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WELFARE IMPLICATIONS OF ELECTRIC-BIKE SUBSIDIES: EVIDENCE FROM SWEDEN

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ABSTRACT

Electric bikes are a potentially important tool to address global warming since they can be a viable alternative to cars in urban areas. Governments are using subsidies to promote household adoption. Welfare analyses are challenging, requiring pass-through estimates from transactions, incidence of non-additionality (i.e. those who would have bought even without the subsidy), and resulting substitution from driving. We combine administrative, insurance and survey data from a large-scale Swedish subsidy program in 2018, which is similar to other programs around world, to evaluate these implications. We find (1) complete pass through of the average $500 subsidy to consumers, (2) a near doubling of E-bikes sold but one-third of adopters are non-additional; and (3) a savings of 1.3 tons of carbon emissions during the life of the E-bike. Combining these estimates, an E-bike subsidy program can only be justified with a social cost of carbon that is several hundred dollars higher than what is typically used.

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1 Introduction

Greenhouse gas (GHG) emissions from transportation account for about 29 percent of total US GHG emissions, making it the largest contributor by sector to global warming. Within the transportation sector, cars are responsible for 58% of all transportation emissions according to the US Environment Protection Agency. Along with electric cars, electric bikes or pedelecs (E-bikes) are a potentially important tool to address global warming. With rechargeable batteries and hence capable of long distances, they can replace car trips for work in dense and growing urban areas around the world.

But E-bikes are not cheap, around a few thousand dollars of upfront costs along with several hundred additional dollars for each battery replacement. A number of governments have or are in the process of implementing subsidy programs to promote household adoption of E-bikes (see Table 1). There is even an E-bike bill (H.R. 1019) introduced in the US House of Representatives for the 117th Congress (2021-2022). Hence, a welfare analysis of these programs would be valuable.

However, such analyses of these E-bike subsidy programs are challenging for several reasons. First, a welfare analysis requires measures of tax incidence or the passthrough of any given subsidy to consumers in order to appropriately account for consumer and producer surplus. Second, beyond obtaining reliable passthrough estimates, there is also the concern over inframarginal participation (i.e. those consumers who would have adopted an E-bike even in the absence of a subsidy, see Joskow and Marron (1992)).[1] Third, this difference also raises the issue of whether a family that buys an E-bike will necessarily cut down their driving.

To address these issues, we combine administrative, insurance and survey data from a large scale Swedish E-bike subsidy program in 2018. The Swedish subsidy program is similar in structure to programs run and proposed in other countries around the world and the choice of E-bikes ought to have commonalities across dense urban areas. Hence,

[1] Credible estimates of infrarmarginal participation obtained in the adoption of home solar energy programs using various techniques point to sizeable but a wide range of estimates (Boomhower and Davis (2014), Ito (2015)). These estimates may not port over to E-bikes since the goods are quite different — an E-bike does necessarily replace the family car.

our findings are likely to be extrapolable to other settings.

The 1 billion Kronas program was intended to last for three years but exceeded its per year spending limit already during its first year (October 2017 to October 2018). With a cost of 425 million Kronas, it was suspended in 2018 and was not subsequently renewed after a change in political leadership following elections. We obtain from the Swedish Environmental Protection Agency (SEPA) all the E-bike transactions in Sweden that received a subsidy. The subsidy was for 25% of the retail price with a limit of 10,000 Kronas (or around $1,100). The SEPA data has the transaction price, the subsidy amount, the model, and the retailer. There is also basic demographic information about the customers such as income, gender, age, martial status, education and zip-code of residence.

We merge the subsidy data with sales data from Solid, the leading insurance provider for bicycles in Sweden. Solid offers insurance at the point of sale of new bikes, covering approximately 90% of the specialized bicycle dealers.[2] Around 50% of all new bikes sold in Sweden are registered with Solid and we find that 76% of all subsidized E-bikes were sold by retailers in the Solid sample. Hence Solid and the SEPA data allows us to create a panel of transactions by customer i at retailer j at time t, for before, during and after the subsidy program.

The subsidy program coincided with a temporary surge in purchase of E-bikes. Aggregate data suggest that total E-bike sales grew from around 67,000 to 103,000 in annual terms between 2017 and 2018. The number of E-bikes insured by Solid also increased by around 70% year-on-year to 47 thousand registered new E-bikes in the subsidy period. We can use a subset of this panel data to estimate the passthrough rates.

We then use data from a follow-up survey conducted by the SEPA of several thousand representative households that used the subsidy. We use their responses to the survey question of whether the subsidy was important for their purchase decision to assess the inframarginality issue. We then use their self-reported usage of their family car pre and post the purchase of their E-bike to assess the environmental impact of the E-bike subsidy.

In the first part of our paper, we estimate passthrough by regressing the transaction

[2] Most bicycles receive a free three-month insurance policy from Solid which is renewable at expiration.

price net of the subsidy on the subsidy attached to that transaction (following Busse, Knittel, Silva-Risso, and Zettelmeyer (2012) Busse, Silva-Risso, and Zettelmeyer (2006)). We estimate this panel regression using E-bike model, retailer, county and time fixed effects. If there is complete passthrough to the consumer, then the slope coefficient of this regression is 1. If there is no passthrough to the consumer, then the slope coefficient is zero. Pooling together all retailers, we estimate a passthrough of 0.99, i.e. consumers receive the bulk of the subsidy.

Second, we find using the follow-up survey data that around one-third of households did not list the subsidy as an important reason for their purchase. This incidence sensibly increases to over 53% for households in the highest income bracket of two million Kronas ($225k) and decreases to 28% for those younger than 35. In regressions where we control for all demographics, we find that subsidy importance decreases with income, age and among women living in Green Party strongholds. Notably, we find the importance of the subsidy to be unrelated to stated commuting distance to work.

Third, we find using the same survey data meaningful changes in car driving behavior. Almost two-thirds of our sample report using a car to some extent for commuting before buying an E-bike and more than half of them use it on a daily basis. After having bought the bike, only 4% keep using the car every day, 54% use the car less frequently of which 23% stop using the car for commuting altogether compared to before the purchase. The change in commuting behavior by car is more pronounced than for other means of transportation, such as regular biking or public transport.

The change of car use can be translated to kilometers through commuting distance. On average, we estimate that car drivers reduce driving by 1,870 kilometers per year, reducing carbon emissions by around 260 kilos (140 grams per kilometer). Since the policy targets also people not driving cars, the reduction falls to 177 kilos per year if everyone is included. The average subsidy paid is around $494 and is very similar across groups of car drivers and others. But the program also covers non-additional consumers who would have bought an E-bike even without the subsidy. Adding the cost of the program to the estimated 64% additional consumers, the cost per bike rises to $766. Simple back-of-the-envelope calculations pricing a ton of carbon shows that it will take a carbon emission price of $600 to recoup the cost of the subsidy. If the policy would have been able to target only car commuters, this number falls to below $400 considering the full cost of the program. The social cost of carbon is typically calculated to be around $50 to $100 (Nordhaus (2017)).

