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PERSPECTIVE

Near-term policy pathways for reducing car and light-truck emissions

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1. Introduction

Vehicle electrification features prominently in policy frameworks to improve energy security, diversify energy stock and most importantly, reduce greenhouse gas (GHG) emissions [1]. Yet, challenges persist. Range anxiety—the fear an electric vehicle (EV) will be unable to complete its trip due to insufficient electrical charge—coupled with long recharging times and inadequate charging infrastructure remain prominent (though not sole) impediments to widespread EV adoption [2]. However, higher up-front costs may be the most pressing concern.

Despite realization of production efficiencies, EVs remain costlier—on average—than vehicles powered by an internal combustion engine (ICEV), owing to practical limits on battery price reduction [3]. Policy makers have sought to address this by offering significant fiscal incentives for EV adoption. Yet, the overall efficacy of this approach—which is designed to reduce consumers' out-of-pocket expenses—remains nebulous.

Research suggests that EV incentive program beneficiaries are largely inframarginal. That is, this demographic group would—owing to high socioeconomic status—have purchased EVs were fiscal incentives unavailable in the first place [4–6]. High socioeconomic status is also associated with substituting away from ICEVs with a fuel economy higher than the overall fleet average [7]. Collectively, these findings challenge the prudency of existing incentive programs.

In this paper, we propose an approach that rectifies the aforementioned externalities, with the goal of implementing a revenue neutral, emission reduction pathway. This approach is timely given that

governments are—in an effort to provide COVID-19 related economic aid—spending unprecedented amounts of money, exacerbating deficit spending concerns [8].

1.1. Policy pathway
A key component of our approach is promoting hybrid electric vehicles (HEVs) as an incentive-backed alternative to EVs. HEVs combine an internal combustion engine with a battery and electric motor. These two on-board propulsion systems can operate one-at-a-time or simultaneously, which—when coupled with regenerative braking—improves vehicular efficiency thereby reducing GHG emissions [9].

First we clarify our powertrain terminology. By electrified vehicles (EVs) we mean both battery electric vehicles (BEVs) solely powered by electricity obtained from the power-generating electric grid, and plug-in hybrid electric vehicles (PHEVs) which can recharge their battery pack from the grid, have an on-board internal combustion engine that can drive the vehicle as needed, and recharge the batteries through driving a generator. Both HEVs and PHEVs can be driven by the engine or the battery alone; or both can drive together, as needed. Powertrain shifts from HEVs to PHEVs to BEVs for a given vehicle requires corresponding battery size increases to provide increasing all-electric driving range from some 15 miles to 40 miles to 200 miles, respectively. Recharging times from a close-to-discharged state to 85% recharged state increase in proportion to battery size with a given electrical power charger, from a few minutes to up to an hour, to one to several hours. All three powertrains, as noted above, benefit by some 30% in driving efficiency from their

regenerative braking energy recovery, whereas ICEVs do not.

For an average mid-size car vehicle basis, we estimate that HEVs now cost up to 12% more than equivalent ICEVs but emit GHGs in quantities approximately about 0.73 times that of an ICEV [10, 11]. By comparison, EVs cost (as an average of a PHEV and a BEV) approximately 40% more than ICEVs and emit GHGs in quantities about 0.63 times that of an ICEV (see supplementary information (available online at stacks.iop.org/ERL/16/061003/mmedia)). The magnitude of EV cost penalties relative to their GHG emission benefits makes HEVs—we argue—a more promising near-term emissions reduction pathway.

To fund a revenue-neutral HEV incentive program, we propose reducing the size of current EV incentive per vehicle, and reallocating funding thereby saved to incentivize HEV purchases. This reallocation is guided by the recognition of limited available capital for such programs, coupled with the reality that preference for HEVs over EVs remains high for most consumers [2]. Their preference is noteworthy given that HEV procurement incentives are, when available, smaller than those available for purchasing EVs [12]. This differential—set by policy makers—admittedly reflects the recognition that although EVs carry fewer public health externalities than HEVs, they impose a higher up-front fiscal burden. The larger subsidies directed towards EV purchases are designed to mitigate this cost burden. Yet, existing data suggests this approach may not significantly increase EV adoption *relative* to HEV adoption [12].

