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The Dynamic Role of Subsidies in Promoting Global Electric Vehicle Sales

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Key Points

We offer the most comprehensive analysis to date of global plug-in electric vehicle (PEV) subsidies. We accomplish this by estimating vehicle choice models for 23 countries using 2010–2019 sales data and using counterfactual simulations to assess the cost-effectiveness of PEV incentives.

We also provide the first-ever analysis of medium-run effects, finding that subsidies increase sales not only in the year they are offered but also in subsequent years.

Incentive policies are expensive, costing between $14,857 and $62,443 per additional PEV sold ($11–$36 per additional gallon of gasoline avoided, considerably more than the price and social cost of gasoline). However, when medium-run effects are factored in, most countries' cost-effectiveness improves substantially.

The cost-effectiveness of PEV subsidies was generally flat to improving over this decade, suggesting that subsidies, though expensive, remain an important driver of PEV adoption.

Introduction

The transport sector accounts for roughly 20% of carbon dioxide emissions globally, over one-third of which come from passenger road travel (IEA 2019). Decarbonization of the transport sector will be a necessary component of many countries' strategies to reduce greenhouse gas (GHG) emissions and meet Paris Agreement objectives (Axsen, Plötz, and Wolinetz, 2020; Plötz et al., 2019). A recent Intergovernmental Panel on Climate Change report stated, *"Reducing global transport GHG emissions will be challenging since the continuing growth in passenger and freight activity could outweigh all mitigation measures unless transport emissions can be strongly decoupled from GDP growth (high confidence)"* (Sims et al. 2014). To achieve this decoupling, plug-in electric vehicles (PEVs), including both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), are widely regarded as a crucial technology. The prospect for reducing emissions through electrification is deemed substantial (Liang et al. 2019), although this potential is diminished if PEVs are acquired as secondary vehicles in multivehicle households (Nunes, Woodley, and Rossetti 2022).

To encourage adoption and meet policy goals, many governments provide a variety of incentives for purchasing and driving PEVs, including rebates, tax credits, and tax exemptions. PEV incentives may remain important in increasing the market share for these vehicles over the next decade, particularly considering that PEVs are unlikely to achieve price parity with internal combustion engine vehicles (ICEVs) until 2035 (Chakraborty, Buch, and Tal 2021). In addition, the need for deep electrification—up to 90% by 2050 according to some estimates in order to close the "mitigation gap" (Milovanoff et al. 2020)—necessitates continued aggressive policy support. For example, the USA's recent Inflation Reduction Act extends previously existing federal PEV tax credits.[1] Furthermore, a survey of California PEV buyers from 2010 to 2017 found that financial incentives are becoming more important over time (Jenn et al. 2020). This finding is consistent with the diffusion of innovation theory, which posits that as adoption moves beyond innovators and early adopters to early- and late-majority consumers with moderate incomes, additional price reductions may be needed to encourage them to buy PEVs.

While an increasingly large body of literature on PEV incentives exists, relatively few papers have quantified incentive cost-effectiveness, i.e., the cost per additional PEV sold under the policy. Most of these studies focused on developed economies, including the USA (Tal and Nicholas 2016; DeShazo, Sheldon, and Carson 2017; Sheldon and Dua 2018, 2019; Xing, Leard, and Li 2021), Europe (Münzel et al. 2019) and Canada (Azarafshar and Vermeulen 2020), whereas only Sheldon and Dua (2020) examine a developing economy, such as China. Most focus on a single year (Sheldon and Dua 2018, 2019, 2020), and two use stated preference data rather than actual vehicle sales data (Tal and Nicholas 2016; DeShazo, Sheldon, and Carson 2017). In general, these papers find that PEV financial incentives are effective in spurring adoption but expensive. Moreover, they examine only the effect of current subsidies on current PEV sales, and none examine the dynamic effects of current subsidies in promoting future PEV sales, which may vary due to spillovers (e.g., learning by doing), economies of scale, and peer effects.

We fill this significant gap in the literature by conducting the first-ever analysis of the medium-run impacts of PEV subsidies. To accomplish this, we first present an overview and comparison of new vehicle fleets across 23 countries, including the price elasticities of demand and PEV preferences. Using a longer time frame and a larger number of countries than those examined in previous studies, we analyze PEV subsidies in countries that offer them,[2] quantifying their effectiveness and cost-effectiveness both in the static short run and dynamic medium run. Together, these results provide useful information to policymakers worldwide in considering new vehicle fleet trajectories and future policies to decarbonize transport.

Methods

In this paper, we estimate vehicle choice models using new vehicle registration data for 23 countries and identifying consumer preferences for various vehicle characteristics (e.g., fuel economy), including price elasticities of demand. Quantifying the price elasticity of demand (PED) for new vehicles can help in quantifying the effect of financial incentives. Specifically, we estimate an ordinary least squares (OLS) instrumental variables (IV) logit, instrumenting for vehicle price to address price endogeneity concerns and including a partial adjustment factor that allows us to estimate the long-run PED for new vehicles (e.g., Paul, Myers, and Palmer [2009]). Counterfactual simulations using the estimated models allow us to investigate the impact of PEV incentives over both the short and medium runs. Further details of our data and approach are provided in the Methods section and Supplementary Information.

Vehicle Choice Model

Our base empirical specification is a logit model with fixed effects, similar to those used by Chandra, Gulati, and Kandlikar (2010), Gallagher and Muehlegger (2011), and Azarafshar and Vermeulen (2020). We start with a conventional discrete choice model in which the utility of consumer *n* selecting vehicle *i* in year *t* is:

$$U_{nit} = V_{it} + \varepsilon_{nit}\,, \tag{1}$$

where ε_{nit} is the idiosyncratic independent and identically distributed error term that follows the standard Gumbel distribution. V_{it} is a linear function of the observed vehicle characteristics:

$$V_{it} = \boldsymbol{x}_{it}'\boldsymbol{\beta} + \vartheta_{it}\,, \tag{2}$$

where $\boldsymbol{x}_{it}$ is a vector of vehicle attributes and ***b*** is a vector of marginal utilities. The probability of consumer *n* purchasing vehicle *i* in year *t* is the probability that her utility from that vehicle is greater than that from any other available vehicle or the utility of the outside option (not to purchase a new vehicle):

$$\pi_{nit} = Prob(U_{nit} \geq U_{njt});\ \forall j \neq i. \tag{3}$$

The market share for vehicle *i* is the integral over the preferences of all individual consumers in the market:

$$s_{it} = \int_{\varepsilon} I(V_{nit} - V_{njt} > \varepsilon_{nit} - \varepsilon_{njt}\ \ \forall j \neq i)\, f(\varepsilon) d\varepsilon, \tag{4}$$

where the index I equals one if the inequality is satisfied and zero if not. Following McFadden (1973) and Berry (1994), we model the market share of vehicle *i* in year *t* using the conditional logit model:[3]

$$s_{it} = \frac{\exp(\boldsymbol{x}_{it}'\boldsymbol{\beta} + \vartheta_{it})}{\sum_{j=1}^{J} \exp(\boldsymbol{x}_{jt}'\boldsymbol{\beta} + \vartheta_{it})}. \tag{5}$$

By dividing the market share of vehicle *i* in year *t* by the share of the outside good, s_{0t}, we can specify the log-odds of purchasing vehicle *i* in year *t* with a standard logit:

$$ln\left(\frac{s_{it}}{s_{0t}}\right) = \boldsymbol{x}_{it}'\boldsymbol{\beta} + \vartheta_{it}. \tag{6}$$