Our paper provides a holistic framework to evaluate subsidy programs to replace personal transportation. The previous literature primarily research behavior and substitution, such as Hendriksen et al. (2008) and Winslott and Åse Svensson (2017) with the main objective to acquire more information on who buys E-bikes, how they are used, and what modes of transport they replace. A second literature, as for example McQueen, MacArthur, and Cherry (2020) and Fyhri, Sundfør, and Weber (2016), targets the emission reductions and how to calculate savings by replacing (mainly) cars by E-bikes. Our study combines these literatures in that we are able to tie administrative data, sales data and survey data with the main objective to evaluate the combined outcome of the policy.

2 Data

First we describe the subsidy in Sweden and how it relates to other subsidy programs in the world. Then we report on the E-bike data we obtain from the Swedish EPA and Solid. And finally, we outline the survey which covers a subsample of the subsidy data.

2.1 The Swedish E-bike Subsidy

On September 20, 2017, the Swedish government announced a scheme to increase green transportation through a subsidy of E-bikes. The aim of the subsidy was to improve conditions for climate-smart transportation and to contribute to improved public health. The program was formally in place on February 1 of 2018 but allowed consumers to retroactively apply for the subsidy from the date of announcement. The Swedish government's original plan, to be implemented by SEPA, was to spend approximately one billion Krona ($113 million) on E-bike subsidies over a three year period from 2018 to 2020. According to the scheme, an E-bike consumer could get a subsidy of 25 percent of the purchasing price with an upper limit of 10,000 Kronas, corresponding to around $1,100.

To claim the subsidy, individuals were acquired to fill out a detailed form online or by regular mail. In addition to personal details, the form included information on bike and model as well as the retailer selling the bike and the receipt of purchase. The claimants were required to be at least 18 years of age, and restricted to only one purchase. The program covered only new pedelecs and excluded smaller electrical vehicles e.g. hoverboards, scooters and Segways, but did include bigger ones, such as quadri-cycles and cargo bikes provided that they fulfilled the European Electrically Powered Assisted Cycles (EPAC) standard.

Due to exceptionally high demand, the money budgeted for 2018 did not last the entire year. The pace at which people wanted to claim the subsidy was deemed unsustainable given the allocated resources. In July 2018, 45 million Kronas was added. And in September 2018, an additional 40 million Kronas intended for the 2019 subsidy program were moved to the 2018 program. On October 18 in 2018, the program was ended prematurely due to its popularity after having used a total of 425 million Kronas ($48 million). Any E-bikes sold after this date were no longer eligible to receive the subsidy.

The subsidy was not extended. The elections in the fall of 2018 gave no stable parliament majority. The center-right opposition was skeptical of the subsidy program—viewing it as inefficient use of tax money. The Red-Green government proposed to continue the program in 2019. The result of the post-election negotiations was that the Red-Green government remained in place, but an opposition budget for 2019 passed in parliament with a budget that did not include funds for a continuation of the E-bike subsidy program.

2.2 *Similarity to E-bike Subsidies Around the World*

According to the European Cyclists' Federation (ECF), there are more than 300 tax-incentive and purchase-premium schemes for cycling across Europe offered by national, regional and local authorities in place at the end of 2021 to make it attractive to cycle more and drive less. While many incentives in Europe were already introduced in the last decade, the number of schemes has increased significantly since 2019. In the US, there is a recent E-bike bill (H.R. 1019: "Electric Bicycle Incentive Kickstart for the Environment") that aims to introduce a 30% tax credit for E-bike purchases, but there are already many regional incentives in place across the country. In Germany, the Green Party proposes to promote the purchase of cargo bicycles with subsidies totalling up to one billion Euros in the next legislative period.

Table I provides a sample overview over the more well-known E-bike incentive programs that are or have recently been in place in North America and Europe.[3] We note three things when relating the Swedish program to other existing subsidies.

Table I here

First, a capped discount targeted directly towards consumers, like in Sweden, is according to our investigation by far the most popular type of intervention, followed by tax credits and flat rates that sometimes are also combined with scrapping a fossil fuel vehicle (known as "Cash-for-Clunkers" programs, Mian and Sufi (2012)). To the extent other programs in the world are similar in structure, we believe that our results should be tranportable.

Second, the size of Sweden's program is substantial in comparison with others that are currently in place. But there are even larger programs going forward. The €1 billion program proposed by the Green Party in Germany and the $4.1 billion E-BIKE bill in the US shows that subsidies of E-bikes are likely not only here to stay, but become part of general policies to steer households towards green transportation.

[3]See for instance McQueen, MacArthur, and Cherry (2019) and Newson and Sloman (2019) for earlier overviews. The European Cyclists' Federation offer a website with an overview of the European programs available at https://ecf.com/resources/financial-incentives.

Finally, the available documentation surrounding the conditions and uptake of the international programs is sparse, making it difficult to evaluate them. With more detailed data at hand, this paper aims to fill this gap.

2.3 E-Bike Subsidy Data

We obtain the subsidy data from SEPA containing 96,869 observations from which we classify 89,042 as regular pedelecs or E-bikes.[4] The subsidy data includes detailed information of all bikes, individuals and retailers that received the subsidy. Specifically, the subsidy data includes detailed demographics for receivers of the subsidy on zip code, age, income, education, marital status and gender. The data for the retailers includes the corporate identity number as well as location. Of the 1,578 retailers in sample, about one-third only sold one E-bike and the top 85 retailers selling more than 200 E-bikes accounts for two-thirds of the total volume. Finally, the bike data includes name, model and purchase price along with the subsidy paid out. Although the SEPA data is detailed and accurate, we have no observations outside of the subsidy.

2.4 Solid Insurance Data

In order to obtain estimates of pass-through, we need detailed data from outside the subsidy period. The Swedish Cycle Association (a trade organization) reports only aggregated data year-on-year defined from September to August, but shows a clear increase for the period of the subsidy. For the year 2016/2017 sales were 67,000 growing to 103,000 for the 2017/2018 period. This aggregation is based on data from importers for which there is no way to identify individual E-bike transactions, and the measured time period does not exactly coincide with the subsidy period.

Instead, our second E-bike data source comes from the insurance company Solid. An important business of Solid is to co-insure bikes. Even though all home insurance poli-

[4] We delete 7,827 transactions that were paid out for light mopeds, electric wheelchairs and other light electric vehicles, including some 800 E-bikes purchased abroad.

cies in Sweden also cover bikes, they are normally capped and come with substantial deductibles. Solid offers additional coverage for every new bike sold in its network of retailers, which customers can choose to extend after three months. The insurance policies are offered at purchase of new bikes through a network of bike retailers. Solid's customers include all major retailers specializing in bikes, and an estimated 50% of all bikes sold in Sweden are sold with a Solid insurance. When comparing retailers across the Solid data versus the SEPA data, retailers not attached to Solid are typically larger retailers who do not specialize in bikes (such as department stores and online-only retailers).

