The bonus–malus policy for private vehicles: how large is the carbon emission reduction?

Rob Hart, Chandra Krishnamurthy, Tingmingke Lu

1. Purpose and aims

Following the Swedish Climate Act, Sweden aims to be GHG emission-free by 2045. A milestone on the way is a reduction of GHG emissions from domestic transport by 70 percent (relative to 2010) no later than 2030. Policy hitherto has focused on increasing the carbon-efficiency characteristics of the car fleet by encouraging purchase of low-emission vehicles – especially electric vehicles (EVs) – rather than encouraging retirement of highly emitting vehicles or discouraging vehicle ownership and driving altogether. Consequently, while EV uptake is accelerating, the number of private passenger cars and total mileage are also rising (according to our preliminary assessment, by 16 percent and 7 percent respectively since 2010). A recent policy initiative, the bonus–malus scheme, also targets the emission profile of new vehicle purchases, by penalising the purchase of higher emission vehicles (the "malus") and subsidising purchase of lower emission vehicles (the "bonus"). Our main goal in this project is an explicit evaluation of the effect of the bonus–malus scheme on carbon emissions, whose reduction is the ultimate objective of the Swedish Climate Act.

Many challenges to evaluating the extent to which this policy is successful arise, partly because the policy affects emissions only indirectly (by altering the relative price between more and less polluting vehicles), and is consequently a second-best policy (the first best involves directly targeting the source of emissions, car usage, with a tax). The effects of bonus–malus upon carbon emissions will depend upon usage of cars, new and old, and upon household response to the policy. Thus, net change in carbon and non-carbon emissions resulting from the policy will depend upon three aspects: net change in vehicle purchases ("purchases"); market shares of cars with varying emission profiles ("market shares"); and usage of vehicles with varying emission profiles ("usage" or "mileage"). While the bonus–malus policy directly targets one facet, market share, its effects upon the other two facets are both important and difficult to measure in the aggregate.

This policy directly affects the market share of green vehicles, which is one metric of success. Another, more meaningful, metric is net carbon emissions avoided that may be attributed to the policy. A similar policy in other countries has often led to unexpected results, including an increase in carbon emissions and in vehicle purchases. We outline in this proposal two complementary ways, corresponding to these two metrics, to quantify the effect of the bonus–malus policy. In addition, the methods we propose also provide a means of evaluating different aspects important to policy making, including understanding the effect of different variants of this policy (e.g. increased stringency via reduced threshold for bonus, increased malus amounts) and the effects of this policy upon different household types. In this sense, our proposal provides a comprehensive means of evaluating a policy whose effects upon transportation-related emissions operate through a variety of channels.

Our analysis proceeds two steps, each of which constitutes a distinct but non-sequential work package (WP):

1. In the first step (WP1), we evaluate the effect of the policy on the outcome it most directly targets, the share of high and low emission vehicles in the new car market (and the implied reduction in carbon and non-carbon emissions);

2. In the second step (WP2) we evaluate the effects of the policy on household decisions in the entire car market (including both new and used vehicles) and with regard to mileage.

The analysis is of direct relevance to Swedish authorities such as the Swedish EPA and the Swedish Transport Agency (STA). It evaluates the effects of bonus–malus on transportation not only in regards to the market share of low-emission vehicles (LEVs) but also via the channels through which household choices are affected by the bonus–malus and in turn affect emissions. Furthermore, we also propose conducting counter-factual simulations of alternative versions of the bonus–malus, which can provide a rich menu of alternative directions to the Swedish EPA and the STA for refining existing policy. In addition, our analysis can highlight the effects of this policy on different types of households and provide evidence on the extent to which it exerts adverse distributional effects. Finally, the approaches to policy evaluation that we outline are applicable to many transport-related policies, and we outline how the Swedish EPA and the STA can use these tools to quantify the effect of these policies.

2. Research questions and hypotheses

The proposed project focuses on two three research questions related to the bonus–malus policy.

1. What is the effect of bonus–malus on the share of high- and low-emission vehicles in the new car market? Based only on changes in the new car market, what are the expected effects on consumer welfare, manufacturer profits, public revenues, and CO_2 emissions?