Vector $\boldsymbol{x}_{it}$ includes price (manufacturer suggested retail price [MSRP] minus PEV incentives), fuel economy, acceleration (maximum horsepower normalized by weight), size (length, width, height), and BEV, PHEV, diesel, and autogas (compressed natural gas [CNG] or liquefied petroleum gas [LPG]) indicators as well as year, body type, and make fixed effects (δ_t, $\lambda_i^{bodytype}$, and λ_i^{make}). Similar to Small and Van Dender (2007), Hughes, Knittel, and Sperling (2008), Li, Timmins, and Von Haefen (2009), and Tamm et al. (2007), we include a partial adjustment process in the model to allow for gradual changes in market share following policy changes (e.g., changes in PEV subsidies). Specifically, we include a one-year lagged dependent variable.[4] This also allows us to estimate the long-run PED. Equation 6 then becomes:

$$ln\left(\frac{s_{it}}{s_{0t}}\right) = \beta_1 price_{it} + \beta_2 fuel\ economy_{it} + \beta_3 acceleration_{it} + \beta_4 length \times width_{it} + \beta_5 height_{it} + \beta_6 BEV_{it} + \beta_7 PHEV_{it} + \beta_8 diesel_{it} + \beta_9 autogas_{it} + \delta_t + \lambda_i^{bodytype} + \lambda_i^{make} + \gamma ln\left(\frac{s_{it-1}}{s_{0t-1}}\right) + \vartheta_{it}. \quad (7)$$

Manufacturers could increase the MSRP after an introduction of or increase in a PEV subsidy in order to “capture” part of the subsidy. Although there is evidence against this type of capture in both the early hybrid and PEV markets (Sallee 2011; Muehlegger and Rapson 2018), we use an instrumental variables approach to address the concern that unobserved vehicle attributes may be correlated with price. Specifically, we instrument for MSRP with vehicle characteristics as well as instruments in the style of Berry, Levinsohn, and Pakes (1995) (BLP), which are common in the vehicle choice literature (e.g., Grigolon, Reynaert, and Verboven [2018]). BLP-style instruments include sums of characteristics (fuel economy, size, horsepower, weight, seating capacity, number of doors, body type, powertrain/fuel type) of other vehicles produced by the same firm as well as sums of characteristics of other firms’ vehicles in a given year. Our final empirical specification is as follows, where $\widehat{price}_{it}$ is the predicted MSRP from the first-stage price regression minus any subsidies for which the vehicle qualifies:

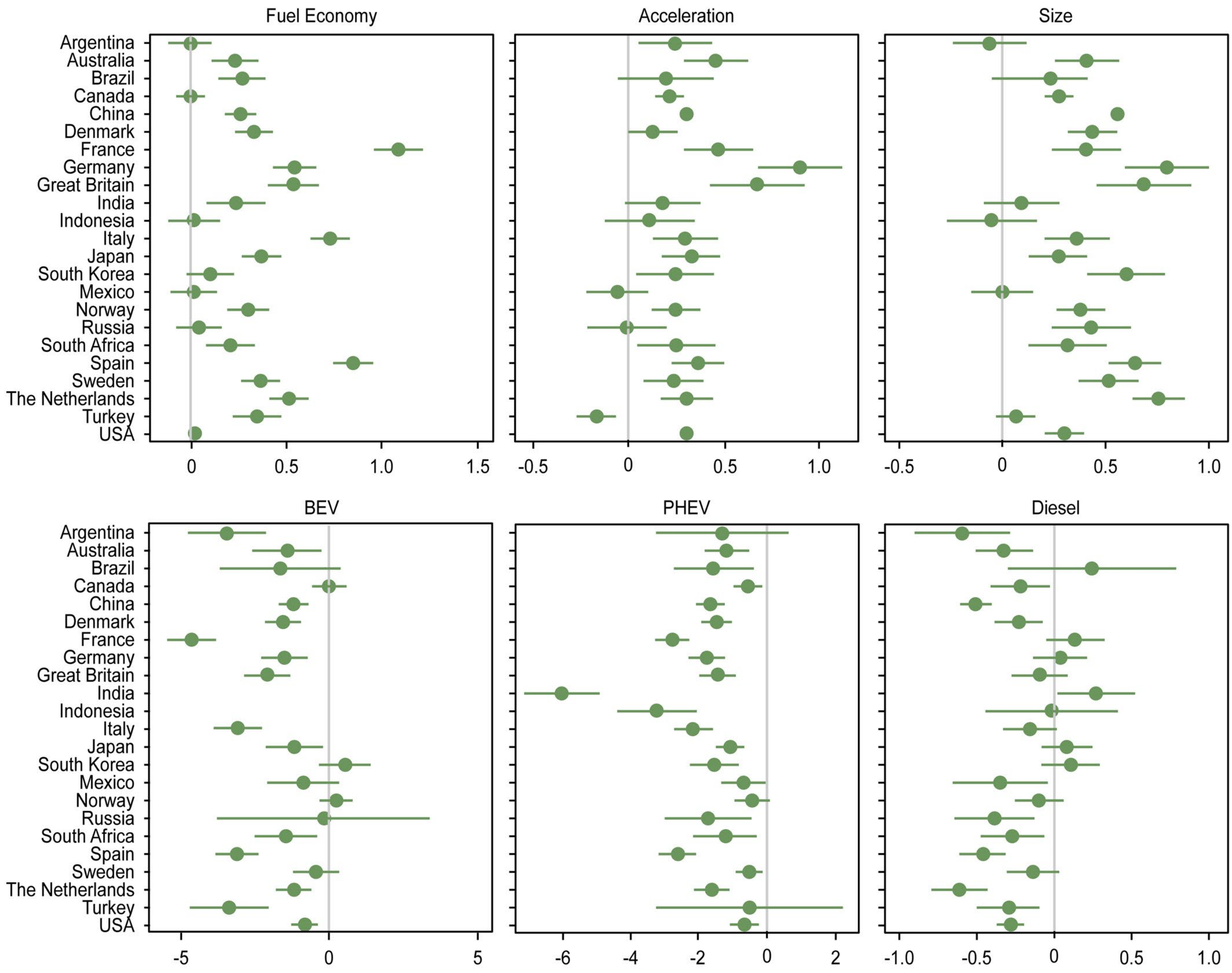
$$ln\left(\frac{s_{it}}{s_{0t}}\right) = \beta_1 \widehat{price}_{it} + \beta_2 fuel\ economy_{it} + \beta_3 acceleration_{it} + \beta_4 length \times width_{it} + \beta_5 height_{it} + \beta_6 BEV_{it} + \beta_7 PHEV_{it} + \beta_8 diesel_{it} + \beta_9 autogas_{it} + \delta_t + \lambda_i^{bodytype} + \lambda_i^{make} + \gamma ln\left(\frac{s_{it-1}}{s_{0t-1}}\right) + \vartheta_{it}. \quad (8)$$

Our standard errors are clustered at the make-model-body type-powertrain-fuel type level and estimated via bootstrap to account for measurement error introduced by the first stage. We estimate Equation 8 separately for each country to allow for country-specific preferences.

Figure 1 displays estimated preferences for various vehicle attributes by country. A full table of estimated coefficients can be found in the Supplementary Information. Consumers in European countries value fuel economy most, especially those in France, Spain, and Italy, followed by those in Germany, Great Britain, and the Netherlands. Consumers in Argentina, Canada, Indonesia, Mexico, Indonesia, South Korea, Russia and the USA value fuel economy least—not at all. Consumers in nearly all countries, particularly Germany and Great Britain, prefer larger vehicles and those with greater acceleration.

All significant diesel preferences are negative except in India, suggesting a preference for gasoline vehicles in the majority of countries. The diesel coefficients for France and Germany are not significantly different from zero, suggesting indifference to diesel in these countries and reflecting their historically high market share. Similarly, most countries have a negative and significant indicator for autogas (CNG or LNG) vehicles, though Italy and Japan have positive and significant preferences.

Figure 1. Estimated preferences for vehicle attributes by country



Source: KAPSARC analysis.
Blue points represent estimated coefficients, and blue bars represent 95% confidence intervals. Fuel economy, acceleration, and size coefficients are X-standardized, showing the impact of a 1-standard-deviation improvement in these variables on the log-odds of choosing a vehicle. BEV, PHEV, and diesel are binary variables equal to one for vehicles with these technologies. These coefficients show the impact of the respective technologies on the log-odds of choosing a vehicle.

Of the triple interactions in the model that capture Chinese vehicle registration/ownership incentives, none are statistically significant (see Methods and Supplementary Information); i.e., the implementation of the vehicle ownership lottery/auction policies fails to show a significant effect on PEV sales. These triple interactions are likely nonsignificant due to lack of variation in the pre-period, as the policies were introduced early in the sample, when PEV sales were generally low.

