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Total cost of ownership and its potential implications for battery electric vehicle diffusion

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ABSTRACT

Battery electric vehicles (BEVs) have been slow to diffuse on the international as well as the Swedish market. Previous studies have indicated situational factors such as economic factors, size and performance to be of major importance for vehicle purchasers in their choice of vehicle. In this paper, the authors explore a consumer centric total cost of ownership (TCO) model to investigate the possible discrepancy between purchase price and the TCO between internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs) and BEVs. The creation and testing of the TCO model reveals that computation could be a challenging task for consumers due to bounded access of relevant data and the prediction of future conditions. The application of the model to the vehicle sample found that BEVs could be cheaper compared to ICEVs and HEVs. The findings in this paper could prove to be of importance for policy and marketing alike in designing the most appropriate business models and information campaigns based on consumer conditions in order to further promoting the diffusion of BEVs in society.

1. Introduction

In the urgent need for society to reduce its CO_2 emissions, disruptive eco-innovations such as battery electric vehicles have a great potential. As now emerging in the mainstream markets, they have the potential to reduce CO_2 emissions from transports and hence benefit society at large. Despite its potential, however, electrification of the vehicle fleet has so far been slow to diffuse in the Swedish market, as represented in the 0.37% share of new vehicle sales during 2014 in Sweden, (BIL Sweden, 2015; Power Circle, 2015). In order for this share to increase, it is of great importance to understand the factors that make-up the demand for new vehicle purchases in general and BEVs in particular. This study will outline an approach to illuminating vehicle costs, that is one of several key factors for vehicle choice, one that is specifically perceived by users, but needs to be managed by policymakers and producers delivering new products to the market. This study will specifically focus on BEVs, since they are the only mass-market zero emission vehicles on the roads today.

Eco-innovations are normally not self-enforcing in their diffusion, as illustrated by the low degree of user adoption for solar power and hybrid-electric vehicles in the US (Zhang, Gensler, & Garcia, 2011). Roy, Potter, & Caird (2005) identified four barriers for cleaner vehicles. First, high purchase prices and long payback times associated with many low carbon products and systems often act as a major adoption barrier. Second, pioneering low carbon products tend to be engineering-led and hence lack ease and convenience of use. Third, a lack of system integration such as refuelling infrastructure hinders adaptation of low carbon products. Fourth, the importance of the vehicle as a status symbol is not always present with low carbon vehicles. Specifically for BEVs, extensive research has been conducted on the barriers of limited range and performance (Egbue & Long, 2012) and charging infrastructure challenges (Struben & Sterman, 2008), less so on the role of perceived and actual costs.

The general consensus within the industry, press and the public seems to be that BEVs are significantly more expensive than internal combustion engine vehicles, (ICEVs) and hybrid electric vehicles (HEVs), which following the results of previous works would then negatively affect its diffusion (Rosenberg, 1972). However, it is not clear whether this is the case and whether different pricing distribution schemes would lead to different purchasing behaviours. To explore the real cost of owning and operating a vehicle, one needs to go beyond the purchasing price to also include operating and capital cost. The total cost of ownership (TCO) calculation method has been used in numerous studies to compare cost between different vehicle technologies but not always including BEVs (Al-Alawi & Bradley, 2013a; Lin et al., 2013; Thiel, Perujo, & Mercier, 2010). However, previous studies have relied on uncertain or lacking vehicle cost assumptions and conceptualized vehicle examples, particularly in the case of BEVs, largely because of a lack of data due to the newness of BEVs on the market (Wu, Inderbitzin, & Bening, 2015). Previous studies that have relied on abstract theoretical frameworks and simulations have increased understanding among the scientific community but have not fully envisioned a TCO calculation method that could be comprehended and used by consumers. This

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study intends to extend previous research efforts by constructing a TCO model in the consumer context by using contemporary vehicle and market data that is available to the general public, and by exploring how BEVs compare to equivalent ICEVs and HEVs for the first vehicle owner when calculating TCO. This could be an important contribution in practice if such a model is disseminated to consumers. More important in research on BEVs and their diffusion: it is first with the application of data available to consumers a valid discussion on how TCO could actually affect the consumer's behaviours could be held. Therefore, the authors aim to discuss the results potential implication of the diffusion of BEVs. It is important to understand such potential since this could be the basis for new and potentially improved public policy and marketing of BEVs relying on a deepened understanding of this potential, based on real consumers' possible behaviour.

