China’s electric vehicle subsidy scheme: Rationale and impacts

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HIGHLIGHTS
- China’s phase I and phase II electric vehicle subsidy schemes were reviewed.
- Major electric vehicle models in China’s vehicle market were reviewed.
- The ownership costs of five defining electric passenger vehicle models were compared.
- Policies to promote electric vehicle deployment in China were discussed.

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ABSTRACT
To promote the market penetration of electric vehicles (EV), China launched the Electric Vehicle Subsidy Scheme (EVSS) in Jan 2009, followed by an update in Sep 2013, which we named phase I and phase II EVSS, respectively. In this paper, we presented the rationale of China’s two-phase EVSS and estimated their impacts on EV market penetration, with a focus on the ownership cost analysis of battery electric passenger vehicles (BEPV). Based on the ownership cost comparison of five defining BEPV models and their counterpart conventional passenger vehicle (CPV) models, we concluded that in the short term, especially before 2015, China’s EVSS is very necessary for BEPVs to be cost competitive compared with CPVs. The transition from phase I to phase II EVSS will generally reduce subsidy intensity, thus resulting in temporary rise of BEPV ownership cost. However, with the decrease of BEPV manufacturing cost, the ownership cost of BEPV is projected to decrease despite of the phase-out mechanism under phase II EVSS. In the mid term of around 2015–2020, BEPV could become less or not reliant on subsidy to maintain cost competitiveness. However, given the performance disadvantages of BEPV, especially the limited electric range, China’s current EVSS is not sufficient for the BEPV market to take off. Technology improvement associated with battery cost reduction has to play an essential role in starting up China’s BEPV market.

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1. Introduction

China is facing severe environmental and climate challenges (Guan et al., 2008). Road transport emits around 8% of China’s total energy related greenhouse gas (GHG) emissions (IEA, 2013) and the share is increasing very fast with the boom of vehicle stock (Hao et al., 2011d). As EVs offer the potentials to address oil security, air pollution and climate change, China took EV deployment as an essential strategy to tackle local pollution and GHG emissions issues. In the “Energy Saving and New Energy Vehicle Industry planning” issued in 2012, the accumulated sales of battery electric vehicle (BEV) and plug-in hybrid electric vehicles (PHEV) were projected to reach 0.5 million in 2015 and 5 million in 2020. To accomplish this target, China has launched comprehensive programs and policies to promote EV market penetration.
Among all the policy instruments, vehicle purchase subsidy plays an essential part in starting up China’s EV market. Vehicle purchase incentives for EVs, notably subsidies and tax credits, have been adopted in many countries. In the U.S., activated by the Energy Policy Act of 2005, a maximum of $3400 tax credit was provided to hybrid electric vehicle (HEV) purchase between 2006 and 2010. The incentive for PHEV and BEV purchase started in 2010, which offers $2500–$7500 tax credit to PHEV and BEV purchase depending on vehicle’s battery capacity (Internal Revenue Service, 2011). In Japan, the “Green Vehicle Purchasing Promotion Measures”, which was passed by the Japanese Diet in 2009, provides purchase of environmentally friendly vehicles with up to 100,000 Yen subsidy and a combination of tax reduction and exemption incentives (JAMA, 2010). Under the “Clean Energy” subsidy program, EV purchase is eligible for a maximum of 850,000 Yen subsidy in 2013. As the world’s most determined EV propellant, China launched the Electric Vehicle Subsidy Scheme (EVSS) in Jan 2009, followed by an update in Sep 2013, which we named phase I and phase II EVSS, respectively. The two-phase subsidy scheme specifies the subsidy duration, scope, standard, phase-out mechanism and pilot cities for both public and private EV purchase. It is one of the world’s most comprehensive and incentive-strong subsidy schemes.

Vehicle purchase incentive can pose a wide range of impacts on vehicle market. Existing studies have evaluated the impacts of vehicle purchase incentive on many aspects, with a focus on consumer purchase behavior and vehicle market penetration. These studies typically employ an agent-based consumer choice model to simulate the effect of cost and other non-cost factors on vehicle choice. Mueller and de Haan (2009) established a two-stage model of individual decision process to estimate the effect of energy-efficiency feebates on consumer choice of new cars, concluding that consumers can have different reactions to feebates, either switching to a smaller car or a more efficient car with the same class. Eppstein et al. (2011) developed a spatially explicit agent-based vehicle consumer choice model to study the various influences, including policy incentives, on PHEV market penetration. Their study indicates that a ready-estimate of ownership cost to consumers can significantly enhance the market penetration of PHEVs. Al-Alawi and Bradley (2013) examined existing EV market modeling studies, calling for an improved interface with federal and state policy and its effect on automotive markets. Several studies discussed vehicle subsidy in a strategy framework. Yang (2010) argued that subsidy alone is not sufficient for the commercialization of electric vehicles, while limiting conventional vehicles could be more effective. Skerlos and Winebrake (2010) argued that a consumer income and location of purchase specific subsidy policy would yield higher social benefits. Ross Morrow et al. (2010) compared the policies of fuel tax, fuel economy standard and vehicle purchase tax credit, concluding that vehicle purchase tax credit is expensive and inefficient at reducing emissions.