Data

We utilize annual data from JATO Dynamic Limited on trim-level vehicle purchases from 2010 to 2019 for 23 countries. The countries include all Group of Twenty (G20) members except Saudi Arabia.[5] Data include the price, currency, make, model, fuel type, powertrain type, maximum horsepower, seating capacity, size (length, width, height), curb weight, carbon dioxide emissions, and number of sales for each year in the sample. We aggregate the data to the make-model-body type-powertrain-fuel type level. Some countries include sales by region or state. Price is the MSRP, inclusive of national taxes and luxury taxes where relevant. We calculate fuel economy based on carbon dioxide emissions and conversion factors.[6] For internal combustion vehicles (ICEs) for which carbon dioxide emissions data are missing, we utilize fuel economy values from alternative sources, including the US Environmental Protection Agency and the European Environmental Agency. We collect additional data for BEVs and PHEVs, including electric range and battery size.[7] We calculate the fuel economy of BEVs and PHEVs in miles per gallon equivalent (MPGe), assuming a utility factor of 0.5 for PHEVs.[8] To account for data entry errors and outliers in the raw data, for each country, we drop observations in the bottom and top 5% of the distribution for price, curb weight, maximum horsepower, size (length, width, and height), and fuel economy. PEVs and HEVs are excluded from the distribution and trimming based on fuel economy, as they have very high fuel economy by design. Summary statistics are shown in the Supplementary Information.

Over half of the countries in our sample offered at least one type of national- or regional-level incentive for the purchase of PEVs. Some incentives, such as Australia's luxury tax reduction for PEVs, are already captured in the price variable. However, price does not include grants or subsidies. We collect information on national-level direct financial purchase incentives for PEVs from various publicly available sources. For countries for which the data include region/state, we also collect information on regional/state direct purchase incentives. These policies are summarized in the Supplementary Information.

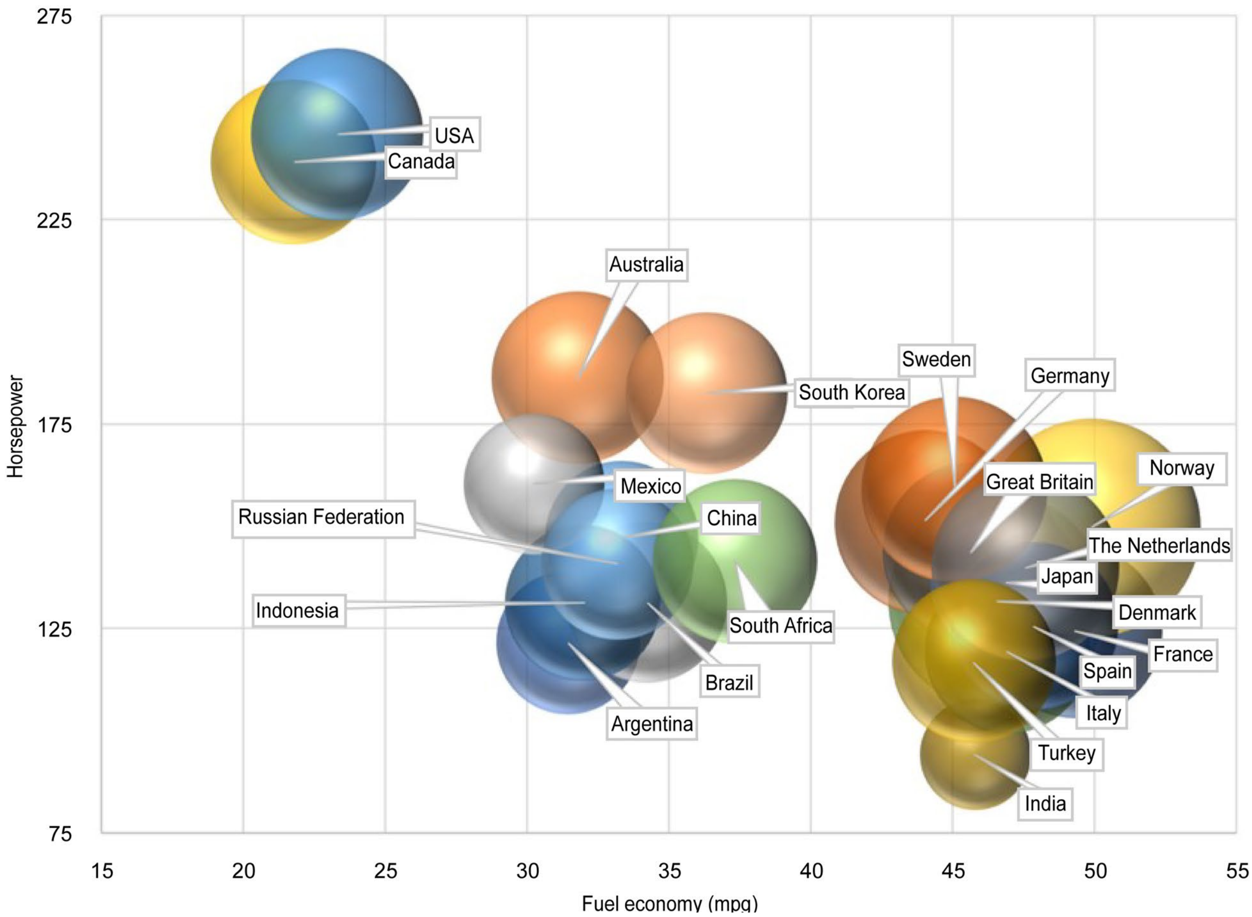
For the three countries in our sample that have regional-level subsidies and for which our data specify sales region (Canada, China, and the USA), we calculate market shares by region (province or state) and include region indicators as well as region-by-PEV indicators in Equation 8 to allow for different general sales and PEV sales trends by region. For provinces in China with vehicle registration/ownership incentives,[9] we include a triple interaction between region, PEV, and a postpolicy introduction indicator. Although these policies are enacted at the city level, the cities are large and likely to account for a large portion of provincial-level sales. Nevertheless, the triple indicator should be biased toward zero given that not all observations in the province are treated.

In our estimation, we adjust price by any national or regional direct financial incentives for which each PEV qualifies. Given the geographic level of our data, we are unable to account for any subregional incentives (or regional incentives in some cases). However, since we include BEV and PHEV indicators in the utility function, these coefficients should absorb the effects of any unaccounted-for incentives. For example, if regional and/or local incentives encourage more consumers to buy BEVs, this unaccounted-for "popularity" of BEVs will appear as a more positive estimated BEV indicator.

We convert all prices and subsidies to USD using average annual currency conversion rates.[10] The share of the outside good, s_{0t}, in Equation 8 is the number of households in the market that year that did not purchase a new vehicle. We calculate the number of households in each country and each year by dividing annual, country-level population estimates by average household size. Population estimates are obtained from the World Bank.[11] Average household size by country is collected from the United Nations and the Organisation for Economic Co-operation and Development.[12]

Figure 2 shows average fleet characteristics by country across the sample. New vehicle fleets in the USA and Canada have the lowest average fuel economy and highest horsepower. Scandinavian countries (Norway, Denmark, and, to a lesser extent, Sweden) have the highest-priced and some of the most fuel-efficient fleets. Most other European countries have very fuel-efficient fleets and similar horsepower but somewhat lower prices than Scandinavia. India has by far the least expensive and least powerful fleet but is nevertheless quite fuel efficient. China, South Korea, and Japan have similarly low-to-moderate-priced new vehicle fleets, but the South Korean fleet has significantly higher horsepower and the Japanese fleet significantly higher fuel economy than the other two.

Figure 2. Average new vehicle characteristics by country, 2011–2019



Source: KAPSARC analysis.
Bubble sizes are proportionate to the average sale price (USD), which ranges from $13,932 (India) to $53,968 (Norway).

Price Elasticity of Demand

We estimate PED for new vehicles over our sample period (2010–2019) by country, assuming a vehicle price of $30,000 USD. The own-price elasticity for a vehicle is equal to the estimated price coefficient multiplied by price and by (1-*s*) (Levin 2009), where s is the share of households purchasing that vehicle among the total number of households in that country. (1-*s*) approximates to 1, given that the share of households purchasing a particular vehicle among the total number of households (including those that do not purchase a vehicle) in a country is very low. The long-run elasticities are found by dividing the short-run PED estimates by $(1-\gamma)$, where γ is the estimated coefficient on the lagged dependent variable, as shown in Equation 8 (Barreto and Howland 2006).

