The Dual-credit Policy: Quantifying the Policy Impact on Plug-in Electric Vehicle Sales and Industry Profits in China

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Citation: Ou S, Lin Z, Qi L, Li J, He X, Przesmitzki S. The dual-credit policy: Quantifying the policy impact on plug-in electric vehicle sales and industry profits in China. Energy Policy 2018; 121:597–610. doi: https://doi.org/10.1016/j.enpol.2018.06.017.

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ABSTRACT

The *Passenger Cars Corporate Average Fuel Consumption and New Energy Vehicle Credit Regulation* (dual-credit policy) was enacted by the Chinese government in 2017 to stimulate the fuel-efficient and electrification technologies in the China's passenger vehicle market. This study summarizes the dual-credit policy and develops the New Energy and Oil Consumption Credits Model to quantify the impacts of this policy on consumer choices and industry profits, where internal subsidies as decision variables are used to represent industry responses to the policy. Scenarios in 2016-2020 are simulated and discussed. Key findings from the model results include: (1) the Corporate Average Fuel Consumption rules alone may stimulate more plug-in electric vehicle (PEV) sales than the dual-credit policy; however, (2) the dual-credit policy could stimulate more battery electric vehicles (BEVs) in market, compared to other policy scenarios; (3) the industry could "lose" approximately $2,122/vehicle by 2020 under the dual-credit policy; (4) battery electric sedans with a range greater than 250 km and plug-in hybrid SUVs could be popular under the dual-credit policy; (5) credit allocations for BEVs in the dual-credit policy can influence the PEV production; and (6) reduction of the fuel-efficient technology costs helps to minimize profit losses impacted by the policy.

Keywords: China's vehicle market; policy analysis; quantitative model; corporate average fuel consumption; plug-in electric vehicle; industry profits.

1. Introduction

According to data provided by the China Automotive Technology and Research Center (CATARC), national annual vehicle sales have reached over 28.88 million units in 2017, reinforcing China's position as the world's largest vehicle market since 2009 (CATARC, 2018). The rapid growth of the Chinese vehicle market has a profound impact on economics, energy security, and greenhouse gas (GHG) emissions (Ou et al., 2017). Chai et al. estimated that the energy consumption of the transportation sector in China has reached 258 million tons of standard oil in 2013, almost double the consumption from 2000. In addition, the road traffic consumes 80% of energy in the transportation sector (Chai et al., 2017). At the same time, imported oil makes up more than 60% of the total oil consumption in China in 2015 (Jiao et al., 2017), and imported oil consumption is anticipated to be greater than 63% by 2020 and as high as 76% of total oil consumption by 2035 (van Moerkerk and Crijns-Graus, 2016). The growing vehicle population and increasing dependence on foreign oil bring the Chinese government much pressure on the energy security. Another policy motivation for the Chinese government to intervene the vehicle market's technological trend is to mitigate vehicle emissions that contribute to the severe air quality in many metropolitan areas. The third policy driver is related to climate change. Han et al. anticipate that carbon emissions from the road transport sector will reach 6.6 billion tons in China by 2020, which are more than a six fold increase compared with 2014 emissions (Han et al., 2017).

Concerned with energy security and environmental impacts from rapid motorization, the Chinese government has long committed to promoting fuel-efficient technologies in conventional vehicles (CVs) and new energy vehicles (NEVs), which by the official definition include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs) (Ou et al., 2017). Since only a few units of FCVs have been sold for the demonstration project in

China (Ou et al., 2017), FCVs are not considered in this study, thus NEV in this paper is an equivalent concept to the plug-in electric vehicle (PEV), which is frequently used in the United States (U.S.). In 2009, the Chinese government launched the PEV promotion program, *Ten Cities, Thousand Vehicles Demonstration*, as a component of the *Government Eleventh Five-Year Plan (2006-2010)* (Xu and Su, 2016). Since then, generous governmental subsidies and non-monetary incentives have been adopted to stimulate the demands for PEVs. The total PEV sales in the passenger vehicle segment from 2011 to 2016 were estimated at 616,689 units, which make China one of the largest PEV markets in the world (Block and Brooker, 2017). The excess subsidies brought enormous financial burdens to the government while had the PEV market rely more on government monetary incentives (Ou et al., 2017; Zhou et al., 2015). Therefore, the government has been gradually reducing its direct subsidies on PEV purchase (Ou et al., 2017).

