_r denote the price, or marginal value, of one unit of compliance within pool r .

Conditional on ρ_r , manufacturer $f \in \mathcal{F}_r$ chooses its prices and credit position according to

$$\max_{\{p_j\}_{j \in \mathcal{J}_f}, \eta_f} \left\{ \sum_{j \in \mathcal{J}_f} (p_j - c_j + \rho_r \eta_f) q_j(\mathbf{p}) \right\} \quad (16)$$

subject to

$$(\bar{e}_f - T_f) + \eta_f \leq 0 \quad (17)$$

The interpretation is simple: a manufacturer whose fleet is cleaner than its target can supply the resulting compliance surplus, while a manufacturer whose fleet exceeds its target must acquire compliance from other members of the pool.

Whenever $\rho_r > 0$, constraint (17) binds. Hence,

$$\eta_f = T_f - \bar{e}_f. \quad (18)$$

The supply of credits by each manufacturer is therefore determined directly by the distance between its fleet-average regulatory emissions and its target.

As long as the pool complies through internal reallocation, total credit supply must equal total credit demand:

$$\sum_{f \in \mathcal{F}_r} \eta_f Q_f = 0. \quad (19)$$

Using equation (18), this implies that the pool satisfies

$$\sum_{f \in \mathcal{F}_r} Q_f (T_f - \bar{e}_f) = 0, \quad (20)$$

which is precisely the joint fleet-averaging condition at the compliance margin. Manufacturers nevertheless remain independent Bertrand competitors: they take ρ_r and the prices of competing manufacturers as given when setting their own prices.

4.2.4. Pricing incentives and the excess-emissions premium

Substituting equation (18) into equation (16) gives

$$\Pi_f = \sum_{j \in \mathcal{J}_f} (p_j - c_j) q_j + \rho_r Q_f (T_f - \bar{e}_f). \quad (21)$$

Using the definitions of T_f , $\bar{m}_f$ and $\bar{e}_f$, this can be written directly at the product level as

$$\Pi_f = \sum_{j \in \mathcal{J}_f} \left\{ p_j - c_j - \rho_r \left[e_j - T_0 - a \frac{m_j - M_0}{1000} - \kappa_f \right] \right\} q_j. \quad (22)$$

The corresponding first-order condition for product $k \in \mathcal{J}_f$ is

$$q_k + \sum_{j \in \mathcal{J}_f} \left\{ p_j - c_j - \rho_r \left[e_j - T_0 - a \frac{m_j - M_0}{1000} - \kappa_f \right] \right\} \frac{\partial q_j}{\partial p_k} = 0. \quad (23)$$

Hence, the regulation modifies the marginal cost relevant for pricing as

$$c_j^{eff} = c_j + \rho_r \left[e_j - T_0 - a \frac{m_j - M_0}{1000} - \kappa_f \right]. \quad (24)$$

A vehicle that pushes the manufacturer above the standard therefore carries an implicit regulatory cost, whereas a vehicle that creates compliance capacity receives an implicit regulatory benefit. The

magnitude is governed by ρ_r , the value of compliance within the pool.

This mechanism is central to the Utility Factor reform. The reform increases the regulatory emissions e_j attributed to PHEVs without directly changing the nominal CO₂ target. It therefore reduces their contribution to compliance and increases their effective marginal cost relative to vehicles such as BEVs.

Finally, compliance is not mandatory at any cost. A pool that exceeds its target can instead pay the statutory excess-emissions premium (EPP), denoted by ϕ , equal to €95 per gram of CO₂ per kilometer and per vehicle. The EPP therefore caps the marginal value of compliance: a pool has no incentive to incur a marginal compliance cost above ϕ .

Three regimes can arise:

$$\begin{cases} \rho_r = 0, & \sum_{f \in \mathcal{F}_r} Q_f(\bar{e}_f - T_f) < 0, \\ 0 < \rho_r < \phi, & \sum_{f \in \mathcal{F}_r} Q_f(\bar{e}_f - T_f) = 0, \\ \rho_r = \phi, & \sum_{f \in \mathcal{F}_r} Q_f(\bar{e}_f - T_f) > 0. \end{cases} \quad (25)$$

A pool that remains below its target has excess compliance capacity and $\rho_r = 0$. When the marginal value of compliance is below the EPP, ρ_r adjusts until internal credit supply and demand balance and the pool meets its joint target. If reaching the target would require a marginal compliance value above ϕ , the pool instead stops adjusting at $\rho_r = \phi$ and pays the excess-emissions premium on its remaining emissions deficit.

5. Estimation

5.1. Identification and instruments

The demand equation contains two potentially endogenous variables: vehicle price and the within-nest market share. Prices may be correlated with unobserved vehicle quality, while the within-nest share is mechanically related to the demand shock. We therefore estimate the demand equation using instrumental variables.