PEV Policy Counterfactual Analysis

Using the results from estimating Equation 8, we remove direct purchase incentives from BEV and PHEV prices and predict sales in the absence of these policies. We calculate policy additionality as follows:

$$Additionality\ (\%) = \frac{PEV\ \ Sales\ \ w\,/\,Subsidy\ -\ PEV\ \ Sales\ \ w\,/\,o\ \ Subsidy}{PEV\ \ Sales\ \ w\,/\,Subsidy} * 100 \tag{9}$$

Additionality measures the share of PEV purchases that were induced by the subsidy policy. Table 4 shows the predicted policy additionality by country and by year for direct purchase incentives. Mean incentive is the average incentive across PEV models. The cost per additional PEV is calculated as follows:

$$Cost\ \ per\ \ Addt'l\ PEV = \frac{Total\ Cost\ \ of\ \ Subsidies}{PEV\ \ Sales\ \ w\,/\,Subsidy\ -\ PEV\ \ Sales\ \ w\,/\,o\ \ Subsidy} \tag{10}$$

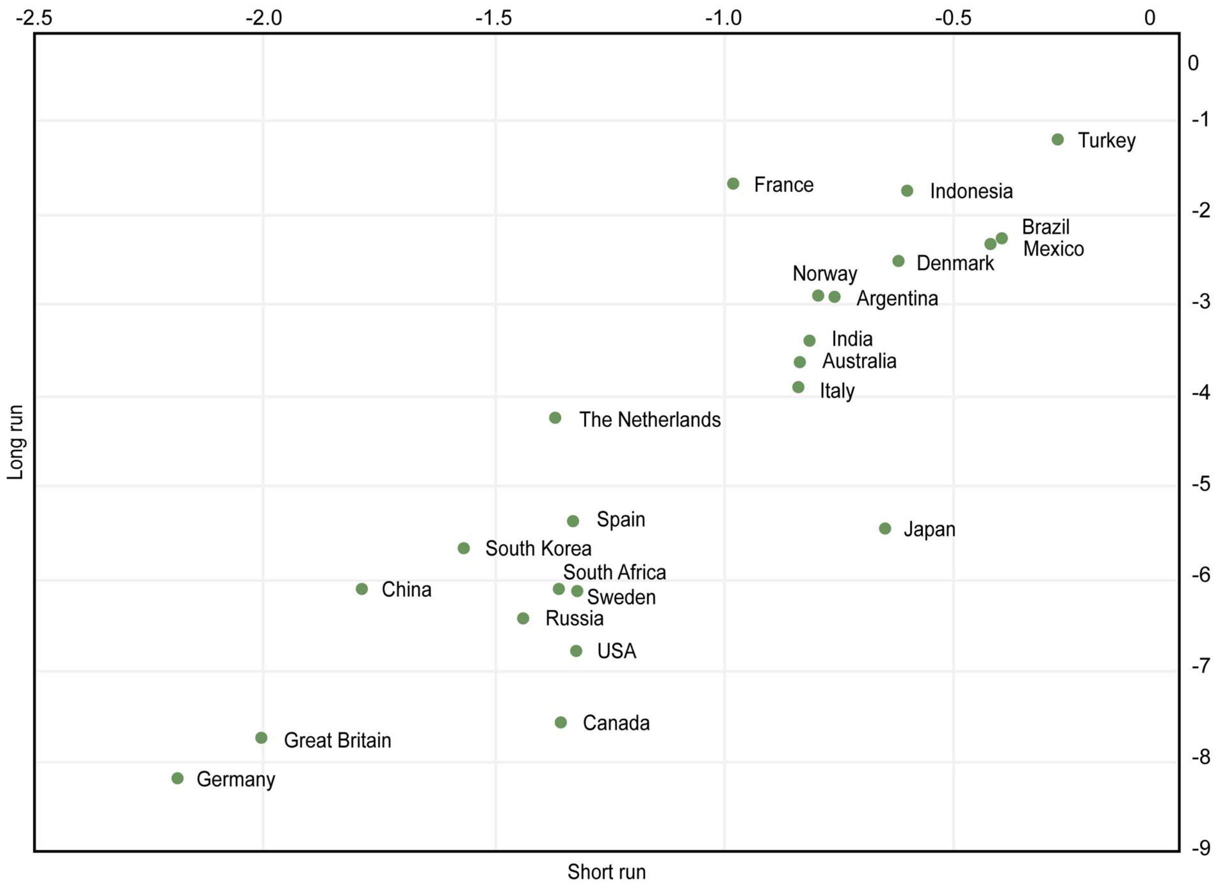
We explore medium-run impacts in a second counterfactual analysis in which we include the dynamic effects from the lagged dependent variable ($\gamma ln\left(\frac{s_{it-1}}{s_{0t-1}}\right)$ from Equation 8). Specifically, we predict sales in 2011 and then feed predicted sales from that year into the prediction for 2012 and so on. We do so by first assuming subsidies in all years and then assuming zero subsidies in all years and examine the difference in PEV sales across the two scenarios.

Results and Discussion

Price Elasticities and PEV Preferences by Country

Figure 3 shows estimates of both short-run and medium-run PED for new vehicles by country (i.e., sensitivity in demand to a change in price).[13] The PED, or the consumer's sensitivity to changes in vehicle price, provides the basis for determining the cost-effectiveness of PEV subsidies. In the short run, demand for new vehicles is inelastic in roughly half of the countries and elastic in the rest, with most having nearly unit elasticity.[14] In the medium run, demand is elastic in all countries. Germany and Great Britain have the most elastic demand for new vehicles, while Turkey, Mexico, and Brazil have the least. In general, higher-income countries tend to have more elastic demand. Although this finding is counterintuitive,[15] we offer the following explanation. Higher-income countries tend to have larger household fleets, with many households owning more than one car.[16] In contrast, the average household in India or Indonesia likely does not own a vehicle. This means that in higher-income countries, the decision to purchase a new vehicle is often the decision to replace an existing car or add another car to the household fleet. In contrast, the decision to purchase a new vehicle in a lower-income country is often the decision to

Figure 3. Estimated price elasticity of demand



Source: KAPSARC analysis.
Estimated price elasticity of demand (PED) for new vehicles over the sample period (2010–2019) by country, assuming a vehicle price of $30,000 USD.

become a vehicle-owning household. Thus, a new vehicle purchase in a higher-income country could be viewed as more of a luxury versus more of a necessity in a lower-income country. Our estimated elasticities are consistent with the PED being greater for non-necessities.

While a large body of literature exists on the PED for gasoline, there are relatively few estimates of the PED for new vehicles, especially for recent years and outside the USA. Nevertheless, our short-run estimates fall within the range of existing estimates for the USA, which, using aggregate data, range from -0.8 to -1.63 (Hess 1977; Levinsohn 1988; McCarthy 1996) and, using disaggregate data, range from -0.51 to -6.13 (Lave and Train 1979; Mannering and Mahmassani 1985; Mannering and Winston 1985, 1991; Tay and McCarthy 1991).

Most countries have statistically significant negative preferences for both BEVs and PHEVs. This suggests that after price, incentives, and other characteristics are controlled, consumers prefer ICEVs on average. This could be at least in part due to concerns about electric driving range, charging infrastructure, high recharging time, etc.[17] Consumers in Canada, Norway, South Korea, and Sweden value BEVs the most (in that they are indifferent to the choice between BEVs and ICEVs). Consumers in the same countries also have relatively stronger preferences for PHEVs.[18] Consumers in France, Argentina, Turkey, Spain, and Italy least prefer BEVs.

Electric Vehicle Policy Effectiveness

To evaluate PEV policy additionality and cost-effectiveness, we perform a counterfactual analysis for all countries in the sample with direct purchase incentives (e.g., rebates, tax credits) during 2011–2019. We calculate both additionality (share of PEV purchases induced by the subsidy policy) and cost per additional PEV induced by the policy.

Additionality is determined by the ratio of additional to nonadditional consumers (i.e., those who would purchase PEVs regardless of the subsidy). All else being equal, larger subsidies increase additionality because they increase the number of marginal consumers. The degree to which they do so is also influenced by consumer vehicle preferences. All else being constant, additionality decreases with the number of nonadditional or inframarginal consumers.