Despite cutting its subsidies, the government is not turning its back on PEVs. In September 2017, a new policy, *Measures for Passenger Cars Corporate Average Fuel Consumption and New Energy Vehicle Credit Regulation* (dual-credit policy), was implemented to take effects starting in 2018 by the Ministry of Industry and Information Technology. To motivate production of the fuel-efficient and electrification technologies by using administrative penalties (as opposed to direct subsidies), China's dual-credit policy consists of two components: the Corporate Average Fuel Consumption credit (CAFC-credit) rules, which set targets for the production-weighted average fuel consumption rate for eligible vehicle manufacturers/importers, and the New Energy Vehicle credit (NEV-credit) rules, which stipulate credits by PEV type and require certain NEV credit quotas. In a sense, the policy can be viewed as combining some features of the Corporate Average Fuel Economy standards in the U.S. and the Zero Emission Vehicle (ZEV) Program in California.

Considering the enormity of the Chinese vehicle market and its design, the dual-credit policy is expected to have a vast influence on the vehicle market structure, company strategic plans, R&D investment, industrial profits, etc. Since the first draft release of the dual-credit policy in 2016, this policy has attracted a great deal of attentions from the stakeholders in the vehicle industry, institutional investors, and academic researchers all round the world, and has stimulated much discussion and public comments. Wang et al. suggested that the CAFC-credit rules should be separated from the NEV-credit rules in the dual-credit policy to avoid confusion to and abuse by vehicle manufacturers (Wang et al., 2017). Some believed that the dual-credit policy was implemented in haste (Wang, 2017). In response, the government postponed the full implementation of the dual-credit policy from the originally-planned 2018 to the year 2019. The current leading PEV automakers are predicted by (Yang et al., 2016) to benefit from the dual-credit policy. Several think tanks also published their opinions about this policy. The Economist Intelligence Unit predicted that the change of game rules in the Chinese vehicle market will affect the global carmakers that dominate the CV segment in China (Economist Intelligence Unit, 2017). iCET (Innovation Center for Energy and Transportation) also suggested the CAFC-credit rules and NEV-credit rules be mutually independent to avoid implementation complexity (iCET, 2016). Although these published studies offer diverse views, few have systematically and quantitatively analyzed this policy and its potential effect on the vehicle market in China.

By using the New Energy and Oil Consumption Credits (NEOCC) model, this study simulates and analyzes the impact of the dual-credit policy with consideration of alternative policy scenarios. The NEOCC model was funded by Aramco Services Company and developed by the Oak Ridge National Laboratory to simulate the vehicle industry's compliance responses under various vehicle policies and incentives. In contrast to other models commonly emphasizing the long-term effects (González Palencia et al., 2017), the NEOCC is more focused on the short-term

impacts of the dual-credit policy, which itself is for the short-term 2017-2020 period. It is certainly important to analyze the continuation and long-term effect of the policy, but that is outside the study scope. Instead, this study aims at addressing the following questions:

- How to calculate the CAFC credits and NEV credits according to the rules in the dual-credit policy?
- How will the vehicle market evolve when the industry complies with the dual-credit policy? What will the vehicle industry profits be under the dual-credit policy?
- Comparing to the CAFC-credit rules only or NEV-credit rules only, is the dual-credit policy the best option to motivate the PEV market?
- What types of PEVs will be more popular in 2016-2020 if the industry complies with the dual-credit policy?
- How will the industrial corporate average fuel consumption change from 2016 to 2020 under different vehicle policies?
- How will the fuel-efficient technology impact the market share of CVs and the industry profits under the dual-credit policy?

This paper consists of five sections. The first section presents the motivations and objectives of this study, and reviews the background and literature on the dual-credit policy. The second section presents the rules and credit calculation in the dual-credit policy. The third section clarifies the assumptions and methodology of the NEOCC model adopted for the policy analysis. Section four focuses on the scenarios analyses of the vehicle market with the implementation of different vehicle policies - the dual-credit policy, CAFC-credit only, and NEV-credit only, no-rules. This section also discusses the sensitivity analysis of fuel-consumption technology in CVs on the industry. The last section presents the conclusions in this study. In this paper, the yearly average

currency exchange rate of $ 1.0 USD = 6.910 CNY in 2016 is used (U.S. Internal Revenue Service, 2017). Besides, the calculated future monetary values in 2017-2020 are discounted to be the present values in 2016 by assuming the annual discount rate to be 4% (Investing.com, 2017).

