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Abstract
The rationale for public support of battery electric vehicles (BEV) is sound. However, in spite of subsidies for vehicle purchase and other incentives, BEVs remain costly. Here, we argue that while lump-sum investment subsidies have some advantages at the very early stages of diffusion, given some salient developments in personal transportation, the timing is just right for a delivering subsidies in a more targeted manner. Use-based incentives together with financial assistance for BEV purchase and creation of a fast-charging infrastructure, would exploit the proliferation of high-use vehicles associated with on-demand transportation services while also continuing to support BEV adoption for private household use. Such a shift has the potential to deliver greater environmental benefits faster, directly benefit poorer households, and can be designed to minimize transaction costs.

Main text
Compared with gasoline- and diesel-powered vehicles, pure battery electric vehicles (simply, BEVs) are much more energy efficient, make essentially zero contribution to urban air pollution, and hold enormous potential for climate change mitigation.[1,2] The climate benefits indeed depend on the greenhouse gas intensity of the electricity source,[19] but we take it as a given that decarbonizing electricity is also a policy priority for jurisdictions serious about EVs. Diffusion of BEVs is therefore key to reducing global crude oil consumption, decarbonizing transportation, and improving urban air quality.[3,4,5]

BEV adoption is supported through various types of incentives for vehicle purchase, including income tax credits (e.g., U.S.), vehicle subsidies (e.g., in France and China), exemptions from Value-added taxes (e.g. UK, Norway, Sweden), rebates on annual ownership fees (e.g., in the UK, Norway, Sweden, and Germany), and waivers from carbon dioxide taxes (e.g., in the UK).[6,7] Some jurisdictions, including California and China, are implementing policies that require vehicle manufacturers to produce a certain share of zero-emission vehicles or buy credits from others to meet the requirement. Finally, BEV users also benefit from policies such as free public charging, free access to toll roads, free parking, and access to high-occupancy-vehicle lanes.[6,7]

While the current policies have increased EV adoption, and are helping the industry mature, they are not fully exploiting the potential of EVs. One reason is that in spite of incentives amounting to about 25% of the vehicle cost, BEVs still seem costly not only upfront but also on a lifecycle cost (LCC) basis, a plausible explanation for their slow adoption.[4,8,9] For example, the $7,500 U.S. federal tax credit alone amounts to a 20%-- 25% discount on the retail price of popular EVs in the US market today. Even with this level of incentives, at the US average daily vehicle kilometer travelled (VKT), which is 43 km per day[10,11], the payback to EVs relative to a comparable pure gasoline vehicle is about a decade long. Furthermore, when discounting future savings at 10%, the lifecycle cost savings are, in fact, negative (Figure1a). For BEVs to even just breakeven on a LCC basis requires twice the average daily VKT, which is the 90th percentile of the VKT distribution[11], and this level of use would still entail a 5-year long payback. Of course, these estimates are sensitive to electricity and gasoline prices but it is clear the economics are still unfavourable for most private households.[12] This implies current adopters differ in their characteristics when compared to rest of the society. Even though battery cost is expected to decline,[12] the larger battery packs required to meet longer driving range expectations could temper the

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decrease in upfront cost of BEVs. Lastly, without a carbon price, any reduction in gasoline and diesel demand due to a global transition away from fossil fuels would reduce gasoline and diesel prices, increasing the payback period.[7] This implies a sustained—and potentially even greater—reliance on public subsidies. Recent developments lend some support to this claim. Under current US federal policy, the full $7500 subsidy is available only to the first 200,000 vehicles sold by each automaker. However, efforts are underway to extend the per automaker cap for the full federal subsidy while another effort aims to increase the state subsidy California from $2500 to $4500 per EV.[20,21]

