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Are environmental tax
policies beneficial? Learning
from programme evaluation
studies

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PAPERS

**ARE ENVIRONMENTAL TAX POLICIES BENEFICIAL? LEARNING FROM
PROGRAMME EVALUATION STUDIES – ENVIRONMENT WORKING
PAPER N°150**

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(1) OECD

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Abstract

This paper provides a concrete example of how policy analysts can use empirical programme evaluation studies to perform ex-post assessments of environmentally related tax policies. A number of studies credibly identify causal effects of environmentally related tax policies, but do not necessarily provide all the information needed to fully inform the policy-making process.

This paper argues that cost-benefit analysis (CBA) could enrich ex-post assessments of environmentally related tax policies, given that CBA provides decision makers with a broader perspective of social costs and benefits and allows the identification of potential trade-offs among policy objectives.

These points are developed and illustrated by reference to the initial effects caused by the French feebate programme for CO₂-efficient motor vehicles after its introduction in 2008. The way the feebate system was designed in the first year not only led to a decline in CO₂ emissions (by an estimated 4.8 million tonnes over vehicles' lifetime), but also came with non-climate effects, such as increased local air pollution, fiscal revenue losses, and changes in producer and consumer surplus. With respect to the first year of the policy, non-climate effects are estimated to have outweighed the climate effects in a CBA framework. The policy has, however, since been revised several times.

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Résumé

LES POLITIQUES DE TAXES ENVIRONNEMENTALES SONT-ELLES UTILES ? LEÇONS À TIRER DES ÉTUDES DE PROGRAMMES D'ÉVALUATION

On trouvera dans le présent rapport un exemple concret de la manière dont les analystes des politiques peuvent exploiter les évaluations empiriques des programmes pour dresser le bilan des écotaxes. Un certain nombre d'études mettent en évidence de façon convaincante les effets causaux de ces dispositifs sans toutefois nécessairement fournir l'ensemble des informations requises pour éclairer pleinement l'élaboration des politiques.

Les auteurs de ces travaux affirment que l'analyse coût-avantages (ACA) pourrait utilement compléter les évaluations ex-post des écotaxes, dans la mesure où cette technique procure une vision plus large des coûts et avantages sociaux et permet de dégager les rapports d'interdépendance susceptibles d'exister entre les objectifs de l'action publique.

Pour développer et illustrer ces points, ils s'appuient sur les premiers effets causaux du système français de bonus-malus écologique instauré en 2008 en vue de favoriser l'acquisition des véhicules à moteur qui émettent le moins de CO₂. Du fait de sa conception, la première année de son application a été marquée par une diminution des émissions de CO₂ (estimée à 4.8 millions de tonnes pour toute la durée de vie des véhicules), mais aussi par des phénomènes non liés au climat : exacerbation de la pollution atmosphérique locale, manque à gagner fiscal et modification de la rente du consommateur et du producteur. D'après les estimations obtenues dans un cadre d'ACA, ces effets non climatiques l'emportent sur ceux liés au climat. Cela dit, le dispositif a depuis lors été revu plusieurs fois.

Codes classification : D61, D62, H23, H31

Mots Clés : analyse coût-avantages, évaluation quantitative des politiques, taxes environnementales, bonus-malus écologique, taxes sur l'achat de véhicules.

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Executive summary

This paper provides a concrete example of how policy analysts can use empirical programme evaluation studies to perform ex-post assessments of environmentally related tax policies. A number of studies credibly identify causal effects of environmentally related tax policies, but do not necessarily provide all the information needed to fully inform the policy-making process.

This paper argues that cost-benefit analysis (CBA) could enrich ex-post assessments of environmentally related tax policies, given that CBA provides decision makers with a broader perspective of social costs and benefits and allows the identification of potential trade-offs among policy objectives.

These points are developed and illustrated by reference to the initial effects caused by the French feebate programme for CO₂-efficient motor vehicles after its introduction in 2008. The way the feebate system was designed in the first year not only led to a decline in CO₂ emissions (by an estimated 4.8 million tonnes over vehicles' lifetime), but also came with non-climate effects, such as increased local air pollution, fiscal revenue losses, and changes in producer and consumer surplus. With respect to the first year of the policy, non-climate effects are estimated to have outweighed the climate effects in a CBA framework. The policy has, however, since been revised several times.

This paper makes a number of observations on ex-post CBAs of environmentally related tax policies that should be of broader policy relevance:

- Even ex-post CBA involves forward-looking elements, which requires making assumptions about future impacts of the changes triggered by the policy beyond the programme evaluation period. These assumptions should be made explicit.
- The consideration of impacts that accrue after the end of the programme evaluation period can fundamentally alter results. Ex-post CBAs that build on programme evaluation studies should discuss the magnitude and reason for these differences.
- If the social costs and benefits of a quantified effect are uncertain, it can be prudent to apply a reasonable range, even if only econometric analysis would make it possible to establish the degree of confidence one could have in such an interval.
- CBA should not be limited to considering climate externalities, but should include all relevant externalities.
- If there are relevant fiscal effects beyond the analysed environmentally related tax policy itself, these additional fiscal costs should be considered as well.
- The application of a tax provision that reduces net public revenues causes a social cost per unit of revenue foregone that is equal to the marginal cost of public funds of the instrument used to raise the necessary additional revenue. Fiscal costs should be corrected accordingly.
- CBA of environmentally related tax policies should not solely assess externalities and fiscal effects, but should consider consumer and producer surplus issues as well.
- As the distribution of costs and benefits can be of great interest – for the people involved and from a political perspective – case studies should seek to discuss distributional issues at least qualitatively.

Are environmental tax policies beneficial? Learning from programme evaluation studies

1. Introduction

This paper considers how policy analysts can make better use of empirical programme evaluation studies to perform ex-post assessments of environmentally related tax policies. A number of peer-reviewed academic studies identify the causal effects of environmentally related tax policies on health and environmental outcomes, especially with respect to transport policies. However, quantified effects typically represent a small subset of the potential impacts of the evaluated policies. In addition, rarely do researchers complement their econometric work with an assessment of the social costs¹ and benefits of the policies.

Cost-benefit analysis (CBA) could enrich ex-post appraisals of environmentally related tax policies due to its focus on total economic surplus. Specifically, CBA allows the identification of potential trade-offs among policy objectives (OECD, 2018^[1]). For example, CBA will not only reveal if the environmental consequences of a policy are as expected, but can additionally provide information on both intended and unintended co-benefits and costs, e.g. with respect to local air pollution and energy poverty. Ex-post CBA can therefore inform a revision or discontinuation of the evaluated policy or suggest the need to improve or introduce complementary policies.

This paper identifies several key challenges analysts that seek to carry out ex-post CBAs of environmentally related tax policies based on programme evaluation studies are likely to face and suggests pragmatic solutions. In particular, the paper includes some guidance on how to define the scope of the CBA as well as on the valuation of external costs, discusses how to account for revenue changes that result from the policy, and emphasises the importance of considering the implications of environmentally related tax policies for consumers and producers.

These points are developed and illustrated by reference to the French feebate programme for motor vehicles introduced in 2008. The rationale behind studying the French vehicle feebate is that such a study allows a number of high-quality programme evaluation studies to be drawn upon (D'Haultfœuille, Givord and Boutin, 2014^[2]; D'Haultfœuille, Durrmeyer and Février, 2016^[3]; Durrmeyer, 2018^[4]). The French vehicle feebate provides tax incentives for the purchase of relatively CO₂-efficient vehicles.²

Building on existing studies of the French feebate (D'Haultfœuille, Givord and Boutin, 2014^[2]; Durrmeyer, 2018^[4]), the present paper discusses and attempts to quantify the full social costs and benefits of the identified effects on the 2008 vehicle cohort, taking into account impacts on vehicle usage over the vehicle lifetime. Going beyond the climate impact of the feebate, the analysis considers the social cost of other externalities, such as

¹ In this paper, social costs refer to the sum of private and external costs.