2. How sensitive are the results to changes to the thresholds for bonus and malus, and the size of the monetary incentives? Could the policy be adjusted (through for instance changes to the thresholds for bonus and malus) to achieve the same emission reductions at a lower cost, or yield higher welfare gains?

3. How much do emissions change following the bonus–malus scheme, when we account for changes in the entire car market, including the second-hand market and mileage choices?

4. Which household types (e.g. by income or regional location) are more affected by the policy? What is the effect of the policy on overall economic welfare? How may the policy be redesigned to further reduce carbon emissions, while not adversely affecting specific groups of households?

Our initial hypotheses regarding these questions are as follows.

Hypothesis 1. The aggregate effect, in terms of market share of lower emission cars of the policy is lower than assumed, and insufficient to meet the goals outlined in the Climate Act.

Hypothesis 2. Welfare gains from the scheme could be increased if higher fees (malus) and lower rebates (bonus) were applied.

Hypothesis 3. Emission reductions resulting from the bonus–malus policy are moderate, largely due to household responses to the policy modulating its intended effect.

3. Expected results

The project is anticipated to provide two types of results:

1. The first set of results relate to the degree to which the policy has succeeded, and how it could be improved. These results arise from an explicit evaluation along two metrics of the bonus–malus program: market share of low emission vehicles; and effects of this policy upon net carbon emissions from private cars.

2. Second, two sets of methodological tools will be developed, which are anticipated to be of significant relevance to ex-post policy evaluation related to transportation and environmental policies. These tools can be used to further refine the policy, and to explore other policies that share key similarities.

As to timelines, results relating to the evaluation of the program on aggregate outcomes is anticipated towards the end of the second year. An intermediate result, the development of the household microdata set, is anticipated towards the middle of 2022, together with the development of the econometric discrete-continuous choice model. An evaluation of the emission implications of the policy is anticipated towards the end of 2023, the conclusion of the project.

4. Benefit for the Swedish EPA – relevance and practical use

The project is directly relevant to the Swedish EPA's work because it both provides a snapshot of the effects of the bonus–malus policy today and outlines a rigorous and consistent way of evaluating proposed future changes. Thus, the relevance of the proposed project is not only in the near future but also to the more distant medium-term, when a redesign of this policy may be needed to further the goals enshrined in the Climate Act. Indeed, many other transportation-related policies (e.g. subsidies and/or taxes) and their interactions with the bonus–malus may be accommodated in the model framework proposed here, making some of the approaches outlined here a potential workhorse for the Swedish EPA/Transport Agency. The proposed project develops a means for quantification of the effects of policy upon local and global pollutants. In consequence, it directly contributes to advancing the Swedish Environmental Goals related to *Reduced Climate Impact* and *Clean Air*. Furthermore, it provides a data-based means of quantifying the effects of changes in policies upon these two goals, ensuring that the approaches developed in the project stays relevant for future policies affecting these two goals.

To our knowledge, ours is the first formal evaluation of the bonus–malus policy that quantifies its effects along two distinct channels: the direct channel, market share of low emission cars; and a more comprehensive analysis of the channels through which household choices affect carbon emissions. These aspects, especially concrete evidence regarding the effect on carbon and local/regional emissions, are of direct relevance to the Swedish EPA and the STA. Furthermore, our counterfactual simulations of different bonus–malus alternatives (e.g. greater levels of malus/bonus, different emission set points at which bonus and malus are applicable) will provide a rich menu of alternative directions to the Swedish EPA and the STA for refining existing policy. And an understanding of the effects of this policy on different types of households provides the Swedish agencies key information for ensuring that adverse distributional

effects of these policies (which have been identified in scientific literature) are identified and addressed.

Methodologically, we outline complementary approaches to ex-post evaluate the effect of large-scale public policies (i) that are not normally easily evaluated in the aggregate, and (ii) whose effects are determined by indirect and household-based channels. These characteristics apply to many transport-related policies, meaning that the proposed project provides the Swedish EPA and the STA with a range of tools and approaches to evaluate many of those policies.