Table 1 shows the results of the counterfactual policy analysis. Additionality in Japan is the lowest among the countries examined at 1%–3%. This is likely due to a combination of factors: a relatively low price sensitivity means consumers are less responsive to financial incentives, and a more modest preference for fuel efficiency and acceleration suggests lower value for key characteristics of PEVs, which are highly fuel efficient (in mpg equivalence) and tend to be powerful with strong acceleration. The relatively small incentive amounts of approximately $1,000–$2,000 USD are likely not large enough to be a key decision-making factor for consumers. Despite the modest size of the incentive, since it is given to all eligible consumers, the total cost of the policy is quite high in terms of the number of dollars spent to induce a PEV purchase, at approximately $45,000 USD. A similar case can be made for India, which has an additionality of 2%, though its cost per additional PEV is smaller Japan's because there are relatively few nonadditional consumers, as the PEV market in India is newer and smaller.

The greatest additionality is in South Korea, where it peaked at 54% in 2014. Additionality is likely high there because consumers are relatively price sensitive, it is one of the few countries that does

Table 1. Policy additionality and cost-effectiveness of direct purchase incentives.

Country	Sales year	Mean incentive	Additionality (%)	Cost per addtl PEV	Country	Sales year	Mean incentive	Additionality (%)	Cost per addtl PEV
Canada	2011	$5,055	23	$25,262	India	2017	$678	2	$37,135
	2012	$5,214	34	$25,639	Italy	2019	$2,437	9	$34,759
	2013	$4,631	27	$24,972	Japan	2011	$1,250	3	$45,344
	2014	$3,465	20	$24,541		2012	$1,250	3	$45,670
	2015	$2,855	12	$23,960		2016	$1,329	2	$45,121
	2016	$2,938	19	$23,964		2017	$1,492	1	$45,541
	2017	$3,203	23	$24,364		2018	$1,486	1	$45,620
	2018	$2,935	18	$23,850		2019	$1,657	1	$45,626
	2019	$3,791	19	$24,512	South Korea	2014	$7,125	54	$26,183
China	2011	$7,750	38	$20,362		2015	$3,300	51	$25,528
	2012	$8,157	39	$20,513		2016	$3,440	42	$23,783
	2013	$5,535	28	$19,278		2017	$6,853	45	$24,689
	2014	$5,253	11	$19,423		2018	$6,424	42	$23,909
	2015	$5,506	16	$19,275		2019	$5,497	33	$22,108
	2016	$7,075	33	$22,361	Spain	2011	$6,950	32	$26,018
	2017	$5,738	28	$19,984		2012	$5,676	23	$25,142
	2018	$5,218	25	$19,583		2013	$6,610	28	$25,638
	2019	$1,942	14	$17,741		2014	$6,734	29	$25,555
France	2011	$6,884	19	$32,555		2015	$5,251	23	$24,711
	2012	$7,437	25	$33,782		2016	$427	7	$23,862
	2013	$7,436	25	$33,873		2017	$154	4	$23,136
	2014	$7,172	23	$33,348	Sweden	2012	$5,732	23	$24,496
	2015	$5,717	21	$32,800		2013	$6,160	25	$24,711
	2016	$2,893	16	$32,701		2014	$5,840	24	$24,547
	2017	$3,938	15	$32,511		2015	$4,760	20	$23,975
	2018	$3,089	17	$32,757		2016	$2,897	12	$23,023
	2019	$3,919	17	$32,589		2017	$2,730	12	$23,067
Germany	2016	$3,331	24	$14,873		2018	$4,025	16	$23,982
	2017	$3,317	24	$14,867		2019	$3,792	16	$23,982
	2018	$3,205	26	$15,028	USA	2011	$7,850	32	$24,811
	2019	$3,161	24	$14,857		2012	$6,244	25	$24,345
Great Britain	2011	$4,010	43	$18,367		2013	$6,080	28	$24,672
	2012	$6,849	35	$18,017		2014	$6,978	28	$24,676
	2013	$7,801	43	$18,234		2015	$6,839	30	$24,923
	2014	$8,225	44	$18,492		2016	$6,859	29	$24,729
	2015	$7,251	42	$18,145		2017	$6,927	31	$25,040
	2016	$4,320	26	$16,451		2018	$7,009	33	$25,336
	2017	$3,838	24	$16,304		2019	$7,178	26	$24,273
	2018	$3,914	23	$16,303					

Source: KAPSARC analysis.

not have a statistically significant negative BEV preference, and the incentives are large enough (the largest on average out of all countries) to sway consumers' decisions.

Mean and median additionality across countries and time in the sample are both 24%. Additionality in the remaining countries mostly ranges near the mean/median, from the high teens to the low thirties. These estimates are roughly in line with prior single-country and single-year estimates from the literature. Tal and Nicholas (2016), using stated preference data for 11 states in the USA, estimate the additionality of the federal incentive of 30%. Additionally, using stated preference data, DeShazo, Sheldon, and Carson (2017) find that California state rebates (not including the federal tax credit) induced less than 10% of PEV sales at a cost of approximately $30,000 USD per additional PEV. A more recent set of papers use revealed preference data. Sheldon and Dua (2019) estimate a federal and state policy additionality in the USA in 2015 of 17% and a cost per additional PEV of $35,000 USD. Li et al. (2017) calculate an additionality of 40% for the federal USA policy, though their analysis includes feedback loops from charging infrastructure. Sheldon and Dua (2020) find that 34% of PEV purchases in 2017 in China were due to PEV subsidies, costing approximately $24,500 USD per additional PEV purchase.

Münzel et al. (2019) use a panel data regression model on aggregate market share data for European countries from 2010 to 2017, finding that a 1,000 euro financial incentive yields an approximately 5%–7% relative sales share increase. Using a similar methodology, Azarafshar and Vermeulen (2020) find that a $1,000 CAD increase in Canadian provincial PEV incentives increased sales by 5%–8% from 2012 to 2016, with the incentives accounting for 35% of PEV purchases over the time period.

The cost per additional PEV is highest in Japan for the reasons previously discussed. The cost per additional PEV is lowest in Germany, at approximately $15,000 USD. The incentive in Germany is modest, but German consumers are the most price sensitive and value both fuel economy and acceleration relatively highly compared to consumers in other countries. This suggests that the policy achieves more "bang for the buck" and that additionality could likely be increased substantially with a larger incentive.

Note that while the cost per additional PEV is approximately $25,000 USD in many countries, additionality varies across these countries. For example, though Canada has a cost per additional PEV similar to that of the USA on average across years ($24,563 USD v. $24,756 USD), its additionality is approximately two-thirds that of the USA on average (22% v. 29%).

Table 1 also shows that additionality has generally been trending downward in most countries over time. This trend appears to be driven by the decrease in average incentives in most countries over the time period, especially since the cost per additional PEV has been flat or decreasing in most countries. This suggests that while smaller subsidies lead to fewer additional purchases overall, cost-effectiveness is if anything improving over time. Indeed, Jenn et al. (2020), using a comprehensive survey of PEV owners, find that in California, incentives became more important for potential PEV adopters between 2010 an 2017.

Some countries, particularly in Europe, have indirect purchase incentives instead of or in addition to direct purchase incentives. Indirect purchase incentives include various tax reductions and exemptions. We perform a second counterfactual analysis on these policies. For European countries, in the counterfactual scenario, we subtract from price the average indirect purchase incentives for 2010–2017 calculated by Münzel et al. (2019). For China, we subtract 10% of the base (pretax) price to account for China's sales tax exemption.[19] Table 2 displays the results. For countries with a direct purchase incentive, we combine it with the indirect incentive and calculate additionality and cost per additional PEV based on the combined total incentive.

Additionality is highest in Great Britain and Denmark. Norway has the highest PEV market share of all countries in the study, at over 20% for 2010–2019. Our results suggest that nearly 40% of PEV purchases in Norway over that time period were due to purchase incentives. Denmark has the largest indirect incentive, and though additionality is high, the cost per additional PEV is the highest of any country in our analysis. This is in part because Denmark has the second-to-least price-sensitive consumers of the countries examined.