Our preferred specification relies on differentiation instruments following [Gandhi and Houde \(2019\)](#). The intuition is that the location of a product in the space of exogenous characteristics affects the intensity of competition it faces and therefore equilibrium prices, while being determined by the characteristics of the products available in the market.

We construct two types of differentiation instruments. For a characteristic x_j , the local instrument counts the number of other products in the same market whose characteristic lies within one standard deviation of x_j . Products located in a denser part of the characteristics space face more close competitors. We also construct quadratic differentiation instruments, defined from the sum of squared distances

between product j and the other products in the market. These capture more continuously how isolated a product is in characteristics space.

Specifically, we use local differentiation instruments based on vehicle weight and fuel cost, a quadratic differentiation instrument based on weight, and the number of products available in the vehicle's nest. The latter provides variation for the endogenous within-nest share: conditional on product characteristics, a larger choice set within the nest affects the denominator of the within-nest market share.

5.1.1. Demand estimates

We report preference estimates in Table 8. Instrument relevance is assessed using the first-stage F-statistics for the two endogenous variables. The instruments are strongly predictive of both log price and the within-nest share, with first-stage F-statistics of 282.9 and 100.6, respectively, well above conventional weak-instrument thresholds. We also test the validity of the over-identifying restrictions using the Sargan test. The null hypothesis that the excluded instruments are jointly exogenous cannot be rejected (Sargan statistic = 1.53, $p = 0.465$).

Table 8: Nested-logit demand estimates

	Nested Logit Model
Log price	-1.678** (0.596)
Within-nest correlation, σ	0.312* (0.142)
Weight	0.101 (0.332)
Fuel cost	-0.0266* (0.0132)
Domestic brand	0.591*** (0.130)
Compact SUV	0.591*** (0.150)
Large SUV	0.805*** (0.196)
Large	1.058** (0.405)
Midsize	0.262* (0.132)
Market fixed effects	Yes
Brand fixed effects	Yes
Observations	8,340
First-stage F-stat., log price	282.89
First-stage F-stat., within-nest share	100.61
Sargan statistic	1.53
Sargan p -value	0.465

Notes: The dependent variable is the log market-share ratio relative to the outside option. Log price and the within-nest market share are instrumented using differentiation instruments. Standard errors, clustered at the country-year market level, are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The estimation results indicate that both vehicle prices and fuel costs enter utility negatively, with

coefficients significant at the 10% and 5% levels, respectively. The within-nest correlation parameter, σ , is estimated at 0.31 and is significant at the 10% level, suggesting stronger substitution among vehicles belonging to the same powertrain nest. Relative to small vehicles, consumers exhibit a preference for larger vehicle segments. However, conditional on vehicle segment, vehicle weight does not have a statistically significant effect on utility. Finally, consistent with [Reynaert \(2021\)](#), we find a positive and significant preference for domestic brands among French and German consumers.

5.1.2. Price elasticities and substitution patterns

The estimated demand system implies an average own-price elasticity of -2.43 . This magnitude is consistent with estimates commonly found in the structural automobile-demand literature. For instance, [Train and Winston \(2007\)](#) report an average elasticity of approximately -2.4 for the U.S. market, while [Durrmeyer and Samano \(2018\)](#) obtain average elasticities of -2.5 in the United States and -3.2 in France. Table 9 reports average cross-price elasticities across powertrains.

Table 9: Price elasticities and substitution across powertrains

Demand for	Powertrain whose price increases				
	BEV	Diesel	Gasoline	HEV	PHEV
BEV	0.0138	0.0031	0.0055	0.0123	0.0047
Diesel	0.0035	0.0103	0.0176	0.0025	0.0012
Gasoline	0.0034	0.0103	0.0180	0.0027	0.0012
HEV	0.0145	0.0031	0.0055	0.0123	0.0046
PHEV	0.0126	0.0030	0.0042	0.0085	0.0053
Mean own-price elasticity: -2.43					

Notes: Entries report sales-weighted average cross-price elasticities. Columns identify the powertrain whose price changes and rows the powertrain whose demand responds. Diagonal entries are cross-price elasticities between distinct vehicles of the same powertrain; own-product elasticities are excluded. The mean own-price elasticity across all vehicles is -2.43 .

The substitution patterns are consistent with the nesting structure. Substitution is particularly strong between gasoline and diesel vehicles and among electrified powertrains. For example, an increase in BEV prices generates a larger demand response for HEVs and PHEVs than for conventional vehicles, while an increase in gasoline prices primarily redirects demand toward diesel vehicles. These substitution patterns determine how changes in the regulatory cost of PHEVs are transmitted to other powertrains in the policy counterfactuals.