From Solid, we obtain bike brand, model and price, but also age, gender and zip-code by the insured, as well as corporate identity number and location of the retailer selling the bike; hence making it possible to merge the two data sets. The Solid data is of high quality with respect to brand, date, retailer and zip-code (due to standardized fields), but is of lower quality with respect to price and model which is sometimes missing, insufficient or unreasonable. The full data set consists of almost 695,587 new bicycle purchases for the time period January 2017 to October 2019. From this data, we identify 91,506 E-bikes that we then seek to find which ones received a subsidy from the SEPA data where we find that 76% of all subsidized E-bikes were sold by stores affiliated with Solid.

2.5 Matching SEPA Subsidy to Solid Data

The solid sample contains 695,587 new insured bikes from January 2017 through October 2019. From this sample, we find 91,506 E-bikes on record.[5]

Among the insured 91,506 E-bikes, there are 47,382 transactions during the subsidy period of October 2017 to October 2018 (or 3,613 E-bikes per month), compared to 17,896 transactions before the subsidy period from January to September 2017 (or 2,084 E-bikes per month) and 26,228 transactions after the subsidy period from November 2018 to October 2019 (or 2,135 E-bikes per month). That is, monthly transactions during the subsidy period is around 1.7 times higher than those outside the subsidy period.

[5]Table OA.I provides an overview of the procedure through which we match SEPA subsidy data to Solid E-bike transactions.

Since price and model is sometimes missing in the Solid data set we match the SEPA subsidy to Solid by dealer, brand, gender, year of birth and month of purchase. During the full subsidy period, we are able to match 29,794 transactions to subsidy information, or roughly 63% of the transactions. In other words, around 37% of the E-bikes sold during the subsidy period did not receive a subsidy. There are two main reasons for this. One is that customers who bought the bike did not submit or properly fill out the paper work required to receive the subsidy. Customers had to send a form to SEPA including the receipt of purchase. The second is data entry error either on the part of Solid or SEPA that prevent a match.

To address the latter data entry issue, we apply a series of screens to our sample. First, we delete observations with missing prices or model names. This brings our overall E-bike sample from 91,506 to 73,795 transactions. In the second step, we remove observations with extreme prices by trimming the tails of the price distribution at 2%, which gives us 68,149 observations.

Third, in order to be able to estimate the pass-through model, we require bike brand models to be sold throughout the full sample period. We also require there be a sufficient amount of bikes sold by each retailer for the estimation to handle fixed effects for both models and retailers. We initially identified 40 top selling bike models that were sold throughout the period for which we selected the top 50 retailers. One retailer only sold two retail-branded models, so we dropped the retailer and models from the sample.

The final regression sample contains 20,586 E-bikes consisting of 38 models sold by 49 retailers during 2017 to 2019. We find that 49 retailers sold 55% of the total 38 top-model volume. Over time, 3,788 E-bikes were sold before, 10,576 were sold during, and 6,222 were sold after the subsidy was in place. Of the 10,576 E-bikes sold during the subsidy period, 7,914 E-bikes are matched to the EPA subsidy data, corresponding to 75% of all bikes during the subsidy period. We are relatively confident now that the remaining 25% of the E-bikes that did not receive a subsidy in the subsidy period is likely due to the customer not following SEPA procedures to claim their subsidy, chose not to do so or did not qualify. This could be for various reasons of which we can only speculate: purchase of a second E-bike or purchase on behalf of someone else, the customer is under the age of 18, a failing to meet the filing procedure of sending in the original receipt, preferences or ignorance.

Figure 1 presents the matched retailer-model data for the same time period in which we highlight the subsidy period in darker color. It provides a graphical representation of the E-bikes sold over time. We also trace out the average price for bikes, in which we hold model and retailer constant throughout. Although the average price of the E-bikes have been rising from 23,000 Kronas ($2,600) to almost 25,000 Kronas ($2,800) at the end of the period, there is no sign of a sharp increase in prices as the subsidy was introduced. As E-bikes are mainly produced in China, and are subject to exchange rate conditions, we also plot the average Krona/$ exchange rate in Figure 1, which indicates that some of the price increase can be due to a weakening of the currency.

Figure 1 here

2.6 Survey Data

SEPA commissioned a research report, in which they invited a representative sample of 10,500 people from the subsidy-takers to take an online survey in March 2019. The survey contains questions about motives to buy the E-bike, commuting distance and means of transportation before and after the E-bike purchase. Around 3,500 people answered the question about how important the subsidy was for their decision to buy an E-bike on the survey, but fewer answered the questions about of how travel behavior had changed. Details about sampling and survey instrument can be found in the report Naturvårdsverket (2019). The survey data helps us identify additional consumers as well as reductions in car use.[6]

[6]The technical report from Statistics Sweden documents that the survey sample is representative of the full subsidy sample. Appendix Table OA.III also shows that survey household demographics are very similar to the full sample.

3 Pass-through Estimates

Following Busse, Knittel, Silva-Risso, and Zettelmeyer (2012) and Busse, Silva-Risso, and Zettelmeyer (2006), we estimate a pass-through regression using E-bike model, retailer, county and time fixed effects.

Let $Subsidy_{i,j,t}$ be the size of the subsidy that consumer i received on her E-bike j purchase at time t. $P_{i,j,r,t}$ be the price that consumer i pays for E-bike j from retailed r at time t net of the $Subsidy_{i,j,t}$. The passthrough regression is then given by:

$$P_{i,j,r,t} = \beta_0 + \beta_1 Subsidy_{i,j,t} + \beta_2 CustomerDemo_i + \beta_3 Krona/\$ + \delta_j + \kappa_r + \nu_t + \epsilon_{i,j,r,t} \quad (1)$$

$CustomerDemo_i$ is customer demographics including age and gender. Krona/$ is the Kronor per US dollar exchange rate to capture pricing effects associated with changes in exchange rates since the E-bikes are imported into Sweden. δ_j is E-bike brand and model fixed effect. Retailer fixed effects is denoted κ_r and ν_t is month times year fixed effects. The coefficient of interest is β_1. The null hypothesis of a full pass through of the subsidy to consumers means that $\beta_1 = -1$. If there is incomplete passthrough, then we expect a coefficient to be negative but smaller in absolute value than 1. That is, retailers are raising their prices for transactions where customers received a subsidy and not raising their prices where customers do not receive a subsidy.

The regression results are presented in Table II. In the first column, we report the results with just model fixed effects, which control for the impact of quality differences in E-bikes sold. We see that the coefficient of interest is -1.021 and highly statistically significant. It cannot be rejected from the null of complete pass-though ($\beta_1 = -1$). The p-value from a t-test that it differs from -1 is only moderately significant at 0.067. Customer demographics to age and gender have no statistical significance in this regression since they are mostly related to bike brand and model.

Table II here

But the coefficient on Krona/$ is significantly positive. The coefficient of 946 means that a one Krona depreciation against the dollar means almost a 1,000 Kronor higher average price for E-bikes. This coefficient is capturing the fact that the Krona is weakening over this sample period, which makes imports more expensive. Hence retailers passthrough some of those costs to consumers (Goldberg and Hellerstein (2008), Nakamura (2008), Nakamura and Zerom (2010)). This can be seen in Figure 1, where we plot the average E-bike price using the black line. The lower and upper 95 percent confidence bounds are also reported. The Krona/$ time series is reported in the dotted line. One can see that there is trend increase in the average price. The USD relative to the Krona is also increasing starting in January 2018.