Medium-Run Effects

Existing PEV subsidy effectiveness analyses, including ours above, focus on short-run effects, i.e., the effect of a subsidy on PEV sales in the concurrent year. However, due to learning spillovers, an increase in PEV sales in one year as a result of a subsidy may in turn spur faster PEV adoption in subsequent years. We explore such medium-run impacts by performing a second counterfactual analysis in which we include dynamic effects.[20] Additionality incorporating the medium-run effects is substantially higher than the short-run additionality shown in Table 2, with the median year's additionality being 56% greater. On average, cost per additional PEV is 43% lower when additional sales from one subsequent year are factored in. This indicates that when medium-run effects are accounted for, PEV subsidies are substantially more cost-effective than the short-run effects described in the literature suggest. Detailed results can be found in the Supplementary Information.

Caveats

We assume full uptake of direct purchase incentives. In the policy simulations, we assume full uptake of direct and indirect purchase incentives. In other words, we assume that every consumer who makes an eligible purchase receives the full incentive. This likely overestimates uptake for three reasons. First, some consumers may not be aware that their purchase qualifies for an incentive. Second, many incentives require some paperwork, which some consumers may choose not to complete. We believe lack of uptake for these two reasons to be minimal, since dealerships typically help consumers with the administrative process and it is irrational to leave "money on the table."

However, in the USA, in particular, full uptake is not always feasible. The federal incentive takes the form of an income-tax credit. Buyers receive full credit only if it is less than or equal to the amount of annual federal income tax they owe. If the credit exceeds the amount of income tax owed, the excess is not applied and does not roll over to a future year. Although most PEV buyers are high income and therefore likely to pay more in income taxes and thus receive the full credit, some buyers may not. However, many PEV buyers prefer leasing, in which case the incentive money goes to the lessor, who typically incorporates the incentive into the lease agreement, thereby allowing even buyers with lower incomes to benefit from the tax credit. If incentive uptake is lower than we assume in our analysis, then our additionality calculations are overestimates. However, the effect on cost-effectiveness would be ambiguous since the total cost would be lower. We believe any such effect would be very small given that uptake, if less than full, is nevertheless probably quite high.

Table 2. Policy additionality and cost-effectiveness of indirect purchase incentives.

Country	Sales year	Mean direct incentive	Mean indirect incentive	Additionality (%)	Cost per addtl PEV (including direct+indirect)
China	2014	$5,253	$3,834	25	$19,618
	2015	$5,506	$4,694	32	$20,705
	2016	$7,075	$4,119	45	$23,590
	2017	$5,738	$3,459	40	$21,451
	2018	$5,218	$3,074	37	$20,924
	2019	$1,942	$2,688	27	$19,093
Denmark	2011		$29,123	47	$62,443
	2012		$27,027	44	$61,189
	2013		$27,865	45	$61,691
	2014		$27,766	45	$61,638
	2015		$23,173	39	$58,974
	2016		$17,781	32	$55,844
	2017		$14,678	27	$54,105
France	2011	$6,884	$3,505	29	$34,456
	2012	$7,437	$3,260	33	$35,574
	2013	$7,436	$4,193	35	$36,172
	2014	$7,172	$4,361	34	$35,748
	2015	$5,717	$3,703	30	$34,823
	2016	$2,893	$3,774	26	$34,443
	2017	$3,938	$4,337	27	$34,499
Great Britain	2011	$4,010	$3,061	55	$20,230
	2012	$6,849	$2,841	47	$19,482
	2013	$7,801	$3,317	55	$20,260
	2014	$8,225	$3,447	57	$20,617
	2015	$7,251	$2,877	53	$19,877
	2016	$4,320	$2,877	40	$18,006
	2017	$3,838	$2,782	38	$17,766
Norway	2011		$17,277	38	$45,119
	2012		$15,505	35	$44,127
	2013		$16,263	36	$44,590
	2014		$15,417	35	$44,188
	2015		$14,511	33	$43,837
	2016		$17,204	38	$45,519
	2017		$17,777	39	$45,949
Spain	2011	$6,950	$1,843	37	$27,067
	2012	$5,676	$1,711	29	$25,974
	2013	$6,610	$1,764	34	$26,591
	2014	$6,734	$1,764	34	$26,530
	2015	$5,251	$1,472	28	$25,499
	2016	$427	$1,472	13	$23,895
	2017	$154	$1,498	10	$23,226
The Netherlands	2011		$2,628	12	$22,489
	2012		$3,759	16	$23,093
	2013		$8,076	32	$25,490
	2014		$8,016	32	$25,443
	2015		$6,874	28	$24,861
	2016		$8,596	33	$25,775
	2017		$11,039	41	$27,155

Source: KAPSARC analysis.

Only provincial- and state-level incentives in Canada, China, and the USA are included in our analysis. Some other countries (France, India, and South Korea) have regional-level incentives, but our data do not specify the region of sales. Many of the countries have other city- and local-level incentives that are not included in our analysis. Our policy simulations do not capture the impact of these incentives. However, since we include BEV and PHEV indicators in the empirical model, the indicators should absorb the average impact of unaccounted-for incentives such that other coefficients (e.g., fuel economy) are not biased.

Our counterfactual analysis assumes that PEV prices remain the same if purchase incentives are removed. One may argue that without strong policy support, including purchase incentives, industry investments might have been lower and the competitive prices and product availability of PEVs might have been less attractive. In this case, there would be fewer nonadditional consumers, and therefore, the incentive cost-effectiveness would be higher than estimated in the paper.

Finally, in the medium-run additionality simulations, we are unable to account for the pull-forward effect. Specifically, the introduction of a new subsidy or announcement of cancellation of an existing subsidy may cause consumers who were planning to buy a PEV in the next several years to buy it sooner than planned. This would increase additionality for the year of the policy change but decrease future sales relative to the counterfactual. Our simulations do not capture such a potential decrease in future sales. The greater the policy uncertainty, the stronger the pull-forward effect would be, as consumers seek to take advantage of current incentives without knowing how long they will last. However, since most countries in our analysis have had consistent and multiyear PEV subsidy policies, we doubt that the pull-forward effect would be substantial in our sample.

Conclusion

We assess PEV incentive cost-effectiveness by calculating the policy cost per additional vehicle purchased with the incentive, as predicted by our counterfactual simulations. We find that the cost-effectiveness of direct purchase incentives is best in Germany and worst in Japan, ranging from $14,857 USD to $45,670 USD, with an average of $25,544 USD. For indirect purchase incentives, cost-effectiveness is best in Great Britain and worst in Denmark, ranging from $17,766 USD to $62,443 USD, with an average of $33,117 USD. The cost per additional gallon of gasoline reduction resulting from the policy ranges from $11 USD (in Germany) to $36 USD (in Denmark) (see the Supplementary Information for details of this calculation). Within each country, additionality has generally been trending downward over time, driven in part by the decrease in average incentives. Nevertheless, the cost per additional PEV has been flat or decreasing in most countries. Although smaller subsidies lead to fewer additional purchases overall, cost-effectiveness is, if anything, improving over time. Furthermore, we offer one of the first analyses of medium-run subsidy effects, finding that accounting for spillover effects improves the additionality and cost-effectiveness of subsidies by nearly 50%. Combined with recent evidence that PEV adoption incentives are more important for new adopters as the market matures (Jenn et al., 2020), this finding suggests that such incentives continue to play an important role in fleet electrification.

Endnotes

[1] Specifically, the Inflation Reduction Act eliminates the cap limiting credits to the first 200,000 PEVs sold by the manufacturer, making Tesla and General Motors PEVs eligible once more. See https://www.nytimes.com/2022/08/12/business/climate-bill-electric-vehicles.html.

[2] Though approximately one-third of the countries in our sample do not offer financial incentives for PEVs, characterization of consumer price elasticities and preferences could provide a rough proxy for the effectiveness of subsidies, were they to be implemented.

[3] The conditional logit model (Equation 5) from which our empirical model (Equation 8) is derived assumes independence of irrelevant alternatives (IIA), which restricts substitution patterns. In the Supplementary Information, we use a robustness check to show that our results do not change substantially when IIA is relaxed by estimating a mixed logit with random parameters.