6. Policy counterfactuals

We now use the estimated model and the resulting elasticities to quantify the market, environmental and welfare consequences of the reform of PHEV emissions accounting. We first evaluate ex-ante the effect of the Utility Factor (UF) reform while holding the fleet CO₂ target, the choice set and the pooling structure of 2024 fixed. We then combine the revised UF with the tighter 2025–2029 fleet target. This

corresponds to reducing the target from 95 g/km to 93.6 g/km. Finally, we examine two additional scenarios and quantify their impact on welfare. First, we change the set of available BEV models, adding popular BEV models commercialized in 2025 onwards. Second, we change the pooling arrangements, taking the 2025 pooling arrangements instead of the one of 2024. All welfare effects are measured relative to the same 2024 reference equilibrium.

6.1. Welfare measurement

We evaluate welfare as the sum of consumer surplus and manufacturers' profits net of climate damages. For a given counterfactual,

$$\Delta W = \Delta CS + \Delta \Pi - SCC \times \Delta E, \quad (26)$$

where ΔCS denotes the change in consumer surplus, $\Delta \Pi$ the change in manufacturers' profits (before excess emission payments), ΔE the change in physical CO₂ emissions, and SCC the social cost of carbon. Manufacturers that have a fleet above the emission standard pay the Excess-emissions premium but these are transfers from manufacturers to the government's budget and therefore cancels out in the welfare function.

6.2. Calibration of parameters

The estimated model provides price elasticities and marginal costs. The remaining parameters are calibrated using institutional sources. Our policy simulations use a social cost of carbon of €190/tCO₂ given by the latest EPA report ([U.S. Environmental Protection Agency \(2023\)](#)).

Based on French public data, we assume that a new car that enters the fleet stays for 20 years before being scrapped or exported and that cars are driven in average 12,000 km per year ([Service des données et études statistiques \(SDES\) \(2026\)](#)). Because the outside option is most likely to purchase a car on the used-car market or to hold to an older, and probably a more polluting car, we need to account for the outside option emissions. We consider that the average car from the outside option is a 10 years old car emitting 120 g/km. It therefore lives for 10 years.

Finally, to compare scenarios on an equal carbon measure, we consider the regulatory emissions of 2027 for PHEV emission accounting.

6.3. Simulation results

We present the market outcomes across policy counterfactual in Table 10 and the impact on welfare in Table 11.

Table 10: Market outcomes across policy counterfactuals

Scenario	BEV (%)	PHEV (%)	HEV (%)	Gasoline (%)	Diesel (%)	New-car sales
Reference 2024	14.62	5.02	31.34	36.46	12.56	4,246,050
UF Step 1	15.10	4.86	31.31	36.24	12.50	4,238,113
UF Step 2	15.87	4.58	31.14	36.02	12.40	4,233,935
2025 target only	26.04	6.39	27.41	29.27	10.89	4,010,269
2025 target + UF Step 1	28.69	4.90	26.83	28.92	10.67	3,984,944
2025 target + UF Step 2	29.92	4.02	26.59	28.87	10.60	3,973,730
2025 target + UF Step 1 + expanded choice set	28.87	4.78	26.62	29.19	10.55	4,036,524
2025 target + UF Step 2 + expanded choice set	30.10	3.93	26.37	29.12	10.48	4,026,191
2025 target + UF Step 1 + 2025 pools	28.83	4.83	26.87	28.75	10.72	4,027,730
2025 target + UF Step 2 + 2025 pools	30.07	3.96	26.70	28.65	10.61	4,018,799

Notes: Market shares are sales-weighted across France and Germany. Unless explicitly stated, the product set and pooling structure are held at their 2024 values.

Table 11: Welfare effects across policy counterfactuals

Scenario	ΔCS (M €)	$\Delta \Pi$ (M €)	$\Delta \Pi$ net of emissions fees (M €)	ΔCO_2 (kt)	Carbon benefit (M €)	ΔW (M €)
UF Step 1	-246.71	98.54	-18.63	-1,396.85	265.40	117.23
UF Step 2	-454.35	51.19	-87.92	-3,989.74	758.05	354.89
2025 target only	-5,616.25	785.98	219.99	-19,493.67	3,703.80	-1,126.48
2025 target + UF Step 1	-7,436.52	321.91	-346.52	-26,142.48	4,967.07	-2,147.54
2025 target + UF Step 2	-8,556.46	-88.51	-787.58	-28,699.11	5,452.83	-3,192.14
2025 target + UF Step 1 + expanded choice set	-5,622.90	425.57	-215.93	-25,869.00	4,915.11	-282.22
2025 target + UF Step 2 + expanded choice set	-6,705.99	13.23	-653.99	-28,410.97	5,398.08	-1,294.68
2025 target + UF Step 1 + 2025 pools	-5,767.31	-225.77	—	-25,692.83	4,881.64	-1,111.45
2025 target + UF Step 2 + 2025 pools	-6,851.32	-686.42	—	-28,306.08	5,378.16	-2,159.59

All changes are relative to the 2024 reference equilibrium. Π denotes profits before excess-emissions fees. Profits net of emissions fees correspond to profits after payment of these regulatory fees. Regulatory fees are treated as transfers in the welfare calculation. Carbon damages are valued using a social cost of carbon of €190/tCO₂.