The next section will present literature regarding technological diffusion, emphasizing factors that influence vehicle choice, the energy paradox and TCO. It will be followed by sections that will present the TCO model with the factors that make up TCO and which are accessible to consumers with available data, and calculations for the sample of vehicles that are referred to in this study. The paper concludes with analysis, discussion and conclusion sections.

2. Perspectives from literature

2.1. Technological diffusion

This study is concerned with the adoption of the BEV technology on an aggregate scale, often called technical diffusion. Kemp & Volpi (2008) describe technological diffusion as the adoption of a technology by a population over time. Diffusion analysis does not seek to find answers as to why a particular unit (firm or consumer) has adopted an innovation at a particular time in any detail, but concerns itself with the adoption decisions of a population of potential adopters. Rogers's (1962)) work on the diffusion of innovations is one of the foundation blocks of modern diffusion research. He describes diffusion of a particular innovation as a gradual process largely dependent on five factors: *Relative Advantage*, *Compatibility*, *Complexity*, *Trialability* and *Observability*. Rogers also describes the diffusion process with the by now familiar diffusion curve where adopters are divided into *Innovators*, *Early Adopters*, *Early Majority*, *Late Majority* and *Laggards* according to their time of adoption. Several schools of diffusion have followed, such as the epidemic model and the probit model. The epidemic model builds on the premise that what limits the speed of usage is the lack of information available about the new technology, how to use it and what it does (Geroski, 2000). The probit model follows from the premise that different actors, with different goals and abilities, are likely to want to adopt the new technology at different times (Geroski, 2000). These models point to a need to put the consumer in centre to understand which factors are of relevance to a possible diffusion and how consumer act due to variances in factors.

2.2. Factors that influence vehicle choice

In order to understand what drives technological diffusion for BEV, it is important to investigate the factors that influence vehicle-purchasing behaviours, which are numerous both for fleet and private buyers. Lane & Potter (2007) divide these into situational factors and psychological factors. Situational factors include: economic and regulatory environments, vehicle performance and applications and the existing fuel/road infrastructure. The fuel/road infrastructure is especially important in the case of BEVs, since it to a large degree cannot use the existing infrastructure for refuelling/charging. Hence, it has been found to be an important factor affecting consumer choice in the case of BEVs (Struben & Sterman, 2008). Psychological factors include: for private drivers – attitudes, lifestyle, personality and self-image; and for fleet drivers – risk-perception, corporate culture and company image. Other studies have found that private vehicle purchases are predominantly driven by situational factors such as price, fuel economy, comfort, size, practicality and reliability (Low Carbon Vehicle Partnership, 2010).

2.3. Fuel economy and the energy paradox

Fuel economy constitutes one of the situational factors, and has been found to be an important factor during the decision-making process (Lane & Potter, 2007; Low Carbon Vehicle Partnership, 2010). However, it seems to be the case that most vehicle buyers expend little effort in comparing the fuel economy of different vehicles during the decision-making process (Low Carbon Vehicle Partnership, 2010). As a consequence, many consumers will consistently undervalue fuel economy savings, which in turn leads to a lower adoption rate of "eco innovations" than theoretical market theory would predict, in the literature this phenomena is called the "energy paradox" (Boardman et al., 2000; Green, Evans, & Hiestand, 2013; Turrentine & Kurani, 2007).

Several possible explanations for the energy paradox have been suggested, including imperfect information, bounded rationality, limited mathematical skills, principle agent problems, and the heterogeneity of consumers' preferences, as explained by Green et al. (2013). Lane & Potter (2007) suggest that consumers of all types have a very low knowledge base regarding the potential impacts of low carbon and fuel-efficient vehicles. This can be attributed to the greater importance of other factors in the vehicle purchasing process. As Lane et al. (p.1089), conclude, "Although it appears that fuel economy influences vehicle choice, other non-environmental issues (cost, performance, styling, image, etc.,) continue to play a more crucial role" (Lane & Potter, 2007).

2.4. Total cost of ownership (TCO)

TCO is defined by Ellram (1995), as a purchasing tool and philosophy, which is aimed at understanding the true cost of buying a particular good or service from a particular supplier. TCO is a useful calculation for consumers and firms alike to assess the direct and indirect cost associated with a purchase. TCO is important, since the purchasing price of most capital goods is not the only cost associated with their use and ownership. Traditionally, firms have mostly used TCO analysis; tools for consumers have so far been limited. As a result, there are reasons to suspect that consumers have limited knowledge regarding the TCO concept that potentially could lead to uneconomical vehicle purchases decisions. This is also interesting from the perspective of the epidemic model (Geroski, 2000), addressing the notion that new technology may not be used due to a lack of information for users.