As vehicle ownership cost is the essential factor affecting vehicle choice, many studies have focused on the evaluation of vehicle ownership cost. These studies typically include a set of computer simulation based or real-world demonstration based fuel economy and cost estimates for alternative vehicles. Plotkin and Singh (2009) compared the ownership costs of several alternative vehicle powertrains for light duty vehicles, concluding that advanced CV and HEV powertrains are likely to offer better cost effectiveness for fuel saving. Burke and Zhao (2012), based on similar approach, projected the ownership costs of alternative vehicle powertrains through 2030, with an evaluation of the impact of battery cost uncertainty. Peterson and Michalek (2013) estimated the cost effectiveness of PHEV battery capacity, finding that low-capacity PHEV and HEV are the more favorable solutions. Several studies further investigated the effect of alternative vehicle penetration on the energy consumption and emissions of the whole vehicle fleet at a macro level (Al-Ghandoor, 2013; Al-Ghandoor et al., 2012; Geng et al., 2013; Hang et al., 2013; Hao et al., 2014a, 2011b, 2010, 2012; Ou et al., 2012; Zhu, 2010). In general, existing studies have established a mature framework for vehicle ownership cost analysis. However, there is a lack of studies on vehicle purchase subsidy and ownership cost in China’s context. Although China is providing intensity subsidy to EV purchase, their effect on consumer’s purchase behavior is unclear. In this study, based on a comprehensive review of China’s EVSS and market available EV models, we estimated the impact of EVSS on consumer’s vehicle ownership cost, with the purpose of providing a thorough vision into the economic aspects of China’s EVSS.

The following sections of this paper are organized as below. Section 2 investigates the rationale of China’s phase I and phase II EVSS in terms of private purchase subsidy and public purchase subsidy, respectively. Section 3 examines the available EV models in China’s vehicle market and their qualified subsidy under EVSS, with a brief discussion of the impacts of EVSS update on vehicle manufactures. Section 4 estimates the impacts of EVSS on vehicle ownership costs based on the comparison between China’s five defining BEPV modals and their counterpart CPV models. Section 5 presents the policy implication derived from the ownership cost analysis. Section 6 draws conclusions from the whole study.

2. Rationale of China’s EV subsidy schemes

Table 1 presents a comprehensive description of China’s phase I and phase II EVSS. In this section, we described China’s EVSS in the order of subsidy duration, scope, standard, phase-out mechanism and pilot cities.

2.1. Subsidy duration

The phase I EVSS started in 2009. In the beginning, subsidy was only available to public procurement, mostly transit buses and taxis. In 2010, subsidy was extended to include private purchase. The phase I EVSS ended at the end of 2012. After nine months of policy absence, the phase II EVSS was announced in Sep 2013 and will continue through 2015. It covers both public and private purchase.

2.2. Subsidy scope

Under phase I EVSS, the subsidy for public procurement covers all categories of EVs (HEV, PHEV, BEV and FCEV). The subsidy for private purchase covers only PHEV and BEV. HEV is considered as fuel-efficient vehicle and is subsidized under Fuel-Efficient Vehicle Subsidy Scheme (FEVSS). But the subsidy intensity of FEVSS (¥3000 per vehicle) is far lower than EVSS (Up to ¥60,000 per vehicle). Under phase II EVSS, subsidy covers PHEV, BEV and FCEV. Both public and private purchases of HEVs are excluded from the subsidy scheme. As nearly half of subsidized public vehicles during phase I EVSS are HEVs, the exclusion of HEV in Phase II EVSS will greatly curtail the subsidy benefits. There has been great controversy over whether HEV should be included in EVSS, as many people believe HEV should be given equal priority to PHEV and BEV. This subsidy scope partially reflects China’s strategy on EV development, which place more priority on pure electric driving technologies.

2.3. Subsidy standard

2.3.1. Private purchase

Under phase I EVSS, subsidies for private purchase of PHEPV and BEPV are based on vehicle’s battery capacity, with subsidy...
2.3.2. Public procurement

Public vehicles qualified for subsidy include transit buses, taxis, government, postal service and refuse vehicle. Under phase I EVSS, around half of subsidized public vehicles are transit buses. In this section, we focused our discussion on transit buses.

Under phase I EVSS, hybrid electric buses and plug-in hybrid electric buses are qualified for ¥200,000–¥420,000 subsidy, depending on the bus’s maximum electric power ratio and fuel saving ratio. The testing procedures of maximum electric power ratio and fuel saving ratio are specified in the “Outline for testing the maximum electric power ratio and fuel saving ratio of energy-saving and new energy vehicles” (CVTSC, 2009). Generally, the maximum electric power ratio is obtained through dividing the maximum motor power by the sum of motor power and engine power. The fuel saving ratio is obtained by comparing the fuel consumption rate of hybrid electric buses with their counterpart conventional bus models. Subsidies for battery electric buses and fuel cell electric buses are fixed to ¥500,000 and ¥600,000, respectively. All subsidized buses are required to be longer than 10 m.

Under phase II EVSS, hybrid electric buses are excluded from the subsidy scheme. Plug-in hybrid electric buses with length of 10 m or longer are qualified for ¥250,000 subsidy. Subsidy for battery electric buses is categorized into three levels. Battery electric buses with length of 10 m or longer, 8–10 m and 6–8 m are qualified for ¥500,000, ¥400,000 and ¥300,000 subsidies, respectively. The subsidy for fuel cell electric buses is fixed to ¥500,000.

2.4. The subsidy phase-out mechanism

For both two phases of EVSS, there are subsidy phase-out mechanisms (SPM). The SPM specifies the condition under which subsidy should be reduced. Under phase I EVSS, SPM is only effective for private purchase. It requires that once the sales of PHEPV or BEPV from one vehicle manufacturer exceed 50,000, subsidy for EVs of this manufacturer should be reduced. The reduction range is not specified. Actually, as no single vehicle manufacturer has sold more than 50,000 PHEPVs or BEPVs, the SPM has never been triggered during phase I EVSS. Under phase II EVSS, the SPM requires that the subsidy for all EVs should be reduced by 10% and 20% in 2014 and 2015, except for plug-in hybrid electric and battery electric transit buses. The SPM reflects the government’s expectation of EV cost reduction with higher level of commercialization.