6.3.1. Evaluating ex-ante the utility factor reform EU 2023/443

We first isolate the effect of correcting PHEV emissions accounting by considering the two step UF changes of 2025 and 2027. The fleet target, product set and pooling structure are held at their 2024 values, and only the UF used to compute the regulatory emissions of existing PHEVs is modified. This exercise therefore separates the measurement reform from the subsequent tightening of the fleet standard.

The first stage of the UF reform that occurred in 2025 already changes the allocation of sales across powertrain. The PHEV share decreases from 5.02% to 4.86%, while the BEV share increases from 14.62% to 15.10%. The second stage amplifies the same mechanism. The PHEV share falls to 4.58% and the BEV share rises to 15.87%. Changes in the shares of conventional vehicles and HEVs are comparatively small.

Total new-car sales decline only slightly, by around 8,000 vehicles under Step 1 and 12,000 under Step 2, showing an overall small effect on the outside option.

The mechanism is simple: as PHEV regulatory emissions increase, the technology is no longer a viable compliance technology and manufacturers with a fixed choice set are incentivized to increase PHEV price alongside other polluting technologies while decreasing the price of lower carbon technologies such as

BEV. We report price changes in the two scenarios in Table 12.

Table 12: Average price changes by powertrain under the Utility Factor reform

Powertrain	UF Step 1 (€)	UF Step 2 (€)
BEV	-659	-1,801
Diesel	201	461
Gasoline	164	319
HEV	65	211
PHEV	586	1,783

The environmental effect is small but significant. Step 1 reduces lifetime CO₂ emissions by about 1.4 Mt relative to the benchmark, while Step 2 reduces them by almost 4 Mt. Valued at SCC = €190/ton, these reductions correspond to climate benefits of €265 million and €758 million, respectively.

The reform entails a moderate loss of consumer surplus, of €247 million under Step 1 and €454 million under Step 2. Total profits increase by €99 million under Step 1 and €51 million under Step 2. The climate benefits more than compensate for the consumer-surplus losses, resulting in welfare gains of €117 million and €355 million.

These results show that correcting PHEV emissions accounting is welfare improving and can improve environmental performance even in the absence of any tightening of the nominal fleet standard.

We find substantial distributive effects of the UF change (step 2) across brands and within pools. Figure 3 present the relative change in profits at the brand level, distinguishing French, German and other brands. The figure shows that, at the brand level net winners but also a few net losers are German brands while French and other European brands are not very affected by the policy. The most affected brands are Ford, Jaguar and Land Rover.

Table 13 shows that, once the regulatory target and the 2024 pool structure are held fixed, the UF Step 2 correction has a modest economic impact for most manufacturers: the majority of brands see their net profit change by less than one percentage point, and pooling appears to absorb much of the shock – multi-brand pools such as Volkswagen, Stellantis and RNM contain both winners and losers whose effects largely offset one another at the pool level. The losses that do stand out, however, share clear characteristics. They concentrate among manufacturers with limited or no pooling flexibility: Ford, which faces the reform entirely unpooled, and Jaguar Land Rover, a two-brand pool with no electrified counterweight to its PHEV-heavy portfolio. Within this pool, Jaguar, whose reference sales are 37% PHEV, absorbs by far the largest loss (-19.10%), underscoring that high PHEV exposure combined with a poorly diversified pool is the main driver of material losses under the correction.

6.3.2. Tightening the emission standard

We next impose the tighter fleet target applying over 2025–2029 while keeping the 2024 product set and pooling structure fixed. Comparing the target-only counterfactual with the scenarios combining the