Literature on vehicle TCO is a fairly new field and therefore also limited in its scope. Wu et al. (2015) contribute with a review of different studies that reveal a large variety in framing of vehicle TCO analysis also including a number of different assumptions concerning applied data. Such previous vehicle TCO analyses have found that plug-in hybrid electric vehicles (PHEVs) and BEVs can be both cheaper or more expensive to own compared to their ICEV competitors depending on cost assumptions and time scales (Al-Alawi & Bradley, 2013b; Electric Power Research Institute, 2013; Propfe et al., 2012; Wu et al., 2015). The electric drive train generally has lower service and maintenance costs, better fuel economy and lower taxes compared to ICEV, but a significantly higher purchase price. Hence, the relevance of investigating the TCO's relation to the purchasing process for BEVs, rather than just fuel economy or purchasing price. The US-based Consumer Report could be claimed to be the leading authority with regards to vehicle TCO, with annual updated calculations and on-going consumer information regarding vehicle TCO. Fig. 1 indicates the relative size of each cost factor for the average new vehicle in the US over a 5-year ownership and have been added for illustrational purposes.

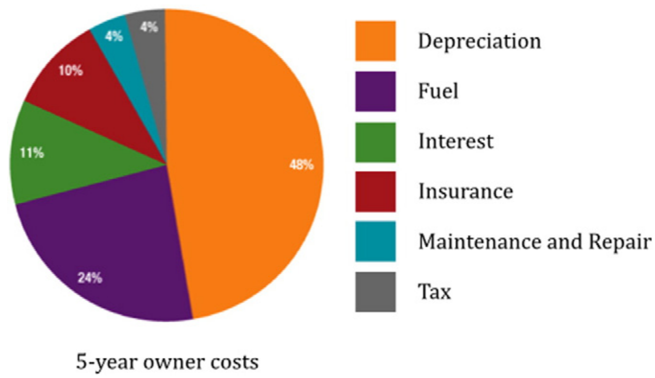

Fig. 1. Total cost of ownership for the typical newly bought vehicle in the US (Consumer Report, 2015).

3. Research gaps

It has been shown above that price plays a significant role in the diffusion of eco innovations such as BEVs. The purchasing price is, however, not the same as the total cost of buying and owning a vehicle. This paper explores how a consumer TCO model can be constructed and test whether TCO is significantly different between BEVs, ICEVs and HEVs, as well as its potential impact on the diffusion of BEVs based on previous literature. The theoretical context is provided from previous work in TCO, diffusion theory and the energy paradox.

This paper explores the answers to the following questions:

1. How can the TCO model for new vehicle purchasing be constructed so as to be as realistic as possible in a consumer context, and what are the potential limitations in the estimates?
2. What differences can be observed when testing the assigned TCO model to compare a small sample of one BEV, two ICEVs and one HEV in the same vehicle class?
3. What are the potential implications of questions one and two on the diffusion of BEV?

The purpose of this study is to deliberate on the creation and usage of a consumer centric TCO model and its implications for theory and practice.

4. Methodology for defining the elements of TCO

The TCO model constructed in this study contains individual factors that have each been defined, analysed and computed into the result. The use of industry and government data, phone and email exchanges with leading automobile authorities and modelling in Excel has made the TCO model possible.

In this study, the TCO model will be used to compare the cost of ownership between one BEV, two equivalent ICEVs and one HEV vehicle in a Swedish market setting. Although the authors acknowledge that the small vehicle sample size, as well as the lack of range in the assumptions made for the average user, will not be sufficient to generalize the results for all vehicles that are for sale in the market, the result can, however, give an indication of the different cost characteristics between different vehicle drive trains. Existing theoretical and empirical literature will be used in order to explore the relevance of the TCO model to the diffusion of BEVs in Sweden. All prices and cost have been converted from Swedish kronor (SEK) to Euros (€) with a conversion rate of €1 to 9.52 SEK as of February 17th 2015 (The European Central Bank, 2016).