2.5. Pilot cities

China’s EVSS is implemented in selected cities and regions. Only EV purchases in the selected places are qualified for subsidy. Fig. 1 presents the cities and regions involved in phase I and phase II EVSS.

Thirteen cities were selected in 2009 as the first batch of pilot cities to implement phase I EVSS for public procurement, including Beijing, Shanghai, Chongqing, Changchun, Dalian, Hangzhou, Jinan, Wuhan, Shenzhen, Hefei, Changsha, Kunming and Nanchang. The second batch of 7 cities and third batch of 5 cities were included in phase I EVSS for public procurement in 2010, including Tianjin, Haikou, Zhengzhou, Xiamen, Suzhou, Tangshan, Guangzhou, Shenyang, Chengdu, Hohhot, Nantong and Xiangfan. The subsidy

Table 1
China’s phase I and phase II EVSS.

<table>
<thead>
<tr>
<th>Phase I</th>
<th>Phase II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target market</td>
<td>Public</td>
</tr>
<tr>
<td>Subsidy scope</td>
<td>HEV, PHEV, BEV, FCEV</td>
</tr>
<tr>
<td>Subsidy standard</td>
<td>HEV, Bus</td>
</tr>
<tr>
<td></td>
<td>PHEV, Bus</td>
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<tr>
<td></td>
<td>BEV, Bus</td>
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<tr>
<td>Phase-out mechanism</td>
<td>Not mentioned</td>
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<tr>
<td>Pilot cities</td>
<td>25 Cities</td>
</tr>
</tbody>
</table>

Notes: L denotes vehicle length; R denotes electric range; PV denotes passenger vehicle; SPV denotes special purpose vehicle.

- a) Lead–acid battery powered passenger vehicles are not included in the subsidy scheme.
- b) The subsidy amount for super-capacitor and Lithium Titanate battery powered electric buses is fixed to ¥150,000.
- c) Battery electric and plug-in hybrid electric buses are not included in the phase-out mechanism.
- d) Subsidy for hybrid electric buses was extended to all the cities in China in 2012.
- e) Maximum subsidy amount limited to ¥50,000.
- f) Maximum subsidy amount limited to ¥60,000.
- g) Maximum subsidy amount limited to ¥35,000.
for hybrid electric transit buses was extended to be nationwide available in late 2012.

The phase I EVSS for private purchase was implemented in 6 cities including Beijing, Shanghai, Hangzhou, Shenzhen, Hefei and Changchun. These six cities were required to provide matching subsidy in additional to the subsidy from central government. Table 2 presents the local matching EV subsidy schemes. The local subsidy schemes are diverse in terms of subsidy criteria and amount. The maximum subsidy for BEPV purchase in Beijing, Hangzhou and Shenzhen is ¥60,000, which is the same as the national subsidy amount. That is, BEPV purchase in these three cities can be qualified for as high as ¥120,000 subsidy per vehicle. Besides matching subsidy, there are also some non-subsidy incentives for PHEPV and BEPV purchase. For example, in Beijing and Shanghai, where the number of vehicle license plates issued per month is under strict control, PHEPV and BEPV are qualified for dedicated and free license plates (the policy in Beijing is temporary and might be canceled in 2014). In Changchun, where vehicle use is restricted in certain regions, PHEPV and BEPV are not subject to vehicle use restrictions.

28 cities and regions have been included in phase II EVSS and the scope might be further expanded. Priority was given to regions with severe particle matter pollutions. The 28 cities and regions are Beijing, Tianjin, Taiyuan, Jincheng, Dalian, Shanghai, Ningbo, Hefei, Wuhu, Qingdao, Zhengzhou, Xinxian, Wuhan, Xiangyang, Chang-Zhu-Tan regions, Guangzhou, Shenzhen, Haikou, Chengdu, Chongqing, Kunming, Xi’an, Lanzhou, Hebei city group, Zhejiang city group, Fujian city group, Jiangxi city group and Guangdong city group.

3. EV models and their qualified subsidies

3.1. Battery electric passenger vehicles

Table 3 summarizes the major BEPV models currently available in China’s vehicle market. For each vehicle model, its manufacturer
With the update of EVSS, the qualified subsidies for most vehicle models have changed significantly. Fig. 2 presents the battery capacities and electric ranges of available BEPV models and the resulting qualified subsidies under phase I and phase II EVSS. As it shows, most BEPV models are equipped with 20 kW h or higher battery packs and are qualified for the maximum subsidy (¥60,000) under phase I EVSS. However, under phase II EVSS, only BYD E6, with electric range of 300 km, is qualified for the ¥60,000 subsidy. Five models (ZOTYE 5008EV, ZOTYE M300EV, LIFAN 620EV, LIFAN 620CEV and SAIL SPRINGO) are qualified for the ¥50,000 subsidy. Other models are only qualified for the ¥35,000 subsidy. There is a general decrease of subsidy amount for these BEPV models. This implies that the subsidy intensity of phase II EVSS is generally lower than phase I.