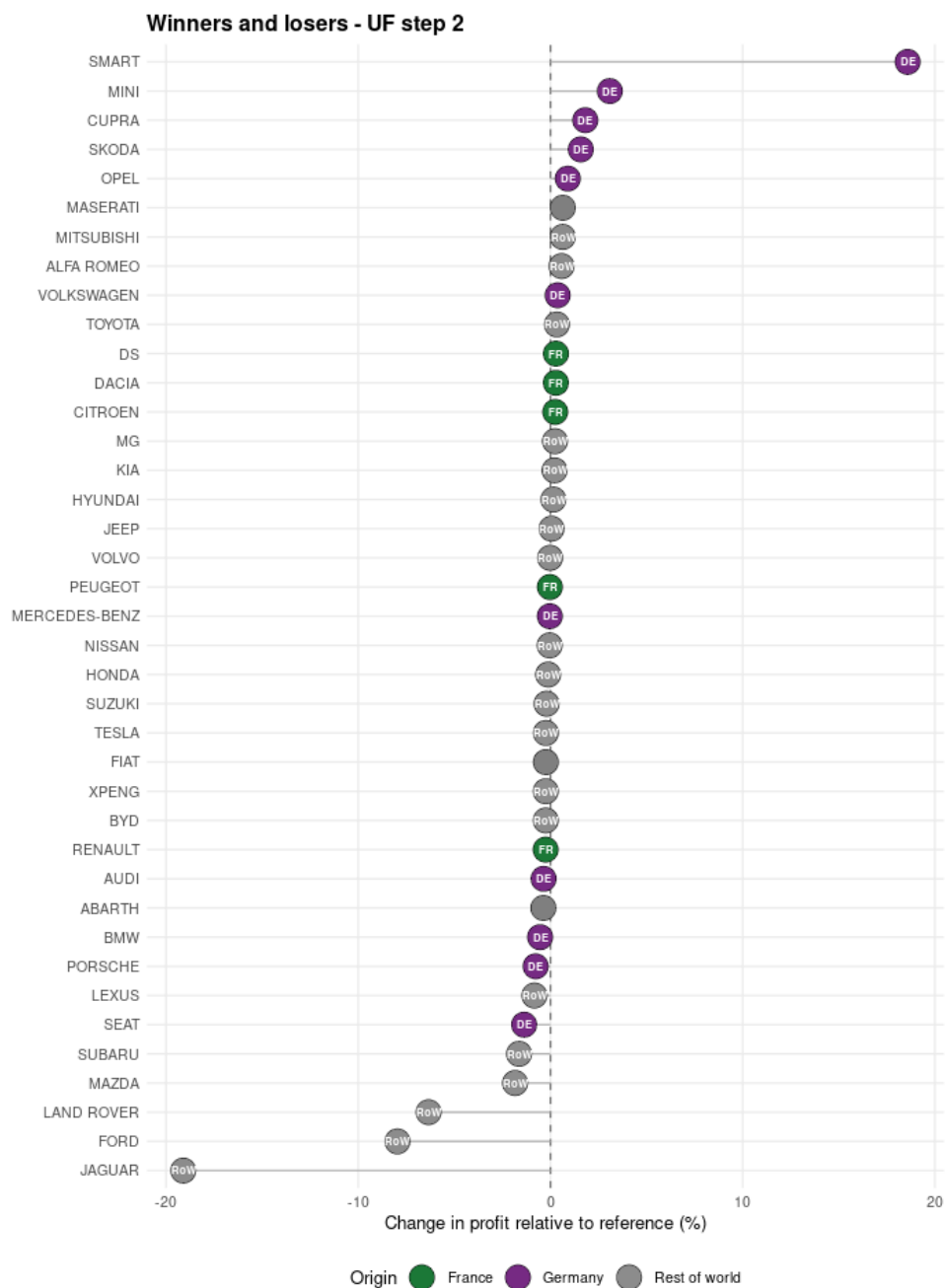


Figure 3: Winners and losers from the UF reform step 2. Results are presented in percentage of change compared to the reference 2024 scenario.

Table 13: Winners and losers under the UF Step 2 correction, grouped by pool

Pool	Brand	Net (%)	PHEV (%)	BEV (%)
FORD	FORD	-7.96	10	4
JLR	JAGUAR	-19.10	37	5
	LAND ROVER	-6.34	20	0
XPENG	XPENG	-0.25	0	100
BYD	BYD	-0.25	2	98
TESLA	TESLA	-0.24	0	100
BMW	BMW	-0.54	12	20
	MINI	3.09	0	31
HONDA	HONDA	-0.12	2	11
TOYOTA	MAZDA	-1.84	3	0
	SUBARU	-1.63	0	12
	LEXUS	-0.83	9	2
	TOYOTA	0.33	1	2
RNM	RENAULT	-0.25	0	16
	NISSAN	-0.04	0	5
	DACIA	0.28	0	4
	MITSUBISHI	0.64	17	0
VOLVO	SUZUKI	-0.20	0	0
	VOLVO	-0.02	41	26
MERCEDES	MERCEDES-BENZ	-0.03	17	14
	SMART	18.59	0	100
HYUNDAI	HYUNDAI	0.15	1	17
KIA	KIA	0.21	4	15
STELLANTIS	ABARTH	-0.37	0	100
	FIAT	-0.24	0	43
	PEUGEOT	-0.03	1	16
	JEEP	0.06	4	26
	CITROEN	0.25	0	10
	DS	0.29	17	0
	ALFA ROMEO	0.58	3	0
	MASERATI	0.64	0	12
	OPEL	0.90	3	9
MG	MG	0.24	0	21
VOLKSWAGEN	SEAT	-1.37	2	0
	PORSCHE	-0.77	30	21
	AUDI	-0.36	6	11
	VOLKSWAGEN	0.37	2	11
	SKODA	1.58	2	14
	CUPRA	1.81	13	25

new target and the revised UF makes clear that the two regulatory margins operate differently.

The tighter target alone induces a major shift toward vehicles classified as low-emission under the existing regulatory metric. The BEV market share rises from 14.62% in the reference equilibrium to 26.04%. Importantly, however, the PHEV share also increases, from 5.02% to 6.39%. Under the old Utility Factor, PHEVs therefore become more attractive as a compliance technology when the standard tightens.