In column (2), we add time fixed effects instead of Krona/$ to capture exchange rate effects and also introduce retailer fixed effects. Our coefficient of interest is little changed as it decreases from -1.021 to -0.993. This -0.993 coefficient is also highly statistically significant but does not differ from the null hypothesis ($\beta_1 = -1$) with a p-value of 0.436. However, the retailer fixed effects are highly significant, consistent with the importance of retailer pricing or marketing heterogeneity in the context of E-bikes (Pless and van Benthem (2019)). In column (3), we also introduce county FE to account for the influence of geographical heterogeneity on passthrough estimates. But the coefficient of interest is little changed moving from column (2) to column (3).

Our complete passthrough estimates are consistent with a spike in sales during subsidy period observed from the Figure 1, with the bars capturing the number of matched E-bikes sold each month. Recall that there were 10,576 E-bikes sold during the subsidy period (or 755 E-bikes per month) in our model/retailer restricted sample compared to 3,788 before the subsidy (or 420 E-bikes per month) and 6,222 after the subsidy (or 622 E-bikes per month). So, the marked increase in the sale of E-bikes during the subsidy period is consistent with the complete passthrough of the subsidy. Moreover, it is interesting to note that E-bike sales after the subsidy were still higher than pre-subsidy levels. This might be due to indirect effects of the subsidy in spurring household adoption. We leave this conjecture for future investigation.

4 Additionality

While the complete passthrough estimate and the large quantity movements are a necessary condition for significant welfare effects from the subsidy, they are far from sufficient due to the issue of inframarginality. Of the sizeable uptick in sales, what fraction of them would have occurred even absent the subsidy? This is a difficult question to answer since it is a counterfactual. Fortunately, we have follow-up survey data from SEPA that can address this issue.

We specifically hone in on the question "How important was the subsidy for your decision to buy the electric bike?". Possible answers are graded on a five-point scale ranging from "Not important at all" to "Crucially important". A salient feature of the survey is the heterogeneity in these responses. There were 3,499 responses to the survey which is summarized in the appendix Table OA.III. About 61% find the subsidy to be important (corresponding to those responding with 4 or 5). 16% responded that it was not important for their purchase (those with 1 or 2). 23% of the people said it was somewhat important (those who answered with 3). Six people responded that they did not know. A conservative estimate of this additionality fraction is then 61% (grouping answers of 4 and 5).

In Table III, we regress these responses on the demographics of those in the survey and show that the responses of 1 to 5 line up in intuitive ways with demographics. The survey demographics are more detailed. We have seven demographic features including age, gender, having kids, marital status, the Green Party election outcome in the municipality in which the respondent live, whether the respondent has a university degree and whether the household lived in an urban area (defined by Sweden's three main city regions Stockholm, Gothenburg and Malmö). In Table III, we relate the importance answer (1 through 5) on these demographic attributes using an OLS regression.

In column (1), log family income is negative correlated with the importance answer. The coefficient of -0.104 is highly statistically significant. Increasing family income by 10% reduces the importance of the subsidy by almost 1%. In column (2), both log family income and age are negatively correlated with the importance answer. The coefficient on log family income hardly moves. Hence, there seems to be independent explanatory power for age above and beyond income for inframarginality.

In column (3), we introduce two additional demographic features of gender and having children. Females are less likely to find the subsidy being important for their purchase. In column (4), we add in university education which is has no explanatory power. Living in an Urban area similarly had no effect in column (5). In column (6), we find that Green party voters are more likely to be inframarginal. Finally, in column (7) we add the reported daily commuting distance for which we have 2,578 responses. We find no relation between how important the subsidy is for purchase and the reported round-trip commuting distance. The other parameters are virtually unchanged.

5 Substitution Away from Other Means of Transportation

We next turn to two additional survey questions that will allow us to pin down the impact of the purchase of an E-bike on the reduction in kilometers driven by adopters. Of the 3,499 households that took the survey, 2,578 reported daily commuting distance and 1,873 also reported their means of transportation (car, public transportation or regular bicycle)—separately for winter and summer before and after the purchase of the E-bike.[7]

When we compare the smaller pool of subjects who responded to the more detailed commuting questions with the full survey sample we find them to be similar.[8] 61% of households reported that the subsidy was important for their purchase in the full sample. This rises to 64% in the smaller sample of the 1,873 who answered the questions about means of transportation. The distribution for this subset of households is similar to the larger set of households who participated in the survey. We also consider an even smaller subset of households who reported they used cars for their commute before the subsidy. There are 1,166 such respondents. Interestingly, around 67% of these respondents said the

[7] The relatively extensive amount of information that was to be provided likely contributed to the lower response rate for these items of the survey.

[8] A detailed summary is provided in the appendix Table OA.III.

subsidy was important for their purchase, slightly more than in the first two instances. Overall, we conclude that our non-additionality estimates conditioning on the sample of households who report their transportation usage are not so different from our earlier estimates using all survey respondents — anywhere from 61% to 67% are additional, or equivalently nearly 39% to 33% are non-additional.

Figure OA.I reports the change in the means of transportation used for the 1,873 respondents. The respondents were asked to provide estimates for summer as well as winter, but we only present the results for summer here. We first consider use of car. Before the E-bike purchase, the mean days of car use is 2.57 days, where 37% never use car for commuting, 29% less than weekly and 34% weekly (at least five days per week). After the E-bike purchase, it is 0.88 days, a near 70% decline in car use days. Whereas 34% of respondents used the car weekly before the E-bike purchase, only 5% use the car weekly after the purchase of the E-bike.

Interestingly, there are also changes in public transport behavior. Before the E-bike purchase, households had 1.10 days in which they used a public transport. After the E-bike purchase, it is only 0.29. Indeed, whereas 12% of households used public transport weekly before their E-bike purchase, only 1% use it weekly after their purchase. Similarly, there is also substitution away from regular bicycles. Households reported 1.71 days in which they used a regular bicycle and this shrank to 0.67 days after their E-bike purchase.

To sum up, we find that around 36% of E-bike consumers are non-additional in the transportation sample of 1,873 respondents. Among the 64% classified as additional, around 23% never use a car which means that the subsidy only reaches 41% additional users who are also car drivers.[9]

6 Cost-and-Benefit Analysis

Finally, we use our above analyses to conduct a cost-and-benefit analysis of a dollar's worth of E-bike subsidy. For our cost-and-benefit analysis, we focus on the benefits ob-

[9] Appendix Figure OA.II provides a graphical illustration of these overall results.

tained from reducing car use and the saving in carbon emissions as a result. We do not consider potential emissions savings from public transportation since this is considered second order compared to car use.[10] Moreover, our estimate of a complete passthrough means we do not need to consider producer surplus in our welfare analysis, since all of it went to the consumer. We can simply focus on how a dollar of subsidy changed consumer behavior in terms of reduction in car kilometer usage. Second, our additionality estimate that around 66% of households can then be used to shrink the benefits of the program since around 34% of households would have bought an E-bike even absent the subsidy. We estimate the per unit cost of the subsidy and compare that to the additional reductions in carbon emissions.