2. Rules of the Dual-credit Policy

The dual-credit policy consists of two complementary parts: CAFC-credit rules, and NEV-credit rules. The CAFC-credit rules require that an auto firm's actual CAFC should be no larger than the target CAFC. The CAFC credits are calculated based on the difference between the actual CAFC and target CAFC. The NEV-credit rules require that the ratio of produced/imported PEVs to CVs in an auto firm should be no smaller than the required minimum ratio, and the NEV credits are calculated based on the difference between achieved NEV scores and the NEV minimum ratios. To avoid penalties, the original equipment manufacturers (OEMs) need to meet both the CAFC and NEV targets, starting in 2019. In 2018, OEMs only need to meet the CAFC targets.

In the CAFC-credit rules, an auto company's actual CAFC and target CAFC are calculated respectively in Eqn. (1) and Eqn. (2), which are based on the national standard - GB27999-2014.

$$CAFC = \frac{\sum_{i=1}^{K} FC_i \cdot V_i}{\sum_{i=1}^{K} V_i \cdot W_i} \tag{1}$$

$$CAFC_T = \frac{\sum_{i=1}^{K} FC_i \cdot V_i}{\sum_{i=1}^{K} V_i} \tag{2}$$

where, i is the car model; K is the quantity of the car models in an auto company; FC_i is the fuel consumption ($L/100km$) of the car model i; V_i is the production (or imports) of car model i; W_i is the multiplier of the production (or imports) of car model i (intended to amplify the contribution of

NEVs to CAFC compliance. E.g., W_i is stipulated to be 3 for a BEV model, and 1 for a CV model in year 2018-2019 in the dual-credit policy, which results a larger denominator when calculating the number of PEVs and generates a smaller CAFC than the calculation in the CVs). Thus, the CAFC credits earned in calendar year j ($Credit_{CAFC,j}$) for an auto company are calculated based on Eqn. (3).

$$Credit_{CAFC,j} = \left(CAFC_T \cdot e_j \cdot s - CAFC\right) \cdot \sum_{i=1}^{K} V_i \tag{3}$$

where, e_j is a multiplier to the final-year CAFC target ($CAFC_T$) in calendar year j (134% in 2016, 128% in 2017, 120% in 2018, 110% in 2019, and 100% in or after 2020). The multiplier e_j decreases over time, so that the industry can achieve a more stringent CAFC target each year toward the final-year target; s is adjustment factor only for the auto companies with annual produced/imported cars at less than 2,000 units, which aims to reduce the CAFC target burdens for small firms.

According to the policy, the vehicle weight, electric range, electricity consumption, fuel consumption (only for PHEVs/EREVs), and battery rated power (only for FCVs) are considered in calculating the NEV credits. Table 1 shows the rules to calculate NEV credits in each type of NEV. In the NEV-credit rules, the total NEV credits earned in calendar year j ($Credit_{NEV,j}$) for an auto firm are calculated by Eqn. (4).

$$Credit_{NEV,j} = NEV_A - NEV_T = \sum_{i=1}^{M} S_{NEV,i} \cdot EV_i - R_j \cdot \sum_{i=1}^{N} CV_i \tag{4}$$

where, NEV_A is the NEV score achieved by an auto firm; NEV_T is the NEV target score; M is the total number of the NEV models; N is the total number of the CV models; $S_{NEV,i}$ is the NEV score earned by the car model i. EV_i is the annual produced or imported volume of the NEV model i; CV_i

is the annual produced or imported volume of the CV model i; R_j is the NEV required minimum ratio in the calendar year j (10% in 2019, and 12% in 2020)[*].

The dual-credit policy also stipulates the trading and transferring rules for the PEV manufacturers or importers on the CAFC and NEV credits, as shown by the following bullet points.

- The NEV credits can be traded among non-affiliated auto firms and can be used for offsetting the deficiency of the CAFC credits. But the purchased NEV credits are not tradable anymore.
- The auto firms who have deficiency of NEV credits must purchase NEV credits from other firms to offset the deficit.
- The conversion ratio between NEV credits and CAFC credits is 1:1.
- The CAFC credits are not tradable but are eligible to transfer among shareholding or affiliated firms and carry forward to future years for their own use.

More detailed information on the credit utilization by auto firms is available by downloading the dual-credit policy from the government website:

http://zqyj.chinalaw.gov.cn/readmore?id=1894&listType=2.

[*] In the drafted version of dual-credit policy in June 2017, the NEV required minimum ratio is 8% in 2018. However, the official version released in September 2017 postpones the implementation of NEV-credit rules one year later, which means only CAFC-credit rules taking effects in 2018.