These factors have profound implications for existing procurement incentive programs. ICEVs constitute the overwhelming majority of vehicles sold in the U.S. and globally, and ICEV buyers—the target market for EV procurement incentive programs—demonstrate an aversion to purchasing non-ICEVs. However, the 'second preference' for this consumer group are HEVs, not EVs [4]. Consequently, aligning procurement incentives with ICEV owners' 'second preference' represents—we argue—a more effective near-term emissions reduction pathway given the greater consumer preference for hybrid technology.

The proposed policy pathway—which is revenue neutral—addresses the inefficiencies in existing EV incentive programs, namely (a) high uptake rates among largely inframarginal consumers, and (b) substitution away from relatively fuel-efficient vehicles. The creation of an HEV specific incentive program addresses these inefficiencies by redirecting capital currently utilized by mostly high-income households towards the purchase of the less expensive, more fuel-efficient vehicles preferred by households that fall outside the aforementioned income bracket.

This approach is not—in our view—necessarily a matter of allocative equity [7, 13, 14]. Our proposed policy pathway does not explicitly strive for more homogenous distribution of purchase incentives across high, middle and low-income households. Rather, we target allocative efficiency, namely, distributing public funds in a manner that maximizes emissions reductions. Realizing this outcome entails considering preferences of consumers less likely to own fuel-efficient vehicles. Data suggests these individuals belong to low and middle-income households [7].

For the aforementioned group, preference for HEVs over EVs remains strong [4]. Although lowering the procurement cost of EVs relative to HEVs may change this sentiment, the logistical and fiscal burdens associated with doing so are considerable. Conversely, (re)allocating capital in the form of procurement incentives towards consumers' 'second choice', namely HEVs, should stimulate greater demand thereby facilitating near term GHG emissions reductions [14, 15].

1.2. Scenario demonstration

Can an HEV incentive program be crafted in a way that provides greater GHG emissions reductions absent changes in existing spending? We explore the efficacy of this approach using the United States as an example (see supplementary information: section 2). Our model considers key market attributes including the Qualified Plug-in Electric Drive Motor Vehicle Credit, powertrain specific emissions advantages and publicly available sales data. Across the scenarios explored, we assume that up to 60% of EV purchases are inframarginal: i.e. would have occurred without fiscal purchase incentives [4, 5]. We, (a) quantify the difference in life-cycle GHG emissions, per mile, between HEVs and EVs, (b) assess the increased HEV sales target required to offset emissions 'increases' associated with decreased EV sales, (c) demonstrate this sales target is feasible, and (d) identify the fiscal incentive available to HEV buyers to meet the proposed targets on a per vehicle basis.

For our baseline scenario, we estimate that a 29% increase in HEV sales above current existing sales estimates is required to offset emission 'increases' that would occur were marginal consumers—owing to EV incentive reduction—to now choose ICEVs (figure 1). Previous research suggests the requisite HEV sales increase is achievable given the provision of a $1000 HEV-specific incentive [14, 15]. However, we estimate that a higher HEV-specific incentive ($2061) can be provided without increasing overall incentive program spending. That would increase HEV sales significantly.