Correcting PHEV emissions accounting changes this technological response. Under the tighter target

and UF Step 1, the BEV share rises further to 28.69%, while the PHEV share falls to 4.90%. Under Step 2, the BEV share reaches 29.92% and the PHEV share falls to 4.02%. The results illustrate the distinction emphasized throughout the paper: the tighter target creates stronger incentives to sell vehicles considered low-emission, while the UF reform changes whether PHEVs fall into that category for compliance purposes.

The interaction also generates much larger emissions reductions. The tighter target alone reduces physical emissions by 19.5 Mt. Adding UF Step 1 raises the reduction to 26.1 Mt, an additional reduction of approximately 6.6 Mt. Under Step 2, emissions fall by 28.7 Mt, around 9.2 Mt more than under the tighter target alone.

With the product set held fixed, however, these larger environmental gains come with substantial consumer-surplus losses resulting in negative welfare change overall. The tighter target alone reduces consumer surplus by €5.6 billion. This loss rises to €7.4 billion under UF Step 1 and €8.6 billion under Step 2. At a social cost of carbon of €190/tCO₂, the additional environmental gains do not fully compensate for these losses. Welfare is therefore €1.1 billion below the reference equilibrium under the tighter target alone, €2.1 billion below under Step 1, and €3.2 billion below under Step 2.

In this exercise, manufacturers can adjust prices and quantities but cannot introduce new products. The large consumer-surplus losses therefore partly reflect the restriction that firms and consumers must adapt to a substantially tighter standard using the 2024 choice set. We partly relax this assumption in the next subsection.

6.3.3. Expanding the BEV choice set

The European market experienced substantial expansion in BEV availability after the estimation period. Holding the 2024 product set fixed may therefore overstate the cost of complying with a standard that itself encourages manufacturers to expand their electric offerings. To assess the importance of this margin, we repeat the tighter-target counterfactuals after adding a set of successful BEV models introduced after the baseline period. Specifically, we add the Skoda Elroq, Renault 4 E-Tech Electric, Hyundai Inster, Mercedes-Benz CLA Electric, and Ford Explorer EV.

For the additional vehicles, observed prices and technical characteristics are taken from the corresponding models. Unobserved product quality and technological marginal costs are imputed from comparable BEVs already present in the estimation sample. The exercise is not intended to model endogenous product entry and does not account for all the new models introduced after 2025. The idea is to provide orders of magnitude and a sensitivity analysis of the fixed-choice-set assumption and to understand whether introducing new products could compensate the welfare losses that we observed in the previous simulation exercise.

The expansion of BEV availability has relatively little effect on aggregate technology shares. Under Step 1, the BEV share increases from 28.69% to 28.87%, while the PHEV share decreases from 4.90% to

4.78%. Under Step 2, the corresponding shares move from 29.92% to 30.10% for BEVs and from 4.02% to 3.93% for PHEVs. The larger effect is on total new-car sales, which increase by about 52,000 vehicles relative to the fixed-choice-set counterfactual.

The welfare consequences are much larger. Under Step 1, expanding the choice set improves consumer surplus by approximately €1.81 billion and operating profits by €104 million relative to the fixed-product counterfactual. The welfare loss falls from €2.15 billion to only €0.28 billion, eliminating approximately 87% of the loss generated with the 2024 choice set.

Under Step 2, consumer surplus improves by approximately €1.85 billion and operating profits by €102 million. The welfare loss decreases from €3.19 billion to €1.29 billion, a reduction of about 59% with only five new models introduced.

This result highlights an important distinction between short-run and medium-run adjustment. Restricting manufacturers to the existing product set forces a larger share of compliance through prices and reduced new-car purchases. Expanding the set of BEV alternatives allows consumers to adapt with substantially smaller welfare losses.

6.4. Pooling as an adjustment margin

We finally examine the role of manufacturer pooling. Manufacturers are able to modify their pooling arrangements. We focus on the policy environment combining the tighter 2025–2029 target and the revised Utility Factor, and keep the product set fixed. We compare the equilibrium under the 2024 pooling structure with the pooling arrangements observed in 2025. This pairwise comparison isolates the effect of manufacturers’ reorganization of compliance.

The change in pooling has relatively modest effects on aggregate technology shares but a larger impact on total sales. Under Step 1, moving from the 2024 to the 2025 pools increases new-car sales from 3.985 million to 4.028 million. The BEV share increases slightly from 28.69% to 28.83%, while the PHEV share falls from 4.90% to 4.83%. Under Step 2, total sales increase by approximately 45,000 vehicles, while BEV and PHEV shares change by only 0.15 and -0.06 percentage points, respectively.

