To buy or not to buy? Vehicle demand and policy for sustainable transport.

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1. Objective and research question

The objective of this project is to investigate what policy instruments are appropriate in order to achieve a transition to zero emissions from private vehicles, paying particular attention to the best way to influence household choices regarding vehicle purchase.

At the household level, to achieve zero emissions the household must either stop driving altogether, or purchase an electric vehicle. In the project we investigate these two possibilities: in the first part we investigate the effect of subsidies to car ownership, and explore policy options; and in the second part the objective is to build a unified spatial urban-transport model that will help us understand the effect of alternative transport policies which aim to promote the use of electric vehicles.

Subsidies to car ownership. The surest way for an individual household to cut its emissions from private vehicles is not to use them at all, i.e. not to own a car. In Stockholm, Gothenburg and Malmö, around 33 percent of households do not own a car, and in other urban areas over 20 percent of households do not own a car (Izzo et al., 2015). Remarkably, these non-car-owning households are obliged to subsidize car owners in a number of ways, not limited to subsidies for electric cars. Most importantly, many of a household's most important purchases are 'bundled' together with free or highly subsidized parking. That is, when a household member takes the bus to their out-of-town shopping centre, the price of the goods they buy includes the cost of parking for all those who choose to drive. And when a household buys an apartment, the price includes most of the cost of parking for those who choose to own a car. Furthermore, when a household member drives to work, parking is frequently paid for by the employer, effectively a tax-free addition to the wage, enjoyed only by car owners. The result is that non-car owners involuntarily subsidize car owners to a very significant extent; for instance, according to Envall (2013) the parking subsidy to car owners in apartments can amount to around 50 percent of the cost, which may be up to 3000 SEK per month; this subsidy of up to 1500 SEK per month to car owners is paid for collectively by all the households in the apartment block. Against this background, in this part of the project we aim to:

1. Identify implicit subsidies to car owners, and quantify the size of the subsidy in each case;
2. Estimate the price elasticity of demand for car ownership, and combine this estimate with the estimate of the implicit subsidies in order to estimate the effect of removing the subsidies on car ownership and travel;
3. Investigate policy options to help remove or reduce implicit subsidies, and estimate the effects of these options on overall emissions in the transport sector.

Spatial patterns in adoption of electric vehicles. The second way to achieve zero emissions (at least at the point of use) is to buy an electric car. Indeed, substituting oil and using electricity as an energy vector for vehicles could ensure a broader use of renewable and carbon-free energy sources in the transport sector which would help achieve the EU targets on CO_2 emissions reduction. However, financial incentives given to electric car users are essential for reducing the purchase cost and total cost of ownership gap between electric and conventional vehicles. In particular, financial incentives are important in the current phase, since through increasing sales and technology learning, they could support cost reduction for batteries and other components in the future. EV incentives can take different forms, such as direct rebates or tax exemptions that could lead to differentiated taxation that favours low-emission vehicles and penalises the ones with high environmental costs. Since cities are suffering the most from air pollution, with urban air pollution from commuting being a major issue for a lot of countries, in this part of the proposal we will focus on traffic-induced pollution in the interior of big cities, by studying alternative policies that could promote the wider use of low-carbon vehicles. More specifically, we aim to:

1. Build a general spatial equilibrium model, inspired by existing models on transport and urban economics (see for instance Verhoef and Nijkamp, 2002; Kyriakopoulou and Xepapadeas, 2017; Habla and Kyriakopoulou, 2017) that will be suitable to deal with policy issues associated with pollution coming from different types of vehicles (polluting and clean ones).

2. Study policies that could lead to the full internalization of the social cost of carbon, as well as second-best policies that could promote the wider use of low-carbon vehicles.

3. Investigate the effects of these policy options and rank them based on their overall effect in urban pollution coming from the transport sector.

2. Current knowledge

This section presents a brief exposition on the issues of parking subsidies and adoption of electric vehicles.

2.1. Parking Regulations and Implicit Subsidies

2.1.1. Existing 'distortionary' regulations

In the introductory section above we mentioned three ways in which car drivers are effectively subsidized by non-drivers: free parking at shopping centres, subsidized parking in apartment blocks, and free parking at work. Here we briefly explain in what sense these regimes are distortionary, and what the existing literature says about the reasons for these policies, and their effects.

The effect of minimum parking requirements is that it creates distortions in the market for parking places as it results in the provision of parking places over and above the level derived from a market equilibrium. Additionally, the supply of parking places is financed through taxes and cross-levies on rents of residential and/or commercial buildings. Hence, the policy can best be described as an implicit subsidy for car owners. As argued by Shoup (1999), "...minimum parking requirements act like a fertility drug for cars" as the subsidy reduces the cost of owning a car thereby inducing demand for cars. Moreover, the policy has the tendency on reducing the housing stock and increasing the rental price of multi-family housing (Andersson et al., 2016; Litman, 2009).

