Energy Policy 67 (2014) 422–430

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Reference-dependent electric vehicle production strategy considering subsidies and consumer trade-offs

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HIGHLIGHTS

- The performance of both electric vehicles (EVs) and internal combustion engine-power vehicles (ICEVs) influences the EV production decisions.
- A loss averse EV manager produces less and obtains less the expected utility than a risk neutral one.
- Subsidies help decrease the EV breakeven quantity, increase the optimal quantity, offset the influence of loss aversion.
- Subsidies should be adjusted according to the performance of both EVs and the ICEVs, demand heterogeneity, and local conditions.
- The high ICEVs costs help offset the influence of loss aversion, whereas the high EV costs enhance loss aversion.

ARTICLE INFO

Article history:
Received 9 July 2013
Received in revised form
9 December 2013
Accepted 11 December 2013
Available online 10 January 2014

Keywords:
Loss aversion
Subsidy
Electric vehicle
Newsvendor model
Consumer adoption

ABSTRACT

In this paper, we extend previous reference-dependence newsvendor research by incorporating both consumer trade-offs and government subsidies to evaluate the relevant influences on the optimal electric vehicle (EV) production decisions. We present the properties of the model, derive the closed-form solutions for the model given the relevant constraints, and use numerical experiments to illustrate the results. We find that subsidies, loss aversion, the performance of both EVs and internal combustion engine-powered vehicles (ICEVs), and the coefficient of variation of demand are significant factors influencing the optimal production quantity and the expected utilities of EV production. The high selling price and other high costs of ICEVs help offset the influence of loss aversion, whereas the high costs of EV enhance loss aversion. Our study enriches the literature on subsidies for EVs by establishing a behavioral model to incorporate the decision bias in terms of loss aversion at the firm level. These findings provide guiding principles for both policymakers and EV managers for making better strategies to promote EVs in the early immature market.

1. Introduction

As one of the most important actions aimed at meeting the climate change targets and energy challenges, the development of electric vehicles (EVs) has been encouraged by many governments. Financial incentives for EVs have become one of the most notable government interventions (Tsang et al., 2012). Almost all electric vehicles on the market receive government subsidies to a certain degree. However, the government subsidy policy is just one aspect.

The successful development of EV market includes at least three aspects: the EV production strategy, government incentive policies, and the adoption of EVs by consumers. Factors of these three aspects interact with each other, and some factors may offset the positive effects of subsidies, which we address in this paper. An interesting question is how the EV managers make production decisions after considering government subsidies and consumer trade-offs between EVs and internal combustion engine-powered vehicles (ICEVs). The answer to this question is not straightforward.

Managers face several barriers when making EV production decisions, including the low adoption rate of the EV market, high initial production costs, and consumer trade-offs between the attributes of EVs and ICEVs such as purchase cost, cruising range, and charging time (Dimitropoulos et al., 2013; Liu, 2012; Daziano and Chiew, 2012; Daziano, 2013; Lin et al., 2013). These barriers may lead to mixed effects of government incentives for promoting EV production and adoption (Michalek et al., 2012). The decision making behavior of the EV manager is also governed by human behavioral and psychological rules, such as loss aversion (Kahneman and Tversky, 1979; Tversky and Kahneman, 1991). The human decision bias brings another uncertainty when predicting the impact of subsidies on EV production and the optimal EV production strategy.

Although the literature on EV policy and consumer choice is extensive, few studies have addressed the impact of incentive polices on the production decisions of EV managers. Because subsidies compete for limited government resources (Tsang et al., 2012) that

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http://dx.doi.org/10.1016/j.enpol.2013.12.028

could otherwise be used to deliver other essential services, it is important to estimate the economic influence of subsidies on EV production. EV managers who are motivated by subsidies intend to make decisions to produce more EVs. However, the market adoption is very limited. It is essential to consider consumer adoption when making EV production decisions.

In this paper, we present an analytical model to investigate the influence of subsidies and consumer trade-offs on the optimal EV production strategy with consideration of the loss aversion of EV managers. The analytical work is based on the newsvendor model (see Khouja, 1999; Qin et al., 2011 for reviews). We provide the closed-form solutions to the model and show properties of the solutions. The proposed model enriches the research literature on government subsidies by establishing a behavioral model to incorporate the decision bias in terms of loss aversion. The findings provide guiding principles for both policymakers and EV managers to determine better strategies to promote EVs in the early immature market.

The rest of the paper is structured in the following manner: we review the research background to identify the missing links in the literature in Section 2. We define the model and derive the properties of the model in Section 3. We then illustrate the relevant properties using numerical experiments in Section 4. We discuss the findings and present conclusions in Section 5.