5. Target groups

Our target group consists of two types of audience: the first is academic researchers whose work intersects transportation and climate change (including economists, engineers and those in a variety of other policy-related fields) and the second is policy makers from a variety of national agencies (primarily the Swedish EPA and the Swedish Transport Agency, but also the Ministries of Environment and Finance of the Government of Sweden). As to the policy audience, our work is of interest not only to those in charge of designing transportation and pollution-related policies but also those interested in their application. To understand why these are our target audience, we note that our work contributes to both academic research and to policy design. For the former, we note that there are few (if any) analyses of bonus–malus policies that explicitly account for the many channels of household response, and the methods we use to do so advance the literature in the field. For the latter audience, we note that our research question is directly inspired by, and therefore relevant to, an actual policy currently in place. Our work directly relates to how different aspects of these policies not only affect households and therefore the outcomes that these policies are meant to advance (carbon emissions) but also how the policy may be redesigned in order to better advance those goals, and to understand the implications of different redesigns for household welfare.

6. Reference Group

A reference group will be vital to the project. Representation from the Swedish EPA is essential. Since we focus on transport, representation from the Swedish Transport Agency would be advantageous, as well as representatives from relevant ministries. Finally, it would be suitable to have group members from the academic community with a background in policy evaluation, especially with respect to the environment.

7. Theory and methodology

Evaluating universal public policies which are effective everywhere at once is a challenging task, especially in the absence of explicit pilot studies (often difficult to arrange for these policies). This is all the more so when these policies, such as the bonus–malus, have multiple choice elements and are known to be sensitive to (often poorly understood) household responses. We approach this task here with a set of two complementary tools, the first a differentiated product model, focused on market-level outcomes (WP1), and the second a discrete-continuous choice model for vehicle choice and mileage, using household level micro-data (WP2).

WP1: Bonus-malus and the market share of new cars

WP1 involves an explicit ex-post evaluation of the aggregate effect of this policy on market shares i.e. the pattern of sales of less and more polluting cars. Analysis here makes use of data on market shares of different car models (and their characteristics) and a concise snapshot of household mileage data at the type-level, and uses econometric choice models to evaluate the effects of the policy. Account will also be taken of the short-run firm response, since manufacturers may adjust prices of existing models to account for the policy.

A bonus–malus system is designed to influence consumer choices in the new car market by altering the relative prices of cars with different emission levels. Our goal in focusing on the new car market is twofold: firstly, to estimate a market equilibrium model consisting of the demand and supply sides using observed consumer choices under the policy; and secondly, to conduct policy counterfactuals and evaluate alternative policies designs. Structural models capture the price effects of feebates and use the implied price elasticities of new cars to simulate new policy outcomes by changing the feebate parameters. Because of the nature of the new car market (highly differentiated products), accurately estimating heterogeneous consumer preference is crucial for obtaining appropriate price elasticities, upon which subsequent policy evaluation is based.

We use market-level data on vehicle shares of different model classes, together with new car buyer characteristics. We start from a random coefficients logit model of individual choice to obtain an aggregate demand system for differentiated new passenger cars. We incorporate household demographics through population moments. Using the empirical mileage distribution from the vehicle inspection records, we follow the recent literature (e.g., Grigolon et al. (2018)) and construct mileage types for new car buyers and therefore account for car use heterogeneity in the demand estimation. We rely on the upfront car purchase price, expected fuel costs, and the annualized ownership cost to capture the monetary effect of the bonus–malus scheme. For the supply side, we consider a multi-product Bertrand competition model and allow car manufacturers to re-optimize prices. In our policy counterfactuals, we change the pivotal point of the policy design to examine shifts of new car market shares by emission categories. Moreover, such a model allows us to compare the bonus–malus system with gasoline and diesel fuel taxes on the externalities-equivalent ground.

We estimate such a model using the method of simulated moments. Variations in car attributes, consumer characteristics, and expected lifetime gas cost allow us to identify flexible substitution patterns for new car buyers. Accounting for mileage heterogeneity in an aggregate demand system allows us to address the self-sorting bias in both demand estimation and policy counterfactual. This is an advantage of our analysis over other similar studies in the literature (e.g., Huse and Lucinda 2014, Adamou et al.,2014, and Durrmeyer 2018).

We will spend the first year on constructing a data set for both work packages. This data set will be constructed by working together with Statistics Sweden and extracting anonymous household information from the Swedish population register (Befolkningsregistret and LISA-registret) and by linking this household microdata to registration records available at Swedish Vehicle Registry (Fordonsregistret). We expect to complete the estimation and policy counterfactuals by December 2022 for the first work package.