Table IV here

In Panel A of Table IV, we begin by reporting the subsidy cost per bike for the full sample, and then calculate the per unit cost given that 34% of sales are classified as non-additional. The first row shows that the average subsidy cost is $494 and the median $471. The maximum subsidy is capped at 10,000 Kronas, equivalent to $1,126. The row below shows the cost for additional users and is calculated by using the received subsidy plus the average cost of the 34% non-additional consumers. This raises the average per unit cost to $766 with a median cost of $742 and a maximum cost for each additional user of $1,398. We use this per unit cost estimate in our analysis.

Next, we turn to the benefits. The upper part of Panel B of Table IV reports the commuting distance reductions for car use. The weekly reduction in car use scaled to kilometers per year.[11] On average, people reduce driving by 1,444 (844) kilometers per year during summer (winter) time. When we average mean yearly reduction for each individual it is 1,146 kilometers, with a median of 414 kilometers. The 25th and 75th percentile

[10]The SEPA reports that the 2018 total carbon emissions from all means of transportation in Sweden was 17 million tons in total of which cars were responsible for 10 million tons—twice to the amount of trucks (https://www.naturvardsverket.se/data-och-statistik/klimat/vaxthusgaser-utslapp-fran-inrikes-transporter/ accessed on December 9, 2021).

[11]The responses are converted by multiplying commuting days and commuting distance assuming 46 working weeks per year.

is 0 and 414 kilometers, which can be explained by the fact that we find that 38% of the respondents never use a car before the purchase (see the plots in Figure OA.I). The maximum reduction of 19,320 kilometers highlights the skewness of the distribution, and translates to 420 kilometers per week.[12] We find only small differences when we restrict the sample to additional users only: 1,262 kilometers per year compared to 1,146 for the full sample. The fraction of car-users within the additionality sample is almost identical (36%) to the full sample (37%), but shows that the subsidy effectively only targets 42% of the users who are both additional and car-users.

The bottom rows of Panel B in Table IV reports the implied greenhouse gas emissions reduction in CO_2 kilograms per E-bike by converting the reduced distance in Panel A combined with assumptions of the life time of the E-bike and emissions associated with both producing and using the bike. First, we convert saved car driving distances using the Swedish Transport Administration's estimate of 0.14 kilos of CO_2 per kilometer based on the 2017 fleet of vehicles and driving patterns.[13] The average 1,262 kilometers of reduced driving per year translates to reduced carbon emissions of 176.7 kilograms.

To construct a per unit net reduction estimate, we make assumptions of an E-bikes life as well as emissions associated with producing and using the E-bike. We discuss how these assumptions change our analysis at the end of this section. The European Cyclist's Federation (Blondel, Mispelon, and Ferguson (2011)) estimates the life-span of an E-bike to eight years and 19,200 kilometers. The manufacturing of an E-bike produces 130 kilograms of carbon emissions of which the battery emits 34 kilograms. These emissions are calculated for a steel frame, but can be both much higher (if aluminium is used) or lower if the frame is made of carbon. To arrive at a comparable distance measure, they combine production emissions and life-cycle estimates (7 grams) with an additional 9 grams of energy consumption and 6 grams per kilometer for additional calories needed for biking to arrive at at total carbon emission of 22 grams per kilometer. Since Sweden has a

[12]The average is however not sensitive for winsorizing around reported extreme values.

[13]The 2017 average emission estimate provided by Trafikverket (2019) is likely an upper bound. Car emissions are decreasing due to better fuel efficiency and a higher adoption of electric cars. According to the same report, emissions dropped by 7% to 0.13kg/km in 2020.

cleaner energy mix compared to other countries and battery efficiency has become better, we use an online energy and emission calculator provided by one of the larger producers of E-bike batteries, Bosch. Using an estimate of an effective energy need of 5.9 watts per hour (Wh) per kilometer and 0.125 kilograms of carbon emissions per KWh, we arrive at a much more modest estimated 0.74 grams of CO_2-emission per kilometer. Combining the same emissions for production over the life-cycle (7 grams), additional emissions from driving (6 grams) with one gram of emissions related to electricity generation, the distance emission estimate we use is 14 grams per kilometer over the life-span of an E-bike.[14] When we apply our estimated emissions of E-bikes to our sample, we need to account for those who receives the subsidy without reducing their driving. We therefore split emissions into variable (consumed energy) and fixed manufacturing emissions.

The last row in Panel B in Table IV presents the net savings over the entire life of an E-bike after reducing saved emissions from driving in the additionality sample. The average total carbon reduction amounts to 1,273 kilograms after deducting carbon emissions of the E-bike. The first quintile is a negative 130 kilos due to production emissions with no reduction in mileage, and the median is 485 kilos. Under our assumptions, E-bike emissions reduce total GHG savings from driving by less than 10% on average, which in turn implies that the calculations are relatively insensitive to assumptions about fuel and production of E-bikes. The bulk of the emission reductions come from reduced driving, making the net reduction estimate sensitive to the composition of the car fleet. With an increased conversion to hybrid and electrical cars, our estimates should be viewed as an upper bound of life-cycle reductions.

Finally, in Panel C of Table IV, we price the emissions reductions using different assumptions of the social cost of carbon. We consider emission savings based on a carbon dioxide price ranging from $100 to $700 per ton. For this calculation, we take the total carbon reduction from Panel B of Table IV and multiply by the assumed carbon cost. At $600, the subsidy program breaks even in the sense that the subsidy cost of $766 in Panel

[14]Our lower estimate is consistent with that of Bosch who refer to the German , see https://www.bosch-ebike.com/us/service/sustainability. Our model would imply a per kilometer emission of 14.6 grams for the UK and 15.6 grams for the US corresponding to CO_2/Kwh electricity emissions of 0.256 and 0.429 kilos.

A is comparable to the carbon emissions savings of $764 in Panel C. We repeat this exercise for two subsamples: those who live outside the three main city areas of Sweden ("rural") and for car users only. We find little differences in geography. If subsidies could have been targeted to car users only, the subsidy would break even at around a carbon emission cost of just below $400 instead of $600.

The lower part of Panel C of Table IV we present the fraction of E-bikes that are profitable in that the benefits exceeds the costs. At a carbon price of $100, less than 3% are profitable. At the calculated break-even price of $600, about one-third of the subsidies are profitable which again highlights how the combination of additionality and reduction of car use generate considerable skewness in the cost-benefit distribution.

The current social cost of carbon is generally estimated to be $50 to $100 dollars (Nordhaus (2017)) which warrants a discussion of our main assumptions. Driving distance and the life of an E-bike are two key variables to obtain the break-even social cost. If we keep the social cost of carbon fixed at $100 we can back out the life-span of an E-bike or saved car distance which puts the benefits in the same range as the costs. A $100 carbon cost requires an average car driving distance reduction of 7,600 kilometers per year or the subsidized E-bike to last for 48 years. We also exclude discounting in our calculations but this would only make the benefits smaller. Hence, our calculations suggest that these subsidy programs cannot be justified on the basis of the social cost of carbon alone.