Regarding the reasons and effects, we look first at free parking at work, where the key reference is Van Ommeren and Wentink (2012). According to Van Ommeren and Wentink, the primary motivation for employers to offer free parking is that it is a tax-free perk, hence it allows employers to deliver higher total benefits to their employees for a given expenditure; if the employer were to charge for parking and use the income to pay for higher wages, some of these wage payments would end up as tax payments to the government rather than with the employees. The policy solution is straightforward: the government should ensure that firms which provide subsidized parking pay tax on this perk.

Whether or not such a policy is worth implementing depends on the size of the distortions in the existing regime. Van Ommeren and Wentink estimate that in the Netherlands, the typical annual cost of a parking space is EUR 750. However, due to the tax distortion, employers provide parking spaces up the point at which the average annual *benefit* to employees is just EUR 375. The result is a deadweight loss corresponding to approximately 10 percent of the total costs of providing parking, or EUR 75 per parking space. See Figure 1.

Turning to cross-subsidization of parking for apartments (non-car-owners subsidize car owners), the reasons for this practice are less clear. The direct cause is obvious: minimum parking requirements. That is, local authorities impose requirements on builders to include

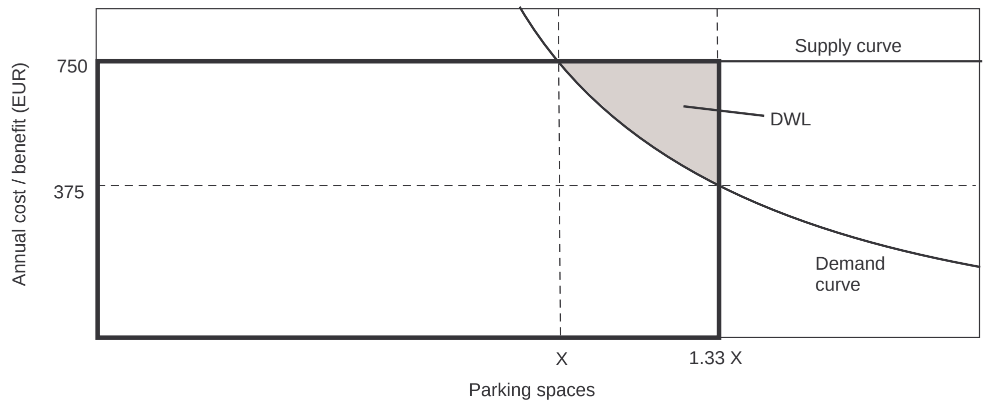

Figure 1: Deadweight losses due to oversupply of parking spaces, according to Van Ommeren and Wentink. The optimum supply of parking spaces would be X, with costs $750X$. In the distorted market total supply is $1.33X$, total costs $1000X$ (the area inside the bold rectangle), of which approximately $100X$ is deadweight loss (shaded).

some minimum number of parking spaces in apartment buildings. But why do local authorities impose these requirements? A reason commonly suggested in the literature is that it is because of a failure to price *other* forms of parking, such as on-street parking: when on-street parking is underpriced, residents will tend to cruise for on-street parking spaces, which causes external costs (see for instance Van Ommeren and Wentink, 2012). As Van Ommeren and Wentink point out, the obvious remedy to this problem is to correct the existing distortion (free on-street parking) rather than creating another one (cross-subsidized parking for apartments).

The minimum number of parking spaces stipulated is typically well above number at which markets would clear (corresponding to X in Figure 1), hence we again find that 'too many' parking spaces are built. However, now the effect is that the owner of the apartment block (for instance the housing association) maximizes the net benefits to residents given the oversupply of spaces, setting a price at which all the places are filled. According to Envall (2013) this price is typically 50 percent of the market price (which is equal to cost), and if we assume a similar demand function to Van Ommeren and Wentink (2012) we again find a 33 percent increase in cars and a 10 percent deadweight loss. However, in this case the deadweight loss would be considerably greater in absolute terms; if we take a modest estimate of the cost of the parking space of SEK 1500 per month then we have an annual cost of approximately EUR 1800, and a deadweight loss of EUR 180.

2.1.2. Minimum Parking Requirement in Sweden

Sweden established a "minimum requirement for parking" for residential and commercial buildings in 1950s, in an attempt to regulate settlement and vehicular conflicts in post-war Sweden (Lundin, 2008; Ekelund, 2014). Since then, several municipalities have revised the requirements in response to growing population.[1] Thus, parking policies in Sweden are based on these "minimum parking requirements" rather than allowing market forces to determine the optimal number of parking places and the associated prices.

Literature on the effect of the minimum standards on parking spaces in Sweden is however scant. Andersson et al. (2016) is the only study, to the best of our knowledge, that has examined the effect of parking regulations in Sweden. The paper estimates the effect of the minimum parking standards on housing stock in Sweden. The authors argue that the building requirement increases production cost of housing construction and thereby reducing profitability of construction companies. Results from the paper suggest that these parking requirements has led to a 1.2% reduction in the housing stock in Sweden. Additionally, the results suggest that the cost of parking spaces are borne by tenants through increase in rental values by 2.4%.