Table 1. NEV Scores Achieved by Various Type of NEVs (Information is organized based on the dual-credit regulation)

Technology	**Electric range** R (km)	**Weight** m (kg)	**Fuel Consumption** FC (L/100km)	**Electric Consumption** Y (kWh/100km)	**Battery Rated Power** P (kW)	**Scores**	**Multiplier**	**Are Credits Tradable?** (Y/N)
PHEV/EREV	50≤R<80		FC < 0.7× (GBT 19578-2014 Test B)			=2	×1.0	Y
			FC ≥ 0.7× (GBT 19578-2014 Test B)				×0.5	N
	R≥80	m≤1000		Y ≤ 0.014×m+0.5			×1.0	Y
				Y > 0.014×m+0.5			×0.5	N
		1000<m≤1600		Y ≤ 0.012×m+2.5			×1.0	Y
				Y > 0.012×m+2.5			×0.5	N
		m>1600		Y ≤ 0.005×m+13.7			×1.0	Y
				Y > 0.005×m+13.7			×0.5	N
BEV	R≥100	m≤1000		Y>0.014×m+0.5		= 0.012×R +0.8, and ≤ 5	×0.5	N
				0.0098×m+0.35 < Y ≤ 0.014×m+0.5			×1.0	Y
				Y ≤ 0.0098×m+0.35			×1.2	Y
		1000<m≤1600		Y>0.012×m+2.5			×0.5	N
				0.0084×m+1.75 < Y ≤ 0.012×m+2.5			×1.0	Y
				Y ≤ 0.0084×m+1.75			×1.2	Y
		m>1600		Y>0.005×m+13.7			×0.5	N
				0.0035×m+9.59 < Y ≤ 0.005×m+13.7			×1.0	Y
				Y ≤ 0.0035×m+9.59			×1.2	Y
FCEV	R≥300				P≥30% × (Motor power), and ≥10 kW	= 0.16×P	×1.0	Y
							×0.5	N

3. New Energy and Oil Consumption Credits Model

The guiding objective of the NEOCC model is maximization of the industry profit in complying with the dual-credit policy. The auto industry is assumed to adjust vehicle prices of different powertrain types (e.g. less-efficient CV, more-efficient CV, PHEV, BEV). The consumer choice component of NEOCC calculates the probabilities of consumers choosing powertrain types, which lead to estimated sales by powertrain or fuel types and the resulting compliance results for the dual-credit policy. The actual decision variables in NEOCC are the internal subsidies, which are the difference between the cost-based prices (i.e. vehicle production cost multiplied by a profitable price markup factor) and the actual prices to consumers. If all internal subsidies are found zero in the optimization result, it means the industry can comply with the policy without any price adjustment, which can occur if fuel-efficient and PEV technologies are cost-competitive against general CVs under the near-term circumstances (e.g. PEV purchase privilege). In the short-term, these technologies are not yet cost-competitive and therefore their prices to consumers must be reduced, by internal subsidies, to stimulate sufficient demands in order to achieve the policy compliance.

The NEOCC model was developed to capture the dual-credit policy as described in Eqn. (1)-(4) and is calibrated to 2016 data of sales, prices, and fuel economies, provided by CATARC. It also considers the phasing-out government subsidies, non-monetary incentives (e.g., the shadow values of a non-PEV license plate purchase), charging infrastructure provision, and driver characteristics. Key assumptions of the model include:

1. Vehicle performance (technology metrics, cost, markup, etc.), unexplained consumer preferences, and the overall vehicle market size in years 2017-2020 will remain the same as they were in year 2016. This is both for simplicity and for the consideration of the short time period.
2. The model considers only sedans and SUVs because these two segments have taken over 85% of the Chinese passenger vehicle market. Also, very few PEV models other than sedans and SUVs are sold (e.g., only 824 units of light-duty PEVs in 2016 were in the multi-purpose vehicle segment) (CATARC, 2018).
3. The characteristics of driver and energy infrastructure such as the driving pattern, recharging situation, refueling situations will not change significantly during 2017-2020.
4. Consumer heterogeneity is currently ignored for simplicity.
5. NEOCC uses the discrete choice model to estimate the percentage of consumers will purchase which powertrain or fuel type.
6. The model ignores quantifying the difference between production and sales, although technically the dual-credit policy is based on production (or imports).
7. Gamma distribution is assumed as the probability distribution of the driver's daily travel, which will be used for calculating energy costs and range anxiety costs of PEVs (Lin, 2014);
8. The research subject is the entire vehicle industry, thus market competition between firms inside the vehicle industry is assumed highly efficient.
9. The conversion ratio between a CAFC credit and an NEV credit is 1:1, which is in consistent with the dual-credit policy. In NEOCC model, the ratio as a model parameter can be revised for sensitivity analysis.