² Feebate programmes, often called bonus/malus systems, provide consumers with a rebate or bonus on the purchase price of certain products (a subsidy), whereas the purchase other products is penalised by a fee (a tax). Rebates and fees may be differentiated by one or several environmentally related criteria, such as grams of CO₂ emissions per kilometre as in the case of the French feebate.

local air pollution, the social cost of the resulting revenue shortfall, as well as changes in producer and consumer surplus.

The objective of the paper is to develop a set of suggestions on how to conduct ex-post CBAs of environmentally related tax policies (Box 1). On the one hand, the aim of these suggestions is to provide some guidance as to how policy analysts can fruitfully tap into academic studies that credibly identify causal effects of environmentally related tax policies, but do not necessarily provide the information needed to fully inform the policy-making process. In addition, the ambition is to encourage more academics to complement their econometric analyses with (as a minimum) some “back-of-the-envelope” cost-benefit calculations as e.g. in Chen et al. (2017^[5]) – which would increase the policy relevance of programme evaluation studies.

Box 1. Suggestions on how to conduct ex-post CBAs of environmentally related tax policies

This paper makes a number of observations on ex-post CBAs of environmentally related tax policies that should be of broader policy relevance. This box collects the set of suggestions developed in this paper for ease of reference:

- Even ex-post CBA involves forward-looking elements, which requires making assumptions about future impacts of the changes triggered by the policy beyond the programme evaluation period. These assumptions should be made explicit.
- The consideration of impacts that accrue after the end of the programme evaluation period can fundamentally alter results. Ex-post CBAs that build on programme evaluation studies should discuss the magnitude and reason for these differences.
- If the social costs and benefits of a quantified effect are uncertain, it can be prudent to apply a reasonable range, even if only econometric analysis would make it possible to establish the degree of confidence one could have in such an interval.
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- CBA of environmentally related tax policies should not solely assess externalities and fiscal effects, but should consider consumer and producer surplus issues as well.
- As the distribution of costs and benefits can be of great interest – for the people involved and from a political perspective – case studies should seek to discuss distributional issues at least qualitatively.
- CBA is not an end in itself and should be proportional to the initiative and its impacts. If a fully-fledged CBA, which is data demanding and thus costly, is disproportional to the expected impacts of the initiative, simplifying assumptions e.g. based on the secondary literature may be warranted.

This paper shall not be considered to be a reassessment of the French feebate policy, feebate policies in general, or ex-ante CBA practices in France or elsewhere. This is important because the analysis makes a number of simplifying assumptions. First of all, the paper only considers impacts resulting from the first year of the policy – even though the programme is still in place – and also ignores the programme’s long-term implications on vehicles’ replacement rates and on technologies deployed in later vehicle vintages. In addition, whereas ex-post cost-benefit analysis typically seeks to improve on ex-ante CBA (Börjesson, Jonsson and Lundberg, 2014^[6]; Kelly et al., 2015^[7]), this methodological exercise only aims to provide guidance on ex-post cost-benefit analyses of environmentally related tax policies. Consequently, the present paper keeps the discussion of the French policy context, the feebate policy instrument as well as ex-ante CBA practices to a minimum.

2. Background and methodology

2.1. Cost-benefit analysis

CBA seeks to establish whether the social benefits of a project or policy exceed its social costs.³ Benefits are measured as increases in human well-being, whereas costs are reductions in well-being. Benefits and costs are typically limited to the country level, but the geographical boundary can also be extended (see the treatment of foreign producer surplus in Section 3.4.).

Aggregating across different individuals, social groups, countries or regions may involve summing costs and benefits regardless of the circumstances of the beneficiaries or losers (see Section 3.5.). CBA is, however, a flexible tool that can also assign higher weights to disadvantaged groups.

Aggregating over time involves discounting future benefits and costs into their present values. In general, future costs and benefits receive less weight than present ones – the higher the discount rate, the lower the present value of future costs and benefits. Defining the social discount rate can be challenging, in particular when the project or policy under assessment has implications for generations in the distant future. In the context of intergenerational projects and policies, there is theoretical and empirical support for the use of discount rates that decline with time.

Cost-benefit analysis can be carried out at various stages. Ex-ante CBA evaluates the merits of a project or policy before it is actually implemented. Interim analysis assesses projects or policies that are still in place. Ex-post CBA considers a project or programme after its implementation. The present paper will show, however, that even ex-post analysis involves forward-looking elements.

Irrespective of the stage at which CBA is carried out, it may be subject to political pressures. At the ex-ante stage, parties that would gain from the project or policy’s implementation may seek to influence the outcome of the CBA accordingly. Similarly, ex-post analysis may be subject to pressures from those who backed the original project or policy or who hope to benefit from its continuation or expansion or the implementation of similar policies or projects in the future.

³ This section is based on OECD (2018^[1]), *Cost-Benefit Analysis and the Environment: Further Developments and Policy Use*.

Considering the large number of channels through which a projects or policy may impact society, and the difficulties associated with quantifying these impacts, CBA tends to be resource intensive and involve considerable uncertainties. For ex-ante analysis, the existence of uncertainty is clear as the analysis involves evaluating the future costs and benefits. But even ex-post analysis has to grapple with the fact that the counterfactual – what would have happened in the absence of the project or policy – is not readily observable.

CBA is not an end in itself, and should be proportional to the initiative and its impacts. If a fully-fledged CBA, which is data demanding and thus costly, is disproportional to the (expected impacts of the) initiative, simplifying assumptions e.g. based on the secondary literature may be warranted.

2.2. Ex-post evaluation in the context of regulatory impact assessments

CBA is not the only form of ex post evaluation. Ex-post evaluation is also practiced in the context of regulatory impact assessments (RIA). RIA typically compare a host of policy options, with the aim to assist decision makers “on whether and how to regulate to achieve public policy goals.” (OECD, 2018^[8]) These assessments are now routinely executed in OECD countries and beyond, and increasingly integrate environmental impacts as well, e.g. in the form of carbon impact assessments (Jacob et al., 2011^[9]).

In the context of RIA, ex-post evaluation “involves an assessment of whether regulations have in fact achieved their objectives, as well as looking as to how they can remain fit for purpose” (OECD, 2018^[8]). This may or may not include the quantification of costs and benefits of the regulation. Stakeholder consultation and non-quantified impacts tend to play a greater role in RIA than in CBA.

While the quantification of impacts is on the rise in RIA as well, RIA do not necessarily quantify all relevant social costs and benefits. Sometimes RIA only quantify the costs, but fail to simultaneously quantify the benefits of regulations (OECD, 2018^[8]). Against this background, CBA could usefully contribute to RIA by providing a comprehensive assessment of all relevant social costs and benefits.

2.3. Related literature

An ex-post assessment of the social costs and benefits of a policy requires assumptions about the counterfactual situation that would otherwise have prevailed in the absence of the policy. Establishing a credible counterfactual is challenging and time-consuming and may not be feasible for resource-constrained policy practitioners. Fortunately, academic researchers frequently engage in establishing such counterfactuals.