[1] `http://www.notisum.se/rnp/sls/lag/20100900.htm`

2.1.3. Relevance for a transition to zero emissions

The deadweight losses discussed above consist of money wasted on building and maintaining parking lots. They do not account for the effects on choices regarding driving and car ownership: if a 33 percent increase in parking spaces at workplaces leads to a corresponding increase in workers choosing to drive to work, and if car ownership and use is already above the socially optimal level, these losses are likely to be considerable. And if a 33 percent increase in parking spaces associated with apartment buildings leads to anything remotely near a 33 percent increase in car ownership then the overall socioeconomic effects would be enormous.

More generally, if the government aims for a transition to zero emissions, the first place to look for policy initiatives in order to help achieve this goal should be where existing government policies lead to market failures which make the goal harder to achieve. That means ensuring that free parking at workplaces is taxed as a perk to car drivers, and removing minimum parking requirements for apartment buildings. The latter policy should—as discussed by Van Ommeren and Wentink (2012)—also be combined with market pricing of on-street parking in order to avoid empty apartment car parks at the same time as drivers engage in an inefficient search for scarce (but 'free') on-street parking.

It is clear that such measures would have a positive effect in helping to achieve the zero emissions goal. The aim of the project is to quantify this effect and also consider other aspects in order to evaluate the overall benefits.

2.2. Adoption of electric vehicles

Rapid urbanization has led to increasing levels of air pollution in major cities, with 56% (98%) of cities in high- (low-)income countries not meeting the WHO limits (WHO, 2106). According to estimations, more than 1 billion people are exposed to urban air pollution every year. Non-point source pollution is a major part of total pollution, since almost 90% of urban air pollution can be attributed to vehicle emissions (UNEP, 2017). Most developed countries though have taken measures to reduce vehicle emissions, by setting standards in fuel quality, providing incentives to drivers to get rid of the old cars, or adopting vehicle emission reduction technologies. In particular, the European Strategy, as it is described by the Commission (2016), is to achieve low emission mobility by moving towards low and zero emission vehicles. In this context, electric vehicles seem to be one of the means that will facilitate the transition towards a more sustainable transport system.

2.2.1. Technical characteristics and global trends

Electric vehicles have a lot of advantages compared to internal combustion engine-based vehicles. They do not produce on-road greenhouse gas emissions and the upstream pollution they produce is considered to be less severe and depends on the electricity source used for battery charging (Mersky et al., 2016; Holdway et al., 2010; Samaras and Meisterling, 2008). However, there are some aspects that prevent their wider use, such as the higher price, the limited ranges, the longer refuelling times and the fewer public infrastructure refuelling opportunities (Zhang et al., 2016; Mersky et al., 2016). This implies that in order to boost the demand for EV and take advantage of the environmental benefits they provide, governments should give some incentives and use policies that will encourage their adoption. Such policies have already increased the number of sales in several European countries, such as Germany, Sweden, the Netherlands and Norway, with the latter being an outstanding example of EV sales success. In particular, Noway, having a long history of adopting policies in favour of EVs, has become the country with the largest per capita fleet of plug-in electric vehicles in the world. At the end of 2016, 5% of all passenger cars on Norwegian roads were plug-ins, while EVs constituted nearly 40% of the nation's newly registered cars. The incentives given during the past years include bus lanes access, vehicle-related tax exemptions, toll exemptions, expansion of charging stations network and free parking spaces in certain municipalities (Zhang et al., 2016; Mersky et al., 2016). These policies have led to significant reductions in the cost of owning an EV and have clearly impacted consumers' car choices.

The environmental benefits coming from the significant energy and emission savings that are associated with EVs call for their wider use all over the world. The higher price compared to the combustion engine-based vehicles requires the adoption of some policies that will incentivise consumers and affect their car purchase choices. In July 2017, Volvo Cars became the first automaker to announce that all the models it introduces after 2019 will be either hybrids or powered solely by batteries. This decision is increasingly viewed as essential to combating climate change and urban pollution. Carmakers expect the share of electric cars to increase quickly as the technology improves, prices fall and public charging stations become more commonplace. As shown in the case of Norway though, these expectations will only come true if they are followed by policies that will help promote the use of EVs, by giving financial incentives to the owners and providing more public charging stations.

2.2.2. Existing models

The objective of this part of the proposal is to study policies that will promote the wider use of EVs in cities by analysing the trade-off between negative pollution externalities and costly commuting in an urban setting. As explained above, the promotion of EVs in urban areas is important since those are the areas that are suffering from high pollution levels and at the same time, it is easier to provide a connected network of charging stations in more densely populated places. Also, urban residents usually drive smaller distances which makes the use of EVs more attractive.

Standard models in urban economics can help us study different first- and second-best policies that will increase the percentage of drivers who will choose an EV. The use of urban (spatial) models to consider non-point source pollution is quite novel. Pollution externalities have been studied in different urban contexts in a number of studies (e.g. Nijkamp and Verhoef, 2003; Arnott, 2006; Kyriakopoulou and Xepapadeas, 2013, 2017) . In these papers, pollution comes from *stationary sources* - such as the industrial activity - and households tend to avoid polluted areas and prefer to locate in cleaner areas and pay higher land rents. When commuting is costly though (as it is modelled in Kyriakopoulou and Xepapadeas, 2013, 2017) , workers have to consider the trade-off between two opposing forces when locating closer to the city center - the shorter commute and the worse air quality. This leads to the emergence of different spatial structures (i.e. endogenously derived residential and industrial areas), depending on the size of agglomeration and dispersion forces.