Next, we consider a scenario in which an EV's emissions advantage (average of a PHEV and a BEV)
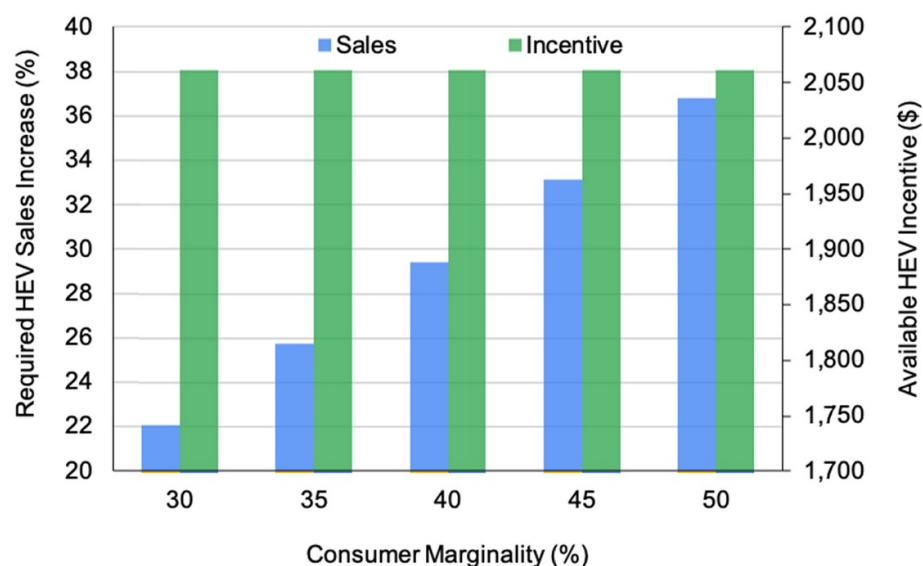
Figure 1. Required HEV sales increase and incentive availability. Blue bars represent the HEV sales increase (%) required to achieve net zero change in emissions. Green bars represent available HEV incentive ($) per HEV sale. This scenario—considered our baseline—assumes preexisting annual HEV sales of 362 416.
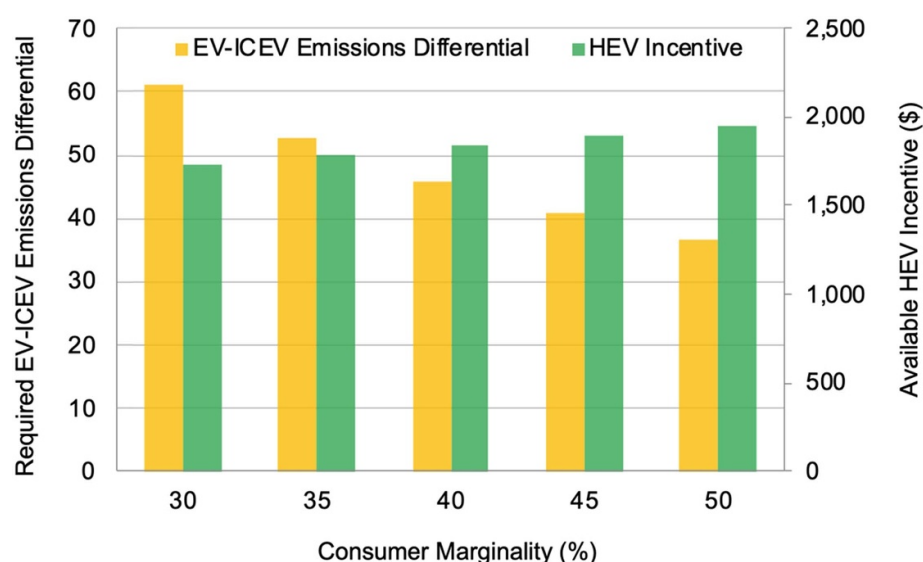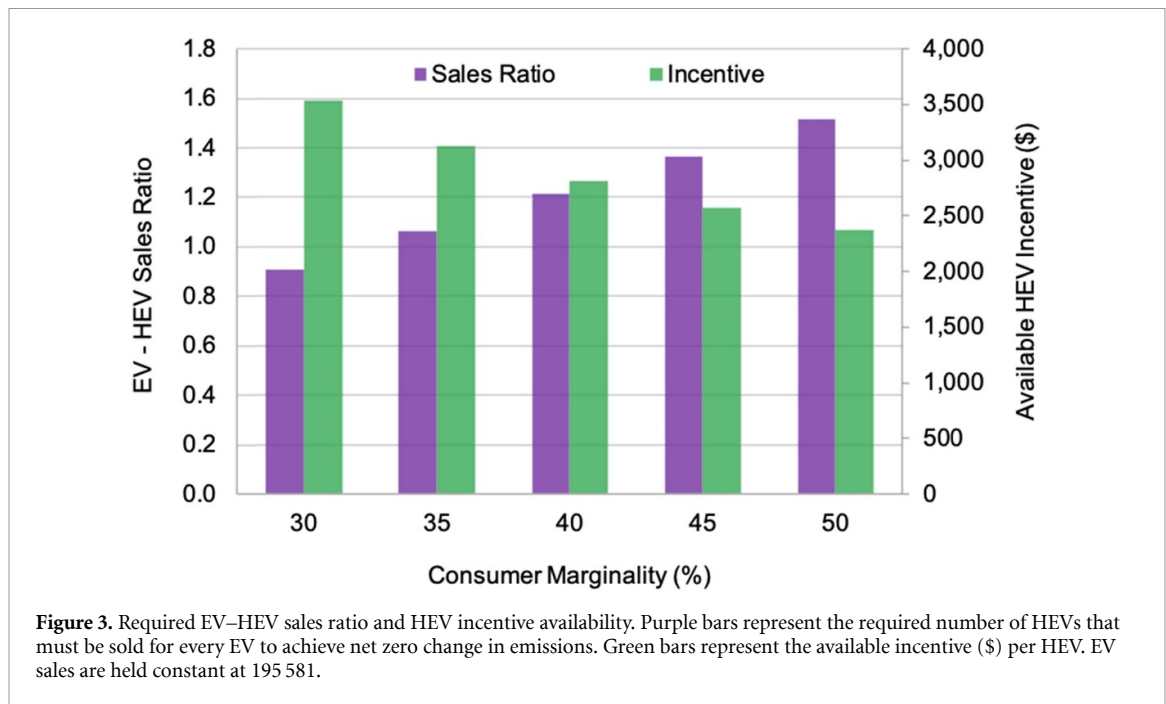