10. To obtain the largest profits in a particular year, all available NEV credits are traded and all available CAFC credits are used. Therefore, the CAFC credits are not assumed to be carried forward to future years in this study, and this is also for simplicity purposes.
11. The vehicle industry is assumed to meet with certainty all the policy requirements, which are implemented as optimization constraints in NEOCC. The administrative penalties of non-compliance are not considered.
12. The purchase tax exemption policy to PEVs is effective since 2014 to 2021. The NEOCC model was calibrated with the prices, incentives, and sales in 2016, thus the impacts of the purchase tax differences between CVs and PEVs have been implicitly reflected by such calibration.

This study uses the 2016 vehicle market as the benchmarking market, as shown in Table 2. The passenger vehicle categories are defined and presented in Table 3. CVs are classified as CV-High, CV-Med, or CV-Low, based on fuel efficiency; the MSRP increases when FC-CS (fuel consumption in charge sustaining mode) decreases because more fuel-efficient technologies are adopted. The FC-CS is used for conventional vehicles, which can be viewed as PHEVs with zero electric ranges. Based on vehicle classifications in the government subsidy policy and the actual sales volume, PHEV sedans are placed in two categories, BEV sedans into four categories; SUV-PEV are not divided because of their smaller sales volume compared with sedan-PEV.

In general, the vehicle industry obtains profits by allocating its internal resources (characterized by internal subsidies) for various vehicle technologies. The objective function is shown in Eqn. (5).

$$Max: R_a = \vec{V}^T \cdot \left(\vec{P} + \overrightarrow{S_{gov}} - \overrightarrow{IN} - \vec{C}\right)$$

$$Constraints: \begin{cases} Credit_{NEV,j} \geq 0; \\ Credit_{CAFC,j} + Credit_{NEV,j} \geq 0. \end{cases} \quad (5)$$

where, R_a is the total gross profit in the vehicle industry, not the more ideal total net profit due to lack of indirect cost information. $\vec{V} = [v_1, v_2, \cdots, v_t]^T$ are the sales volumes of the vehicle technologies shown in Table 2, and t is the number of the vehicle types; $\vec{P} = [p_1, p_2, \cdots, p_t]^T$ are the vehicle price to consumer with subtraction of the government subsidizes; $\overrightarrow{S_{gov}} = \left[s_{gov_1}, s_{gov_2}, \cdots, s_{gov_t}\right]^T$ are the government subsidies (central + local government); $\overrightarrow{IN} = [in_1, in_2, \cdots, in_t]^T$ are the industrial internal investment to the vehicle technologies. $\overrightarrow{IN}$ is assumed to be quantified internal subsidies in order to encourage the sales of more favorable vehicle types (for policy compliance), which may result in profit losses in compliance with the policy; $\vec{C} = [c_1, c_2, \cdots, c_t]^T$ are the vehicle production cost. The industry is assumed to adjust its internal subsidies ($\overrightarrow{IN}$) to different vehicle types (CVs, PEVs in Table 3), which impacts the vehicle prices and total ownership costs to consumers. By the multinomial logit simulation, the sales of different vehicle types ($\vec{V}$) are calculated; and an industrial profit is achieved by Eqn. (5) accordingly. The values of the internal subsidies ($\overrightarrow{IN}$) and corresponding vehicle sales ($\vec{V}$) are continuously solved so that the model obtains the best profit results - $max(R_a)$ under the dual-credit policy constraints: (a) the NEV credits are no smaller than zero, and (b) the sum of CAFC credits and NEV credits are no smaller than zero, as shown in Eqn. (5). The model logic flow and structure are revealed in Appendix.