Pollution coming from *non-stationary sources*, such as commuting, has not been studied extensively in urban frameworks. Some exception are the papers by Nijkamp and Verhoef (2003) and Schindler et al. (2017) who both study pollution coming from conventional vehicles. More precisely, Nijkamp and Verhoef (2003) point out the importance of analysing urban air pollution in a spatial framework since aggregate pollution depends on the total amount of commuting in the interior of a city and not on the absolute number of commuters. In a similar context, Schindler et al. (2017) investigate the effect of urban traffic-induced air pollution on residential choices. The studies above show that ignoring space will only allow us to study the number of drivers in the interior of a city which cannot precisely determine the magnitude of the implying environmental damage. This is important both for spatial planning and for enforcing the right policy that will affect more people who drive the most polluting cars and the longest distances.

Urban models have never considered different types of vehicles that generate different levels of pollution. However, the wider use of EV will basically create two different types of commuters: the polluters and the non-polluters. The spatial framework then will help us study three things: 1. the optimal location of each type of drivers in the interior of a city, 2. the optimal policy that will fully internalize the social cost of pollution and 3. the second-best site-specific policies that will give drivers the incentive to switch to the “cleaner” vehicle.

3. Theory and method

3.1. Parking Subsidies

The goal of the analysis of parking subsidies is twofold. Firstly to estimate the size of the subsidies, and secondly to investigate the effect of these subsidies on the demand for vehicle ownership and travel. Regarding the first goal there is a certain amount of existing literature on which to build, but regarding the second goal our work will be pathbreaking.

3.1.1. Supply and Demand for Parking Spaces

The goal of this section is to identify the implicit subsidies to vehicle owners stemming from the imposition of the minimum parking requirements, thereby leading to the excess supply of parking spaces. This requires knowledge of the demand and supply curve, and the associated price elasticities of demand and supply.

To estimate the supply and demand functions for parking spaces, we assume that both functions are linear and additive. Therefore, we specify our structural equations as follows.

$$\text{Demand}: \qquad q^d_{it}(p_d; Z_{it}) = \alpha^d P_{it} + Z^{'}_{it}\beta^d_z + \mu^d_{it}.$$
$$\text{Supply}: \qquad q^s_{it}(p_s; Z_{it}) = \alpha^s P_{it} + Z^{'}_{it}\beta^s_z + \mu^s_{it}.$$

Here q^d_{it} and q^s_{it} are respectively the number of parking places demanded and supplied at a given city (municipality) at time t; P is the price per parking space; Z is a vector of controls including attributes of the parking places and other socioeconomic determinants; μ^d_{it} and μ^s_{it} are the error terms for the demand and supply equations respectively. The slope of the demand and supply curves requires that $\alpha^d \leq 0$ and $\alpha^s \geq 0$.

By imposing the market clearing condition, where $q^d_{it}(p_d; Z_{it}) = q^s_{it}(p_s; Z_{it}) = q_{it}$, the structural equations can be written as

$$q_{it} = \alpha^d P_{it} + Z^{'}_{it}\beta^d_z + \mu^d_{it}$$
$$\text{and} \qquad q_{it} = \alpha^s P_{it} + Z^{'}_{it}\beta^s_z + \mu^s_{it}.$$

In reality $q^d(\cdot)$ and $q^s(\cdot)$ are not observable, instead we only observe P_{it}, q_{it}, Z_{it}. That is the exact shape of the demand and supply schedules are unobservable, however by imposing assumptions on the functional form (eg. we assume linear and additive functional form), we can recover the demand and supply functions by estimating the parameters of P_{it} and Z_{it}.

Empirical estimation of the structural equations is not straight forward. Given the joint determination of the supply and demand equations, single equation estimation of these functions via OLS will yield biased, inconsistent and inefficient estimates (Lin, 2008). For the parameters to be identified, the equations will have to be either estimated jointly via a structural estimator or using the instrumental variable estimation for each equation where in each case we instrument prices with an exogenous variable.

In view of the above, we propose to estimate our supply and demand equations using three variant estimators: SUR, 2SLS, and 3SLS. The SUR (seemingly unrelated equations) is enables the estimation of the equations jointly using a simultaneous equation framework. The advantage of the SUR is that it is more efficient than the OLS estimates, however given that price is endogenous in the system, the parameter estimates will still be inconsistent (Lin, 2008).

