Computers & Industrial Engineering 113 (2017) 103–122

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

# The evolutionary dynamics of China's electric vehicle industry – Taxes vs. subsidies

Cong Liu *, Weilai Huang, Chao Yang

*School of Management, Huazhong University of Science and Technology, Wuhan 430074, China*

ARTICLE INFO

*Article history:*
Received 24 December 2016
Received in revised form 13 June 2017
Accepted 21 August 2017
Available online 12 September 2017

*Keywords:*
Fluctuation amplitude
Evolutionary game
Taxations
Subsidies

ABSTRACT

The development of the electric vehicle (EV) industry in China has not achieved the desired target even though governments have advanced numerous incentive policies. This paper provides a theoretical explanation for this phenomenon by building an evolutionary game model between auto manufacturers and governments, analyzing the effects of governmental emission taxations and subsidies on the decision making of auto manufacturers and on the dynamic tendency of the EV industry. Considering the governmental politic power both on the consumer demand and on the vehicle supply, this study estimates the influence of government policies on EV industry development under three decision scenarios: the static emission taxations and static subsidies scenario, the dynamic emission taxations and static subsidies scenario and the dynamic subsidies and static emission taxations scenario. The evolutionary stable strategy of the evolutionary game between governments and auto manufacturers is derived. Finally, a case study of China's EV industry is examined with the simulation. The results show that: Under the static condition, the evolutionary game presents amplitude fluctuation and no stable strategy between game players. When governments implement a dynamic taxation strategy or a dynamic subsidy strategy, the evolutionary game exhibits to be stable. Furthermore, the probability of auto manufacturers to produce EV is positively correlated with the upper bound of emission taxations and negatively correlated with the ceiling of subsidies. The simulation results, in the end, indicate that the efficient politic power on consumer demand accelerates the evolutionary path of the EV industry and a policy of dynamic taxations and static subsidies is more effective on EV industry development than other policies.



## 1. Introduction

The development of electric vehicles (EVs) has been considered a particularly promising strategy as the 21st century faces challenges related to climate change and to the scarcity of crude oil in the transportation sector (Metz, 2007). According to HIS (Hersteller Initiative Software), the total number of EVs produced in 2013 was 24.2 million, which accounts for only 0.2% of the vehicles produced worldwide that year. Under pressure from environmental organizations, governments show great interest in finding more effective ways to drive the car industry towards environmental sustainability.

Because of immature technology, high investments in R&D and high costs of production especially uncertain consumer demand, the development of the EV industry has not achieved the desired success (Struben & Sterman, 2008). Taking China as an example, the number of EVs was 142,800 by 2015, which is far from the national goal of 0.5 million as discussed in the demonstration program of the electric vehicle (EV) in 13 Chinese cities. As shown in Table 1, even though the EVs annual production has witnessed an average increase of 103% from 2012 to 2016, the mass adoption of EVs is not as easy as it appears. Fig. 1 shows the total production of EVs per month in 2016 compared with the year 2015, describing that the EV industry in China is still complex and fluctuant. The reasons for Fig. 1 and Table 1 are as follows. First, as Zhang and Bai (2017) pointed out local governments were supposed to be responsible for developing local economy and providing local subsidies in support for the EV industry development, but in fact, this logic also generated local protectionism during the EV development and promotion. Second, the auto manufacturers making decision rely on the governmental policy of EV too much to ignore improving the core technology of EV. Finally, the EV industry in China is still in the infant period, and the uncertain demand makes the manufacturers unwilling to produce EV. China plans to place 5,000,000 EVs on the road by 2020, which means annual sales of new EVs should reach approximately 971,450 in the next five

* Corresponding author.
*E-mail addresses:* cong_liu@hust.edu.cn (C. Liu), huangwl@hust.edu.cn (W. Huang), chao_yang@hust.edu.cn (C. Yang).

http://dx.doi.org/10.1016/j.cie.2017.08.026
0360-8352/

**Table 1**
Total production of EVs in China from 2012 to 2016.

| Year | EV production volume | Vechile production volume |
|---|---|---|
| 2012 | 1.1573 | 1927.18 |
| 2013 | 0.945 | 2211.68 |
| 2014 | 3.78 | 2372.29 |
| 2015 | 14.28 | 2450.33 |
| 2016 | 41.7 | 2811.9 |

[1]Unit: Thousand vehicles.
[2]*Data source:* China Association of Automobile manufacturers.

years. Thus, it is urgent and crucial to adopt relevant policy actions and effective policy mechanisms to stimulate the market for EVs.