[4] On average, 78% of the observations in our data for each country have a non-missing one-year lagged dependent variable. For those missing lagged values, we impute them with mean make-body-year values. We drop observations for which the lagged values are still missing (11% of observations on average). As a robustness check, we also estimate the model without the lagged dependent variable. The results are shown in the Supplementary Information (Tables SI12–SI15).

[5] Specifically, the G20 members are Argentina, Australia, Brazil, Canada, China, the European Union (EU), France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, the United Kingdom, and the United States. We have data for all members except the EU as a whole. Note that France, Germany, Italy, Spain, and (prior to 2020) the UK are both G20 and EU members. We also have data for additional EU member countries—Denmark, the Netherlands, Spain and Sweden, as well as Norway, which is not in the EU. While we have data for Saudi Arabia, the majority of the vehicle characteristics are missing. As such, we are unable to estimate the models for Saudi Arabia.

[6] See https://ecoscore.be/en/info/ecoscore/co2 for details.

[7] Sources include wattev2buy.com, chinaautoweb.com, and carnewschina.com.

[8] See https://www.edmunds.com/fuel-economy/decoding-electric-car-mpg.html for details.

[9] Shanghai, Beijing, Guiyang (Guizhou Province), Guangzhou (Guangdong), Tianjin, Hangzhou (Zhejiang Province), and Shenzhen allocate new vehicle ownership allowances via lottery (some joint with auctions) with exceptions for PEVs. Shanghai's policy has been in place since 1994. Beijing's and Guiyang's policies were enacted in 2011, Guangzhou's in 2012, Tianjin's and Hangzhou's in 2014, and Shenzhen's in 2015 (Dua, 2021).

[10] Sources include www.investing.com, www.macrotrends.net, and www.ofx.com.

[11] Provincial population data for Canada were obtained from https://www150.statcan.gc.ca. Provincial population data for China were obtained from https://data.stats.gov.cn. State population data for the USA were obtained from https://www.census.gov.

[12] Population estimates come from https://data.worldbank.org/indicator/SP.POP.TOTL. Average household size for Denmark and Sweden can be found at http://www.oecd.org/social/soc/doingbetterforfamilies.htm. Average household size for Saudi Arabia is taken from Salam et al., 2014. Average household sizes for the remaining countries were obtained from https://population.un.org/Household/#/countries/840.

[13] These results are based on the estimated vehicle choice models using new vehicle sales data for 23 countries and identifying consumer preferences for various vehicle characteristics (e.g., fuel economy), including price elasticities of demand.

[14] Note that disregarding the dynamic effect, as is common in the literature, results in higher price elasticities, as is evidenced by Table SI13 in the Supplementary Information, where we perform a robustness check excluding the lagged dependent variable. Absent the dynamic effect, elasticities are mostly greater than one and closer to the long-run elasticities that we estimate. This suggests that disregarding the dynamic effect may result in overestimates of short-run price elasticities.

[15] Unfortunately, we are unable to compare our estimates to the literature given the lack of empirical evidence on cross-country comparisons of price elasticities of demand, not only for vehicles but also for durable goods. As such, our estimates may be of broader interest.

[16] According to the 2017 National Household Travel Survey, in 2017, the average American household owned 1.88 vehicles (https://nhts.ornl.gov/households). While a comparable statistic is not readily available for other countries, according to the US Department of Energy, in 2014, there were 816 cars per 1,000 people in the USA, 656 in Canada, 591 in western Europe, but only 206 in Brazil, 31 in India, and 82 in Indonesia (https://www.energy.gov/eere/vehicles/fact-962-january-30-2017-vehicles-capita-other-regionscountries-compared-united-states).

[17] Note that these are captured by the BEV and PHEV fixed effects in Equation 8.

[18] In other words, these countries have smaller negative coefficients on the PHEV indicator variable from Equation 8 than other countries.

[19] https://news.bloombergtax.com/daily-tax-report-international/china-extends-rebates-for-electric-car-purchases-to-revive-sales

[20] Specifically, we incorporate effects from the lagged dependent variable in Equation 8.

References

Axsen, Jonn, Patrick Plötz, and Michael Wolinetz. 2020. “Crafting strong, integrated policy mixes for deep CO_2 mitigation in road transport.” *Nature Climate Change* 10(9): 809-818. DOI: 10.1038/s41558-020-0877-y.

Azarafshar, Roshanak, and Wessel N. Vermeulen. 2020. “Electric vehicle incentive policies in Canadian provinces.” *Energy Economics* 91: 104902. DOI: 10.1016/j.eneco.2020.104902.

Barreto, Humberto, and Frank Howland. 2006. *Introductory Econometrics: Using Monte Carlo Simulation with Microsoft Excel*. Cambridge University Press.

Berry, Steven T. 1994. “Estimating discrete-choice models of product differentiation.” *The RAND Journal of Economics* 25(2): 242-262.

Berry, Steven, James Levinsohn, and Ariel Pakes. 1995. “Automobile Prices in Market Equilibrium.” *Econometrica* 63(4): 841–90.

Chakraborty, Debapriya, Koral Buch, and Gil Tal. 2021. “Cost of Vehicle Ownership: Cost Parity Between Plug-in Electric Vehicles and Conventional Vehicles Is at Least a Decade Away.” UC Davis: National Center for Sustainable Transportation. http://dx.doi.org/10.7922/G2R20ZNX Retrieved from https://escholarship.org/uc/item/8wz0c90f.

Chandra, Ambarish, Sumeet Gulati, and Milind Kandlikar. 2010. “Green drivers or free riders? An analysis of tax rebates for hybrid vehicles.” *Journal of Environmental Economics and Management* 60(2): 78-93. DOI: 10.1016/j.jeem.2010.04.003.

DeShazo, JR, Tamara L Sheldon, and Richard T Carson. 2017. “Designing policy incentives for cleaner technologies: Lessons from California’s plug-in electric vehicle rebate program.” *Journal of Environmental Economics and Management* 84: 18-43. DOI: 10.1016/j.jeem.2017.01.002.

Dua, Rubal. 2021. “Choosing to Diet: The Effect of Vehicle Ownership Restrictions on China’s Car Sales, Fuel Consumption, and Greenhouse Gas Emissions.” KAPSARC Discussion Paper.

Gallagher, Kelly Sims, and Erich Muehlegger. 2011. “Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology.” *Journal of Environmental Economics and Management* 61(1): 1-15. DOI: 10.1016/j.jeem.2010.05.004.

Grigolon, Laura, Mathias Reynaert, and Frank Verboven. 2018. “Consumer valuation of fuel costs and tax policy: Evidence from the European car market.” *American Economic Journal: Economic Policy* 10(3): 193-225. DOI: 10.1257/pol.20160078

Hamelinck, Carlo, Matthias Spöttle, Louis Mark, and Maarten Staats. 2019. “2030 Transport Decarbonization Options.” https://www.farm-europe.eu/wp-content/uploads/2019/06/Ecofys2019_Transport-decarbonisation-2030-CEE.pdf.

Hardman, Scott, Amrit Chandan, Gil Tal, and Tom Turrentine. 2017. “The effectiveness of financial purchase incentives for battery electric vehicles–A review of the evidence.” *Renewable and Sustainable Energy Reviews* 80: 1100-1111. DOI: 10.1016/j.rser.2017.05.255

Hess, Alan C. “A comparison of automobile demand equations.” *Econometrica: Journal of the Econometric Society* (1977): 683-701.

Hughes, Jonathan, Christopher R. Knittel, and Daniel Sperling. 2008. “Evidence of a shift in the short-run price elasticity of gasoline demand.” *The Energy Journal* 29(1). DOI: 10.5547/ISSN0195-6574-EJ-Vol29-No1-9.

International Energy Agency (IEA). 2019. “Tracking Transport 2019.” https://www.iea.org/reports/tracking-transport-2019.

Jenn, Alan, Jae Hyun Lee, Scott Hardman, and Gil Tal. 2020. “An in-depth examination of electric vehicle incentives: Consumer heterogeneity and changing response over time.” *Transportation Research Part A: Policy and Practice* 132: 97-109. DOI: 10.1016/j.tra.2019.11.004.

Johnson, Clair, and Brett Williams. 2017. “Characterizing plug-in hybrid electric vehicle consumers most influenced by California’s electric vehicle rebate.” *Transportation Research Record* 2628(1): 23-31. DOI: 10.3141/2628-03.