The two-stage least squares (2SLS) is an instrumental variable approach which allows us to estimate the demand and supply equations separately while instrumenting for prices. The instrument must satisfy the assumptions of being relevant (i.e. correlated with the parking prices) and the exclusive restriction (i.e. affect the outcome variables only through parking prices). In the demand equation, we propose to use the construction year of the property as an instrument for parking prices. The intuition behind the use of this instrument is that, construction year affects current parking prices through the historic provision of parking spaces affects demand for parking spaces only through prices (Van Ommeren and Wentink, 2012). This is because variations in land prices and building costs over time has ensured that relatively new properties attract higher prices than old properties. In the supply equation, we use cost of parking fines as an instrument for parking prices. Parking fines measures the cost of non-compliance to parking regulations in a given city: the higher the fine the greater the compliance rate. We posit an inverted-U shaped relationship between parking prices and parking fines. At lower parking fees, a higher penalty is required to deter non-compliance; however beyond a given threshold, the marginal increase in parking fines begins to fall, as there is some reasonable ceiling for parking fines. Also, the level of parking fines are largely determined by factors other than supply of parking places and thus affect supply only through prices.

In spite of the appeal of the 2SLS in consistently estimating parameters the demand and supply equations by resolving the issue of endogeniety its application in this structural framework has a limitation in the sense that by estimating the equations the parameter estimates remain inefficient. The three-stage least square (3SLS) is therefore chosen as our preferred estimator, as it achieves both efficiency and consistency of estimates. The 3SLS is analogous to the 2SLS except that rather than estimating two equations separately it estimates them jointly, while still utilizing their respective instruments. Estimating the 3SLS via generalized methods of moments (GMM) improves efficiency.

In all estimations, we include fixed effects for municipality, area and year. Municipality fixed effects absorb the effect of differences in regulations especially with regards to parking; area fixed effects absorbs within municipality (observable/unobservable) variations; while year fixed effects capture time trends.

3.1.2. Effects on vehicle ownership and travel

The next, crucial, step is to estimate effects on vehicle ownership and travel. In both cases we need to find so-called 'natural experiments', i.e. cases in which we can identify two populations—as similar as possible to each other—one of which has been subjected to an increase in costs beyond their control, and the other of which has not been subject to that increase. Furthermore, we need relevant data on both populations before and after the cost increase.

Effects of Parking Charges on Travel Decisions. In this section, we aim to estimate the responsiveness of households' travel decisions to parking charges. Specifically, to the extent to which parking charges influence a household's (individual's) decision to use public transport or private cars as a means of transport. Other things being equal, high parking charges increases the travel cost thereby reducing the incentive of travelers to drive in private cars relative to public transport. Data from the Swedish National Travel Survey (SNTS), complemented with administrative and geographic data on built environment and transport infrastructure will be used for the analysis. The SNTS is an annual houshold survey that elicits information on vehicle use patterns, travel choices, access to home and work place parking spaces (either dedicated or public), cost of parking, among other things.

Thus using the above dataset, we will estimate a travel choice model to identify the effect of parking charges on private vehicle use. To ensure causal interpretations, the instrumental variable approach will once again be used. This is necessary to correct any potential reverse causality between vehicular use in a given area and the price of parking spaces.

Effects of Transport Charges/Taxes on Vehicular Demand. Our aim in this section is to causally estimate the elasticity of car ownership with respect to a vehicle transport tax. Studies exist on the effects of transport taxes such as gasoline tax and vehicular taxes on demand for cars (d'Haultfoeuille et al., 2014; Klier and Linn, 2015; Gerlagh et al., 2016; Yan and Eskeland, 2016), however the effect of other transport levies such as parking charges or congestion charges remain understudied.

To understand the possible effect of a policy shock such as removal of implicit parking subsidies on demand for private vehicles, we propose to examine the effects of the implementation of the congestion charges in Stockholm and Gothenburg on vehicle demand as a proximate measure of the potential impact of the former. Congestion charges in Stockholm and Gothenburg were implemented in August 2007 and January 2013 respectively, with the goal of reducing emissions and traffic congestion in the two most populous cities in Sweden. The policy imposes fees on vehicles used within the catchment areas[2] during working hours with charges (Stockholm) ranging from SEK 11 and SEK 35 depending on the time of the day with maximum levy of SEK 105 per day.[3]

Our empirical approach is to causally estimate the impact of the congestion charges on vehicle demand using the difference-in-difference (DiD) strategy. Using data on monthly vehicle registration statistics across Swedish municipalities, we will explore variations across

[2] Unlike the London congestion charges, these policy imposed the same rates on vehicles irrespective of whether the owner is resident in the city or otherwise. Exemptions were however given to green cars under the Stockholm Congestion pricing policy until 2012 when it was abolished (Eliasson, 2014).

[3] `https://transportstyrelsen.se/en/road/Congestion-taxes-in-Stockholm-and-Goteborg/`.

municipalities and time in terms of the implementation of congestion charges to estimate the effect of the policy on vehicle demand. By so doing, we implicitly compare the average car ownership in municipalities affected by the policy (treated) with other municipalities unaffected by the policy, before and after the implementation of the policy. The main outcome variables of interest are: the number of vehicles in the municipality, and vehicle per household (as a measure of vehicle density). It is noteworthy to mention that the Stockholm Congestion charge policy provided exemptions for ‘green’ (alternative fueled vehicles) cars until 2012 when it was phased out. This exemption is likely to increase demand for ‘green cars’ thereby increasing the vehicular fleet in the region rather than the anticipated negative impact. Therefore, to identify the true effect of the congestion charge on vehicle demand, we will estimate a variant model where the outcome variable is the number of conventionally fueled vehicles.