The change of subsidy standard favors long-electric-range BEPVs. Under phase II EVSS, manufacturers are encouraged to produce BEPVs with larger battery capacity and higher energy efficiency. It should be noted that there are quite a few BEPV models whose electric ranges are around 150 km. Considering the big gap between the lowest (¥35,000) and medium (¥50,000) subsidy levels, these models are likely to be improved to overcome the 150 km threshold. 150 km might become the bottom-line-electric-range for major BEPV models in the near future. Besides, the change of subsidy criteria from battery capacity to electric range might pose a positive impact on manufacturers to place higher priority on vehicle’s energy efficiency.

It should be noted that PHEPV and BEPV powered by lead–acid batteries are not qualified for subsidy. Among all BEPV models listed in Table 3, CHERRY QQ3EV is the only BEPV model powered by lead–acid battery. Even without subsidy, CHERRY QQ3EV is the top-selling BEPV model in China in 2012. The exclusion of lead–acid battery powered BEPVs can be mostly attributable to their relative low cost compared with lithium ion battery powered BEPVs. Besides, the government considers lead–acid battery a low-end technology and shows less interest in its development.
3.2. Plug-in hybrid electric passenger vehicles

There are currently only a few available PHEPV models in China. Taking BYD F3DM for example, its battery capacity is 16 kW h, which can sustain an electric range of 60 km. Under phase I EVSS, it is qualified for ¥48,000 subsidy. However, under phase II EVSS, it is no longer qualified for subsidy as its electric range is lower than 80 km. Chevrolet Volt, as another example, also faces decrease in subsidy amount (from ¥48,000 to ¥35,000) after the implementation of phase II EVSS.

The impact of subsidy changes on PHEPV manufactures is significant. Considering the 80-km electric range requirement of phase II EVSS, PHEPV manufactures will be encouraged to produce PHEPVs with electric range of higher than 80 km. Despite this, from the subsidy perspective, manufactures do not have the motivation to produce PHEPVs with electric range of much higher than 80 km, as the subsidy is fixed to ¥35,000 regardless of the electric range. 80 km (50 mile) might become the preferred electric range for the design of PHEPV in the near future. This change in subsidy standard reflects China’s strategy on PHEPV development, which place more focus on high-capacity PHEPV rather than low-capacity PHEPV.

3.3. Buses

The impact of subsidy scheme update on hybrid electric buses is significant. Taking the YUTONG 12-m hybrid bus for example, under phase I EVSS, it is qualified for ¥360,000 subsidy, which covers around one third of its price. In current situation, this subsidy is necessary for hybrid electric buses to compete with conventional diesel buses. As hybrid electric buses are excluded from phase II EVSS, heavy burden will be put on hybrid electric bus manufactures.

The subsidy for 10-m or longer battery electric buses maintains. Considering the 80-km electric range requirement of phase II EVSS, BEPV manufactures will be encouraged to produce BEPVs with electric range of higher than 80 km. Despite this, the subsidy perspective, manufactures do not have the motivation to produce BEPVs with electric range of much higher than 80 km, as the subsidy is fixed to ¥35,000 regardless of the electric range. 80 km (50 mile) might become the preferred electric range for the design of PHEPV in the near future. This change in subsidy standard reflects China’s strategy on PHEPV development, which place more focus on high-capacity PHEPV rather than low-capacity PHEPV.

4. Impacts of EVSS on passenger vehicle ownership cost

Consumer’s vehicle choice is affected by several factors, among which the cost factor, which we measured using vehicle ownership cost, shows dominating impact. In research perspective, consumer’s vehicle choice has been widely modeled based on consumer choice theory, which relates preferences to consumption expenditures. Greene (2001) employed nested multinomial logit model, a kind of discrete choice model, to analyze the market penetration of alternative vehicles. Vehicles are fit into a three-level nesting structure. The first, second and third level of nesting predict the probability of choice of fuel types, vehicle technologies and technology sets, respectively. Each vehicle choice alternative is assigned with a utility, which is a function of its attributes and other variables. The considered vehicle attributes include vehicle price, fuel cost, non-fuel operation and maintenance (O&M) cost, range capacity, acceleration performance, luggage space etc. Among these attributes, the cost-related items, including vehicle price, fuel cost and non-fuel O&M cost, which are commonly summarized as vehicle ownership cost, shows dominating impact on the entire utility. In this sector, we focused our analysis on the impacts of EVSS on the ownership cost of BEPVs.

4.1. Vehicles to be compared

The top 5 best-selling BEPV mods in 2012, which are CHERY QQ3EV, JAC iEV3, BYD E6, ZOTYE 5008EV and BAIC E150EV, accounted for over 95% of total BEPV sales. We chose these five BEPV models to analyze their ownership costs.

To make the ownership cost analysis on a comparable basis, we also chose five similar CPV models as counterparts of the five BEPV models. Except for BYD E6, all other 4 BEPV models are modified based on existing CPV models, which we chose as the counterpart models. For BYD E6, which is a 5-seat MPV, we chose BYD M6, a MPV from the same manufacturer, as the counterpart model. Regarding engine displacement, JAC TONGYUE, ZOTYE 5008 and BAIC E150 are optional with 1.3 L and 1.5 L. Considering the comparability of vehicle performance, we chose the 1.3 L engine displacement for these three models. CHERRY QQ3 is optional with 0.8 L and 1.0 L models, between which we chose the 1.0 L model. BYD M6 2.4 L model was chosen. All models chosen are equipped with Automatic Transmission (AT), Automated Mechanical Transmission (AMT) or Continuously Variable Transmission (CVT), depending on the availability of transmission types. Under same engine displacement and transmission configurations, some vehicle models are optional with different accessories and interior trim configurations. Under this situation, we chose the models with highest configurations. The parameters of counterpart CPV models are presented in Table 4. It should be noted that the fuel consumption rate (FCR) values, which were obtained from China’s official FCR database (Ministry of industry and information technology of PRC, 2013), are labeled values, which were tested under NEDC. The real-world FCR is around 15% higher than the labeled FCR (Hao et al., 2011a, 2012).