4.1. The vehicle buyer profile

The number of vehicle buyers' profiles are as many as there are buyers, hence the difficulty of estimating a generic profile that is applicable for all drivers. Following the scope of this study, to illustrate the relative cost differences between different vehicles and their drive trains the authors, however, need to decide on a profile that reasonably represent an average driver. New vehicles are often sold with some predetermined conditions such as financing periods, leases, warranties and driving range restrictions that can act as a good proxy for this analysis. The scope of this study is to construct a TCO computation for the first vehicle owner; hence the shorter length of ownership compared to previous studies, (Electric Power Research Institute, 2013). When estimating insurance cost, an owner profile is needed that includes age, gender, address and accident history. Therefore one of the author's personal information has been used in the computation. The conditions for the TCO analysis are:

- Length of ownership: 3 years
- Annual kilometres driven: 15 000 km
- Owner: Male, 30 years old, living close to Stockholm, 12 accident-free years of driving

4.2. Selection of sample vehicles

In this study, it is expected that the result will be of most relevance to vehicle buyers that have access to charging and have range expectations within the range of a typical BEV (not claiming that BEVs are always perfect substitutes for ICEV). Chosen vehicles share similar size, equipment and performance, which have been critical in sample choice, leaving little room for more samples due to availability on the current market. The authors also acknowledge that equipment needs will vary for individual buyers, which could have a significant effect on the TCO results. The vehicles in the sample will be compared with their basic equipment packages. The authors included a petrol and a diesel version of one of the most sold vehicle in Sweden, the Volvo V40, together with the Toyota Prius Hybrid and the BMW i3 (BEV). Table 1 below illustrates key data points for each model.

4.3. TCO model

In order for a TCO model to be of relevance, it is of great importance to identify and compute the necessary cost categories for the product or service in question. The cost of buying and owning a vehicle entails several different cost categories that have been defined by previous literature and automobile authorities (Al-Alawi & Bradley, 2013b; Electric Power Research Institute, 2013; Consumer Report, 2015). The following consumer affable TCO equation encapsulates our calculation approach:

$$TCO = (PP - RP) + FC(TKD) + \left(\frac{rP}{1-(1+r)^{-N}}N - P\right) + IC + MR + T - S$$

where *TCO* is the total cost of ownership for the ownership period, *PP* is purchasing price, *RP* is resell price in the end of the ownership period and the difference between *PP* and *RP* constitute the depreciation of the vehicle. *FC* is fuel cost per kilometres, *TKD* is total kilometres driven, $FC(TKD)$ is the total fuel cost, r is monthly interest rate, P amount borrowed, N is number of monthly interest payments, P is amount borrowed, $(rP/(1-(1+r)^{-N}))N - P$ is equal to total interest cost. *IC* is insurance cost. *MR* is maintenance and repairs. *T* is government taxes and *S* is government subsidies.

The TCO model presented in this paper will isolate direct costs associated with vehicle use and ownership. As a result, indirect costs such as opportunity cost of refuelling/recharging will be omitted. It is, however, possible that significant opportunity cost differences could exist between different vehicle technologies. BEVs require long recharging times and charging is needed more often due to the shorter range compared to conventional fuel vehicles. Charging is usually conducted overnight at home or in daytime at work where the user is only required to carry out the quick plug-in procedure, but occasionally also at fast

Table 1
Vehicle descriptions.

Volvo V40 D3 - 2015	Volvo V40 T4 - 2015
Purchasing price: €25 630 Horsepower: 150 hp Fuel type: Diesel Fuel consumption (mixed): 4.3 l/100km Carbon dioxide emissions: 114 g/km	Purchasing price: €25 210 Horsepower: 180 hp Fuel type: Petrol Fuel consumption (mixed): 5.5 l/100km Carbon dioxide emissions: 129 g/km
Toyota Prius - 2015	**BMW i3 - 2015**
Purchasing price: €28 824 Horsepower: 136 hp Fuel type: Petrol/electricity Fuel consumption (mixed): 3.9 l/100km Carbon dioxide emissions: 89 g/km	Purchasing price: €35 609 Horsepower: 170 hp Fuel type: All-electric Fuel consumption (mixed): 12.9 kWh/100km Carbon dioxide emissions: 0 g/km

Vehicle prices and specifications have been extracted from www.volvocars.se, www.toyota.se and www.bmw.se in February 2015. One Swedish krona (SEK) is approximately 0.12 US$ in February 2015.

charging stations where the user needs to be on site for 30 to 40 min provided that the charging station is available and fully operational. For conventional fuel vehicles, refuelling requires five to ten minutes spent at the filling station. The difference in time spent waiting for the vehicle to refuel/be recharged is hence dependent on user behaviour, where overnight or day recharging would claim less otherwise productive time from the user compared to the extensive use of fast charging. The section following will in detail explain the individual cost categories that make up vehicle TCO and its relevance to the purpose of this study.