Having found the effect of the congestion charge on vehicle demand, the next step is to derive estimates of the effect of parking-subsidy removal on vehicle demand. Since the congestion charge is to some extent avoidable, it should have a smaller effect on vehicle demand than an unavoidable increase in the cost of ‘storing’ (parking) the vehicle. This is because, for instance, congestion charges are not applicable during holidays, weekends and evenings. Nevertheless, at the least we will be able to derive a lower bound on the effect of removing implicit parking subsidies on vehicle demand.

3.1.3. Policy options

Finally, and based on the results of our econometric analysis, we intend to analyse policy options in practice. The economic prescription is straightforward: ‘get prices right’ by removing subsidies to parking, whether explicit or implicit. However, in practice things are rarely so simple. Based on the calculated effects of alternative policies (such as taxation of the perk of free parking, and removal of minimum parking requirements together with market pricing of on-street parking) we will investigate more broadly what hindrances there are to carrying out such policies, and how they might be overcome. We will identify and compare alternatives used in different jurisdictions, both in Sweden and abroad. And search for and evaluate novel policy alternatives which reduce or remove subsidies to car owners.

3.2. Adoption of electric vehicles

The proposed part will combine the literature of urban and transportation economics in order to build a general spatial equilibrium model that will help us understand how different first- and second-best policies will affect the spatial structure of the city and the drivers’ incentives to switch to EVs (or any type of low carbon car). This economic model will be built on work that has been previously done by the authors (see for instance Kyriakopoulou and Xepapadeas, 2013, 2017) and is already well advanced (Habla and Kyriakopoulou, 2017). This will result in a more sophisticated version that will capture pollution coming from non-stationary sources (commuting) with the aim of using this model for policy simulations. Specific policies to simulate are, among others, one-off subsidies, free parking in the city center, use of bus lanes, exception from the congestion charge, spatial location and subsidies for public charging stations.

3.2.1. An urban model of polluting commuting

In our spatial urban model, we assume that there are N workers (or households) who differ (ex ante) only with respect to their choice of vehicle. More precisely, workers own either an electric vehicle, which is environmentally friendly, or a conventional vehicle with an internal combustion engine, which generates more emissions. Households derive positive utility from the consumption of a numeraire basket of goods (z) and housing space (h), while they are negatively affected by pollution (P). Their utility at each spatial point r is given by:

$$U(r) = h(r)^{\alpha} z(r)^{1-\alpha} P(r)^{-\beta}$$

where we assume that $0 < \beta < 1$. The budget constraints of each type of driver depend on the spatial point r they will decide to locate and are given by:

$$R(r)h(r) + z(r) = w - T - \tau_C r \qquad \text{if CV}$$
$$R(r)h(r) + z(r) = w - T - \tau_E r \qquad \text{if EV}$$

where $R(r)$ is the residential rent at spatial point r, while τ_C (τ_E) is the per trip cost of driving a CV(EV) (that includes the depreciation per trip and fuel /energy cost). We assume that $\tau_E > \tau_C$, which implies that without any subsidy it is not attractive of people to buy an EV. The type and the level of the subsidy (or any policy) that will be used to promote the adoption of EVs will affect the sales of this type of vehicle in a different way and will result in different levels of pollution in the interior of the city under study. More specifically, we assume that local pollution at spatial point r is caused by commuters who use CVs and pass through this point. We also assume that people commute to the city center by car on a daily basis meaning that the spatial points closer to the city center are more polluted compared to the areas closer to the boundaries. Households then have to consider the trade-off between shorter commute and pollution. In other words, households want to locate closer to the city center which will decrease the cost of commmuting (by saving both money and time), but at the same time they have to take into account that the central spatial points are more polluted. By locating closer to the boundaries, they can enjoy better enviromental amenities, but they have to drive longer distances contributing even more to pollution. In terms of our model, commuting with CVs causes local pollution P:

$$P(r) = 1 + \varepsilon \int_r^S \delta_C(r) n(r) dr$$

where $\delta_C(r)$ is the percentage of CV drivers at r, $n(r)$ gives the density of workers at r and ε gives the emissions per unit of distance driven. More polluting vehicles imply higher ε value. We now assume that our city size is $[0,S]$, where the city center is located at $r = 0$, while the residential area stretches from $r = 0$ to $r = S$, with S denoting the endogenous city boundary. This means that commuters who locate in the spatial interval $[r,S]$ have to pass through point r when driving to work which means that they pollute this spatial point (as well as all other spatial points lying between $[0,r]$.