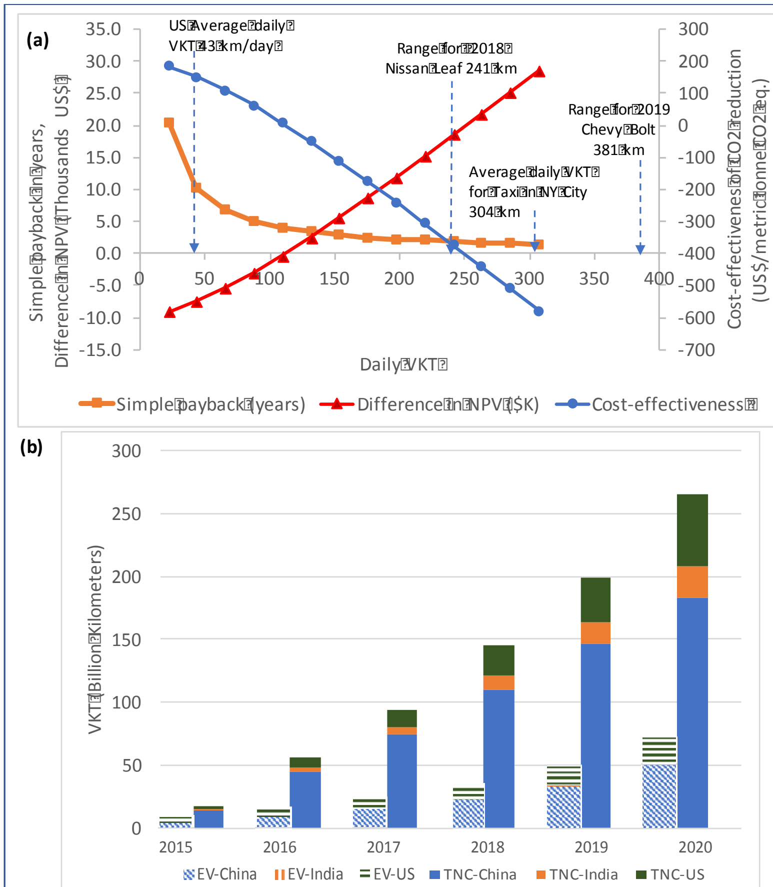

Figure 1: **(a)** Payback, Difference in net present value at 10% discount rate, and cost-effectiveness of GHG emission reduction for EV relative to comparable gasoline vehicle as a function average daily vehicle kilometers travelled (VKT). Also shown are the average daily VKT for US based on 2017 NHTS and the advertised range for two popular pure BEVs in the market – the Nissan Leaf and Chevy Bolt. **(b)** Growth in VKT for EVs and TNC in three markets – US, China and India. Growth in TNC VKT is much faster relative to growth in EV miles. Detailed calculations along with data sources and assumptions underlying these charts are in a spreadsheet, which is attached as supporting documentation.

Second, under current policies, BEVs compete with plug-in hybrid EVs (PHEVs), which offer only a fraction of the electric driving range relative to BEVs. PHEVs account for about 50% of all passenger EVs in the United States, and 47 of the 77 distinct models eligible for federal tax credits are PHEVs, which is an implicit subsidy for gasoline or diesel use. (See www.fueleconomy.gov/feg/taxevb.shtml)

Third, BEV ownership is disproportionately concentrated among high-income households and communities. Data from California's Clean Vehicle Rebate Project suggest that only 6% of the California rebates for BEVs were captured by households in disadvantaged communities.[13] Therefore, under current policies, the benefits to low-income households of BEV policies accrue mainly indirectly through reduced pollution due to BEV adoption by wealthier households. Specifically, in the case of income tax credits, poor households might also not have the level of tax liability to take full advantage of the tax credits. Viewed through an equity and environmental justice lens, policies must change if low-income households are to benefit directly from public support for BEVs.

Indeed, there are other barriers impeding EV adoption including lack of a widespread fast-charging infrastructure, which is the reason for the so-termed range anxiety, credit constraints, limited choice set of vehicle models, and well-known behavioral failures that inhibit adoption of efficient technologies with lower lifecycle cost. We relate to some of these issues when we discuss the merits of the policy innovation we outline below.

To address these issues and for the simple reason that payback is inversely correlated with VKT, we suggest pivoting public policies to target high usage vehicles and applications. As an illustrative example, in the US, EV payback falls from 10 years to 2 years when VKT increases five-fold from the national average of 43 km/day to 215 km/day (Figure 1a). But high-VKT users who could benefit from the lower LCC of EVs even in the absence of subsidies would still face barriers in the form of range anxiety, while some might additionally also face credit constraints. However, the stock of private vehicles with such high levels of VKT is small (about 0.2% of the population in the US)[13] and diffuse, which in fact weakens the economic case for public investment in expensive fast-charging infrastructure.