7 Conclusion

E-bike subsidies are a popular government intervention around the world to foster the adoption of E-bikes as a substitute to cars so as to combat global warming. However, welfare analyses of these subsidy programs are challenging for several reasons, particularly surrounding the issue of additionality. We combine administrative, insurance and survey data from a large-scale Swedish subsidy program in 2018 so as to be able to conduct such an analysis. We find (1) complete pass through to consumers, (2) one-third of adopters are non-additional; and (3) a decline of around 1.3 tons of carbon during the life of the average E-bike. Using our estimates, the cost of carbon has to be $600 for the government to break even—well above all current conventional estimates for the social cost of carbon emissions.

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Table I: Subsidy Programs

This table reports a non-exhaustive list of E-bike subsidy programs across the world divided into programs on the national and regional level. We report type of subsidy, discount level, target of the discount, the maximium funding (if any) of the incentive, total earmarked funds (if any) of the whole program, number of participants and a short remark where applicable. The data of this table has been acquired from various online sources, including the European Cyclists' Federation (EFC). The Swedish program was planned for three years at a cost of $113 million, but ended prematurely in 2018 at an actual cost of $48 million.

Location	Type*	Discount	Target**	Max. funding	Tot. earmarked	Period	Participation	Remark
National programs								
Sweden	D	25%	C	$1,100	$48 mn	2017-2018	97,000	$113 mn planned 2017-2020
Austria	D	25%	B	€300	n/a	2016 -	n/a	Increased to €700 in 2021
Belgium	TC	€0.10/km	C	n/a	n/a	n/a	n/a	Mandatory employer contribution (max 40 km)
France	FR	€200	C	€1,000	n/a	2017 -	n/a	€1,000 for cargo bikes
Germany	D	n/a	C	€1,000	€1.0 bn	2021 (prop.)	est. 1,000,000	German Green Party cargo E-bike proposal
Italy	D	70%	C	€500	€125 mn	2020	n/a	E-bikes, E-scooters, sharing services
Luxembourg	D	50%	C	€600	n/a	2020-2022	n/a	One E-bike p.p.
Scotland	L/FR	n/a	C/B	$8,000	$1.2 mn	2018-	19 projects	Interest free loan for purchase, E-bike grant fund
United Kingdom	TC	25%-39%	B	n/a	n/a	2019-	n/a	Cycle scheme, 25%-39% tax break
United States	TC	30%	C	$1,500	$4.1 bn	2021 (prop.)	n/a	Proposed E-BIKE Act
Regional programs								
Paris, France	D	50%	C	€500	€12.0 mn	2020-	est. 10,000	Provided by Île-de- France Mobilités
Oslo, Norway	D	25%	C	$600-$1,200	$1.2 mn	2016-2020	1,000-2,000	E-bikes/Cargo bikes
Guernsey , UK	D	25%	C	$500	$130 k	2018	366	Retailer must finance 5% of 25%
Jersey, UK	D	$230/$200	C	n/a	$130 k	2016/2019	550	
British Columbia, CAN	FR	$850 (CAD)	C	$1,000 (CAD)	n/a	2019-	n/a	Mandatory car replacement
California State, US	D	n/a	C	n/a	$10 mn	2020-	Proposed	CalBike and California Air Resources Board
San Gabriel Valley, CA, US	D	n/a	C	$700	$70 k	2017	100	
Boulder County, CO, US	D	10% - 25%	C	n/a	n/a	2013-2018	439	
Austin, TX, US	D	25%	C/B	$300/$400	n/a	2019-	1,196	Austin Energy
Utah, US	D	10% - 20%	C	n/a	n/a	Sep-Nov	43	Commercial discounts
Munich, Germany	D	20%	C	€500	n/a	2021-2024	n/a	Cargo-bikes
Rome, Italy	D		C	€500	n/a	2020	est. 50,000	Bikes and e-scooters
Wallon Brabant, Belgium	D	20%	C	€200	n/a	2020-20222	n/a	
Vermont, US	FR	$200	C	$200	n/a	2018-	n/a	Four utilities offering discounts for E-bikes >$500

*) Type of subsidy where (D) denotes discount proportional to price, (TC) tax credit, (FR) flat rate per unit, and (L) for government loans.
**) Target for subsidy where (C) denotes individual consumers and (B) denotes businesses.

Table II: Subsidy Pass-Through Regressions

This table reports OLS regressions where the dependent variable is purchase price net of subsidy. The independent variables are the value of the subsidy, age, gender and the Krona to US dollar exchange rate. Fixed effects include E-bike model and retailer. Time fixed-effects in columns (2)-(3) replaces the currency time-series with fixed effects on a month-year frequency. Column (3) includes fixed effects for the county in which the consumer lives. The sample includes 20,586 E-bikes sold from January 2017 to November 2019 in total where 7,914 E-bikes were sold during the subsidy period between September 20, 2017 to October 18, 2018. The two bottom rows display the rejection probability for a t-test that the retailer indicator variables are jointly zero and the subsidy coefficient is different from -1. Standard errors are clustered on retailers.

	Price net of subsidy		
VARIABLES	(1)	(2)	(3)
Subsidy	-1.021***	-0.993***	-0.994***
	(0.011)	(0.008)	(0.008)
Age	-0.815	-0.341	-0.424
	(1.546)	(0.635)	(0.606)
Female	18.722	13.477	13.850
	(20.826)	(14.237)	(14.365)
Krona/$	946.185***		
	(64.031)		
Constant	24,240.199***	23,081.882***	22,835.021***
	(346.211)	(516.237)	(536.280)
Observations	20,586	20,586	20,558
R-squared	0.905	0.934	0.934
Model FE	Yes	Yes	Yes
Time FE	No	Yes	Yes
Retailer FE	No	Yes	Yes
County FE	No	No	Yes
p-value Retailer FE = 0	-	0.001	0.001
p-value Subsidy = -1	0.067	0.436	0.483

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table III: The Importance of the Subsidy for Purchase

This table reports OLS regressions where the dependent variable is based on the question "How important was the subsidy for your decision to buy an E-bike?". Possible responses ranges from"Not important at all" (1) to "Crucially important" (5). There are $N = 3,499$ responses to this survey question: 253 in group 1; 321 in group 2; 799 in group 3; 1,191 in group 4; 929 in group 5; and 6 reported that they did not know. Independent variables include various demographics about households. Column (7) includes reported commuting distance based on 2,578 survey responses. Robust standard errors within parenthesis.