The spatial framework analyzed above will help us derive the equilibrium and optimal location decisions of both type of commuters which will implicitly determine their choice of vehicle and will in turn define the spatial pattern of pollution. We can show that the optimal policy is a *lump-sum site-specific tax* imposed on CV drivers that will fully internalize the environmental damage of conventional vehicles. When CV users decide to locate at a spatial point (say r) that is located at a larger distance from the city center, they affect negatively a higher number of residents locating in the spatial interval $[0,r]$. In other words, if $x \in [0,r)$, the CV driver locating at x will pay less compared to the CV driver locating at r, since the latter will create a larger environmental damage by additionally affecting people locating at $(s,r]$. This tax will be equal to $\mu(r)$ and increases across space $(\mu'(r) > 0)$ to capture the increasing number of people who are suffering, when a CV driver decides to move to a place closer to the city boundary.

Although this first-best policy may seem unrealistic, this is in line with some policy that is currently under study by researcher in different cities (for instance, Oslo and London) according to which vehicles will not be levied a tax when entering or exiting the central area of a city (as it is the case in Stockholm or Gothenburg) but drivers will be charged based on the distance they have driven and the time of the day they have decided to drive (see Wangsness and Rødseth, 2017). The first part (distance) is designed so as to capture the environmental damage caused by driving longer or shorter distances and the second part (time) is basically important for the congestion they create at the different times of the day. The calculation of the charge will be done by a gps and will depend on the type of vehicle in a way that polluting vehicles will pay more by klm compared to their cleaner alternatives. This will hopefully move us a step closer to the full internalization of the damage created by each type of vehicle.

Going back to the description of the theoretical model, that will help us study alternative policies for EV users, we can show that at the optimum, long-distance commuters rely on electric vehicles, which is the most beneficial allocation, in terms of aggregate pollution, for the whole city. Charging heavily vehicles and drivers who pollute the most (not only in terms of emissions/klm but also in terms of aggregate emissions they generate when driving longer distances) gives incentives to these drivers to swich to cleaner vehicles. Thus, the benefit of building and using a general equlibirum urban-transport model is clear: in contrast to spaceless models, it will help us study aggregate commuting with different type of vehicles (polluting and more environmentally friendly ones) and not only the number of commuters. Moreover, our model will allow us to enrich the assumptions and introduce other characteristics, such us longer leasure trips which depend a lot on existing recharging infrastructure, wage heterogeneity and global pollution. The aim is to incorporate these extensions to the theoretical model and simulate it again for the different policies under study.

3.2.2. The effect of Swedish policy

In February 2017, Sweden signed the most important climate reform in the history of the country, which calls for a 70 percent reduction of greenhouse gas emissions in the transportation sector by 2030. To meet this target, passenger cars will have to be decarbonized and Sweden should give more incentives to increase the purchase of eco cars. Already in 2012, Sweden introduced the so-called "super green car rebate" (supermiljöbilspremie) with the aim of promoting EV purchases. In this context, EV buyers receive a rebate of 40000 SEK for new cars that do not emit more than 50 grams of carbon dioxide per kilometer. Figure 2 shows monthly market shares of battery electric vehicles (BEVs) and plug-in hybrids (PHEVs) from January 2012 to January 2017. During this period, the share of electric vehicles increased from 0.3 percent in 2012 to 3.6 percent in 2016. The actual disruptions / delays of the program triggered drops in market shares, but overall the rebate program seemed to work. Sweden had a 3.6 percent market share in 2016, which placed the country fourth among European EV markets, after Norway, the Netherlands and Iceland.

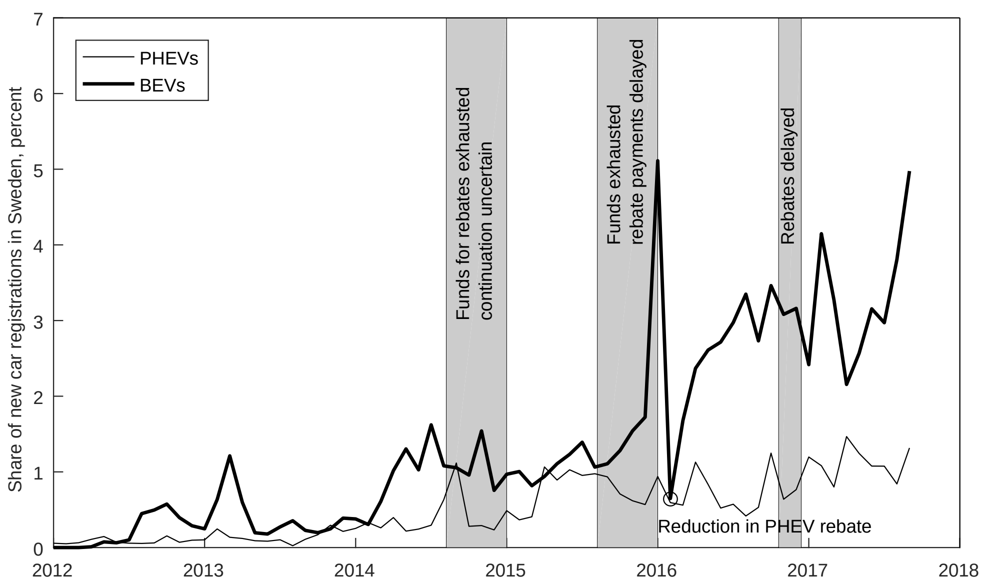

Figure 2: Market share of new car registrations in Sweden. PHEV: plug-in hybrid electric vehicle, BEV: battery electric vehicle. Source: Statistics Sweden.