4.2. Ownership cost decomposition

Vehicle ownership cost is defined as the present value of consumer cost caused by owning a vehicle (Lin et al., 2013). For ease of comparison, we used per km cost, measured in yuan/km, as the index for vehicle ownership cost. We classified vehicle ownership cost into vehicle purchase cost, fuel cost, non-fuel O&M cost and vehicle salvage value, as Eq. (1) shows. Eqs. (2)–(5) present the decomposition of each ownership cost component.

\[
OC_n = \frac{PC + \sum_{i=1}^{n} \left( \frac{FC_i + OC_i}{1 + DR_i} \right)}{\sum_{i=1}^{n} DT_i} \times RV_n (1)
\]
where, $OC_n$ is the ownership cost for vehicles lasting $n$ years (yuan/km); $PC$ is the vehicle purchase cost (yuan); $FC_i$ is the fuel cost at vehicle age $i$ (yuan); $OC_i$ is the non-fuel O&M cost at vehicle age $i$ (yuan); $RV_n$ is the vehicle salvage value at vehicle age $n$ (yuan); $DR$ is the discount rate, which is assumed to be 6\% in the analysis (Hao et al., 2014b); and $DT_i$ is distance traveled at vehicle age $i$ (km).

4.2.1. Vehicle purchase cost and salvage value

\begin{equation}
PC = MSRP + VPT + VRF - SUB
\end{equation}

\begin{equation}
RV_n = MSRP \times (1 - VDR)^n
\end{equation}

where, $MSRP$ is the manufacturer suggested retail price (yuan); $VPT$ is the vehicle purchase tax (yuan); $VRF$ is the vehicle registration fee (yuan); $SUB$ is the vehicle purchase subsidy (yuan); and $VDR$ is the vehicle value depreciation rate.

Eq. (2) presents the calculation of vehicle purchase cost. Vehicle purchase cost consists of vehicle price, vehicle purchase tax, vehicle registration fee and subsidy. We used MSRP to measure vehicle price. Except for CHERY QQ3EV, which is powered by lead-acid battery, the MSRP of other four BEPV models is 2.4 to 3.8 times the MSRP of counterpart CPV models. The higher MSRP can be mostly attributable to the high cost of Li-ion batteries. Vehicle purchase tax is calculated as 10\% of before-VAT (Value Added Tax, 17\%) vehicle price, i.e. MSRP divided by 1.17. It should be noted that vehicle purchase tax for BEPVs is calculated based on post-subsidy vehicle price. Registration fee is around ¥500 per vehicle. Qualified subsidy for each vehicle model is drawn from Table 3. Subsidy from local government is assumed to be 50\% of subsidies from central government.

Vehicle salvage value can be estimated by the resale price of second-hand vehicles. In this study, we introduced the parameter of vehicle value depreciation rate to estimate vehicle salvage value, as Eq. (3) shows. There is little information of vehicle value depreciation rate of China’s passenger vehicles. We assumed the depreciation rate to be 20\%, which is backed by the U.S. second-hand vehicle market data (Kelley Blue Book, 2013). It should be noted that even in the U.S. market, there is little information on the depreciation rate of BEPVs. BEPVs confront the issue of battery performance degradation and might yield a higher depreciation rate. However, due to lack of data, we used the same depreciation rate for BEPV and CPVs.

4.2.2. Fuel cost

\begin{equation}
FC_i = FCR \times FP \times DT_i
\end{equation}

where, $FCR$ is the vehicle fuel consumption rate (L/100 km or kWH/100 km); and $FP$ is the fuel price (yuan/L or yuan/kWH).

As Eq. (4) shows, fuel cost is determined by FCR, fuel price and distance traveled. The labeled FCRs of CPVs were listed in Table 4. We assumed the real-world FCR to be 15\% higher than the labeled FCR. The FCRs of BEPVs were reported under different driving conditions, including NEDC, urban driving cycle, 30-kph constant speed and 60-kph constant speed driving. We converted the FCR under urban driving cycle, 30-kph constant speed and 60-kph constant speed to FCR under NEDC by multiplying the coefficients of 0.93, 1.28 and 1.33, respectively. These coefficients were obtained by referring to models providing FCR under multi-driving conditions. The FCR under NEDC was then converted to real-world FCR by the same method as CPVs. As of Oct, 2013, the prices for 92# gasoline (comparable to 87# gasoline in the U.S.) and commercial electricity were ¥7.83/L and ¥0.81/kWH in Beijing, respectively. Regarding distance traveled, we assumed a typical driving profile with annual driving distances of 12,000 km. As suggested by existing studies (Davis et al., 2013), vehicle travel tends to decrease as vehicle age grows. We assumed the driving distance to decrease by 3\% per year. Note that we assumed that BEPV is capable of covering all the distance driven. This assumption might not hold when considering the range limit of BEPVs. Hao et al. (2014b) discussed the case when considering alternative transportation cost due to range limit of BEPVs. In this study, to simplify the comparison, we ignored the discussion of alternative transportation cost.

4.2.3. Non-fuel O&M cost

\begin{equation}
OC_i = IS_i + UT_i + MC_i
\end{equation}

where, $IS_i$ is the insurance cost at vehicle age $i$ (yuan); $UT_i$ is the vehicle use tax at vehicle age $i$ (yuan); and $MC_i$ is the maintenance cost at vehicle age $i$ (yuan).