2. Research background and literature review

Electric vehicles (EVs) are more efficient in converting energy to propulsion than the average internal combustion engine vehicles fueled by fossil oil (Mackay, 2009; Sperling and Gordon, 2009); therefore, EVs have the potential to improve energy efficiency (Daziano and Chiew, 2012). EVs also have the potential to reduce greenhouse gas emissions to conserve the natural environment (Michalek et al., 2012), diminish the dependence on fossil oil consumption to secure the national energy supply (Batlle, 2011), and diversify the energy resources to provide for more sustainable transportation (Michalek et al., 2012). However, advances in EVs have not yet been shown to be economically competitive in the current market. In general, the lifetime costs of an electric vehicle are higher than the lifetime costs of a conventional vehicle of similar size and performance, considering present energy prices and technology (Boston Consulting Group, 2011; Gecan, 2012). As a result, it is crucial to implement a subsidy policy that provides the investors with additional support to guarantee a reasonable return on the investments (Batlle, 2011).

A subsidy for EVs is a government intervention policy with the purpose of promoting the market adoption of EVs by decreasing the production costs and/or selling prices, usually in the form of unilateral financial arrangements from the government to relevant institutions or EV consumers (cf. Bacon et al., 2010). Subsidies are widely used by almost all governments to promote the large-scale adoption of EVs. For example, in the US, the federal government has adopted several policies with an estimated total budgetary cost of $7.5 billion through 2019 to encourage the production and purchase of EVs, including financial support for the industry that produces new EVs, tax credits for buyers to purchase EVs, programs to educate consumers about EVs, and programs to improve the infrastructure for recharging EVs (Gecan, 2012).

Tsang et al. (2012) identified seven government subsidies for EVs. Borrowing from the subsidy classification of renewable energy sources (Batlle, 2011), we classified the seven subsidies for EVs into either direct or indirect categories, as shown in Fig. 1. Direct subsidies are explicit and quantifiable payments, grants, rebates or favorable tax credits. Indirect subsidies are institutional support in terms of research and development funding or facilitation provisions of infrastructure, services, or rules. In this paper, we focus on the direct subsidies to EV manufacturers that are quantifiable in the analytical model.

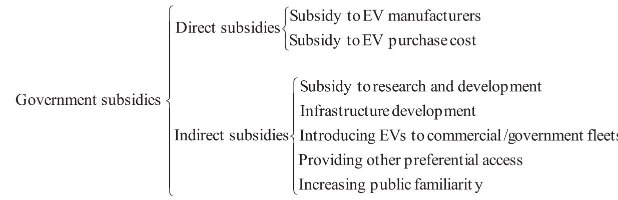

Fig. 1. Category of subsidies for EVs.

Although the government encourages EVs' development by providing subsidies, a large unknown for the wider adoption of EVs is consumer acceptance. The studies on consumer adoption of EVs are extensive, and many barriers to and facilitators of EV adoption have been identified in empirical studies. The potential barriers for consumers to adopt EVs include the high purchase cost, limited range (compounded by the user's range anxiety effect, *i.e.*, the user's extreme caution about the limited cruise range powered by the electricity when planning journeys, Carroll, 2010), long recharge time, limited recharging availability, safety concerns (like batteries in collisions, etc.), consumer attitude-action gap, and unfamiliarity with EVs (Werber et al., 2009; Sovacool and Hirsh, 2009; Tsang et al., 2012; Daziano, 2013). Reductions in monetary costs, purchase tax relief, high gasoline prices, and low emission rates are the facilitators for a wider adoption of cleaner vehicles, whereas incentives such as free parking and permission to drive in high occupancy vehicle lanes have no significant effects (Potoglou and Kanaroglou, 2007; Diamond, 2009).

A common result across the EV adoption studies is that the consumers compare the utility of attributes of EVs and ICEVs when making the purchasing decisions. The typical trade-offs involve purchase cost (*e.g.*, Thiel et al., 2010; Daziano, 2013; Lin et al., 2013), convenience (such as cruising range, availability of charging stations, and charging time, *e.g.*, Dimitropoulos et al., 2013; Liu, 2012), operating cost (such as battery replacement cost), and environmental utility (such as tailpipe emissions, *e.g.*, Funk and Rabl, 1999; McKinsey, 2009; Boston Consulting Group, 2011). Other studies have also considered the trade-offs among different EV attributes, such as the price versus cruising range (see Dimitropoulos et al., 2013), which is not within the scope of this paper. Due to a different research focus, previous EV consumer choice studies have not linked the consumer trade-offs issue to the production decisions of EV managers.

Although there is extensive literature on both government subsidy analysis and EV adoption by consumers, the dynamics of production decisions considering government subsidies and consumer trade-offs are not fully understood. An EV manager has to make production decisions before a selling season. EV production decisions reflect the basic features of the newsvendor model that involves finite production quantity, uncertain demand, and a possibility of overage (and/or underage) production before demand realization is known, we consider the newsvendor model a reasonable approximation to uncover the mechanism of making EV production decisions.

In the newsvendor model literature, there is a wide body of work on various extensions in different contexts (*e.g.*, see Khouja, 1999; Qin et al., 2011 for reviews), but only a small fraction of that the literature considers the influence of government policies (Cohen et al., 2013). Ovchinnikov and Raz (2011) investigate the influence of rebates and subsidies on public interest goods to maximize the social welfare. Krass et al. (2013) study an environmental protection problem where an environmental regulator uses environmental taxes to motivate the choice of innovative and green emissions-reducing technologies. Huang et al. (2013) analyze the suppliers and consumer surplus in a duopoly setting