It is in this context that the explosive worldwide growth of ride services provided by transportation networking companies (TNC) such as Didi, Lyft and Uber presents a new opportunity to re-pivot BEV policies. In 2017, the total VKT of all TNC vehicles in China, India, and the United States was four times the VKT of all EVs combined in these countries (Figure 1b). Although reliable data on average VKT per TNC vehicle are lacking, the average VKT for conventional taxi cabs in New York City is 304 km/day,[14] which translates into a simple payback period of about 1.5 years and a lifecycle cost savings of about $28,000 (at a 10% discount rate) in life cycle ownership cost savings after taking into account battery replacement costs and the US federal subsidy (Figure 1a). High VKT applications also afford greater cushion for BEVs to absorb the cost of bigger battery packs and remain competitive despite future increase in fuel economy of ICE vehicles or a decline in oil price or both.

Although BEVs may deliver significantly greater lifecycle benefits under such (high usage) conditions, they entail some unique adoption challenges. A two-year or quicker payback notwithstanding, the higher upfront cost of BEVs is plausibly still a barrier for TNC and taxi drivers who tend to belong to lower-income households and face credit-constraints. Furthermore, a two-year payback greatly exceeds the expected duration of employment for the vast majority of TNC drivers but not for taxi drivers.[15] Secondly, high mileage users also require convenient access to fast charging infrastructure. The policy approach we outline below to address these issues. In doing so we emphasize TNC and taxis, but the policies apply also to private use vehicles as well as commercial light duty vehicles while the basic insight extends to heavy duty vehicles as well.

In Table 1, we outline potential pivots for each of the different broad categories of policies for targeting high VKT users – financial incentives, public infrastructure creation, mandates on commercial fleets and information provision. But since the salience of our work is on redesigning incentives, it is the focus of the rest of the discussion.

Table 1: Targeted policies for EV adoption by high-VKT applications

Type of policy intervention	**Approaches targeting high VKT adopters**
Incentives	1) Pure subsidy per electric VKT + financing of the incremental cost of vehicle purchase 2) Alternative hybrid approaches: (each along with financing support) a) Lump-sum subsidy initially but gradually replaced by use-subsidy b) Lump-sum subsidy in conjunction with use-based subsidy – non-mutually exclusively c) Lump-sum subsidy in conjunction with use-based subsidy but mutually exclusively 3) Pure lump-sum subsidy but with eligibility criteria such as requiring registering as a commercial vehicle
Infrastructure creation	Fast-charging infrastructure owned and operated by public utilities

Mandates	Clean miles targets for TNCs and other large commercial fleet owners

The direct approach to target high-mileage users is to provide a subsidy per-electric VKT (eVKT) along with an option to finance the incremental cost of EV purchase through a government loan, that is recouped in lieu of the subsidy. The per-eVKT subsidy is also a simple way to avoid implicitly subsidizing gasoline or diesel miles as is the case with PHEV owners who benefit from lump-sum EV subsidies today. Use-based subsidies are a targeted way to internalizing positive externalities that arise from learning-by-seeing and learning-by-experiencing. High mileage users of EVs also provide greater external benefits by creating more familiarity with the technology by simply being on the road more. In the case of taxis and ride-sourcing vehicles, they also help potential adopters experience riding, and also gain actual user insights by potentially conversing with the driver.

Although economists have known use-based subsidies to be efficient[22], actual experience has been minimal plausibly due to the lack of a low-cost reporting and verification mechanism. Use-based subsidies and consumer loans for capital investments have each by themselves been tried in the electric power sector although the two have not been coupled as suggested here. For instance, a subsidy per kilowatt of hour electricity produced, known as a production tax credit (PTC) in the US, has been shown to accelerate diffusion of wind energy.[16,22] A loan for financing purchase of roof top solar panels, known as property assessed clean energy (PACE), has been shown to positively impact residential solar PV diffusion in the US.[17,18]

EVs appear a suitable application for use-based subsidies because low-cost reporting and verification seems plausible. For instance, TNCs already charge consumers on a per-mile basis. The California Clean Miles Standard[23] that requires a certain share of annual total miles serviced by TNCs to be electric is predicated on reporting of this information. For private VKT, there needs to emerge a simple protocol for reporting this information, which is already available to EV owners or is tracked and recorded but not displayed to PHEVs owners. This could be accomplished through a smart phone application or directly relayed by on-board communication systems to a central server belonging to a regulatory agency.