However, typically academic programme evaluation studies focus on assessing whether the stated objective of the policy was achieved. Evaluating whether a policy is successful on its own terms is, however, not sufficient to conduct a CBA that seeks to uncover both intended and unintended impacts of a policy and quantify their social costs and benefits. Studies of vehicle feebates and rebates, as well as related research on differentiated vehicle purchase and circulation taxes, are cases in point.⁴

⁴ As the name suggests, rebates are feebates without the tax component. Differentiated vehicle purchase taxes typically increase with emission-intensity or other environmentally related criteria, providing a general form of tax incentives. Differentiated circulation taxes are similar but levied recurrently, generally on an annual basis.

Most common among these studies is the narrow focus on the impact of the policy on CO₂ emissions and the related issue of fuel efficiency. This applies to assessments of the French vehicle feebate system (D'Haultfœuille, Givord and Boutin, 2014_[2]; D'Haultfœuille, Durrmeyer and Février, 2016_[3]); Swiss annual vehicle registration feebates (Alberini et al., 2018_[10]); CO₂-based tax incentives in the Netherlands (Kok, 2015_[11]) as well as in France, Germany, and Sweden (Klier and Linn, 2015_[12]); and fuel efficiency-related changes to the Danish registration tax on private vehicles (Mabit, 2014_[13]).

Granted, a number of related studies do engage in welfare analysis (see the paragraph below), and therefore go further in the direction of cost-benefit analysis. However, these articles remain incomplete from the perspective of CBA as they do not account for non-climate externalities (see Section 3.2.2.), do not provide a comprehensive treatment of fiscal effects (see Section 3.3.), and generally do not estimate producer surplus effects (see Section 3.4.).

Specifically, all of these points apply to research on a feebate programme in the Canadian province of Ontario (Rivers and Schaufele, 2017_[14]) and a study on Swiss annual circulation taxes that are linked to vehicle CO₂ emissions (Alberini and Bareit, 2017_[15]). A study of Japan's feebate policy estimates producer surplus effects (Konishi and Zhao, 2017_[16]), but does not directly provide the other information that would be needed for a CBA. Against this background, it is useful to illustrate how analysts can nevertheless draw upon these studies when conducting ex-post appraisals.

Non-academic ex-post analyses, on the other hand, tend to make comprehensive assessments of the social costs and benefits – see Becker (2013_[17]) for an assessment of the first five years of the French motor vehicle feebate – but may not identify the causal effects of the policy with the same analytical rigour as academic programme evaluation studies. The present paper aims to make a contribution to bridging this divide.⁵

2.4. Methodology

The starting point of this paper is D'Haultfœuille, Givord and Boutin (2014_[2]), which estimates the effects of the French vehicle feebate on CO₂ emissions. Specifically, the original article compares the vehicle fleet and its usage under the feebate to the counterfactual of no policy change over the period of March to May 2008, following the introduction of the feebate in January 2008 (see Section 3.2.1.).

The original results are based on a demand model that allows consumers to choose between different vehicles and to adjust mileage in response to cost changes. The model was estimated using datasets on monthly car registrations and household characteristics. To deal with price endogeneity, the demand model was combined with a stylised price model. While manufacturers were able to modify prices in response to the feebate, vehicle characteristics were assumed to be unaffected by the reform.⁶ The model accounted for the fact that the new vehicles replace older ones.

The original study is extended here in two main ways. First, the present analysis includes discounted future climate benefits and costs that can be expected to result from the

⁵ See also Ryan et al. (2018_[33]).

⁶ Given that the reform was only announced at the end of October 2007, this assumption makes sense when modelling the effect of the feebate on the 2008 vehicle cohort. However, the assumption implies that one cannot rely on these estimates to assess the feebate's impact on post-2008 vehicle cohorts.

estimated changes to the vehicle stock (see Section 3.2.1.).⁷ Second, the original analysis is extended by modelling non-climate externalities, indirect fiscal effects, consumer and producer surplus (Section 3.2.2. - 3.4.).

External cost estimates as well as estimates of the social costs of public funds and surplus effects are taken from other studies. Given the uncertainty associated with many of these estimates, whenever possible, range estimates are established and added to the graphs. These range estimates should not be seen as confidence intervals in the statistical sense, but are rather meant to give a feeling for the extent of uncertainty associated with the estimates.⁸

3. Revisiting the French vehicle feebate system

This section first provides some context on the introduction of the French vehicle feebate. It then discusses how to account for the lifetime environmental effects that result from the impact the French feebate programme had on the 2008 vehicle cohort – building on quarterly effects identified by D'Haultfœuille, Givord and Boutin (2014_[2]). We then consider the associated fiscal effects and discuss the cost of public funds. Drawing on additional analysis by Durrmeyer (2018_[4]), consumer and producer surplus effects are included as well. Finally, a comparison of all the quantified effects is provided, which gives some indication of the social costs and benefits of the policy.

3.1. Context and policy objectives

The French vehicle feebate was announced in October 2007, and applied to all vehicles registered after 1 January 2008. Under the 2008 version of the feebate, consumers purchasing (non-electric) vehicles that did not emit more than 130 grams of CO₂ per kilometre could benefit from a rebate or subsidy of up to EUR 1 000 (for the least polluting non-electric vehicle class, A-). Those consumers purchasing vehicles with emissions of more than 160 grams of CO₂, on the other hand, had to pay a tax of up to EUR 2 600 (for the most polluting vehicle class, G). The detailed feebate schedule is reported in Table 1.

⁷ Apart from this, the paper takes the identified effects of the original study at face value. Questioning or reassessing the identification strategy, e.g. because the appraisal period coincided with the 2007/2008 financial crisis, is beyond the scope of this paper. Note, however, that the main causal effects are based on an article published in a leading peer-reviewed economics journal. To keep the analysis tractable, this paper also ignores the fact that the original effects come with a confidence interval. In addition, changes in behavioural effects, tax rates or fuel prices after 2008 are not taken into account.

⁸ To the extent possible, follow-up research should seek to estimate proper confidence intervals, ideally jointly with confidence intervals for the causal effects.

Table 1. The feebate in 2008

Vehicle class	CO ₂ Emissions in g/km	Rebate in EUR
A-	61-100	1 000
B	101-120	700
C+	121-130	200
C-	131-140	0
D	141-160	0
E+	161-165	-200
E-	166-200	-750
F	201-250	-160
G	>251	-2 600

The objective of the policy was to reduce CO₂ emissions through providing consumers with incentives for the purchase of more fuel-efficient vehicles, while encouraging manufacturers to develop vehicles with lower emissions. To provide continued incentives for emission reductions, the thresholds would decline in the years following the introduction of the feebate.

The introduction of the policy was associated with a clear shift in sales towards cleaner vehicle classes. For instance, the market share of relatively CO₂-efficient class B vehicles, which represented a mere 20% of sales prior to the feebate, increased to almost 50% one year after the introduction of the feebate. In parallel, the market share of carbon-intensive class E vehicles fell from 15% to 5%. Average emissions of new vehicles nevertheless decreased only by a relatively modest 5%, because many buyers made rather small adjustments to their purchasing decisions (D'Haultfœuille, Givord and Boutin, 2014^[2]).

3.2. External costs

3.2.1. Climate costs

The analysis of the climate effects, measured in tonnes of CO₂ emitted, is based on the short-run effects estimated by D'Haultfœuille, Givord and Boutin (2014^[2]). The original estimates are adjusted to reflect the lifetime emissions that are the result of the feebate-induced changes to the 2008 vehicle cohort (see also Annex A).

Whereas the feebate programme stayed in place after 2008, changes on future cohorts are not taken into account in the present analysis. Limiting the programme evaluation period to 2008 makes sense as policy changes imply that it would be inappropriate to extrapolate information on feebate-induced purchase decisions into the future. In particular, since 2009, owners of vehicles with high CO₂ emissions are charged an annual malus and the feebate schedule itself was also adjusted significantly in subsequent years. In addition, manufacturers will likely have reacted to the existence of a feebate policy and adjusted their vehicle portfolio accordingly, offering cleaner vehicles.