As Eq. (5) shows, non-fuel O&M cost consists of maintenance cost, insurance cost and vehicle use tax. Parking fee and toll are the same for CPV and BEPV, for which we did not include in our analysis. Vehicle maintenance is normally carried out per 5000 km driven, with the maintenance cost of around ¥500. Based on this, we assumed the maintenance fee to be ¥0.1/km. Note that the maintenance fee of BEPV and CPVs could be quite different due to different vehicle configurations, especially when considering the battery replacement cost of BEPVs. But due to lack of data, we ignored this difference.

Vehicle insurance includes the compulsory insurance for traffic liability and optional commercial insurances. The compulsory insurance for traffic liability is ¥950/year for passenger vehicles. The commercial insurances are of wide varieties and most of them are correlated to vehicle price. In this study, we chose the three most commonly purchased commercial insurances, which are vehicle damage insurance, third-party liability insurance, and deductible-exempt insurance, as our comparison basis. The vehicle damage insurance and deductible-exempt insurance are linearly correlated with vehicle price, implying a higher insurance cost for BEPVs. The total insurance cost is finally discounted with a coefficient to reflect the average market discount provided by the insurance companies.

Vehicle use tax was estimated based on Beijing’s vehicle use tax scheme. The vehicle use taxes are graded based on vehicle engine displacements. The vehicle use tax for the five CPVs in our study ranges from ¥300/year to ¥900/year. BEPVs are assumed to be exempted from vehicle use tax, which is in line with Beijing’s current policy.

4.2.4. Scenario assumptions

To help fully understand the impact of subsidy on vehicle ownership cost, we estimated the vehicle ownership cost under phase I EVSS (2012), phase II EVSS (2013) and phase II EVSS under phase-out mechanism (2014 and 2015). We also explored the 2020 scenario. The scenarios were established with one midrange case and one optimistic case to address the uncertainty. The optimistic case reflects the possibility under high gasoline price and successfully reduced Li-ion battery cost. The midrange case reflects the possibility under moderate gasoline price and Li-ion battery cost. In this section, we presented the assumptions needed to establish the scenarios. Among all the factors affecting vehicle ownership cost, vehicle price, FCR and fuel price are with significant uncertainty.

In China’s vehicle market, the vehicle price of CPVs has stabilized over recent years. However, with the tightening of FCR and emission standards, CPVs might confront cost increase associated with fuel saving and emission control technologies. We assumed a 10\% increase in vehicle MSRP in 2020 for CPVs.

The labeled FCR of the five CPV models in our study ranges from 6.3 L/100 km to 10.6 L/100 km. As projected by China’s
passenger vehicle fuel consumptions regulation, the average labeled FCR of 2020 passenger vehicle models should decrease to 5 L/100 km. Based on this target, we assumed that the FCR of CPVs decrease by 5% in 2015 and 20% in 2020.

China’s gasoline price has increased rapidly over recent years. From an international comparison, if only converted based on exchange rate, the gasoline price in China is higher than the U.S. while lower than most European countries. Gasoline price is affected by numerous factors and is unlikely to be projected. We assumed two cases to address the uncertainty. Under optimistic case, gasoline price in 2020 rises to the level of current gasoline price in Germany, which is around ¥13/L. This might happen if international oil price raises continuously or government poses high fuel tax on gasoline. Under the midrange case, gasoline price is assumed to rise at half the rate under optimistic case.

The vehicle price of BEPVs depends critically on battery cost, which normally accounts for over half of total vehicle cost. The current cost of Li-ion battery is around ¥4000/kW h–¥6000/kW h. As projected by China’s “Energy Saving and New Energy Vehicle Industry planning”, the cost of Li-ion battery will decrease to ¥2000/kW h in 2015 and ¥1500/kW h in 2020, implying huge potential for the cost reduction of BEPVs. To address the uncertainty of battery cost, we assumed two cases for battery cost decrease, which is reflected in vehicle MSRP change. Under optimistic case, the battery cost decreases as projected by the planning. The glider cost (vehicle cost other than battery cost) decreases by 10% in 2015 and 20% in 2020, making the MSRP of BEPVs decrease by around 30% in 2015 and 40% in 2020. The decrease of battery cost under midrange case is assumed to be slower than under optimistic case, which was at ¥3500/kW h in 2015 and ¥3000/kW h in 2020. The glider cost decrease rate was assumed to be the same with that under optimistic scenario. Note that as CHERRY QQ3EV is powered by lead–acid battery, we assumed that its MSRP would not change over time.

The energy efficiency of BEPVs is significantly higher than CPVs. Due to the high efficiency vehicle configuration, FCR of BEPVs are likely to maintain at the current level with little improvements. In this study, we assumed that the FCR of BEPVs would not change over time. Regarding electricity price, we assumed commercial electricity price will rise by 15% in 2015 and 50% in 2020. All data in non-mentioned years were obtained through linear interpolation. The scenario assumptions were summarized in Table 5.

4.3. Ownership cost comparison

The ten-year ownership costs of the five BEPV models and their counterpart CPV models were presented in Fig. 3(a) through Fig. 3(e). Note that vehicle ownership cost changes with vehicle age. We used ten years as the basis for calculation and comparison as it is the typical length of owning a passenger vehicle in China (Hao et al., 2011a, 2011c).