We outline the basic mechanics of determining the subsidy per eVKT and compare it to a lump-sum vehicle subsidy. Subsidy per eVKT relates to usage and payback as follows.

$$Payback = \frac{|\Delta\, Vehicle\ cost|}{(|\Delta\ operating\ cost\ per\ km| + subsidy\ per\ km) * eVKT_{annual}}$$

For a given annual eVKT, targeting a quick payback to EVs requires a higher subsidy. Equivalently, targeting higher mileage users for adoptions reduces the minimum subsidy required to target a given payback. For a given payback period, increasing the annual eVKT target reduces the minimum subsidy required. Figure 2 numerically illustrates these relationship for a Chevy Bolt BEV relative to an equivalent gasoline vehicle. An average eVKT of 100 km/day requires a subsidy of $0.13 per km and total subsidy of $5,000 for a 2-year payback, which is 33% cheaper than the current US federal subsidy per EV and delivers more than twice the reduction in gasoline use and GHG emissions assuming the average EV displaces the average gasoline vehicle. An average eVKT of 200 km/day requires a subsidy of $0.05 per km and total subsidy of $3,400 for a 2-year payback. Put differently, policy makers could increase the subsidy per km, and total subsidy per vehicle to achieve a quicker payback. To minimize the total subsidy burden, one could also cap the total subsidy per vehicle. A benefit of such a cap is that it also removes incentives for EV owners from engaging in unintended behavior such as clocking ghost miles, i.e., driving for no reason but just to earn subsidy. Also, such behavior is highly unlikely as the marginal cost of fuel, maintenance, and depreciation likely exceeds the subsidy per km even if one

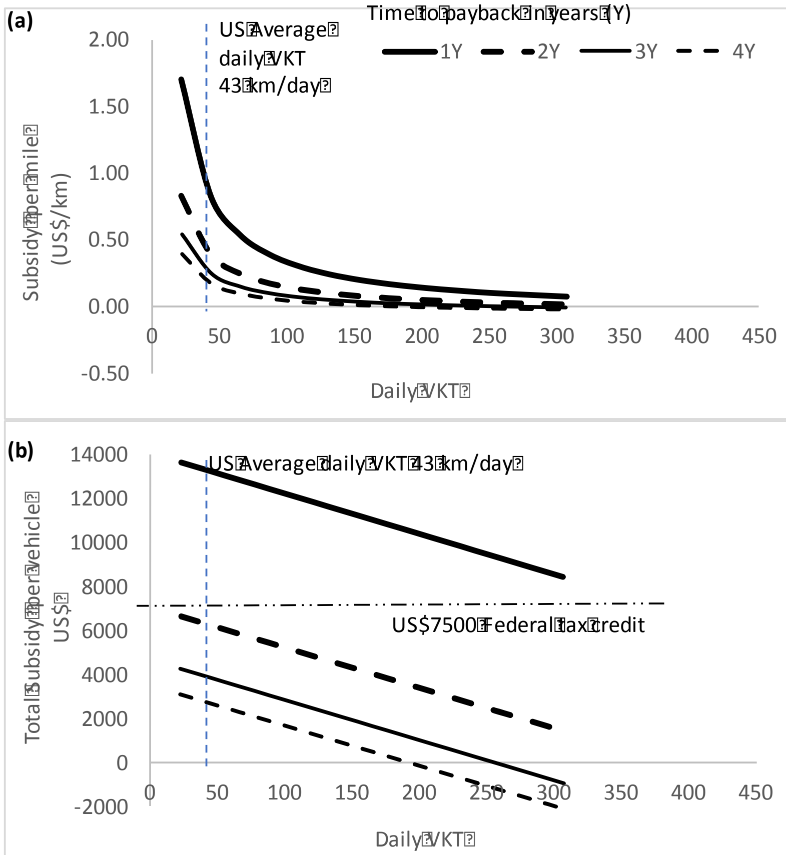

Figure 2 (a): Illustrative estimates of subsidy per km required to achieve a given payback period (1, 2, 3 or 4 years) For a given subsidy, the payback diminishes rapidly with VKT. **(b)** Total subsidy required until a given time to payback is realized. Detailed calculations of payback along with data and references used in estimation of VKT shares are in the spreadsheet attached as supporting documentation.

ignores the opportunity cost of time spent driving. Per-eVKT subsidy policies could be refined and tuned in various ways. One such is capping the total subsidy that any single vehicle could receive, which reduces incentives for empty driving and mitigates rebound, as the life of the vehicle is much longer. Indexing the subsidy to EV efficiency would incentivize adoption of higher-efficiency EVs.