4.3.1. Depreciation

The depreciation rate is the difference between the initial price and the resell price of a product after a period of time. Depreciation is often the biggest cost in the vehicle TCO analysis, as illustrated by Fig. 1, and consequently of great importance to new vehicle buyers. Depreciation is a complex process dependent on factors such as: vehicle features (colour, equipment) brand perception, fuel prices, maintenance costs, quality scores, government regulations and other less quantifiable values. As a consequence, the depreciation rates can vary significantly between brands, models and drive trains. Most finance models (leasing and traditional financing) developed by financial institutes for new vehicle purchases include an expected depreciation rate, usually set at approximately 50% after three years of ownership with 45 000 km and normal wear and tear, (DNB Sweden, 2015). For the ICEV and HEV depreciation rate, the authors will assume the 50% depreciation rate, for the BEV depreciation rate a more thorough analysis is needed. Limited historical data and uncertainty regarding the future conditions of BEV could have contributed to conservative depreciation estimates of BEV by the financial institutes, as evident by the estimated 67% depreciation rate for the VW eUP, (VW, 2015).

Of the new generation of BEVs, one of the few that have been on the market for at least three years and sold in larger volumes is the Nissan Leaf on the US market. The authors have, therefore, conducted a depreciation analysis for the Nissan Leaf SV, bought in the US during 2012 as seen in Table 2 below.

Although the rate is affected by significant tax rebates, the authors conclude that the Nissan Leaf has a depreciation rate of approximately 44%, considerably lower than existing projections by Swedish financial institutes. However, acknowledging the uncertainties in making depreciation estimates for BEVs on the Swedish market (due to limited local historical depreciation data, local market differences, uncertainties regarding future developments of price, performance and battery lifespan) the authors will assume the same depreciation rate of 50% for the BEV as the ICEVs and the HEV in the sample when government subsidies have been included.

Table 2
Depreciation Nissan Leaf SV — 2011.a

	Price in 2012	Price in 2015	Depreciation	Depreciation rate
Nissan Leaf SV	US$25 200[a]	US$14 097[b]	US$11 103[c]	44%[d]

US$35 200–US$7500–US$2500 = US$25 200. Based on information received in an email conversation with the California Center for Sustainable Energy.

[a] Base price: US$35 200. Federal tax refund: US$7500. California state rebate: US$2500.

[b] Mean from sample of 39 used Nissan Leaf SV 2012 with between 20 000–30 000 miles (32 187–48 280 km) on the metre, retrieved from cars.com, (Cars.com, 2015) on the 26/2 2015. Standard Deviation of the sample: US$1271. A 68% confidence interval yields that 68% of the sample is between: US$12 826 and $15 368.

[c] US$25 200–US$14 097 = US$11 103.

[d] US$11 103/US$25 200 = 44%.

4.3.2. Fuel costs

Fuel economy make up the key concept in previous studies concerning the energy paradox, (Green et al., 2013; Turrentine & Kurani, 2007). Fuel cost is calculated by the straightforward formula: *Fuel consumption per kilometre ∗ Fuel price per unit ∗ Total kilometres driven during the ownership period*. Table 3 below illustrates average petrol, diesel and electricity prices over the last year that will be used as a proxy for estimating future fuel prices.

Several recent investigations, such as a white paper from ICCT, (The International Council on Clean Transportation., 2014), have found that actual fuel consumption is higher than the official fuel labels due to unrealistic fuel consumption testing methods used by the vehicle manufactures. Official fuel labels can hence be argued to give misleading fuel and cost information to consumers; the authors, therefore, argue for using more realistic real world fuel consumption figures. The German website Spritmonitor crowd sources fuel consumption figures for most vehicle models on the European market place by asking owners to provide the real world fuel consumption of their vehicles. Table 4 indicates the results from Spritmonitor (2015).

4.3.3. Interest

Based on interviews with leading vehicle authorities, the authors assume that most vehicle buyers finance at least part of their vehicle purchase with a vehicle loan or a private bank loan paid back in regular instalments. In this study, the authors will assume that the purchaser provide a 20% down payment with the reminder of the purchasing cost financed by a 36 month loan at a 6% annual interest, of which 30% is tax deductible; effective interest rates are hence 4.2%. Due to the current low inflation climate in most of the developed world, the authors argue that interest rates can also represent the opportunity cost of capital, i.e. discount rate. Interest payments will be calculated according to the commonly used formulas below.