Our theoretical model suggests imposing high taxes to polluting vehicles, in an attempt to fully internalize the environmental damage, which could be used to provide rebates to low-carbon vehicles. Simulations of the model could provide some intuition regarding how successful the policy will be and how this will affect the market share of eco cars. This is also in line with the feebate program that the Swedish government is planning to introduce in 2018. Feebate programs combine fees and rebates. In particular, revenues coming from penalizing high-emitting vehicles with taxes can be used to incentivize clean vehicles.

4. Practical relevance

The research project is directly relevant to the goals of the research call, i.e. to provide proposals for policy instruments that will promote sustainable and fossil-free transport. Our particular focus is on private vehicles in cities. In cities the transformation to fossil-free transport is easiest to achieve than in rural areas, partly because it is easier to do without a private vehicle in cities (due to the strength of other options such as public transport or cycling), and partly because the switch to electric vehicles is also more attractive in cities, because most journeys are relatively short so battery capacity and charging is not such an issue.

Regarding car ownership and parking subsidies, our aim is to identify and quantify ways in which car ownership is (inefficiently) encouraged by existing regulations, at the expense of those who choose alternative means of transport. This is of course consistent with equity as well as the achievement of the main policy goal (zero emissions). Furthermore, the measures should be easy to justify, even though they are unlikely to be popular with vehicle owners.

The second objective of the project is to study alternative policies that will promote the use of eco cars. This framework will be based on advanced theoretical modelling of a general spatial equilibrium urban-transport model, which will help us understand and predict the effects of alternative policy measures. More precisely, the model will be used for simulations of the different policies analysed above which will lead to concrete and easily understood results and will give us some intuition of how these policies can be implemented in practice. Preliminary results suggest that high-polluting vehicles should be heavily penalized so as to reduce traffic and the actual number of cars on the streets and also to use the revenues to finance alternative eco policies. The comparison of the different policies, such as subsidies to EVs, installation of a higher number of charging stations, determination of the optimal location of the new charging stations, the response of drivers to exception of congestion charges or parking fees for eco cars etc. will provide a clear idea and ranking of the most successful policies. In other words, policy simulations will help design appropriate strategies to implement the transition to clean, sustainable and economically viable transportation system. We will also use the simulation results to evaluate the effects of alternative transport policies from the perspective of environmental impacts, as well as broadly defined economic welfare.

5. Activity plan

This project is intended to last for 3 years starting January 2018 to December 2020. The main activities will be data gathering, analysis and production of research papers

Year 1

- Electric vehicles.
  1. Build a spatial general equilibrium (SGE) model that is suitable to deal with policy issues associated with traffic-induced pollution.
  2. Policy simulations.
  3. Paper: Electric vs. conventional vehicles: environmental externalities and urban spatial policies. Presented in Conferences.
- Vehicle demand and implicit subsidies.
  1. Organize data from various sources relevant for the study.
  2. Data analysis to estimate the welfare loss of parking subsidy.
  3. Paper: The Social Cost of Implicit Parking Subsidies in Sweden.
  4. Submit and present the paper in conferences and seminars.

Year 2

- Electric vehicles.
  1. Policy simulations.
  2. Paper: Electric vs. conventional vehicles: environmental externalities and urban spatial policies. *Submitted for Publication*.
  3. Paper: Adoption of electric vehicles: Second-best urban policies. *Presented in Conferences*.
- Vehicle demand and implicit subsidies.

1. Paper: The Social Cost of Implicit Parking Subsidies in Sweden. *Submitted for Publication*.
2. Analysis on the effect of transport charges and taxes on vehicle demand and travel choices.
3. Paper: Effect of Transport Taxes on Vehicle Demand in Sweden: The Case of Congestion Charges.
4. Paper: How does Parking Fees Influence Travel Decisions? Evidence from Sweden.
5. Submit and present the papers in conferences and seminars.

Year 3

- Electric vehicles.
  1. Paper: Adoption of electric vehicles: Second-best urban policies. Submitted for Publication.
  2. Paper: Electric vs. conventional vehicles: environmental externalities and urban spatial policies. Accepted for Publication.
- Vehicle demand and implicit subsidies.
  1. Paper: The Social Cost of Implicit Parking Subsidies in Sweden. *Accepted for Publication.*
  2. Paper: Effect of Transport Taxes on Vehicle Demand in Sweden: The Case of Congestion Charges. *Submitted for Publication.*
  3. Paper: How does Parking Fees Influence Travel Decisions? Evidence from Sweden. *Submitted for Publication.*
  4. Using the results from the preceding papers, develop a model that explains the policy options for efficient pricing of parking spaces to optimize social welfare.
  5. Paper: Towards Sustaining Urban Transport Management: Policy Options for Parking Pricing. *Present in Conference and Seminars.*
- Overall output
  1. Publication of at least two popular-scientific articles on the theme of sustainable transport management, based on the results of both parts of the project.

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