In spite of the advantages of use-based subsidies, lump-sum subsidies have certain advantages of their own. For instance, learning-by-doing spillovers and scale economies in production that are not fully appropriated by the producer are positive externalities that early adopters of a technology provide to society irrespective of how much they use the technology. This leads us to suggest a hybrid approach that can exploit the advantages of both lump-sum upfront subsidies and use-based subsidies. One such is to use lump-sum subsidies at the very early stages (the first few thousand or few hundred thousand vehicles) number of vehicles after which lump-sum subsidy is gradually replaced with a use-based subsidy. An alternative formulation is to offer both subsidies simultaneously. A third option is to offer both simultaneously but mutually exclusively, where adopters self-select into one of the two schemes. With each of these formulations, policy makers could adjust the level of each type of subsidy and their timing to depending on budgetary constraints and the rate of diffusion.

A general concern with use-based subsidies is that on the margin it provides incentives to drive more, which is referred to as rebound effect. But there are several salient mitigating circumstances in this case. First, the primary effect of shifting subsidies towards target high-use vehicles is greater reduction in gasoline miles while rebound is a second-order effect. Second, as mentioned above the required subsidy per mile is small and capping subsidies per vehicle also limits rebound. Third, for EVs that are powered with clean electricity, rebound is not associated with pollution externalities but only congestion externalities potentially.[24] But arguably only a fraction of the increase TNC and taxi trips adds vehicles because some trips displace private vehicle use and some trips are shared. That said, the direct approach to addressing congestion is to price congestion, or creating targeting incentives for shared-modes and carpooling that are independent of vehicle propulsion technology.

It is worth mentioning there exist indirect strategies to target subsidies to high VKT users, that does not require delivering subsidies on a per VKT basis. the use-based indexing subsidies to usage. One such is to establish eligibility criteria such requiring registration as a commercial vehicle in order to receive special subsidies. Such an approach while simpler has its own disadvantages. For one, its efficacy depends on the incremental cost of acquiring a commercial license plate vis-à-vis the incremental subsidy. Second, it is worth pointing out that TNC vehicles are not required to hold a commercial license in many countries around the world. Third, it is also a blunter instrument for there is tremendous heterogeneity among TNC drivers in their VKT because of heterogeneity in the number of hours they work on the platform.

Although the salient points made here pertain to re-orienting vehicle subsidies, as noted in Table 1, it is but a part of broad suite of policies aimed at EV adoption in high-usage applications. Subsidy reform needs to be complemented with efforts to create a wide and dense fast-charging infrastructure aimed at TNC and taxi vehicles while also ensuring that facilities that are publically-funded are accessible to private-use vehicles. Finally, given that mandates are already being adopted, one can expect this would induce TNCs to facilitate EV adoption through a combination of innovative vehicle leasing programs and incentives, and investments in creation of fast-charging network and driver education and awareness programs. To the extent, use-based subsidies are captured by TNC drivers, it reduces the incidence of the burden on the TNC industry.

To summarize, although EVs are critical to the beneficial transformation of personal road transportation, there is a strong case for redesigning EV incentives because of sustained high subsidy requirements, absence of pollution pricing, but most importantly on account of explosive growth in TNCs and new types of transportation services. Indeed, lump-sum investment subsidies have some advantages at the very early stages of diffusion, but given some salient developments in personal transportation modes, the timing is just right for a gradual shift towards policies that directly targets BEV use. Use-based incentives together with financial assistance for EV purchase and creation of a fast-charging infrastructure, would exploit the proliferation of high-use vehicles associated with on-demand transportation services while also continuing to support EV adoption for private household use. Such a shift has the potential to deliver greater environmental benefits faster, directly benefit poor households, and can be implemented at low administrative cost. Historically, owing to the difficulty of tracking usage, and due to concerns with subsidizing energy use, use-based subsidies presented some challenges. However, with increasing of smart technologies and appliances, it is worth carefully examining the case for use-based incentives in a broader swathe of applications including residential and commercial appliances.

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