However, the feebate-induced changes to the 2008 vehicle cohort will continue to impact the usage of this cohort's vehicles over their lifetime. Following Rivers and Schaufele

(2017^[14]), it is assumed that these effects are constant over the vehicle lifetime.⁹ Specifically, it is assumed that the newly purchased vehicles have a lifetime of 15 years.

The somewhat counterintuitive observation that ex-post analysis involves forward-looking elements would appear to be relevant for ex-post assessments more generally (Box 1):

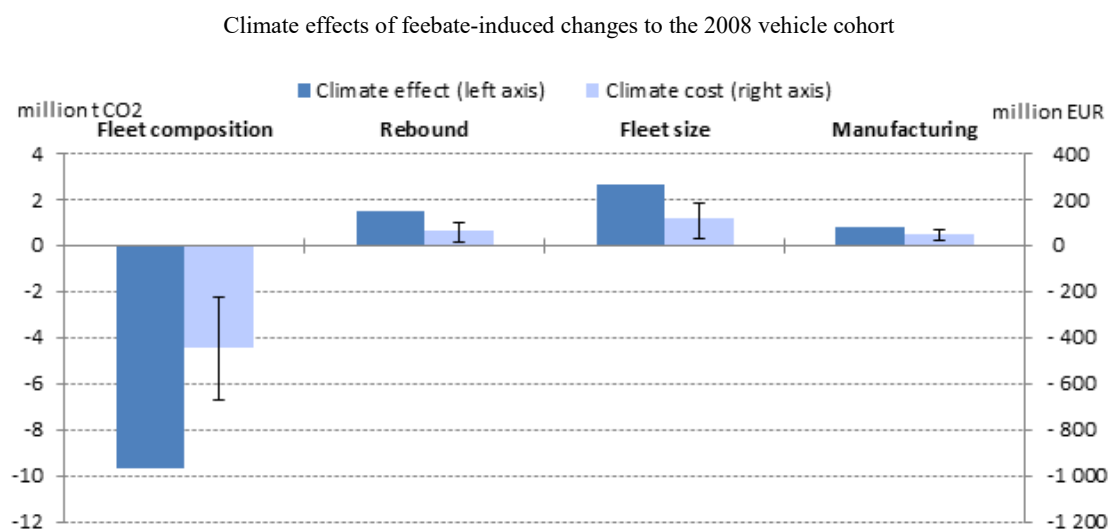
- **Even ex-post CBA involves forward-looking elements, which requires making assumptions about future impacts of the changes triggered by the policy beyond the programme evaluation period. These assumptions should be made explicit.**

Figure 1 reports the estimated fleet composition, rebound, fleet size and manufacturing effects of the feebate scheme. The negative fleet composition effect is due to the fact that feebate-induced cars emit less CO₂ per kilometre than the cars that would have been on the road in the absence of the feebate policy.¹⁰ The positive rebound effect is the result of decreased fuel cost per kilometre driven, which incentivises consumers to drive more, causing additional CO₂ emissions. The fleet size effect is positive because the feebate increased the total sales of cars by 13% compared to the no-feebate counterfactual, meaning there are now additional cars on the road emitting CO₂. The manufacturing effect is positive because the production of additional vehicles is associated with CO₂ emissions,¹¹ which is only partly offset by the fact that feebate-induced vehicles are smaller than the ones that would have been produced otherwise.

⁹ This is different from the long-run effects reported in D'Haultfœuille, Givord and Boutin (2014^[2]), where the authors calculate quarterly effects for the scenario where the entire fleet has been replaced in accordance with the incentives provided by the 2008 version of the feebate. This forward-looking analysis is interesting but is no longer within the realm of ex-post appraisals.

¹⁰ In the original paper, the composition effect also accounts for the fact that manufacturing emissions of feebate-induced cars are lower, given that the models benefitting from the feebate tend to be smaller and lighter. However, as this is a one-off effect that does not persist over the vehicle lifetime, we reassigned this effect to the manufacturing scale effect, and renamed the effects fleet composition and manufacturing (see Annex A).

¹¹ The manufacturing effect is based on the assumption that producing cars is associated with emissions of 5.5 tonnes of CO₂ per tonne of car (D'Haultfœuille, Givord and Boutin, 2014^[2]).

Figure 1. Climate effects

Note: Climate costs assume a social cost of carbon of 60 EUR/t of CO₂. The lower (higher) end of the range estimate refers to a carbon cost of EUR 30 (90) per tonne of CO₂. Post-2008 climate costs are discounted assuming a 4% discount rate (Smith and Braathen, 2015^[18]).

Source: Own analysis (see Annex A) based on D'Haultfœuille et al. (2014^[2]).

The resulting net effect of the feebate is a reduction in CO₂ emissions of 4.8 million tonnes, which suggests that the feebate did indeed achieve its goal of reducing carbon emissions. These results are fundamentally different from the short-run effects estimated by the original paper, which found that the feebate increased quarterly emissions by 169 000 tonnes.

The explanation for these differences lies in the appraisal periods. Whereas the original analysis did not consider climate effects that materialised after the programme evaluation period (March-May 2008), this paper not only considers the whole of 2008 (see Annex A), but additionally accounts for future climate effects that result from the 2008 feebate policy. The reason for this persistence is that the changes to the 2008 vehicle cohort continue to affect vehicle usage patterns. The short appraisal period of the original study implies that in their case the emission-increases of the manufacturing effect dominate.

- ***The consideration of impacts that accrue after the end of the programme evaluation period can fundamentally alter results. Ex-post CBAs that build on programme evaluation studies should discuss the magnitude and reason for these differences.***

Emitting CO₂ into the atmosphere causes damage to society. Figure 1 therefore also reports damage estimates of the CO₂ effects. The marginal damage caused by emitting one tonne of CO₂ caused by the feebate is assumed to be EUR 60.¹² This is within the range of the results from the Stern-Stiglitz Commission which recommends carbon prices of at least USD 40- 80 per tonne of CO₂ by 2020 (High-Level Commission on Carbon Prices, 2017^[19]). In line with the approach taken in the OECD's recent publication on *Effective Carbon Rates* (OECD, 2018^[20]), EUR 30 is used as a low-end estimate. EUR 90 is

¹² The original paper assumes the climate costs to amount to EUR 32 per tonne of CO₂.

considered a high-end estimate for the climate effects, given that the assumption on vehicle lifetime implies that effects only persist until 2022.¹³

- ***If the social costs and benefits of a quantified effect are uncertain, it can be prudent to apply a reasonable range, even if only econometric analysis would make it possible to establish the degree of confidence one could have in such an interval.***

3.2.2. Non-climate external costs

1. CO₂ emissions are not the only external effect of the French feebate. The change in fleet composition could potentially decrease local air pollution per kilometre driven if new cars had better emission control technology than the cars they replaced; or could increase local air pollution per kilometre if diesel vehicles replaced petrol cars.¹⁴ The fact that rebound and fleet size effects were positive does imply that external costs associated with road use; specifically congestion, but also accidents, noise, and wear & tear, will increase.