Pooling nevertheless substantially changes the distribution and cost of regulatory compliance. Under the 2024 pooling structure, three compliance entities reach the statutory €95/gCO₂ penalty under Step 1: Ford, Jaguar Land Rover and Toyota. Under Step 2, Mercedes-Benz also reaches the penalty. Under the 2025 pooling structure, only Jaguar Land Rover remains at the statutory penalty in either scenario. Aggregate statutory penalties fall from approximately €814 million to €107 million under Step 1 and from €844 million to €117 million under Step 2.

Aggregate profits after penalties increase by approximately €159 million under Step 1 and €129 million under Step 2.

The additional flexibility comes with an environmental cost. Relative to the 2024 pools, emissions

Table 14: Effect of moving from the 2024 to the 2025 pooling structure

	UF Step 1	UF Step 2
Δ new-car sales	42,786	45,069
ΔCS (M €)	1,669.21	1,705.14
$\Delta \Pi$ (M €)	-547.68	-597.91
Δ statutory penalties (M €)	-706.21	-727.00
$\Delta \Pi^{net}$ (M €)	158.53	129.09
Δ CO ₂ emissions (kt)	449.65	393.03
Δ carbon benefit (M €)	-85.43	-74.67
ΔW (M €)	1,036.09	1,032.55

Notes: Entries report the difference between the equilibrium under the 2025 pooling structure and the equilibrium under the 2024 pooling structure, holding the fleet target, UF and product set fixed. Π^{net} denotes operating profit net of statutory excess-emissions premiums. Welfare uses operating profits because penalties are treated as transfers.

are around 450 kt higher under Step 1 and 393 kt higher under Step 2. These increases remain small relative to the 26–29 Mt reductions generated by the tighter standard and the revised UF.

Overall, replacing the 2024 pools with the 2025 pooling arrangements raises welfare by approximately €1 billion under both stages of the UF reform.

7. Concluding remarks

This paper studies how the regulatory treatment of PHEVs affects the operation of European fleet-average CO₂ standards. The Utility Factor reform does more than improve the measurement of PHEV emissions: by increasing the regulatory emissions attributed to these vehicles, it changes their value for manufacturer compliance and therefore modifies relative pricing incentives across technologies. Our results show that this mechanism becomes particularly important when the underlying CO₂ standard is more stringent. Correcting PHEV emissions then shifts a larger share of the adjustment away from PHEVs and toward BEVs. Our next step in this regard is to look back and understand what would have been the technology path if the correct measure had been used since 2020.

The analysis also highlights the importance of the flexibility available to manufacturers. The effects of a stringent standard depend substantially on the technologies available in the market: a broader BEV choice set provides an additional margin of substitution and can mitigate the welfare cost of compliance. Pooling provides another important margin of flexibility. By allowing manufacturers with different technological portfolios to share compliance, it changes firms' regulatory incentives, equilibrium prices and the distribution of the costs of the standard. More generally, our results show that the consequences of fleet-average regulation depend not only on the level of the CO₂ target, but also on how emissions are measured, which technological alternatives are available, and how compliance can be shared across manufacturers. In the near future, we will study additional pooling options, including an industry-wide market for credits in the spirit of the US CAFE standard, and a European market in the absence of pooling, as it was the case before 2020.

Our analysis nevertheless has important limitations. First, we take observed pooling arrangements as given and do not model manufacturers' decisions to form a pool or their choice of pooling partners. Yet these decisions may themselves depend on the stringency of the standard and on differences in manufacturers' technological portfolios. Endogenizing pool formation would therefore be a natural extension of the framework and would allow the strategic formation of compliance alliances to be studied directly. Second, our empirical application focuses on France and Germany. Although these are two of the largest European new-car markets and provide substantial variation in technological adoption, they represent only part of the European market over which manufacturers ultimately comply with the regulation. Extending the analysis to additional European countries would provide a more complete representation of manufacturers' regulatory positions and of the heterogeneity of technological transitions across markets.

Overall, the results emphasize that the technological trajectory induced by a fleet standard cannot be inferred from the numerical target alone. The measurement of emissions, the set of technologies available to consumers and the institutional mechanisms through which firms can share compliance jointly determine both the cost of regulation and the technologies through which the automobile industry decarbonizes.

Acknowledgements

We thank participants of the European IAEE 2026 conference in Munich, FAERE 2026 conference in Dijon, AFET 2026 conference in Paris and seminars in CentraleSupélec. The authors gratefully acknowledge the chair Energy and Prosperity at Fondation du Risque and ADEME via APR 25ESD0492 Year 2025 for financial support.

References

- Anderson, D.A., 2010. Environmental economics and natural resource management. 3. ed ed., Routledge, London.
- Berry, S.T., 1994. Estimating Discrete-Choice Models of Product Differentiation. *The RAND Journal of Economics* 25, 242. URL: <http://doi.wiley.com/10.2307/2555829>, doi:10.2307/2555829.
- Birchall, C., Mohapatra, D., Verboven, F., 2024. Estimating substitution patterns and demand curvature in discrete-choice models of product differentiation. *Review of Economics and Statistics* , 1–40.
- Dertwinkel-Kalt, M., Wey, C., 2025. The Economics of Fleet-Wide Emission Targets and Pooling in the EU Car Market. CESifo Working Paper 11762. CESifo. URL: <https://ssrn.com/abstract=5200590>, doi:10.2139/ssrn.5200590. available at SSRN.