Fig. 3(a) presents the ownership cost comparison between CHERRY QQ3 and QQ3EV. As the ownership cost of QQ3EV is not affected by Li-ion battery cost (QQ3EV is powered by lead–acid battery) or subsidy (QQ3EV is not qualified for subsidy), only its value under midrange case was presented. Under both midrange case and optimistic case, the ownership cost of QQ3EV is significantly lower than QQ3. The ownership cost difference tends to be bigger in 2020. This comparison suggests that lead–acid battery powered BEPVs can be quite cost competitive compared with CPVs. The low ownership cost of QQ3EV seems to capture the most important reason why QQ3EV yielded the highest sales among all BEPV models in 2012.

Fig. 3(b) presents the ownership cost comparison between JAC iEV3 and TONGYUE. Under midrange case, if without subsidy, the ownership cost of iEV3 is significantly higher than TONGYUE. This gap becomes smaller over time and tends to be closed in 2020. If with subsidy, the ownership cost of iEV3 is lower than TONGYUE in 2012 (under phase I EVSS). In 2013 (under phase II EVSS), the ownership cost of iEV3 increases significantly and surpasses TONGYUE. In 2014 and 2015 (phase II EVSS with 10% and 20% phase-out), the ownership cost of iEV3 decreases smoothly and is around the same level of TONGYUE.

Under optimistic case, if without subsidy, the ownership cost of iEV3 is also higher than TONGYUE. But the gap closes at around 2015, five years earlier than under midrange case. In 2020, the ownership cost of iEV3 can be considerably lower than TONGYUE even without subsidy. If with subsidy, the ownership cost of iEV3 could get advantage compared with TONGYUE before 2015. The comparison above signifies that subsidy is necessary for BEPV to be cost competitive compared with CPV in the short term, especially before 2015. The transition from phase I EVSS to phase II EVSS might pose an temporary negative impact on BEPV ownership cost competitiveness, which could be soon offset by the projected decrease in BEPV cost. The phase-out mechanism of phase II EVSS is tested to be reasonable in terms of maintaining the cost competitiveness of BEPVs. In the mid term of around 2015–2020, BEPV could become less or not reliant on subsidy to maintain cost competitiveness. The high sales of iEV3, which ranked 2nd in 2012 among all BEPV models, again demonstrates the importance of low ownership cost in yielding good sales.

Fig. 3(c) presents the ownership cost comparison between BYD E6 and M6. The basic trend and interaction of ownership cost between E6 and M6 are similar with the JAC group. The major difference is that E6 is equipped with far larger Li-ion battery pack. Due to the large battery pack, the ownership cost of E6 in 2012 and 2013 is significantly higher than M6, whether with or without subsidy. This seems to be conflicted with the fact that E6 sales ranked the third highest among all BEPV models in 2012. One important fact is that a considerable proportion of E6 sales are associated with public purchase to be used as urban taxis. E6 is favored to be used as urban taxis because it affords the longest

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Table 5
Scenario assumptions for key factors.

<table>
<thead>
<tr>
<th>Scenario assumptions for key factors</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPV MSRP (Relative to 2012)</td>
<td>0</td>
<td>0</td>
<td>+1%</td>
<td>+2%</td>
<td>+10%</td>
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<tr>
<td>BEPV battery (yuan/kW h)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midrange</td>
<td>5000</td>
<td>4500</td>
<td>4000</td>
<td>3500</td>
<td>3000</td>
</tr>
<tr>
<td>Optimistic</td>
<td>5000</td>
<td>4500</td>
<td>3000</td>
<td>2000</td>
<td>1500</td>
</tr>
<tr>
<td>BEPV glider (Relative to 2012)</td>
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<td>0</td>
<td>−5%</td>
<td>−10%</td>
<td>−20%</td>
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<td>FCR</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPV (Relative to 2012)</td>
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<td>−2.5%</td>
<td>−5%</td>
<td>−20%</td>
</tr>
<tr>
<td>Optimistic</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fuel price</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Gasoline (yuan/L)</td>
<td>7.84</td>
<td>7.73</td>
<td>8.05</td>
<td>8.37</td>
<td>10.37</td>
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<tr>
<td>Midrange</td>
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<td>7.73</td>
<td>8.37</td>
<td>9.00</td>
<td>13.00</td>
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<td>0.81</td>
<td>0.87</td>
<td>0.93</td>
<td>1.22</td>
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</table>

* The price was derived by averaging all available price records within one year.
electric range among all BEPV models. This shines a light on another important characteristic, besides low ownership cost, to make BEPV market competitive, notably in the taxi market. In the near term around 2015, benefiting from battery cost decrease, the ownership cost of E6 is projected to drop fast. In 2020, even under midrange case, the ownership cost of E6 is comparable with that of M6.

Fig. 3. Ten-year ownership cost comparison between (a) CHERY QQ3 and QQ3EV (b) JAC iEV3 and TONGYUE (c) BYD E6 and M6 (d) ZOTYE 5008EV and 5008 (e) BAIC E150EV and E150. Note: PI: phase I; PII: phase II; PO: phase out; w/o: without; Sub: subsidy; Mid: midrange scenario; Opt: optimized scenario.
Fig. 3(d) presents the ownership cost comparison between ZOTYE 5008EV and 5008. As the comparison is quite similar with the comparison between JAC iEV3 and TONGYE, we did not go into details for this group.

Fig. 3(e) presents the ownership cost comparison between BAIC E150EV and E150. The 24 kW h-battery pack equipped on E150EV is quite a mainstream configuration. However, the MSRP of E150EV (¥249,800) is unusually higher than the similar-class BEPVs, taking JAC iEV3 with MSRP of ¥158,000 for example. The reason for this unusually high MSRP is not clear. It does illustrate the diversity of technology status and market strategy of China’s BEPV manufacturers. Due to E150EV’s high MSRP, its ownership cost in 2020 is still a bit higher than that of E150 even under optimistic case.