	"How important was the subsidy for your decision to buy an E-bike?"						
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log family income	-0.104***	-0.102***	-0.114***	-0.113***	-0.112***	-0.108***	-0.095**
	(0.033)	(0.033)	(0.035)	(0.035)	(0.035)	(0.035)	(0.041)
Age		-0.010***	-0.010***	-0.010***	-0.010***	-0.010***	-0.008***
		(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Women			-0.127***	-0.127***	-0.128***	-0.128***	-0.175***
			(0.040)	(0.040)	(0.040)	(0.040)	(0.046)
Children			0.072	0.072	0.071	0.075	0.062
			(0.048)	(0.048)	(0.048)	(0.048)	(0.052)
University				-0.003	0.000	0.013	0.016
				(0.043)	(0.043)	(0.043)	(0.050)
Urban					-0.043	0.024	-0.002
					(0.054)	(0.063)	(0.068)
Green votes						-0.020**	-0.021*
						(0.010)	(0.011)
Log distance							-0.010
							(0.024)
Constant	4.294***	4.827***	4.889***	4.889***	4.898***	4.973***	4.860***
	(0.207)	(0.213)	(0.215)	(0.215)	(0.216)	(0.218)	(0.243)
Observations	3,499	3,499	3,499	3,499	3,499	3,499	2,578
R-squared	0.003	0.018	0.022	0.022	0.022	0.023	0.019

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table IV: Cost-and-Benefit Analysis

This table presents the cost and benefit analysis of the Swedish E-bike program. Panel A reports the subsidy cost in USD for all and additional users, where additional users carry the cost for the non-additional. Panel A report the subsidy cost per unit sold, where the cost is based on additionality discussed in Section 4. The second row of Panel A reports the per unit cost for additional consumers who carry the cost for non-additonal units. Panel B reports the difference in weekly distance based on the number of days of commuting by car and commuting distance which is scaled to yearly distance. This calculation is made for assessments for summer and winter use separately assuming 46 working weeks per year. Average estimate is the mean of the two estimates across responses. The lower part of Panel B calculates the implied carbon savings per E-bike over the life-cycle by converting emissions from driving distance and combining them with emissions from E-bike use as described in Section 6. Panel C presents calculations of the benefit from saved emissions assuming a carbon price ranging from $100 to $600 per ton. The bottom rows report the fraction of users where the benefit exceeds subsidy under each carbon price assumption.

Panel A: Subsidy cost

	Subsidy per E-bike				
Subsidy per E-bike	Mean	25%	Median	75%	Max
All (N=1,873)	$494.3	$358.1	$470.6	$671.0	$1,126.1
Additional (N=1,204)	$766.4	$630.1	$742.7	$880.1	$1,398.2

Panel B: Car distance and CO_2 reduction

	Kilometers per year				
Car distance reduction	Mean	25%	Median	75%	Max
Summer (All)	1,444	0	368	4,140	38,640
Winter use (All)	847	0	0	1,104	12,880
Average use (All)	1,146	0	414	3,312	19,320
Average use (Additional)	1,262	0	552	1,840	19,320

	Total CO_2 kilograms				
Total CO_2 reduction	Mean	25%	Median	75%	Max
Per year CO_2 reduction conversion	176.7	0.0	77.2	257.6	2,704.8
Life-time savings per E-bike	1,273.1	-130.0	485.1	1,920.5	21,162.2

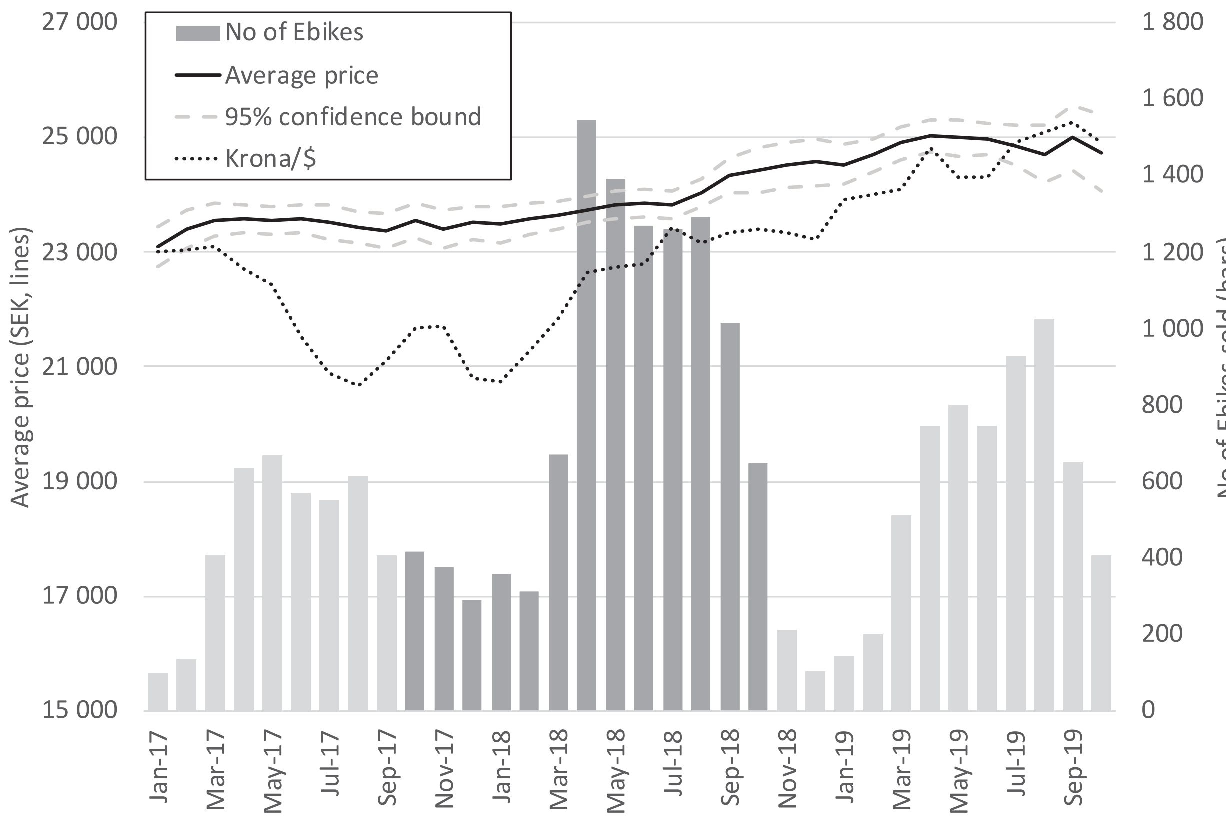
Panel C: CO_2 cost savings

	CO_2 cost/ton assumption				
Gross benefit per E-bike	$100	$250	$400	$500	$600
Additional	$127.3	$318.3	$509.2	$636.5	$763.8
Rural only	$140.6	$351.4	$562.2	$702.8	$843.3
Car users only	$201.1	$502.7	$804.3	$1,005.4	$1,206.5

Fraction of subsidies profitable	$100	$250	$400	$500	$600
Additional	2.7%	10.5%	19.3%	29.9 %	33.7%
Rural only	3.0%	11.3%	20.9%	32.6 %	36.4%
Car users only	4.0%	16.0%	29.7%	45.8 %	51.3%

Figure 1: Matched E-bikes: Purchases and Average Price

This figure displays the number of sold E-bikes of the top selling 38 models sold through the largest 49 retailers during the sample period. Dark grey shaded bars indicate the subsidy period October 2017 to October 2018 (right scale). The solid line displays average price which is recovered from the pass-through regression in Table II (left scale) along with a 95% confidence interval indicated by dashed lines. There are 20,586 observations in total during the time period January 2017 to October 2019. The dotted line shows the Krona per dollar exchange rate which is normalized with the average bike price in January 2017.