- ***CBAs should not be limited to considering climate externalities, but should include all relevant externalities.***

To quantify non-climate external effects (not considered in the original study), this paper draws on Santos (2017_[21]) who provides 2008 emission estimates for France. One limitation of her analysis is that she reports country-level average damage estimates, while these externalities tend to be significantly higher for urban road use than for rural road use (Van Dender, 2018_[22]).¹⁵

Figure 2 reports the non-climate externalities of additional road use triggered by the 2008 feebate programme. The additional road use is the result of the rebound and fleet size effects, which are associated with non-climate external costs (see Annex A). Non-climate external effects are most pertinent for congestion (i.e. the cost of increasing other vehicles' journey time), accidents (the part of the costs that falls on other road users and that are not covered by insurance) and local air pollution (mainly through negative health impacts). Santos' air pollution cost estimates account for the costs for PM_{2.5}, PM₁₀, non-methane volatile organic compound (NMVOC), sulphur dioxide (SO₂) and nitrogen oxides (NO_x).¹⁶

¹³ The marginal damage of CO₂ emissions increases with the concentration of CO₂ in the atmosphere. The social cost of carbon is therefore expected to increase significantly beyond 2030, but this is not relevant here as the 2008 cohort by assumption will no longer be on the road.

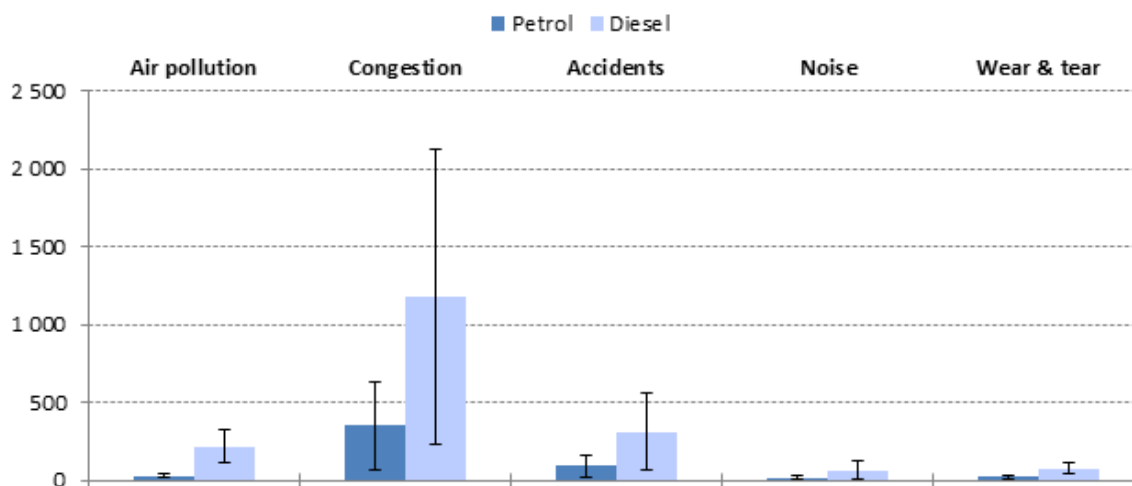
¹⁴ This paper assumes that local air pollution of the 2008 cohort is identical to the 2008 fleet average. Non-climate effects are thus limited to the ones resulting from feebate-induced additional road use.

¹⁵ Using averages is attractive for the purpose of this methodological exercise as it makes the analysis more tractable. Generally, ex-post assessments should, however, avoid working with average damage estimates.

¹⁶ A more detailed breakdown of air pollution costs into their components is not provided in Santos (2017_[21]) and developing such a breakdown would go beyond the purposes of this exercise.

Figure 2. Non-climate related external costs

Non-climate externalities of feebate-induced changes to the 2008 vehicle cohort, in EUR million



Note: Marginal external cost estimates are France-specific and taken from Santos (2017^[21]), with the exception of the estimate for wear & tear which is from Van Dender's (2018^[22]) meta-analysis of external cost estimates in the European Union. The latter's range of estimates is also used to graph the range. Post-2008 external costs are discounted assuming a 4% discount rate. See also Annex A.

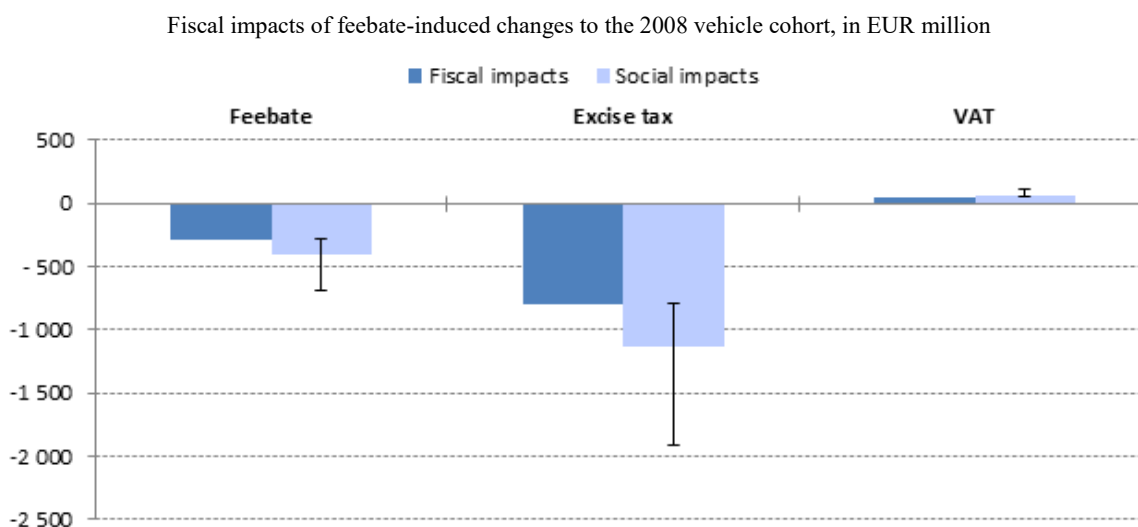
There are two reasons why external costs are higher for diesel than for petrol. The first is that an estimated three quarters of the additional mileage is due to road use by diesel vehicles. With respect to air pollution, this effect is reinforced by the fact that according to Santos' estimate, diesel vehicles pollute twice as much per kilometre driven as petrol vehicles.

Generally, the magnitude of these external cost estimates is quite uncertain, however, as illustrated by the range estimates in the figure. This is reinforced by the fact that parts of these damages are from future road use (as the lifetime of the vehicle cohort is assumed to be 15 years). For instance, if diesel vehicles were banned from entering city centres, local air pollution damages from diesel use would decrease dramatically (and so would the consumer surplus of those who own such vehicles). Similarly, technological improvements to road management systems could mean that congestion and accident costs decrease. In anticipating technological developments, in a future of self-driving vehicles that allow for teleworking and entertainment while being on the road, time spent in a car may no longer be time wasted; congestion cost estimates would have to be adjusted accordingly.

3.3. Fiscal costs

Feebate policies also affect government revenue. Here, the programme evaluation studies of the feebate zoom in on the fact that, while the policy was meant to pay out as much in rebates as it collected in fees, it failed to do so in practice. Specifically, it is reported to have weakened public finances by EUR 285 million in 2008 alone (D'Haultfœuille, Givord and Boutin, 2014^[2]) (see Figure 3).¹⁷

¹⁷ Durrmeyer (2018^[4]) reports EUR 223 million for the same year. The present paper works with the former estimate.

Figure 3. Fiscal impacts

Note: The social impact baseline assumes that the marginal cost of public funds (MCF) is 1.42, whereas the lower (higher) cap of the range bar refers to a marginal cost of public funds of 1 (2.41) EUR per tonne of CO₂. Post-2008 fiscal impacts are discounted assuming a 4% discount rate. See also Annex A.