Monthly payment formula	Total interest paid formula
$c = \frac{rP}{1-(1+r)^{-N}} = \frac{Pr(1+r)^N}{(1+r)^N-1}$ (1)	$I = cN - P$ (2)
c: Monthly payment	I: Interest paid over the lifetime of the loan
r: Monthly interest rate	c: Monthly payment
N: Number of monthly payments	N: Number of monthly payments
P: Amount borrowed	P: Amount borrowed

4.3.4. Insurance

Individual vehicle insurance premiums are determined by a host of different vehicle- and owner-specific factors. Vehicle-specific factors include: performance, safety ratings, weight, vehicle value and other factors. Owner-specific factors include: number of accident-free years, age, gender, address and other factors. In this comparative study, we want to isolate the vehicle-specific factors and will hence use the same owner profile when calculating the insurance cost per vehicle. In order to obtain accurate quotes rather than estimates, the authors will use one of the co-authors' personal information to elicit quotes: Male, 30 years of age, 12 accident-free years and living in a rural community outside Stockholm. Using a specific owner profile will not represent all types of owners, but can give an indication of the vehicle-specific insurance factors. All quotes are elicited from one of the major insurance companies in Sweden, (Trygg Hansa, 2015).

Table 3
Average fuel prices 2013–2014.

Petrol	Diesel	Electricity
€1.504/l[a]	€1.491/l[b]	€0.085/kWh[c]

[a] Mean from Swedish average consumer petrol prices per litre during 2014 from http://www.okq8.se/pa-stationen/drivmedel/.
[b] Mean from Swedish monthly average consumer diesel prices per litre during 2014 from http://www.okq8.se/pa-stationen/drivmedel/.
[c] Mean from 2014 variable consumer electricity prices per kilowatt hours for households based on an online conversation with one of the largest electric utilities in Sweden, E.ON.

4.3.5. Maintenance and repair

Most new cars come with a warranty that covers any malfunctions during the first three years of ownership. Repair costs should therefore be none or small during the first three years. Warranties are, however, only valid if the owner complies with the vehicle specific service intervals. Service costs are calculated by adding the by the manufacturers estimated service cost during the ownership. BEVs have fewer moving parts that need no oil or filter change and less brake pad tear due to its strong regenerative braking. Maintenance and repair cost has been estimated to be lower for BEVs compared to ICEVs (Propfe et al., 2012). Other maintenance costs such as tyre and windscreen wiper changes are to be considered equal between BEVs and ICEVs, and are therefore not included in this study.

4.3.6. Taxes and subsidies

The Swedish transport energy policy is based on CO_2 emissions per km. Vehicles that emit under 50 g of CO_2 per kilometre are exempted from annual vehicle taxes, qualify for a €4202 cash premium from the government and a 40% deduction in benefit taxation for company vehicles; these policies have been in place since the 16th of January 2012, (Trafikverket, 2015). In addition, some local municipalities offer free parking and charging for electric vehicles, although no national policy exists for promotional policies for low CO_2-emitting vehicles, except for the tax reductions and cash subsidies described above. The annual vehicle tax for the vehicles in this study will be extracted through the use of the registration number on the Swedish transport agency's online tax calculator, (Transportstyrelsen, 2015).

5. TCO estimates of sample vehicles

Table 5 below states the computed values based on assumptions given on previously discussed factors. It needs to be noted that all costs are shown in Euro and percentages in brackets indicate each TCO categories share of TCO for each vehicle.

6. Analysis and discussion

Constructing a relevant consumer centric TCO model is a challenging task, especially in estimating the individual cost factors and when applying data available to consumers. Some of the cost factors are predictable and are relatively stable over the length of the ownership, such as *Interest*, *Insurance*, *Maintenance and Repair*, *Taxes* and *Subsidies*. The challenging factors to estimate are *Depreciation* and *Fuel*. *Depreciation* is dependent on untold number of factors, and can rapidly change over the length of the ownership; what is in demand on the second hand car market today does not necessarily have to be the same in three years' time. It is therefore possible that depreciation rates of the four sample vehicles will be smaller or larger than the estimated 50%. When vehicle buyers use leasing as a financing option, the risk of uncertain depreciation rates does however transfer from the individual to the financial institute. Based on the findings of this study, the authors argue however that financial institutes ought to use less conservative depreciation estimates for BEVs, at least to the level of magnitude of equivalent ICEVs and HEVs. Estimating *Fuel* cost is challenging for two main reasons: first, high price volatility in the global fuel markets makes future prices hard if not impossible to predict. In this study, the authors used the average of last year's fuel prices as a proxy for expected future prices. Second, over-optimized fuel consumption testing methods provide official fuel labels that are often far from the real world fuel consumption. The authors addressed this by using real world fuel consumption figures provided by consumers through an online service, where the results also indicate a discrepancy of up to 56% between official fuel consumption and real world fuel consumption as provided by owners of the vehicles. Data usage would be possible for any consumer, however, for usage in practice it is clear that TCO calculations include barriers due to assumptions needed and rather time consuming investigations.