WP2: Bonus–malus and household vehicle and mileage choices

In WP2 we extend WP1 (which focuses only on the new car market) by developing a household-micro-data-based econometric model for household vehicle and mileage choice. This

provides a more comprehensive and accurate perspective of the wide margins of choice available to households, and thus a more complete picture of the effects of the policy. This framework will account for dependence between these two facets of household choice and for heterogeneity across households, including across the income and regional dimension. Using this model, we provide an explicit evaluation of the effect of different policy scenarios related to (carbon and non-carbon) emissions, including an investigation of different bonus–malus policy scenarios and their effect on household vehicle choice, mileage and carbon emissions.

We propose to construct a comprehensive household micro-data set on vehicle choice, mileage and household characteristics. Using this data set, we propose to construct a structural model of household vehicle and mileage choice. To our knowledge, very few studies evaluate transportation policies using such a detailed household micro-data set, and none does so for the bonus–malus policy, for any country.

As already discussed in the "Purpose and Aims" section, the bonus–malus policy directly targets market share, while its effects upon the other two key facets identified previously, change in vehicle purchases and mileage, are important yet difficult to measure. Moreover, accounting for the interdependence between car usage decisions and key attributes of cars (e.g., fuel type) becomes essential if we intend to investigate the impact of a bonus–malus system on emissions of different types (e.g., CO_2, NOx, particulate matter). Secondly, following the findings in Wakamori (2015) and Archsmith et al. (2020), we will also examine so-called "attribute substitution" by multi-vehicle owning households. Specifically, we will account for interactions between preferences over car attributes such as size and horsepower for multiple vehicles within a household.

As to the structural model framework, we follow Bento et al. (2009) and propose to apply a full-information, one step structural approach that simultaneously estimates the extensive (vehicle choice) and intensive (mileage) choice margins within a utility theoretic framework that allows us to recover robust welfare estimates. In our model, a household can choose to have multiple cars or to not own any vehicle. The utility of a car owning household depends on car attributes, transport services produced by cars, and outside goods consumption. To identify the attribute substitution effect, we will extend our discrete-continuous choice model by introducing car bundles that describe the combination of attributes across cars owned by a household as in Feng et al. (2013).

This work package will proceed in two stages: in the first, occupying the first year-and-a-half (January 2021–July 2022) and running in parallel with WP 1, we will assemble the household micro-data set. In the second phase, we set up the econometric model and carry out the model estimation and provide policy relevant counterfactuals, and we anticipate this phase of the work package to occupy the remainder of the project.

8. State of knowledge

Policies aimed at reducing transportation-related carbon and non-carbon emissions are increasingly at the center of policy attention worldwide. A wide-range of policies are in discussion internationally, including subsidies for low emission vehicles and so-called "feebates" or bonus–malus. The bonus–malus system, which is a market-based instrument for addressing transportation-related externalities, is increasingly becoming important in the EU, and is in force in many countries excluding Sweden as of 2018 (including France and Italy). A bonus–malus scheme combines a "bonus" for low-emission cars and increased vehicle taxes ("malus") on

high-emission cars. In contrast to other regional policies (e.g., congestion charges), feebates are often designed as national policies and are rolled out in all regions simultaneously. This feature makes evaluating a feebate problematic because effective control groups required for applying quasi-natural experimental approaches are difficult to identify.

For evaluating the effect of incentive schemes with these features, recent literature relies on estimating differentiated products demand and supply models. Because the main channel through which a feebate works is through altering the relative costs of holding cars with different emission levels, structural demand models capture price effects of feebates and use the implied price elasticities to conduct policy counterfactuals by changing feebate parameters. In addition, unobserved aspects such as welfare (often computed as consumer surplus), can be expressed as functions of model parameters. This approach often compares outcomes with and without the feebate. To our knowledge, there is no study evaluating how household choices affect policy performance and outcomes, which have been suggested to be of significant importance in transportation policy evaluation (Bento et al (2008)), particularly for policies promoting green cars (Muehlegger and Rapson (2018)) or scrapping older vehicles (Archsmith et al. (2020).