Table 2. China's 2016 Passenger Vehicle Market

Segment	Technology	Sales	Weight* (kg)	Electric Range* (km)	FC-CS* (L/100km)	EC-CD* (kWh/100km)	MSRP* ($2016)
Sedan	CV-High	9,809,923	1302.7	-	6.57	-	20,317
	CV-Med	1,952,849	1302.7	-	5.58	-	22,566
	CV-Low	457,884	1302.7	-	4.59	-	25,786
	PHEV-50	24,736	1725.3	55.77	4.77	13.61	39,176
	PHEV-70	18,952	1720.0	70.00	5.08	20.00	30,354
	*PHEV-85***	0	*1900.0*	*85.00*	*6.23*	*20.50*	*35,100*
	BEV-150	166	1296.5	101.61	-	14.56	29,192
	BEV-250	150,881	1104.5	159.93	-	14.40	25,916
	BEV-350	62,799	1677.0	280.81	-	16.92	35,063
	BEV-400	13,584	2420.0	400.00	-	20.50	53,517
SUV	CV-High	8,208,582	1550.2	-	7.73	-	25,005
	CV-Med	651,270	1550.2	-	6.26	-	30,279
	CV-Low	4,098	1550.2	-	4.78	-	38,806
	PHEV	26,499	2388.0	84.61	8.75	20.49	38,995
	BEV	2,620	1575.3	211.40	-	18.82	31,659

* are all sales-weighted. FC-CS refers to fuel consumption in charge sustaining mode, EC-CD refers to electricity consumption in PEV charge-depleting mode, MSRP refers to manufacturing suggested retail price.

**The 2016 market in China has no records of PHEV-85 sales; the featured elements for PHEV-85 are presumed based on unlisted vehicle models from OEMs.

Table 3. Passenger vehicle definitions

PEV Category	Electric Range (R, km)	CV Category	Fuel Consumption*
PHEV-50	50≤R<70	CV-High	CVs with a high fuel consumption.
PHEV-70	70≤R<85	CV-Med	CVs with a medium fuel consumption.
PHEV-85	R≥85	CV-Low	CVs with a low fuel consumption.
BEV-150	R<150		
BEV-250	150≤R<250		
BEV-350	250≤R<350		
BEV-400	R≥350		

* The CVs are categorized into three segments by fuel consumptions. The average fuel consumptions, average MSRPs, and vehicle sales in each segment shown in Table 2 are all calibrated based on the 2016 vehicle market information offered by the CATARC.

4. Scenarios Analysis

4.1. Vehicle Market in 2016-2020 under Dual-credit Policy

The dual-credit scenario is compared to the no-rules scenario, so to reveal the impacts of the policy. The dual-credit scenario is the market in compliance with the dual-credit policy. The policy constraints in the dual-credit scenario are: in 2017-2018, only the CAFC credits are required to be no less than zero; in years 2019-2020, both the NEV credits and the sum of CAFC and NEV credits should be no less than zero. The no-rules scenario is the market without any policy constraints and is used as a benchmark for comparison.

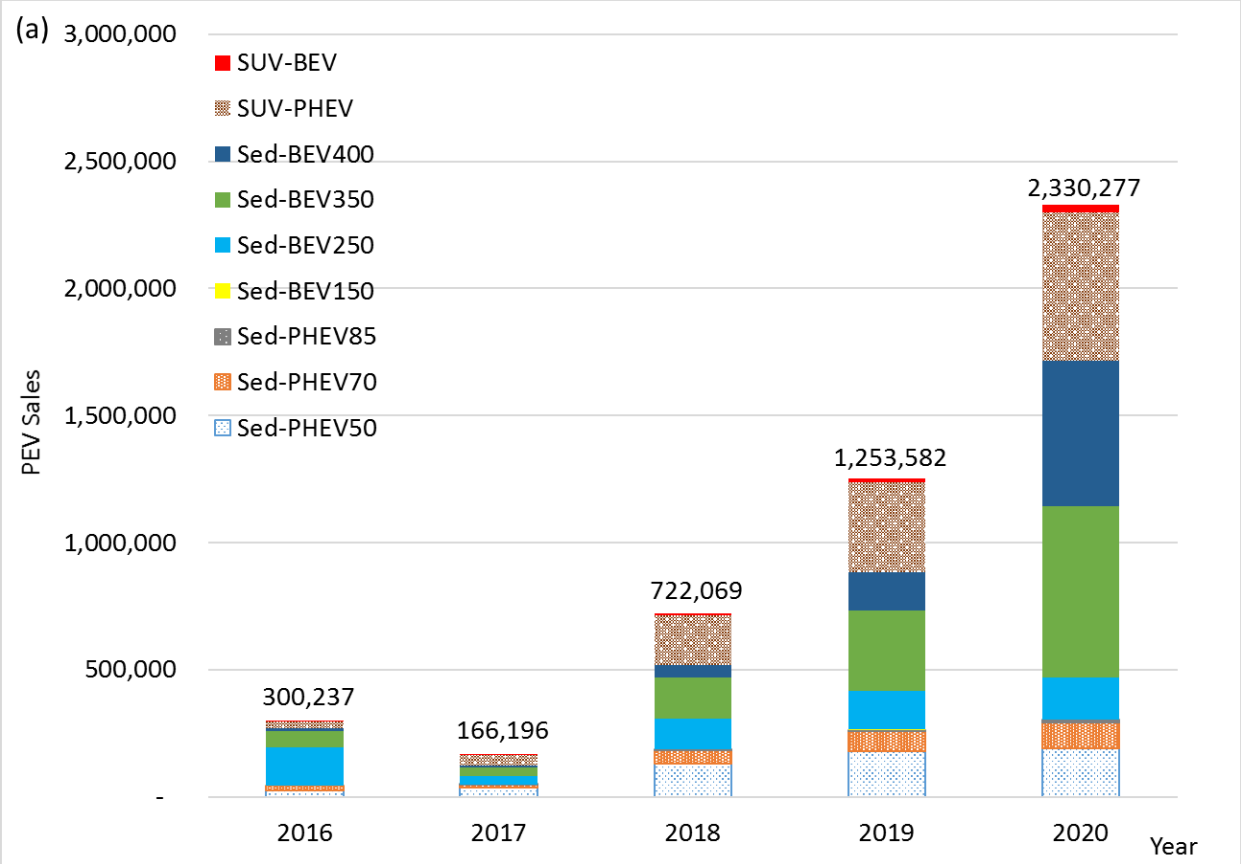
In the dual-credit scenario, the annual sales of PEVs are estimated to be over 2.33 million in 2020, resulting in a total of more than 4.75 million PEV units sold during 2016 -2020, slightly