Lave, Charles A., and Kenneth Train. 1979. “A disaggregate model of auto-type choice.” *Transportation Research Part A: General* 13(1): 1-9.

Levin, Jonathan. 2009. “Differentiated products demand systems (b).” *Economics* 257.

Levinsohn, James. 1988. “Empirics of Taxes on Differentiated Products: The Case of Tariffs in the U.S. Automobile Industry” in *Trade Policy Issues and Empirical Analysis*, edited by Robert E. Baldwin, 11-40. Chicago: University of Chicago Press.

Li, Shanjun, Christopher Timmins, and Roger H. Von Haefen. 2009. “How do gasoline prices affect fleet fuel economy?” *American Economic Journal: Economic Policy* 1(2): 113-37.

Li, Shanjun, Lang Tong, Jianwei Xing, and Yiyi Zhou. 2017. “The Market for Electric Vehicles: Indirect Network Effects and Policy Design.” *Journal of the Association of Environmental and Resource Economists* no. 4(1): 89-133. doi: 10.1086/689702.

Liang, Xinyu, Shaojun Zhang, Ye Wu, Jia Xing, Xiaoyi He, K. Max Zhang, Shuxiao Wang, and Jiming Hao. 2019. “Air quality and health benefits from fleet electrification in China.” *Nature Sustainability* 2(10): 962-971. DOI: 10.1257/pol.1.2.113.

Lieven, Theo. 2015. “Policy measures to promote electric mobility–A global perspective.” *Transportation Research Part A: Policy and Practice* 82: 78-93.

Mannering, Fred, and Clifford Winston. 1985. “A dynamic empirical analysis of household vehicle ownership and utilization.” *The RAND Journal of Economics* (1985): 215-236. DOI: https://doi.org/10.1016/j.tra.2015.09.008.

Mannering, Fred, Clifford Winston, Zvi Griliches, and Richard Schmalensee. 1991. “Brand loyalty and the decline of American automobile firms.” *Brookings Papers on Economic Activity. Microeconomics*: 67-114.

Mannering, Fred, and Hani Mahmassani. 1985. “Consumer valuation of foreign and domestic vehicle attributes: econometric analysis and implications for auto demand.” *Transportation Research Part A: General* 19(3): 243-251. DOI: 10.1016/0191-2607(85)90013-5.

McCarthy, Patrick S. 1996. “Market price and income elasticities of new vehicle demands.” *The Review of Economics and Statistics*: 543-547.

McFadden, Daniel 1973. “Conditional logit analysis of qualitative choice behavior” in *Frontiers in Econometrics*, edited by P. Zarernbka. New York: Wiley.

Miess, Michael, Stefan Schmelzer, Milan Ščasný, and Vedunka Kopecná. 2022. “Abatement Technologies and their Social Costs in a Hybrid General Equilibrium Framework.” *The Energy Journal* 43(2). DOI: 10.5547/01956574.43.2.mmie.

Milovanoff, Alexandre, I. Daniel Posen, and Heather L. MacLean. 2020. “Electrification of light-duty vehicle fleet alone will not meet mitigation targets.” *Nature Climate Change* 10(12): 1102-1107. DOI: 10.1038/s41558-020-00921-7.

References

Muehlegger, Erich, and David S. Rapson. 2018. “Subsidizing mass adoption of electric vehicles: Quasi-experimental evidence from California.” National Bureau of Economic Research working paper w25359. https://www.nber.org/papers/w25359.

Münzel, Christiane, Patrick Plötz, Frances Sprei, and Till Gnann. 2019. “How large is the effect of financial incentives on electric vehicle sales?–A global review and European analysis.” *Energy Economics* 84:104493. DOI: 10.1016/j.eneco.2019.104493.

Nunes, Ashley, Lucas Woodley, and Philip Rossetti. “Re-thinking procurement incentives for electric vehicles to achieve net-zero emissions.” *Nature Sustainability* (2022): 1-6. DOI: 10.1038/s41893-022-00862-3.

Paul, Anthony C., Erica C. Myers, and Karen L. Palmer. 2009. “A partial adjustment model of U.S. electricity demand by region, season, and sector.” Resources for the Future Discussion Paper 08-50. DOI: 10.2139/ssrn.1372228.

Plötz, Patrick, Jonn Axsen, Simon A. Funke, and Till Gnann. 2019. “Designing car bans for sustainable transportation.” *Nature Sustainability* 2(7): 534-536. DOI: 10.1038/s41893-019-0328-9.

Salam, Asharaf Abdul, Ibrahim Elsegaey, Rshood Khraif, and Abdullah Al-Mutairi. 2014. “Population distribution and household conditions in Saudi Arabia: reflections from the 2010 Census.” *SpringerPlus* 3(1): 1-13.

Sallee, James M. 2011. “The surprising incidence of tax credits for the Toyota Prius.” *American Economic Journal: Economic Policy* 3(2): 189-219. DOI: 10.1257/pol.3.2.189.

Sheldon, Tamara L., and Rubal Dua. 2018. “Gasoline savings from clean vehicle adoption.” *Energy Policy* 120: 418-424. doi: https://doi.org/10.1016/j.enpol.2018.05.057.

———. 2019. “Measuring the cost-effectiveness of electric vehicle subsidies.” *Energy Economics* 84:104545. doi: https://doi.org/10.1016/j.eneco.2019.104545.

———. 2020. “Effectiveness of China’s plug-in electric vehicle subsidy.” *Energy Economics* 88: 104773. doi: https://doi.org/10.1016/j.eneco.2020.104773.

Sierzchula, William, Sjoerd Bakker, Kees Maat, and Bert Van Wee. 2014. “The influence of financial incentives and other socio-economic factors on electric vehicle adoption.” *Energy Policy* 68: 183-194. DOI: 10.1016/j.enpol.2014.01.043.

Intergovernmental Panel on Climate Change (IPCC). 2014. “Transport” in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, U.K, and New York, U.S.: Cambridge University Press.

Small, Kenneth A., and Kurt Van Dender. 2007. “Fuel efficiency and motor vehicle travel: the declining rebound effect.” *The Energy Journal* 28(1). DOI: 10.5547/ISSN0195-6574-EJ-Vol28-No1-2.

Tal, Gil, and Michael Nicholas. 2016. “Exploring the impact of the federal tax credit on the plug-in vehicle market.” *Transportation Research Record* 2572(1): 95-102. DOI: 10.3141/2572-11.

Tamm, Marcus, Harald Tauchmann, Jürgen Wasem, and Stefan Greß. 2007. “Elasticities of market shares and social health insurance choice in Germany: a dynamic panel data approach.” *Health Economics* 16(3): 243-256. DOI: 10.1002/hec.1167.

Tay, Richard S., and Patrick S. McCarthy. 1991. “Demand oriented policies for improving market share in the U.S. automobile industry.” *International Journal of Transport Economics/Rivista internazionale di economia dei trasporti*: 151-166.

Train, Kenneth. 1998. "Recreation Demand Models with Taste Differences over People." *Land Economics*, 74(2): 230-39.

Xing, Jianwei, Benjamin Leard, and Shanjun Li. 2021. "What does an electric vehicle replace?" *Journal of Environmental Economics and Management* 107:102432. doi: https://doi.org/10.1016/j.jeem.2021.102432.

Zhou, Yan, Michael Wang, Han Hao, Larry Johnson, and Hewu Wang. 2015. "Plug-in electric vehicle market penetration and incentives: a global review." *Mitigation and Adaptation Strategies for Global Change* 20(5): 777-795.

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About the Project

Promoting the adoption of energy-efficient vehicles has become a key policy imperative in both developed and developing countries. Understanding the impacts of various factors on adoption rates forms the backbone of KAPSARC's efforts in the light-duty vehicle demand field. These factors include (i) consumer-related factors—demographics, behavioral, and psychographics; (ii) regulatory factors—policies, incentives, rebates, and perks; and (iii) geotemporal factors—weather, infrastructure and network effects. Our team is currently developing models at different levels: microlevel models using large-scale data comprising new car buyers' profiles and macrolevel models using aggregated adoption data to understand and project the effects of various factors affecting the adoption rate of energy-efficient vehicles.

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