In any case, using aggregate structural models outlined above, Huse and Lucinda (2014) show that the Swedish green car rebate, largely focused on flexible fuel vehicles (FFVs), which predated the bonus–malus, increased the market share of green cars by 5.5 percent while costing five times as much as an emission permit (even higher if drivers arbitrage over fuel prices). They also suggest that consumers would have switched to FFV even without the rebate. A similar study, Adamou et al. (2014), uses a demand system to evaluate the effects of a hypothetical feebate for Germany. Its main findings is that revenue-neutral feebates reduce total welfare, since the gains from reduced CO_2 emissions are insufficient to compensate for reduced consumer surplus and producer profits. They suggest that non-revenue-neutral schemes could improve welfare. Durrmeyer (2018) uses a similar framework to evaluate the French bonus–malus scheme (implemented in 2008). This study finds that the policy reduced average carbon emissions by 1.6 percent, at the cost of additional emissions of nitrogen oxide and particulate matter, and that, once the costs of these additional emissions costs are subtracted, the French bonus–malus system generated a net benefit of at least 110 million euros.

The new Swedish bonus–malus system went into effect in July 2018, and featured credits (up to SEK 60,000) for cars with CO_2 emission no higher than 60g/km and higher annual road tax (depending on the CO_2 emissions and fuel-type) for the first three years for cars exceeding 95g/km. Habibi et al. (2019) is the only study exploring the effect of the hypothetical Swedish bonus–malus system (prior to its introduction) using a structural aggregate demand and supply model. Relying on pre-specified product clusters, they use a nested logit model to characterize changes in new car market shares with and without feebate incentives. Their simulations suggest that the bonus–malus system proposed by governmental investigation in Sweden in 2014 and its variations are not effective in reaching the target of maximum 95g/km of average CO_2 emissions for new car sales by 2020.

In this project, we aim to analyse the Swedish bonus–malus system along two dimensions. First, recognising that the policy is designed primarily to increase the share of low-emission vehicles in the new car fleet, and that household characteristics influence car choices, we analyse to what extent the policy increases market share of low-emission vehicles. This part of our work (WP1) will incorporate household demographics and urban structure information to account for households' preference heterogeneity in car choices. Allowing flexible substitution patterns in new car markets is particularly important because low-emission cars and those running on fossil

fuels are rarely perfect substitutes. Moreover, we are unaware of any studies combining rich micro- and macro- data to investigate Swedish household demand for new cars. Our work is intended to fill this gap.

Secondly, we recognize that properly accounting for households' car usage decisions is crucial because these decisions are a key component of emissions reductions. More importantly, a household's car holding and car usage decisions are interdependent. To account for the joint nature of these decisions, our second work package (WP2) will develop a model incorporating the discrete choice of cars and the continuous choice of mileage at the household level, allowing for a wide range of choices: choose new cars, used cars, or not to own a vehicle at all. Therefore, we examine the effects of the bonus–malus system in a model that links the markets of new car choice with existing household car holdings . This will be the first comprehensive analysis of the impacts of different energy policies on household transport choices.

9. Organisation and management

Organisation. Both parts of this project rely on car registration data and the price data of new and used cars. During the first year, we will assemble the data set and construct models for both studies. The analysis focusing on the new car market will be largely done by the end of the second year, while the investigation on household choices in both new and used car markets, and on mileage will expand through the third year.

Year 1

WP1 Market level analysis.

1. Organize data from various sources relevant to the study.
2. Build a market equilibrium model of the Swedish new car market.
3. Manuscript: Welfare implication of the Swedish feebate in the new car market.

WP2 Household-level analysis

1. Organize data, build a one-step, full information discrete-continuous choice model.
2. Commence development of the estimator.

Year 2

WP1 Market level analysis

1. Further develop the manuscript, consider and compare alternative model specifications.
2. Carry out policy simulations.
3. Present the paper in conferences and seminars for further feedback.

WP2 Household level analysis

1. Apply the model to household microdata, analyse effect on demand and mileage.
2. Paper: prepare draft manuscript, present at international conferences and seminars.

Year 3

WP1 Market level analysis

1. Submit draft manuscript for publication.
2. Develop a framework for evaluating options for incentivizing LEVs.

WP2 Household level analysis

1. Submit manuscript for publication.
2. Use the model to provide policy implications for the markets of both new and used cars.