The result from the TCO model in Table 5 shows a discrepancy between TCO and purchasing price among the sample vehicles. The BMW i3 has the highest purchasing price but has the lowest TCO in the sample. Volvo V40 T4 has the lowest purchasing price but the highest TCO of the vehicles in the sample. Significant running cost differences can be observed between the vehicles. The BMW i3 is the cheapest to own in the fuel cost, maintenance and repairs, and taxes and subsidies categories. Table 5 indicates that purchasing price only directly influences two factors in the TCO: depreciation and interest costs. These costs can, nevertheless, contribute to a significant part of the total, as seen in the case of the BMW i3 that has depreciation and interest cost making up 105% of TCO. The government subsidy of −22% of TCO consequently has a large effect in bringing down the cost to a competitive level compared to the ICEVs and the HEV. The authors find that a BEV can be considered TCO-competitive with ICEVs and HEVs on the Swedish market when considering a consumer centric TCO model with the assumptions provided in this paper; there are even reasons to believe that BEV can be considerably cheaper. As seen in Table 6 does TCO represent 53% of the purchasing price for the BMW i3 compared to 78–84% for the two Volvo V40s and 73% for the Toyota Prius, indicating the large effect of running cost for the TCO.

TCO is a mind-broadening concept in the sense that it through facts contradicts budgeting vehicle purchase by purchasing price, which is the common observed behaviour among car buyers and consumers in general as explained by the energy paradox. If vehicle buyers assume a similar cost structure for BEVs as for ICEVs and HEVs, then they run the risk of making uneconomic budgeting decisions. The BMW i3's TCO represents 53% of its purchasing price, whereas if vehicle buyers

Table 4
Real world average fuel consumption.

	Volvo V40 D3	Volvo V40 T4	Toyota Prius	BMW i3
Fuel consumption	6.16 l/100 km	8.59 l/100 km	5.01 l/100 km	16.52 kWh/100 km
Difference from official fuel consumption	+43%[a]	+56%[b]	+28%[c]	+28%[d]

Means from a sample of vehicles that have been driven at least 1500 km. Individual sample size: Volvo V40 D3 (39), Volvo V40 T4 (4), Toyota Prius (107) and BMW i3 (6).
[a] (6.16–4.3)/4.3.
[b] (8.59–5.5)/5.5.
[c] (5.01–3.9)/3.9.
[d] (16.52–12.9)/12.9.

Table 5
Total cost of ownership computation result (€).

	Volvo V40 D3	Volvo V40 T4	Toyota Prius	BMW i3
Depreciation	€12 815 (64%)	€12 605 (60%)	€14 412 (68.5%)	€19 905[a] (105%)
Fuel	€4132 (20.5%)	€5814 (27%)	€3391 (16%)	€633 (3%)
Interest	€1355 (7%)	€1332 (6%)	€1524 (7%)	€1660 (9%)
Insurance	€908 (5%)	€844 (4%)	€714 (3.5%)	€926 (5%)
Maintenance and Repair	€374 (2%)	€374 (2%)	€1029 (5%)	€0[b] (0%)
Taxes and Subsidies	€343 (1.5%)	€189 (1%)	€0 (0%)	−€4202 (−22%)
TCO	€19 927	€21 158	€21 070	€18 922
TCO per month	€554	€588	€585	€526
TCO per kilometres	€0.443	€0.470	€0.468	€0.420

( ) Rounded percentage of the particular TCO factor in relation to the TCO of that vehicle.
[a] Depreciation rate without the government subsidy. Percentage over 100% of the total reflect the large effect of the government subsidy.
[b] BMW includes free service for the first 3 years of ownership for all their new cars, BMW only has a 2-year warranty but the BMW i3 will in this study be assumed to not suffer any technical malfunction during the third year of ownership.

assume a similar cost structure as the other three vehicles in the sample, they would overestimate the cost of owning the BMW i3 by 20–31% or in financial terms €3782–€5882 over a three year ownership period.