under the 5 million-target announced by the government (*The Planning for the Development of the Energy-Saving and New Energy Automobile Industry (2012-20200)*). In addition, about 60% of PEVs are BEVs, and more than 70% of PEVs are sedans. As shown in Fig. 1(a), PEV sales will decrease to approximately 166,000 units in 2017 since only the CAFC-credit rules are implemented in 2017 and 2018. Rapid increase in PEV sales starts in 2019, the first year when the dual-credit policy (including both CAFC-credit rules and NEV-credit rules) take full effect. Fig. 1(b) adds up the respective PEV sales by vehicle type from 2016 to 2020. It shows that the BEV with longer electric range will be more popular than any other PEV types in the dual-credit scenario. Specifically, the BEV-350 sedan will be the best seller among the 15 PEV types in the simulations. Unlike the sedan segment where BEVs are popular, the PHEV is more favorable type in the SUV segment. Considering that in reality the vehicle industry does not only pursue profit maximization for the current year, but is also concerned with future competition and profitability, it is expected that actual PEV annual sales in 2017 will be higher than are estimated by NEOCC in the dual-credit scenario. Besides, the current NEOCC model considers only the personal vehicles, while many PEVs are purchased as the fleet cars by government or companies in China. This expected difference in 2017 PEV sales between the model results and the actual number, however, does not affect the conclusions of this study.

The no-rules scenario is also used as the benchmark to quantify the policy impacts on profit (PIP) and the actual CAFCs in the dual-credit scenario. The PIP is the difference in the gross profit between the dual-credit scenario and the no-rules scenario in the given year. Compared to no-rules scenario, the vehicle industry as estimated in the dual-credit scenario will lose around $2,122 per vehicle in 2020, as shown in Fig. 1(c). Note that the PIP is intended to reflect the effect of the policy, and by no means indicates the industry's actual profitability. 2016 is the calibration year, when the dual-credit policy is not yet implemented, thus the PIP in 2016 is zero. Nevertheless, the

PIP magnitude gradually increases after 2016, especially starting in 2019 when both rules are implemented. This is because the gradually phasing-out PEV subsidies and the increasingly more stringent CAFE and NEV targets force the vehicle industry to internally subsidize more on the efficient CV and PEV products to achieve their sales that are sufficient for policy compliance. This causes more loss of profits.

