Environmental Externalities, Product Attributes, and Market Power: Implications for Government Subsidies

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Summary: many countries use subsidies to promote the diffusion of energy-efficient products to combat climate change. These subsidies are often designed to target product attributes that are related to their environmental benefits and are referred to as "Attribute-Based Subsidies" (ABS). At the same time, manufacturers of these products often wield significant market power and change product attributes in response to government policies. We develop a theoretical framework for the optimal design of such policies to account for endogenous product attributes, environmental externalities, and market power. We use China's electric vehicle market as a case study to evaluate the welfare impacts of various subsidy designs. Compared to uniform subsidies, commonly used ABS designs lead to higher product quality and are more effective in mitigating market power, albeit with a modest environmental cost. Between 42% to 62% of welfare gains under ABS relative to uniform subsidies are attributed to more desirable product attributes, with the remainder explained by reductions in market power distortions. Allowing subsidy redistribution through product-level subsidies, as suggested by our theoretical model, further enhances welfare gains by an additional 34% to 62%. Among the ABS designs, China's notched subsidy design based on driving range leads to vehicle downsizing that undermines welfare benefits. Subsidies based on battery capacity, as implemented in the U.S., achieve the highest welfare gains by effectively balancing market power and environmental impacts.

Many countries use subsidies to promote the diffusion of energy-efficient products to combat climate change. These subsidies are often designed to target product attributes that are related to their environmental benefits and are referred to as "Attribute-Based Subsidies" (ABS). At the same time, manufacturers of these products often wield significant market power and change product attributes in response to government policies. Prominent examples include consumer subsidies for energy efficient products (Davis, 2024) and Climate Vouchers.[2]

Existing literature on the optimal policy design of these subsidies, and more generally, attribute-based regulations (Ito and Sallee, 2018; Kellogg, 2018), has abstracted away from firms' market power, a

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[2] See https://www.pub.gov.sg.

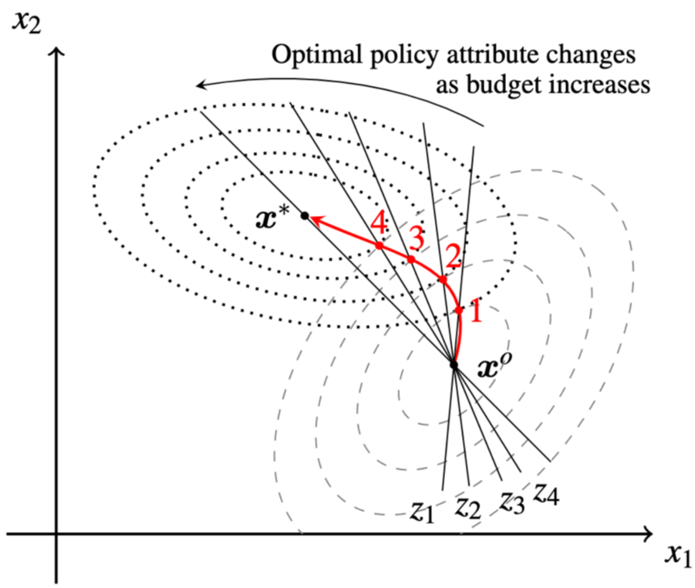
common feature in markets subject to attribute-based regulations. Our recent paper (Barwick, Kwon, and Li, 2024) bridges this gap and analyzes both theoretically and empirically the optimal design of attribute-based subsidies in oligopolistic industries. To the best of our knowledge, our framework represents the first attempt in the literature to incorporate three key features — namely market power, externalities, and endogenous attributes of products by multi-product firms — in the context of attribute-based policy design.

ABS takes the form of a two-part subsidy (i.e., a two-part tariff) in our setting: a base subsidy that is the same across products and a variable subsidy that is tied to product attributes. This is common in practice and standard in the theoretical literature. Our theoretical analyses begin by considering an ideal benchmark where a government can perfectly target the environmental externality and faces no budget constraints, and there is a single-product monopoly. It is straightforward to show that the government can achieve the first-best social outcome with a Pigouvian policy design, where the base subsidy fully addresses quantity distortion, and the variable subsidy corrects environmental externality. In practice, all three assumptions are likely violated. Environmental externality may be hard to quantify and target, governments face limited budgets, and many industries are characterized by multi-product oligopolies.

When a government has a limited budget, it is sub-optimal to tie the variable subsidy to environmental externality as prescribed by the traditional Pigouvian subsidy. This would entail a limited base subsidy to address market power distortions when the budget constraint is binding. We show that the optimal policy design for a single-product monopoly is characterized by the contract curve between the social surplus indifference curves and the private surplus indifference curves in the product attribute space (Figure 1 below). With multi-product oligopolies, optimality conditions require higher subsidies to products that exhibit high welfare gains for the marginal unit and products whose demand is more responsive to subsidies in order to equalize the marginal social surplus generated by each subsidy dollar across all products.