5. Policy implications

The major policy target of EVSS is to promote the EV market penetration. As Table 3 presents, the sales of BEPV models in 2012 ranged from fewer than 100 to more than 5000, with total sales of 12,085. Compared with the 15.5 million passenger vehicles sold in 2012 in China, BEPV accounted for less than 0.1% of total sales. That is to say, the implementation of EVSS did not successfully start up the BEPV market. In this section, we tried to discuss the reasons for the low sales of BEPVs.

Given the many disadvantages of BEPV compared with CPV, among which electric range limit is the essential one, BEPV has to yield a relatively lower ownership cost compared with CPV to gain market share. As we estimated based on the five top-selling BEPV models in 2012, except for QQ3EV, their ownership costs under phase I and phase II EVSS are just around or significantly higher than their counterpart CPV models. This partially explains the fact that BEPV gained little market share in 2012. The current EVSS is necessary but not enough to start up the BEPV market. As we projected, under phase II EVSS from 2013 to 2015, there are two major possibilities. Under optimistic case, which implies a successful decrease in Li-ion battery cost, the ownership cost of BEPVs would gain significant advantage versus CPVs. This could lead to the successful take off of BEPV market. However, under midrange case, which implies a bottleneck of Li-ion battery cost at around ¥3000/kWh, the ownership cost of BEPVs might just sustain around the current level. Under this case, it is difficult for BEPVs to gain larger market share. Here we reach an important policy implication. Phase I and phase II EVSS set a stage for BEPVs to increase their cost competitiveness. However, the EVSS itself is never enough to start up the BEPV market. Another necessary condition for BEPV market penetration is technology improvement associated with battery cost decrease. The future of BEPV depends critically on if and when battery cost can be successfully reduced. Note that diversity exists in the configuration and cost of current BEPV models, resulting in different ownership cost comparison against their counterpart CPVs. However, the major trend of ownership cost is robust for most BEPV models.

The relatively better market performance of lead–acid battery powered CHERY QQ3EV is an important paradigm, as it demonstrates that when ownership cost is low enough, BEPVs are attractive to consumers regardless of BEPVs’ electric range limitations. The rapid development of what is called Shanzhai BEPVs, which denotes the low-end BEPVs, typically manufactured by local small-scale vehicle manufactures and powered by lead–acid battery, also proves this conclusion. Lead–acid battery powered BEPVs have benefited from China’s large electric bike industry in terms of technology synergy and component sharing. Under current circumstance, there seems to be at least a temporary niche market for the development of these BEPVs.

Despite the market penetration of CHERY QQ3EV and other lead–acid battery powered BEPVs, there is continuing controversy over whether the so called low-end BEPVs should be encouraged. Many people consider that these low-end BEPVs oriented from low technologies and do little good to the competitiveness of China’s automotive industry. Besides, the manufacturing and recycling of lead–acid battery can raise a series of environmental issues. Currently, China’s central government basically holds a negative attitude towards the development of low-end BEPVs. There are many institutional barriers for the low-end BEPVs, such as lack of standard, difficulty in obtaining vehicle qualification, etc.

6. Conclusions

In this paper, we presented the rationale of China’s phase I and phase II EVSS and estimated their impacts on vehicle ownership cost with a focus on BEPVs. We concluded that China’s EVSS is very necessary for BEPVs to be cost competitive compared with CPVs in the short term, especially before 2015. The transition from phase I EVSS to phase II EVSS will generally reduce subsidy to private purchase of PHEPVs and BEPVs. Thus, the ownership cost of BEPVs will temporarily rise at the beginning of phase II EVSS. However, with the decrease of BEPV manufacturing cost, the ownership cost of BEPVs is projected to decrease despite of the phase-out mechanism of phase II EVSS. That is to say, the phase-out mechanism of phase II EVSS is tested to be reasonable to maintain the cost competitiveness of BEPVs. In the mid term of around 2015–2020, BEPV could become less or not reliant on subsidy to maintain cost competitiveness. However, given the disadvantage of BEPVs, especially the limited electric range, China’s current EVSS is not sufficient to start up the BEPV market. Technology improvement associated with Li-ion battery cost reduction has to play an essential part in the taking off of China’s BEPV market. Although excluded from the subsidy scope of China’s EVSS, the lead–acid battery powered BEPVs has gain good market responses due to their low ownership cost, regardless of their disadvantage of electric range limitation.

The transition from phase I to phase II EVSS will pose considerable impact on vehicle manufacturers. The electric range-based subsidy standard under phase II EVSS, rather than the battery capacity based subsidy standard under phase I EVSS, has explicit implications for vehicle manufacturers to optimize the electric range of PHEPVs and BEPVs. As we projected, 80 km (50 mile) might become the preferred electric range for the design of PHEPV in the future. The change of subsidy standard favors long-electric-range BEPVs. 150 km might become the bottom-line-electric-range for major BEPV models in the future. The exclusion of HEV from phase II EVSS, both in public and private sector, will greatly curtail the overall subsidy benefits and halt the incentive for HEV manufacturers.

We proposed several topics that need further study. First, this paper focuses on the impact of EVSS on passenger vehicles rather than transit buses. Further investigation is needed in consideration of EVSS’s impact on ownership cost of China’s transit bus fleet. Second, the vehicle value depreciation rates and maintenance costs of BEPV and PHEPV can be quite different from CPV, which affect the estimation of ownership costs. Due to lack of data, we ignored the differences in this study. This drawback can be addressed with more supporting data available in the future.

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