However, excise tax revenue would have been affected as well. On the one hand, fuel tax revenue per kilometre declines as the composition effect implies that cars are more fuel efficient because of the feebate. On the other hand, excise revenue increases because of rebound and fleet size effects. The composition effect dominates rebound and fleet size effect as shown in Figure 3. Notably, the net excise tax effect is almost three times as large as the direct fiscal cost of the feebate (see Annex A).

The feebate policy additionally affects VAT revenue through two channels. VAT revenue increases due to higher car sales, but decreases because of lower fuel consumption per kilometre (which is only partly offset by additional road use). Figure 3 demonstrates that the former effect dominates somewhat but the net effect is rather small compared to feebate and excise tax effects.¹⁸

Whether one focuses on direct fiscal effects or additionally considers excise and VAT issues also makes a difference when calculating the fiscal cost per tonne of CO₂ avoided – a common metric in programme evaluation studies. Specifically, in the former case, it amounts to EUR 59 per tonne of CO₂; in the latter, the fiscal cost increases to EUR 214 per tonne of CO₂.

- ***If there are relevant fiscal effects beyond the analysed environmentally related tax policy itself, these additional fiscal costs should be considered as well.***

On the face of it, the fiscal costs from the feebate merely represent a transfer from taxpayers who have to pay for the revenue shortfall to those consumers who now pay lower taxes (see

¹⁸ The analysis of the fiscal effects disregards tariff revenue from imports of additional cars. The fiscal effects related to the French annual circulation tax on polluting vehicles (which would be affected through fleet size and composition effects) are not considered as that tax was only introduced in 2009 – and this paper only considers fiscal measures that were already in place in the time period for which the causal effect was estimated. In addition, we do not consider additional corporate tax income that could result from the positive producer surplus effects (see Section 3.4.).

Section 3.4.). The fiscal cost resulting from the French vehicle feebate may, however, be accentuated by the fact that raising tax revenue to make up for the revenue shortfall could cause a distortion in the resource allocation in the economy, a cost typically referred to as the marginal costs of public funds (MCF) (Dahlby, 2008^[23]).

Consequently, Figure 3 also reports the social cost of the identified fiscal effects. The baseline estimate refers to an MCF of 1.42, which is what Barrios et al. (2013^[24]) have estimated for green taxes in France and is therefore appropriate if the revenue shortfall is recovered through a rise in fuel tax rates.

There is considerable controversy as to how one ought to value MCF in the context of CBA. Several studies recommend to not consider MCF at all (MCF=1) for a variety of reasons, ranging from the argument that they merely represent distributional preferences (Jacobs and de Mooij, 2015^[25]) to pragmatic considerations (European Commission - Directorate-General for Regional and Urban policy, 2014^[26]). The lower caps of the range bars are drawn in accordance with this view. The upper caps that bound the range, on the other hand, assume a very high MCF of 2.41, which corresponds to Barrios et al's. (2013^[24]) estimate for the marginal costs of French labour taxes.

- ***The application of a tax provision that reduces net public revenues causes a social cost per unit of revenue foregone that is equal to the marginal cost of public funds of the instrument used to raise the necessary additional revenue. Fiscal costs should be corrected accordingly.***

3.4. Consumer and producer surplus

The French vehicle feebate affects consumer and producer surplus (profits). Given that the feebate subsidises clean vehicles while making polluting vehicles more expensive, the programme increases consumer demand for clean vehicles while depressing demand for polluting vehicles.¹⁹ Consumers with an underlying preference for clean vehicles benefit, whereas consumers favouring polluting vehicles could see their surplus decrease.

In a differentiated product market, such as the market for new vehicles, producers enjoy some market power. Suppliers will therefore react to the feebate by adjusting market prices. In particular, vehicle suppliers can be expected to enjoy higher (lower) margins on clean (polluting) vehicles. Which effect dominates is an empirical question.

- ***CBA of environmentally related tax policies should not solely assess externalities and fiscal effects, but should consider consumer and producer surplus issues as well.***

As D'Haultfœuille, Givord and Boutin (2014^[2]) do not estimate impacts on consumer and producer surplus, the present paper relies on a recent working paper that was carried out using a similar model on comparable data (Durrmeyer, 2018^[4]). Specifically, the results are derived in a structural model of car demand and supply that draws on town-level demographic data to incorporate preference heterogeneity, as in Nurski and Verboven (2016^[27]).

Durrmeyer measures the consumer surplus effect as the difference between consumers' expected utility of their preferred car under the feebate and the expected utility associated with their first choice in the absence of the policy. Utility is a function of car characteristics such as expected fuel costs as well as the vehicle purchase price net of the feebate. In the

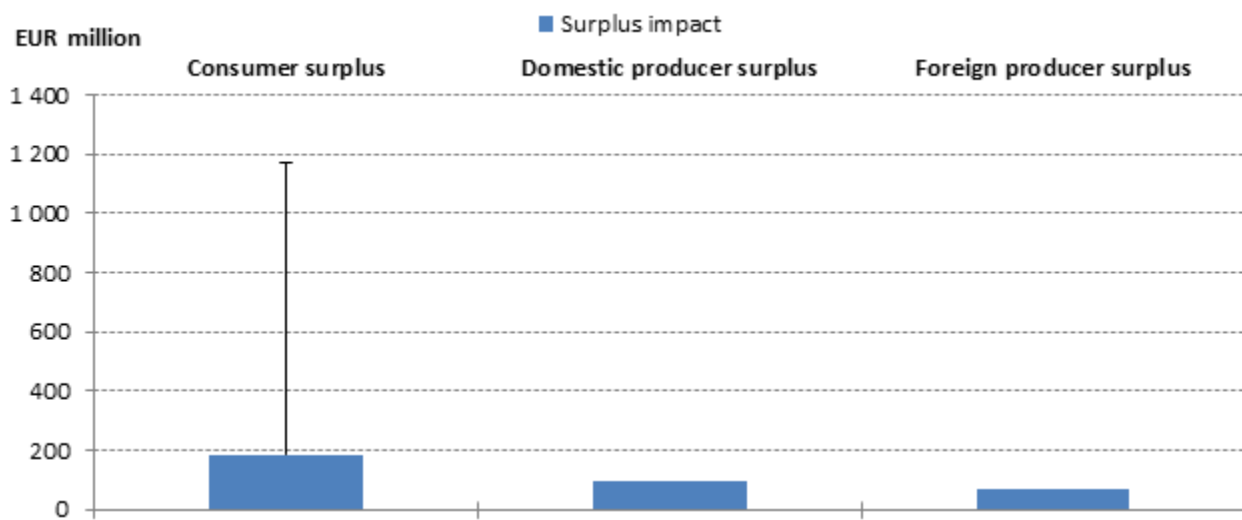
¹⁹ In addition to the price effect, feebates may also affect social norms (Hilton et al., 2014^[32]).

model, the feebate policy affects consumer surplus in three main ways. First, consumers who buy clean vehicles benefit from a subsidy, whereas consumers of polluting vehicles have to pay a tax. Second, the feebate may modify consumer choices as the rebate could induce consumers favouring polluting vehicles to instead buy cleaner ones and e.g. suffer from foregone performance. Third, consumers could be affected by supplier price changes.

Figure 4 shows that the net effect of the feebate on both consumer and producer surplus appears to be positive – before considering who funds the fiscal deficit caused by the feebate.

Figure 4. Consumer and producer surplus

Surplus effects of 2008 vehicle feebate, in EUR million



Note: Surplus effects are based on Durrmeyer's preliminary analysis (2018_[4]), see Annex A. The upper cap of the consumer surplus assumes that 25% of discounted future fuel cost savings represent a consumer surplus gain (Allcott and Wozny, 2014_[28]). No range bars indicate a lack of information regarding the appropriate range.