Online Appendices

Table OA.I: E-bike Sales and Subsidies

This table reports the number of E-bikes in the Solid insurance sample and the coverage in the subsidy data from the Swedish EPA (SEPA). The original sample consists of 695,587 insured bikes of which 91,506 are identified as E-bikes. The columns presents the number of insured E-bikes by time period: before the subsidy (9 months from January 2017 to September 2017); during the subsidy (13 months from October 2017 to October 2018), and after the subsidy (10 months November 2018 to October 2019). The two data sets are matched by considering purchases from the same retailer and insurance policies that correspond to subsidy data on zip-code, retailer, birth-year and brand. We use a subsample for the regressions to ensure that E-Bike models are sold in all the three sub-periods and that they are distributed among a sufficient number of retailers. The regression sample contains the most popular 38 models sold by 49 retailers with of 20,586 observations that overlap. The final row shows that 7,914 out of 10,576 E-bikes were sold with a subsidy in the Solid sample during the period it was in effect.

	Solid				**SEPA**
Sample (No. of months)	All (34)	Before (9)	During (13)	After (10)	During (13)
All bikes	695,587				
All E-bikes	91,506	17,896	47,382	26,228	29,794
Top models	37,155	7,233	19,495	10,427	14,655
Top retailers	20,586	3,788	10,576	6,222	7,914

Table OA.II: Survey Summary Statistics

This table reports summary statistics across characteristics for each response category for the question "How important was the subsidy for your decision to buy an E-bike?". Possible responses ranges from "Not important at all" (1: Low) to "Crucially important" (5: High). Six "Don't know" responses are excluded. The last two columns report the survey averages (Survey) and the full Swedish EPA subsidy sample (All).

	Importance of subsidy						
	Low				High		
	1	2	3	4	5	Survey	All
N	253	321	799	1,191	929	3,499	88,937
Family Income (KSEK)	912	641	662	632	601	651	652
Age	57	55	54	50	52	53	53
Women	0.51	0.51	0.48	0.45	0.45	0.47	0.48
Kids	0.26	0.25	0.31	0.41	0.33	0.34	0.31
Married/Partner	0.66	0.63	0.64	0.62	0.60	0.62	0.58
Green votes	4.96	4.72	4.89	5.15	4.66	4.91	4.58
University	0.52	0.55	0.58	0.66	0.53	0.59	0.49
Urban	0.12	0.15	0.16	0.17	0.14	0.15	0.13

Table OA.III: Survey Sample

This table reports the fraction survey responses to the question "How important was the subsidy for your decision to buy an E-bike?". Possible responses ranges from "Not important at all" (1) to "Crucially important" (5). Entries are fraction of responses in each category. The first row considers the full survey sample of 3,499 responses. The second row only the 1,873 responses that included the questions about means of transportation before and after the E-bike purchase, and the third row (among those) the 1,166 who reported using a car before their purchase of an E-bike.

		Subsidy importance (frequency)				
		Low				High
Sample	Responses	1	2	3	4	5
Survey	3,499	7%	9%	23%	34%	27%
Means of transport	1,873	6%	8%	21%	38%	26%
Car users before subsidy	1,166	5%	7%	21%	39%	28%

Figure OA.I: Means of Transportation Before and After the Subsidy

This figure displays the fraction of respondents indicating that they use car / public transportation / regular bike daily (five days per week or more), less than daily or never for commuting before versus after the purchase of an E-bike. The average number of days per week used by each means of transportation is printed in parenthesis at the bottom of the bars. All responses are for transportation during summer time only. There are 1,873 observations in sample.

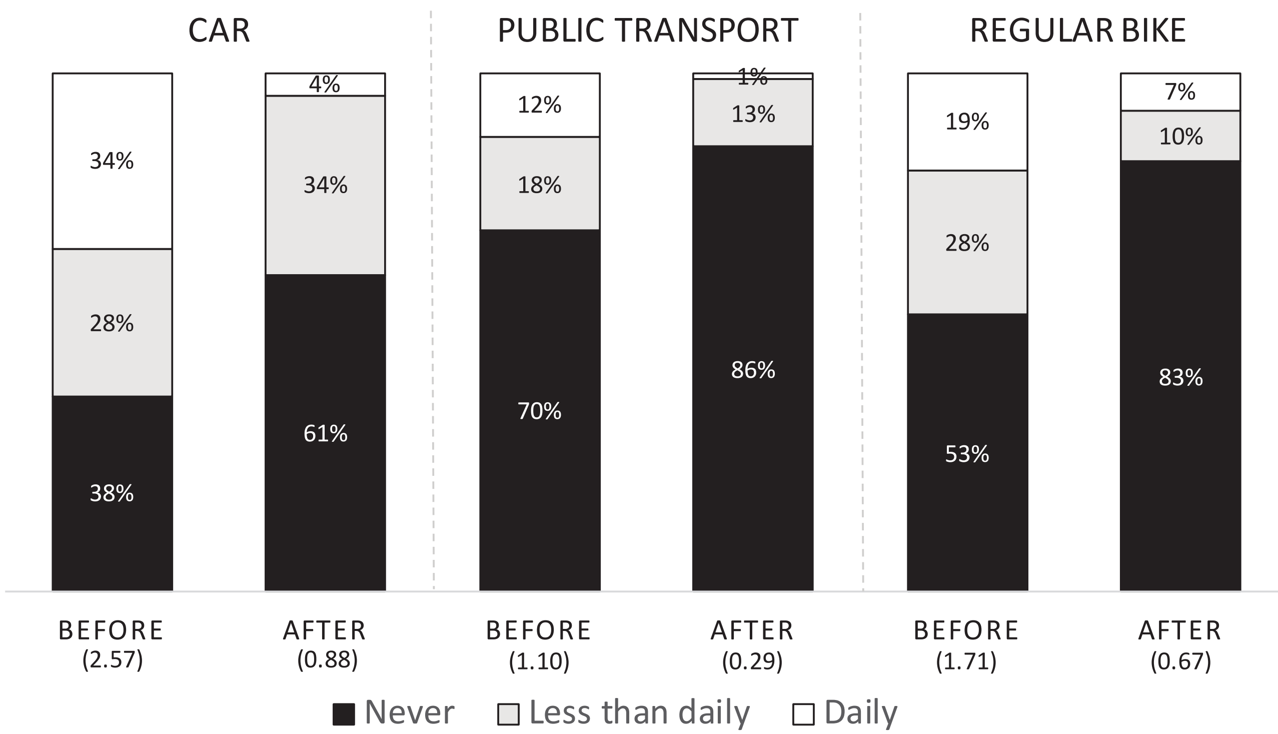


Figure OA.II: Additionality and Car Use

This figure displays the fraction of the 1,873 survey respondents classified as being non-additional (669 observations, 36% white area) or additional (1,204 observations). The 64% additional users are broken up into car-users (779) and non car-users (425).