Many countries provide an economic plan and incentive policies on consumer adoption and on manufacturers to induce EV industry development during the infancy stage. In the year 2008, the United States launched the Advanced Technology Vehicle Manufacturing Loan Program to develop and foster the EV industry (DOE, 2008). As part of this program, the manufacturers' research project on advanced technology and production of key parts of electric vehicles would receive grants and loans from the government. In March 2009, the Obama administration further allocated $2.4 billion in grants for the new advanced battery and electronic drive projects (DOE, 2009). Similarly, the United Kingdom (UK) provided approximately 400 million to encourage the development and uptake of ultra-low carbon vehicles. With respect to manufacturers, if they wanted to gain incentives, they needed to produce more effective and environmentally friendly vehicles, such as EVs, which have lower or even zero emissions (DBERR, 2009). In China, the eighth Five-Year Plan (1991–1995) was the first time the government promoted EV R&D, announcing the "Research of the Key Technologies of EVs" as a national key scientific and technological project (Chen, Lai, & Wen, 2006). In the year 2012, China launched an engineering demonstration on energy savings and on the adoption of new energy – efficient automobiles, recommending consumers to purchase more environmentally efficient cars. The central and local governments provided subsidies based on travel distance to the consumers who purchased electronic vehicles corresponding with the demonstration engineering directory. In 2015, the central government began to provide a dynamic subsidy policy (Zhang, Liang, Yu, Rao, & Xie, 2017). In addition to incentives for the use of EVs, Europe also focused on punishing for carmakers that produced high emission vehicles, while offering credits to carmakers that produced vehicles emitting less than 50 g of $CO_2$ per km (Wilde & Kroon, 2014). The U.K. government modifying the tax mechanism based on the $CO_2$ emissions in grams per km ($g.co_2$/km) with respect to the car property tax in 2007. The European Union (EU) established related legislation that guarantees to research new cars, with a fleet average of 130 $g.co_2$/km to 90 $g.co_2$/km, by 2015. To achieve this goal, manufacturers must pay an excess emissions premium for each car registered. The American government proposes some policies on tax reduction to encourage manufacturers to promote the development of EVs. The state governments, especially California, have supported the production and sales of low emission vehicles or zero emission vehicles by placing the onus on the manufacturers to reduce high tailpipe emission vehicles and by imposing civil penalties on manufacturers for non-compliance. Holtsmark and Skonhoft (2014) reviewed the Norwegian EV policy, which included tax exemptions and various driving privileges, and discussed whether this policy can be justified and implemented by other countries to achieve the desired results.

Hence, we conclude that taxations and subsidies are two important ways for governments to induce EV industry development. From the perspective of current practice, it is difficult to evaluate which is more effective – taxations or subsidies. Hirte and Tscharaktschiew (2013) discussed whether the use of EVs should be subsidized, and if so, what the optimal subsidy rate should be. The results showed that EVs should be taxed rather than subsidized. Reviewing the relevant policies that different countries adopt for stimulating the EV market, Zhang, Xie, and Liang (2014), based on an empirical analysis, recommended that the Chinese government should imitate the practices of the U.K. and France, rewarding those manufacturers who produce and sell a new car with low carbon emission level and punishing those who produce cars with high carbon emission level. In this paper, we provide a theoretical framework to explain the impacts of taxations and subsidies on China's EV industry by establishing an evolutionary game model between governments and auto manufacturers. The auto manufacturers produce two types of products – fuel vehicles (FVs) and electric vehicles (EVs). These two products differ in their prices and in their impacts on the environment. The governments also have two strategies to implement relative policies – intervention and non-intervention. When the governments make a strategic decision to intervene in the development of the EV industry, they provide finance incentives for auto manufacturers, taxing those that produce FVs due to the higher $CO_2$ emissions and subsidies for those that produce EVs. In this

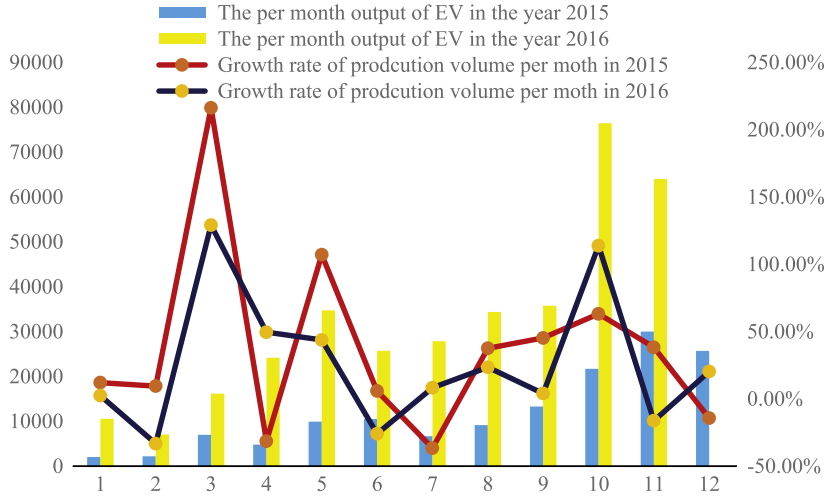


**Fig. 1.** The per month output of EV in 2015 and in 2016.