Policies that modify consumer choices do not necessarily represent an allocative distortion from a social welfare perspective. Given that consumers may undervalue future fuel costs, the feebate could in fact incentivise consumers to buy vehicles that are in their long-term private interest. While some argue that this effect is generally overstated (Leard, Linn and Zhou, 2017_[29]), empirical analysis on US data suggests that consumers may in fact only value approximately 75% of the (discounted) cost of gasoline when they buy vehicles (Allcott and Wozny, 2014_[28]). If this was the case in France, feebate-induced consumer surplus would increase sixfold – cf. the range estimates in Figure 4.

The consumer surplus effects also have distributional implications. Before considering the potential social costs of the fiscal transfer needed to fund the deficit created by the feebate, it was estimated in relation to the French feebate system that people with a higher income gain more. In fact, in absolute terms, feebate benefits increase monotonically with the income decile (Durrmeyer, 2018_[4]). A plausible explanation is that low-income households

are less likely to buy a car in the first place. These distributional implications can change depending on how the fiscal deficit is funded in practice.²⁰

- *As the distribution of costs and benefits can be of great interest – for the people involved and from a political perspective – case studies should seek to discuss distributional impacts at least qualitatively.*

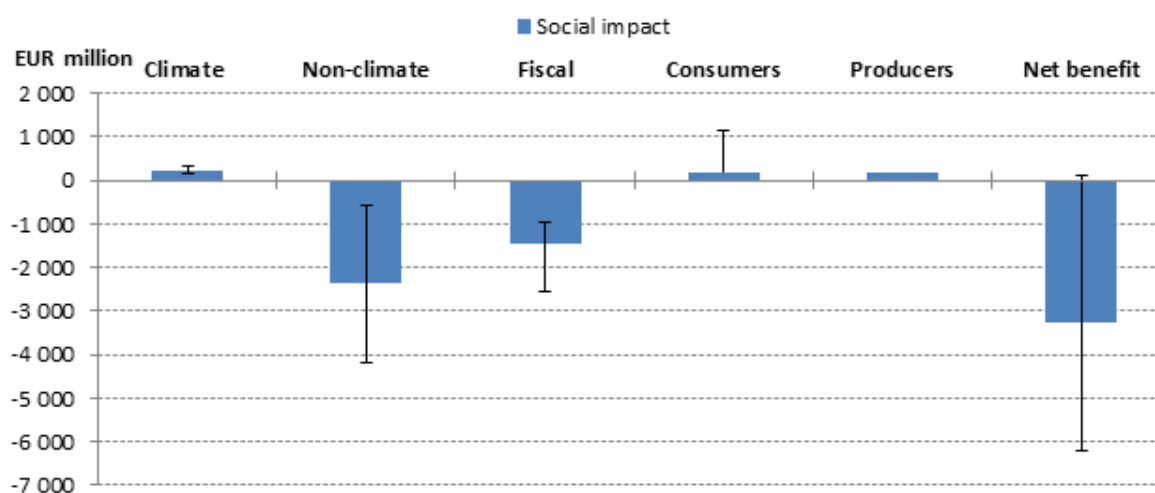
Figure 4 also shows the effects of the feebate on producer surplus, differentiated by domestic and foreign producers. Both gain from the feebate, which makes sense, as the feebate boosted vehicle sales and potentially allowed firms to charge higher margins for clean vehicles. In absolute terms, the increase in producer surplus was higher for domestic producers than for foreign producers, which is not surprising, considering that they enjoy a higher market share. Durrmeyer's (2018^[4]) results suggest that in relative terms, Fiat's profits increased the most (6.2%), where the estimated gains were somewhat smaller for the Peugeot Group (4%) and Renault (3.4%). Daimler's and Porsche's profits, by contrast, are estimated to have declined in relative terms.

3.5. Comparison of social costs and benefits

Figure 5 sums up the results of the preceding analysis.²¹ The 2008 feebate does indeed appear to have decreased CO₂ emissions, which is estimated to come with a social benefit of EUR 212 million. However, the additional road use caused negative non-climate externalities. Under the assumptions of the baseline model, these are ten times larger than the climate benefits.

Figure 5. Comparison of social costs and benefits

Social benefits of the 2008 vehicle feebate, in EUR million



Note: Estimates are based on the analysis presented in Figures 1-5. Range estimates are the sum of the range estimates presented there.

²⁰ Durrmeyer (2018^[4]) analyses two concrete scenarios that seek to shed some light on how net consumer surplus (after a tax to fund the revenue gap is levied on consumers) is affected by the feebate. In the first scenario, the direct fiscal cost of the feebate is funded by a lump sum tax on consumers. The other scenario considers a proportional income tax.

²¹ The analysis assumes that market power is limited to manufacturing, whereas all other industries (in particular car retailers and gasoline suppliers) are perfectly competitive. Feebate-induced additional profits by the motorway companies are not considered either.

The feebate-induced revenue losses amount to EUR 1.5 billion – which is more than six times as large as the estimated value of the climate benefit. Consumer surplus increases by EUR 223 million, but this gain only represents some 15% of the fiscal cost in the baseline specification. However, should consumers fail to internalise 25% of the discounted future fuel cost savings at the time of purchase, the feebate may increase consumer surplus six fold. Producer surplus increases by EUR 162 million, 12% of the fiscal cost.

The resulting net effect of the 2008 feebate is consequently negative in our baseline specification where it is estimated to decrease social welfare by EUR 3.3 billion.²² The net effect is, however, quite sensitive to the modelling assumptions. In particular, in a favourable scenario – where climate costs are high (making feebate-induced emission-reductions worth more), non-climate external costs are low, fiscal transfers are costless, and consumers undervalue fuel savings – welfare might have increased by around EUR 100 million.

The comparison invites three observations. First, negative non-climate externalities are large in road transport. This suggests that there is a need and merit in complementing vehicle feebate policies with policies that internalise these non-climate externalities. Against this background, it is encouraging that effective tax rates in road transport have been on the rise in France (OECD, 2018_[30]), highway tolls are common, and French cities such as Paris are taking steps to reduce urban pollution from road transport.

Second, revenue changes from feebate systems can be significant, even when they are designed to be revenue neutral. In particular, this paper emphasised the need to also consider indirect fiscal effects – and the estimated excise tax revenue losses turned out to be substantially larger than the direct fiscal effects from the feebate. To the extent that raising taxes brings about important distortions to economic activities (the magnitude of which is unfortunately quite uncertain), this can have substantial social costs. Carefully adjusting the feebate schedule to avoid or limit such revenue shortfalls is thus worth considering.²³

Finally, vehicle feebate systems and related policies may have substantial benefits for consumers as well – should they fail to internalise future fuel costs at the time of purchase. Given the potential magnitude of fuel savings related welfare gains, obtaining more reliable estimates of whether – and, if so, by how much – consumers undervalue these savings in practice would appear an important research agenda.

²² We assume that there is no preference in favour of consumers or producers in the social welfare function.

²³ An alternative way to achieve emission reductions would be to implement marginal external cost pricing, e.g. in the form of excise and carbon taxes. This would generally be more economically efficient (Grigolon, Reynaert and Verboven, 2017_[31]), as also discussed in Van Dender (2018_[22]).

4. Conclusions

This paper has illustrated how one can use the results from programme evaluation studies to assess the social costs and benefits of environmentally related tax policies ex post. Given that the analysis is only based on the year 2008 – the very first year of the French policy – the results cannot be generalised and do not reflect an evaluation of the French feebate as such, which has now been in place for more than 10 years. If another year been chosen for the analysis, the results may have been different.