The cost difference between BEVs, ICEVs and HEVs brings up some interesting scenarios for the future. The largest single contributor to the high purchasing price of BEVs is the cost of the battery pack that costs significantly more than the drivetrain of an ICEV. Battery prices are expected to decrease in the future, a development that will make BEVs more competitive both in terms of purchasing price and TCO. The low running ownership cost of BEVs also presents a potentially interesting effect on their resell value and for longer ownership periods. Without the high rate of depreciation and interest costs associated with buying a new BEV, the TCO for a used BEV could be significantly lower than comparable used ICEVs and HEVs. These are factors that could potentially positively affect the resell value of BEVs and hence also make new BEVs even more TCO-competitive. A similar effect could also make BEVs more TCO competitive for longer ownership periods since running cost make up an increasing share of the total cost for older vehicles. The limited battery lifetime and the cost associated with its replacement could, however, have a negative effect on the resell value and long term TCO of BEVs.

If BEVs indeed then could be cost competitive with ICEVs and also come with added environmental and societal benefits, why then are BEVs slow to diffuse? Part of the answer certainly comes from the limited range of BEVs and low access to charging infrastructure that do not fit into the lifestyle of some vehicle buyers, as discussed earlier in this paper. For some vehicle buyers, those factors might not present the main barriers; other factors such as cost could be of major significance. Since economic factors have been found to be important for vehicle purchasing in general, the authors have no reason to believe that they would not also be of importance in the case of BEVs. This study gives reasons to suspect that part of the answer to the slow diffusion of BEV could be a low awareness and the use of comprehensive TCO analysis, i.e. lack of information (Geroski, 2000), although further research is needed to confirm this suspicion. That consumers have the true picture is important as innovation diffusion is largely driven by

Table 6
Relationship between TCO and purchasing price.

	Volvo V40 D3	Volvo V40 T4	Toyota Prius	BMW i3
TCO/purchasing price	78%	84%	73%	53%

relative advantage — if advantages are not known, the market will remain reluctant, (Rogers, 1962). This study indicates that there might be untapped economic benefit in BEVs; potential that can be extracted by public policy and vehicle marketing in order to increase the speed of BEV diffusion. Policies could be designed to increase the vehicle buyer's awareness and knowledge regarding the economic advantages that BEVs possess compared to conventional vehicles. Increasing the relative advantage of BEVs through information rather than increased cash subsidies has the potential to yield a higher return on investment. One suggested initiative for policy makers to increase consumer knowledge would be a credible and easy-to-use TCO comparison tool that would aggregate available vehicle cost data to illustrate TCO divergences between different drive trains. This study finds that vehicle TCO data is not easily accessible. Vehicle producers that wish to sell more BEVs would be wise to consider experimenting with information campaigns and/or new business models that better internalize the inherent running cost benefits of the electric drive train. One could imagine that a TCO business model where all cost are considered and vehicle buyers pay in monthly instalments could yield a positive effect rather than marketing the intimidating high purchasing price of BEVs as it is conducted currently. This has proved effective for other products such as mobile phones bundled with a calling, texting and data plan, and if done correctly could be of significance for BEVs as well.

7. Conclusion and future research

The purpose of this study is to deliberate on the creation and usage of a consumer centric TCO model and its implications for theory and practice. This study finds that creating a consumer centric TCO model is a challenging task dependent on access to relevant data and reasonable assumptions about future conditions. Once constructed and tested on current vehicles and conditions it can nevertheless be of great value to both practice and theory. The authors find a discrepancy between purchasing price and TCO among the different vehicle drive trains, where the BEV had significantly lower running cost compared to ICEVs and HEV, leading to a competitive TCO. Previous work on the energy paradox and factors that affect choice of vehicle have confirmed that most vehicle buyers do not place great significance on the operating costs of owning a vehicle. Armed with that assumption, this study concludes that the TCO framework likely contributes less to the individuals' current choice of vehicle than rational economic models would predict. Lack of TCO realization among vehicle buyers might hence be a significant contributing factor to why BEVs are diffusing so slowly. More studies that investigate the prevalence of TCO analysis among vehicle buyers and their reasoning for using or not using TCO are preferably needed in order to confirm this, studies that can also consider possible weaknesses in the current TCO computations relating to the small vehicle sample and assumptions made. Nevertheless, this study points out an interesting direction for further studies and the possible need for credible and easy-to-access tools in order to compare TCO between different vehicles as well as experimentation with information campaigns and new business models. Future studies could yield high impact results that could prove valuable for governments, which, through policy, wish to increase the share of BEVs, and for vehicle manufacturers, which more clearly would like to point to the cost benefits with BEVs in their marketing.

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