Management. Prof. Rob Hart (RH), the project leader, will coordinate and assist on both WPs, especially relating to policy analysis and relevance for Swedish agencies. He will work approximately 10 percent of full time on the project. Asst. Prof. Chandra Krishnamurthy (CK) will work about 50 percent of full time on the project and will be involved in both work packages. A large part of the funding will go to Doctor Tingmingke Lu (TL) who will be involved in both WPs and will work 70 percent of full time on the project.

The project group members have skills that complement one another. RH, the project leader, has a long and successful record of research regarding markets which involve the use of natural resources and emission of pollution. His focus is on understanding market evolution at large scales and over long time periods, and drawing policy conclusions. He is thus ideally suited to manage the overall project. TL, whose dissertation was on the economics of motor vehicle energy efficiency, will contribute to the project with his expertise in demand estimation. His current work studies transport related energy policies on both effectiveness and distributional grounds. CK is an empirical resource economist with a strong background in economics of electricity markets and transportation and has experience in working with large data sets in both research areas, with a focus on ex-post project evaluation. To illustrate: he has worked, in the past two years, on ex-post evaluation of a transportation-related public policy project for San Francisco and is working on an ex-post evaluation of the effects of the entry of Uber on congestion and pollution (for California). In light of their specific skills sets, TL and CK will largely be responsible for assembling the household micro-dataset and constructing the structural econometric model. The econometric skills of CK and TL are complementary: CK has worked largely on ex-post evaluation (and has some experience in demand estimation) while TL has largely worked on differentiated product demand models. RH will assist them in understanding the specific Swedish context as well as in assessing the most relevant policy- and household-specific aspects to be considered. All three will be involved in writing the manuscripts.

The key scientific deliverables of the project are two scientific papers submitted to top environmental economics or general interest economics journals.

Networks. All project participants are part of a network of economists interested in working on transportation and urban issues. RH and TL are part of a small group at SLU Uppsala working on transportation and urban questions. CK is increasingly a part of the network at Uppsala and also has strong connections, including in the form of published and ongoing papers, with researchers working on transportation and pollution-related questions at the University of Oregon, which has a very strong and long-standing transportation and urban economics focus and research center.

10. Data publication plan

The data used for the project will be of two types: household level micro-data, including household characteristics and vehicle choice, mileage, and aggregate level car data (registration

annually, by model-make-year and its characteristics). The latter data set is intended to be made available to the Swedish EPA and for research purposes for anyone interested. The former data set is assembled from different sources together with the SCB, and cannot be shared with anyone, due to privacy and other concerns, as stipulated by the SCB. The Swedish EPA, however, may be able to use the dataset for research purposes, should the SCB be able to approve such a request.

11. References

Adamou, A., Clerides, S., Zachariadis, T., 2014. Welfare implications of car feebates: A simulation analysis. The Economic Journal 124, F420–F443.

Archsmith, J., Gillingham, K., Knittel, C.R., Rapson, D.S., 2020. Attribute substitution in household vehicle portfolios. Accepted, RAND Journal of Economics.

Bento, A.M., Goulder, L.H., Jacobsen, M.R., Von Haefen, R.H., 2009. Distributional and efficiency impacts of increased US gasoline taxes. American Economic Review 99, 667–99.

Durrmeyer, I., 2018. Winners and losers: The distributional effects of the French feebate on the automobile market. TSE Working Paper.

Feng, Y., Fullerton, D., Gan, L., 2013. Vehicle choices, miles driven, and pollution policies. Journal of Regulatory Economics 44, 4–29.

Grigolon, L., Reynaert, M., Verboven, F., 2018. Consumer valuation of fuel costs and tax policy: Evidence from the European car market. American Economic Journal: Economic Policy 10, 193–225.

Habibi, S., Sundbergh, P., Algers, S., others, 2019. Car fleet policy evaluation: The case of a bonus–malus system in Sweden.

Huse, C., Lucinda, C., 2014. The market impact and the cost of environmental policy: Evidence from the Swedish green car rebate. The Economic Journal 124, F393–F419.

Muehlegger, E., Rapson, D. S. (2018). Subsidizing mass adoption of electric vehicles: Quasi-experimental evidence from California (No. w25359). National Bureau of Economic Research.

Wakamori, N., 2015. Portfolio considerations in differentiated product purchases: An application to the Japanese automobile market. SFB/TR 15 Discussion Paper.