Figure 2. Required EV–ICEV emissions differential and HEV incentive availability. Yellow bars represent the requisite EV–ICEV emissions differential (lb CO_2/100 mi) required to achieve net zero emissions, holding ICEV emissions constant at 81.57 lb CO_2/100 mi. Green bars represent the available incentive ($) per HEV. Note, electrified vehicle (EV) represents the average of a PHEV and a BEV.

may be further improved by using low-polluting energy sources for electricity generation and/or by leveraging yet-to-be-realized propulsion technologies. We quantify the requisite level of emissions advantage required of EVs to place HEV demand increases associated with an HEV incentive policy outside previously documented ranges (figure 2). Absent improvements in ICEV technologies, a 53% (or higher) further reduction in EV's emissions advantage is required for our policy pathway to worsen emissions.

We further explore how existing popularity of HEVs relative to EVs—as evidenced by sales volume ratios—may impact the efficacy of an HEV-incentive policy at varying levels of an EV's emissions advantage. We estimate that absent improvements in this emissions advantage, equivalent emissions levels are only achieved by our proposed policy if baseline HEV sales are at least 21% higher than EVs (figure 3). We note that the realization of such 'near equivalent' scenarios remains challenging across key auto markets owing to fiscal and operational challenges

Figure 3. Required EV–HEV sales ratio and HEV incentive availability. Purple bars represent the required number of HEVs that must be sold for every EV to achieve net zero change in emissions. Green bars represent the available incentive ($) per HEV. EV sales are held constant at 195 581.

associated with EV purchase and use, challenges that have thus far impeded widespread adoption.