The theoretical characterization of optimal policy design crucially hinges on the underlying consumer preferences and production technology. We illustrate our theoretical insight using an empirical analysis of the market for electric vehicles (EVs) as a case study. Together with a cleaner electricity grid, EVs offer considerable promise for reducing carbon emissions and local air pollution. Many governments have provided generous consumer purchase subsidies, with global public spending on consumer EV subsidies approaching $30 billion in 2021 (IEA, 2022). The design of these subsidies varies across countries. Some countries tie the subsidy amount to vehicle attributes, such as driving range in China and Japan, battery capacity in the U.S. and India, and vehicle size and weight in South Korea. Other countries offer uniform subsidies, as seen in Germany, the Netherlands, and Sweden. Our analysis focuses on China, by far the world's largest automobile and EV market, accounting for 40% of global new passenger vehicle sales and 60% of global EV sales in 2022.

Figure 1: Optimal Policy Design with Budget Constraints



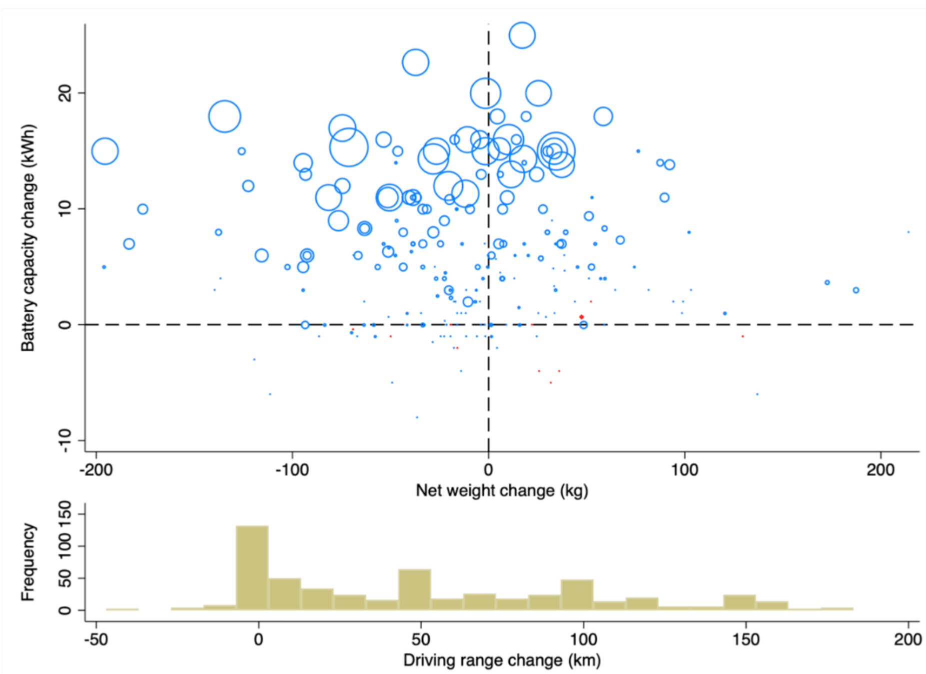
Note: the y-axis and x-axis represent different product attributes. The dotted oval-shaped curves on the upper left are iso-quant curves for social surplus, while the dashed oval-shaped curves on the lower right are iso-quant curves for firm's private surplus. The solid red line from x^0 to x* traces the optimal policy design that consists of the tangency points between the two groups of iso-quant curves.

China became the largest EV market in 2015, and its global share increased to 60% by 2022. The rapid growth of the EV market in China was at least partly driven by the generous consumer subsidies from both central and local governments as well as non-financial incentives as documented in Li et al. (2022). The Chinese government considers the EV sector a strategic priority to increase the global competitiveness of its domestic automobile industry and to reduce energy consumption and emissions from the transportation sector.

The subsidies are based on the driving range and set differently for battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). For BEVs, the subsidies are notched with several cutoffs. The minimum range requirement increased from 80km in 2013 to 100km in 2016 and further increased to 150km in 2018, while the amount of subsidies was reduced over time. For PHEVs, the subsidy was uniform across models with a minimum range requirement of 50km that remained constant, though the subsidy amount decreased over time.

How did automakers manage to enhance their driving ranges in response to policy changes? The driving range is primarily affected by battery capacity and vehicle weight, both of which can be adjusted relatively quickly. Figure 2 illustrates the year-to-year changes in vehicle weight (excluding battery weight) on the x-axis and battery capacity on the y-axis. Blue circles represent models with increased driving ranges, while red diamonds are models with decreased driving ranges. The size of the symbol corresponds to the magnitude of the change. Almost all vehicles in our sample expanded their driving ranges, with some increases exceeding 100km. These enhancements in the driving range were accompanied by significant increases in battery capacity and, quite often, a reduction in net vehicle weight.