Notwithstanding this caveat, and the significant uncertainty about the precise effects of environmentally related tax policies in general, the analysis makes a number of suggestions with a view to informing future ex-post CBA studies (Box 1). Some final remarks are in order.

First, even ex-post CBA can involve forward-looking elements. Valuing these elements requires assumptions regarding discount rates and the persistence of behavioural impacts. In the case of the French feebate system, considering lifetime carbon emissions, as opposed to limiting the analysis to quarterly effects, leads to very different conclusions to those drawn in the original study. Whereas the French feebate was originally estimated to have caused a rise in CO₂ emissions, our results suggest that it may in fact have led to a decrease in such emissions. This is reassuring, considering that reducing CO₂ emissions was the very objective of the policy.

Second, quantified effects, as well as associated social costs and benefits are often uncertain. Ex-post assessments may thus not deliver authoritative evidence on the exact net welfare effects of environmentally related tax policies – or any other policy or project. In the example of the French feebate system, the main uncertainties relate to non-climate external costs as well as the consumer surplus effects of feebate-induced fuel cost savings. It is therefore appropriate to acknowledge this uncertainty upfront and provide decision makers with a range of estimates – as opposed to only reporting net welfare effects that would hide the uncertainty.

Naturally, uncertainty is not limited to the quantified impacts of the policy; unquantified impacts can equally affect results. Specifically, an important long-run objective of the French feebate – not considered in this paper due to its focus on the early impacts of the policy – is to encourage vehicle manufacturers to develop cleaner cars. Given that decarbonising transport remains a major challenge, contributing to meeting this objective could in fact represent an important long-run benefit of feebate policies.

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Annex A. Technical appendix

The cost-benefit analysis is based on the following welfare function:

$$W = CS + PS + (1 + \lambda)T - E$$

In the formula, CS stands for consumer surplus, PS is producers' surplus, $1 + \lambda$ is the marginal cost of public funds (λ is the marginal excess burden of taxation), T is tax revenues and E is external costs.

The paper then calculates $\Delta W = \Delta CS + \Delta PS + (1 + \lambda)\Delta T - \Delta E$

where $\Delta W \equiv W_1 - W_0$. Here W_1 refers to the social welfare under the 2008 vehicle feebate, whereas W_0 is the counterfactual situation where no feebate was implemented. ΔCS , ΔPS , ΔE and ΔT are defined analogously. The results of the modelling exercise are shown in the table:

Table A A.1. Modelling results

Welfare changes induced by the 2008 vehicle feebate, in EUR million

	Baseline	Low estimate	High estimate
ΔCS	187	187	1 169
ΔPS	162	162	162
$(1+\lambda)\Delta T$	-1 462	-2 549	-961
ΔE	2 167	263	4 023
ΔW	-3 225	-6 169	161

Note: The low welfare estimate is based on the high external cost estimate, given that the latter enters the welfare equation with a negative sign. Analogously, the high welfare estimate uses the low external cost value.

The remainder of this annex discusses how these effects are modelled, following the order in which these are reported in the paper, i.e. ΔE , ΔT , ΔCS , ΔPS . Assumptions already discussed in the main text are generally not repeated.

Changes in external costs, ΔE , that were induced by the 2008 feebate include both climate and non-climate related external costs. With respect to climate costs, this paper only takes into account the effect of the 2008 feebate on CO₂ emissions. Here we rely on the short-run effects estimated by D'Haultfœuille, Givord and Boutin (2014_[2]). Their estimates are adjusted in four main ways.

First, half of the emissions that the original paper considered to be part of the composition effect are reassigned to the manufacturing scale effect. Specifically, in the original paper, the composition effect also accounts for the fact that manufacturing emissions of feebate-induced cars are lower, given that the models benefitting from the feebate tend to be smaller and lighter. However, as this is a one-off effect that does not persist over the vehicle lifetime, we reassigned this effect to the manufacturing scale effect, and renamed the effects fleet composition and manufacturing.

Second, these adjusted quarterly effects are transformed into yearly effects, assuming that vehicle choices are made at the beginning of the year and that quarterly effects scale proportionally.

Third, yearly effects are extrapolated into the future based on the assumption that the 2008 vehicle cohort has a lifetime of 15 years and that composition, rebound and fleet size effects persist unaltered over the lifetime of the vehicle.

Finally, the estimated effects are monetised and discounted to 2008, assuming a social cost of carbon of EUR 60 EUR per tonne of CO₂ and an annual discount rate of 4%. The sensitivity analysis additionally considers carbon cost values of EUR 30 and EUR 90.

In terms of non-climate effects, only those resulting from additional road use are modelled. The additional road use is derived from the rebound and fleet size climate effects, using sales and mileage information reported in D'Haultfœuille et al. (2014_[2]). Specifically, CO₂ effects are converted into kilometres using the average CO₂ emissions of new vehicles sold over the study period (138 g/km), and then split into vehicle types assuming that 77% (23%) of these kilometres result from diesel (petrol) vehicle use.

The kilometre estimates are then monetised by multiplying them with the marginal external cost estimate per km provided by Santos, after converting these into 2008 prices using OECD inflation data. As before, external costs are discounted to 2008 using a 4% discount rate. Based on Van Dender's (2018_[22]) meta-analysis, the sensitivity analysis considers the possibility that air pollution and wear & tear might be 50% larger or smaller than estimated by Santos; whereas congestion, accidents and noise estimates could be 80% off.

With respect to the change in government revenue that results from the 2008 feebate, i.e. ΔT , three components are modelled. The first is the direct fiscal effect of the feebate, i.e. the difference between the sum of the taxes collected and the sum of the subsidies paid out in 2008 – reportedly EUR -285 for the whole of 2008 (D'Haultfœuille, Givord and Boutin, 2014_[2]).

The second is the excise tax effect, which is calculated by multiplying the 2008 effective excise tax rates per tonne of CO₂ (EUR 161 and EUR 261 per tonne of CO₂ for diesel and gasoline, respectively)²⁴ with the estimated change diesel and gasoline emissions associated with the fleet composition, rebound and fleet size effects. The estimated loss in excise tax revenues is EUR 69 million per year. The yearly excise tax effect is then extrapolated into the future, assuming that the effect remains constant over the vehicle lifetime. As usual, post-2008 effects are discounted.

The third fiscal effect relates to feebate-induced changes to VAT revenue which may come through feebate-induced changes to (i) fuel sales over the lifetime of the vehicles and (ii) 2008 car sales. The fuel component of the VAT effect is calculated analogously to the excise tax effect, also using IEA data. The car sales component of the VAT effect is modelled assuming that 13% of 2008 vehicle sales were induced by the feebate, and that the average ex VAT price of these cars was EUR 16 000.

The sum of these fiscal effects is then multiplied the marginal cost of public funds, $(1+\lambda)$, drawing on France-specific estimates (Barrios, Pycroft and Saveyn, 2013_[24]).

Estimates for ΔCS and ΔPS are based on Durrmeyer's aggregate welfare analysis (2018_[4]). The sensitivity analysis additionally explores how much larger the consumer surplus effect of the 2008 feebate would be if consumers failed to internalise 25% of discounted future fuel costs when making their purchase decisions (Allcott and Wozny, 2014_[28]). Fuels savings are calculated by taking the absolute value of the product of composition effect (in tonnes of CO₂) and total fuel costs as reported by the IEA (after converting these to the CO₂ base). Future fuel savings are discounted using a 4% discount rate.

²⁴ Statutory excise tax rates from the IEA are converted from litres to CO₂ assuming that combusting one litre of petrol (diesel) causes emissions of 2320 (2650) grams of CO₂.