Collectively, our analysis indicates that an HEV incentive program represents a viable pathway towards realizing near-term emissions reductions. Furthermore, our figures may underestimate the benefit of an HEV incentive program for several reasons. Firstly, existing marginality estimates presuppose that the absence of an EV incentive produces fewer EV sales. We propose reducing—but not entirely eliminating—EV incentives. Hence, our approach may produce a more muted marginality effect. Secondly, our model assumes EV incentive reductions would cause consumers to subsequently procure ICEVs with a fuel economy indicative of the overall fleet average. Research however shows that EV buyers would, on average, have purchased relatively fuel-efficient ICEVs had they not purchased an EV [7]. This suggests that the true emissions increase arising from foregoing EV purchases is less than our model predicts which means a lower HEV sales target is required to achieve equivalent emission reductions. Finally, previous studies estimate HEV demand increases assuming the provision of a $1000 HEV-specific incentive [14, 15]. However, our results suggest higher incentives can be provided without increasing overall program spending. This HEV incentive increase may serve to further encourage an ICEV–HEV switch.

1.3. Incentive design
One concern with offering a concurrent HEV/EV incentive program is that it may encourage current ICEV owners to choose HEVs over EVs. However, research suggests that this approach would not produce sizable declines in EV purchases given that

such purchases are concentrated among high-income households; a group that typically shows significantly less price sensitivity [16, 17]. Instead, HEV incentives would likely encourage ICEVs to HEVs purchase shifts among low and middle-income households; groups that are more price sensitive.

Success of our approach relies on HEV demand stimulation. The aggregate amount of emissions reductions realized by an ICEV-to-HEV switch must exceed emission 'increases' that may be realized were consumers—owing to EV incentive reduction—to choose higher fuel-consuming vehicles. Behavioral research suggests an incentive's delivery mechanism is an important influencer of demand stimulation [18]. Sales tax waivers can yield HEV demand increases as high as 45% compared to income tax credits of equivalent size which would stimulate demand by as little as three percent [14, 15]. Hence, careful consideration of the incentive delivery mechanism is warranted given the heterogeneity of policy levers governments can leverage to incentivize vehicle procurement.

1.4. Political practicality, racial equity and limitations
Because vehicle electrification is important in combating climate change via GHG emissions reductions, the magnitude of incentives should gradually be shifted to favor EVs (PHEVs and BEVs) over HEVs, this occurring as HEVs displace ICEVs to become consumers' preferred vehicle choice. However, this process will take time. Consequently, reducing emissions in the near-term entails enacting public policies that are politically palatable and practical, and thus effective. An HEV incentive program provides this opportunity.

HEV proliferation has particular significance for low-income and marginalized communities. These groups are more likely to suffer climate change related externalities, owing in part to living in neighborhoods with the greatest exposure to climate and extreme weather events [19]. Low-income and marginalized groups are also—owing to their socioeconomic status—less likely to be able to afford EVs *relative* to HEVs and are less likely to own fuel-efficient vehicles [20]. Consequently, offering stronger HEV incentives offers these communities an opportunity to more fully participate in addressing an externality that disproportionally affects them.

Because access to clean electricity underpins efforts towards decarbonization, the efficacy of our approach depends in part on an EV's electricity source [1]. Increased reliance on renewable electrical energy sources further improves the value proposition of EVs relative to HEVs, which may make EVs the better longer-term choice. However, key auto markets like China, India and the United States currently derive only a fraction of their overall energy from renewable energy sources. Moreover, our results demonstrate that substantial improvements in an EV's emissions advantage is required to offset the potential for larger near-term GHG emissions reductions benefits available through an HEV incentive program.

Finally, we note that using such cleaner electricity sources would not address consumer apprehension of EV technology, highlighting the need for the near-term hybrid-incentivizing strategy shift. Our proposal addresses political, socio-economic and environmental concerns posed by the existing state of EV technology and provides a viable pathway policymakers may consider to remedy negative externalities associated with gasoline consumption while ensuring revenue neutrality.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Acknowledgments

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