- Dornoff, J., Tietge, U., Mock, P., 2024. On the way to “real-world” CO₂ values? Evidence from 2021–2023 on-board fuel consumption monitoring data in the European passenger car market. White Paper. The International Council on Clean Transportation (ICCT). URL: <https://theicct.org>.
- Durrmeyer, I., Samano, M., 2018. To Rebate or Not to Rebate: Fuel Economy Standards *Versus* Feebates. *The Economic Journal* 128, 3076–3116. URL: <https://academic.oup.com/ej/article/128/616/3076-3116/5251687>, doi:10.1111/ecoj.12555.
- Gandhi, A., Houde, J.F., 2019. Measuring Substitution Patterns in Differentiated-Products Industries. NBER Working Paper 26375. National Bureau of Economic Research. URL: <https://ssrn.com/abstract=3472810>.
- Goldberg, P.K., 2003. The Effects of the Corporate Average Fuel Efficiency Standards in the US. *The Journal of Industrial Economics* 46, 1–33. URL: <https://onlinelibrary.wiley.com/doi/10.1111/1467-6451.00059>, doi:10.1111/1467-6451.00059.
- Jacobsen, M.R., 2013. Fuel Economy and Safety: The Influences of Vehicle Class and Driver Behavior .
- Joint Research Centre (JRC), 2025. Towards zero CO₂ emissions: Insights from EU vehicle on-board data. JRC Science for Policy Report. European Commission, Publications Office of the European Union. URL: <https://europa.eu>.
- Plötz, P., Funke, S.A., Jochem, P., 2018. Empirical Fuel Consumption and CO₂ Emissions of Plug-In Hybrid Electric Vehicles. *Journal of Industrial Ecology* 22, 773–784. URL: <https://onlinelibrary.wiley.com/doi/abs/10.1111/jiec.12623>, doi:10.1111/jiec.12623. _eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1111/jiec.12623>.
- Plötz, P., Moll, C., Bieker, G., Mock, P., 2021. From lab-to-road: real-world fuel consumption and CO₂ emissions of plug-in hybrid electric vehicles. *Environmental Research Letters* 16, 054078. URL: <https://iopscience.iop.org/article/10.1088/1748-9326/abef8c>, doi:10.1088/1748-9326/abef8c.
- Reynaert, M., 2021. Abatement Strategies and the Cost of Environmental Regulation: Emission Standards on the European Car Market. *The Review of Economic Studies* 88, 454–488. URL: <https://academic.oup.com/restud/article/88/1/454/5917028>, doi:10.1093/restud/rdaa058.
- Reynaert, M., Sallee, J.M., 2021. Who Benefits When Firms Game Corrective Policies? *American Economic Journal: Economic Policy* 13, 372–412. URL: <https://www.aeaweb.org/articles?id=10.1257/pol.20190019>, doi:10.1257/pol.20190019.
- Service des données et études statistiques (SDES), 2026. Données sur le parc automobile français au 1er janvier 2026. Ministère de la Transition

écologique. URL: <https://www.statistiques.developpement-durable.gouv.fr/donnees-sur-le-parc-automobile-francais-au-1er-janvier-2026>. accessed: 2026-08-30.

Tansini, A., Pavlovic, J., Fontaras, G., 2022. Quantifying the real-world CO2 emissions and energy consumption of modern plug-in hybrid vehicles. *Journal of Cleaner Production* 362, 132191. URL: <https://linkinghub.elsevier.com/retrieve/pii/S0959652622017978>, doi:10.1016/j.jclepro.2022.132191.

Train, K.E., Winston, C., 2007. VEHICLE CHOICE BEHAVIOR AND THE DECLINING MARKET SHARE OF U.S. AUTOMAKERS*: vehicle choice. *International Economic Review* 48, 1469–1496. URL: <http://doi.wiley.com/10.1111/j.1468-2354.2007.00471.x>, doi:10.1111/j.1468-2354.2007.00471.x.

Transport & Environment, 2025. Smoke screen: the growing PHEV emissions scandal. Technical Report. European Federation for Transport and Environment AISBL. URL: <https://transportenvironment.org>.

U.S. Environmental Protection Agency, 2023. Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances. Technical Report. U.S. Environmental Protection Agency. Washington, DC. URL: https://www.epa.gov/system/files/documents/2023-12/epa_scghg_2023_report_final.pdf. national Center for Environmental Economics, Office of Policy, and Climate Change Division, Office of Air and Radiation.

Verboven, F., 1996. International Price Discrimination in the European Car Market. *The RAND Journal of Economics* 27, 240. URL: <http://doi.wiley.com/10.2307/2555925>, doi:10.2307/2555925.