Figure 2: Changes in Vehicle Attributes



Note: The top figure plots the year-to-year changes in net vehicle weight (exclusive of battery weight) on x-axis, and battery capacity on y-axis by vehicle model. The blue circles depict models with increasing driving ranges; the size of the circle represents the magnitude of the change. The red diamonds depict models with decreasing driving ranges; these changes are small, as shown by the sizes of the diamonds. The bottom figure depicts the histograms of the changes in driving range.

We estimate an equilibrium model of the Chinese automobile market and incorporate endogenous attributes. Our model allows firms to change product designs in response to subsidy schemes, which is a crucial factor in the welfare impacts and policy comparisons. The demand side captures rich consumer preference heterogeneity and controls for extensive fixed effects to capture local variations that affect demand for EVs and ICEs. On the supply side, firms choose prices and design vehicle attributes (battery capacity and vehicle weight net of battery) for EVs to maximize profits. Crucially, both the marginal and fixed cost of production depend on vehicle attributes.

With model primitives estimated, we next conduct counterfactual simulations to compare the uniform subsidy (which does not target attributes) with commonly used ABS, such as those based on driving range, battery capacity, and vehicle weight. Our counterfactual simulations provide several key findings. First, China's notched subsidy design leads to a large welfare loss relative to a linear subsidy, consistent with findings in the public finance literature. Compared to a linear subsidy, the current policy generates excess bunching at the range cutoffs and distorts automakers' choices of vehicle weight and battery capacity to reach the cutoffs. On the other hand, it provides no incentives for firms to improve the driving range between the cutoffs.

Second, ABS generates significant gains in consumer surplus relative to the uniform subsidy, ranging from ¥226 million in 2017 under the notched range-based design to ¥643 and ¥680 million under capacity- and weight-based subsidies, respectively. ABS induces more desirable vehicle attributes and more effectively addresses quantity distortions than the uniform subsidy. The increase in consumer surplus is relatively modest for range-based policies because it leads to vehicle downsizing, which is undesirable to consumers. Firms producing BEVs also benefit from the ABS design that redistributes subsidies from the low-end spectrum of the vehicle attribute space to the high-end spectrum, though such profit gains are an order of magnitude smaller than increases in consumer surplus and are more than offset by profit losses of ICEs. The environmental performance of the EV fleet deteriorates moderately under ABS as sales shift to larger and less environmentally friendly EVs. In total, ABS designs result in significant welfare gains compared to the uniform subsidy, ranging from ¥97.2 million under the current notched range subsidy to¥448 million under the capacity subsidy in 2017.

Third, a decomposition exercise indicates that changes in vehicle attributes account for 42- 62% of total welfare gains under ABS relative to the uniform subsidy. The reduction in market power distortions explains the remaining 38% to 58% of the welfare gains. Allowing subsidy redistribution at the product level, as suggested by the theoretical discussions, further enhances welfare gains by another 34% to 62%. Fixing vehicle attributes, as is commonly done in the literature, significantly understates aggregate welfare gains and leads to the erroneous conclusion that firm profit increases for the auto sector. These findings underscore the role of endogenous product attributes in understanding the impacts of attribute-based subsidies.

References

Barwick, Panle Jia, Hyuk-Soo Kwon, and Shanjun Li: "Attribute-based Subsidies and Market Power: an Application to Electric Vehicles," NBER Working Paper 32264, March 2024

Davis, Lucas, "The distributional effects of US tax credits for heat pumps, solar panels, and electric vehicles," Berkeley working paper, 2024.

IEA, "Global EV Outlook 2022," Technical Report, IEA, Paris 2022. https://www.iea.org/reports/global-ev-outlook-2022.

Ito, Koichiro and James M Sallee, "The economics of attribute-based regulation: Theory and evidence from fuel economy standards," Review of Economics and Statistics, 2018, 100 (2), 319–336.

Kellogg, Ryan, "Gasoline price uncertainty and the design of fuel economy standards," Journal of Public Economics, 2018, 160, 14–32.

Li, Shanjun, Xianglei Zhu, Yiding Ma, Fan Zhang, and Hui Zhou, "The Role of Government in the Market for Electric Vehicles: Evidence from China," Journal of Policy Analysis and Management, 2022, 41 (2), 450–485.

Stavins, Robert N., "Vintage-Differentiated Environmental Regulation," Stanford Environmental Law Journal, 2006, pp. 29–63.