In contrast to the no-rules scenario, the actual CAFCs in the dual-credit scenario substantially improve, yet the deficits between the actual CAFCs and target CAFCs are gradually amplified. As shown in Fig. 1(c), although the actual CAFC will reach 5.54 L/100km in 2020, which is much smaller than the no-rules CAFC (6.84 L/100km) in 2020, the actual CAFC fails to meet the target CAFC (5.28 L/100km) in 2020 in the dual-credit scenario. This is because, instead of pushing the industry to meet the target CAFC with efficient CV technologies only, the dual-credit policy starting in 2019 allows the industry to use the extra NEV credits to offset the deficit of CAFC credits. It can be concluded from the NEOCC model results that the design of the dual-credit policy motivates the industry to produce PEVs so as to gain extra NEV credits in preparation for the CAFC deficit.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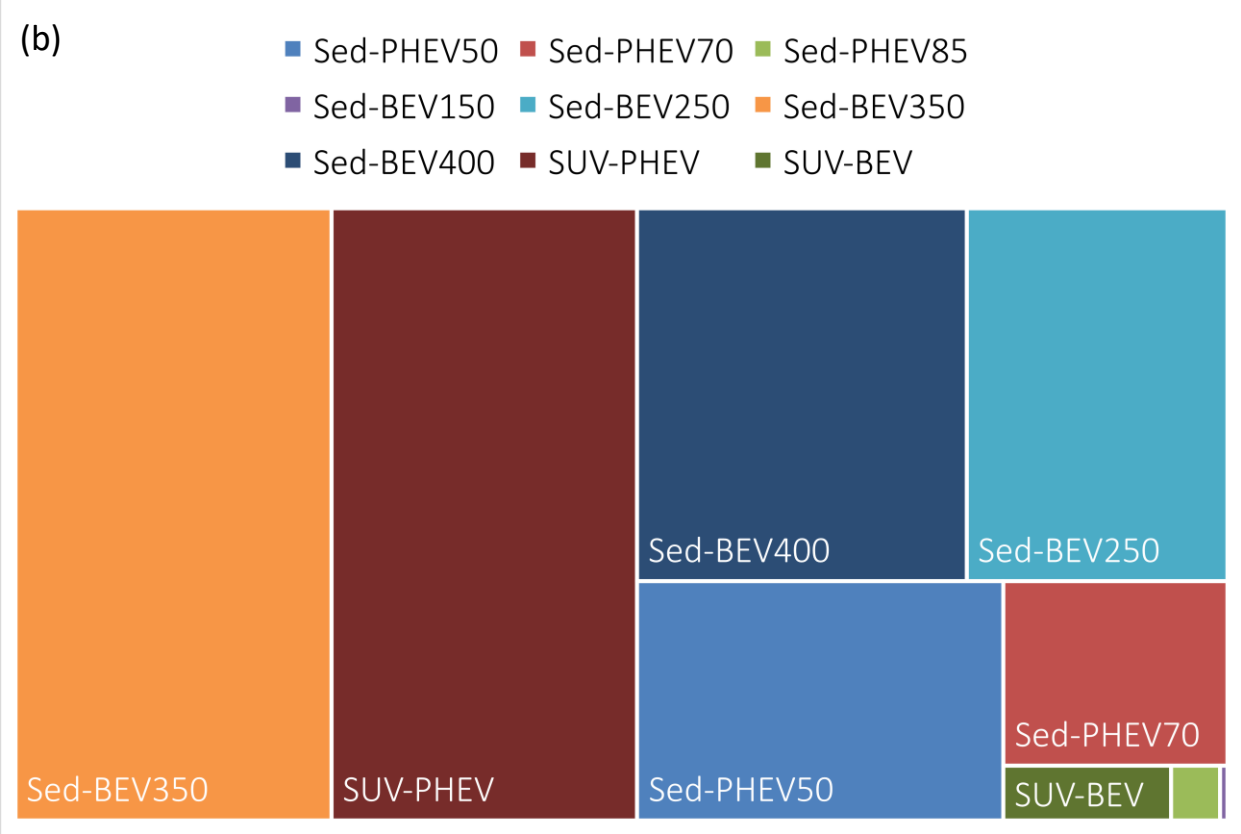
PEV Sales
SUV-BEV
SUV-PHEV
Sed-BEV400
Sed-BEV350
Sed-BEV250
Sed-BEV150
Sed-PHEV85
Sed-PHEV70
Sed-PHEV50
300,237
166,196
722,069
1,253,582
2,330,277
2016
2017
2018
2019
2020
Year


(b)
Sed-PHEV50
Sed-PHEV70
Sed-PHEV85
Sed-BEV150
Sed-BEV250
Sed-BEV350
Sed-BEV400
SUV-PHEV
SUV-BEV
Sed-BEV350
SUV-PHEV
Sed-BEV400
Sed-BEV250
Sed-PHEV50
Sed-PHEV70
SUV-BEV

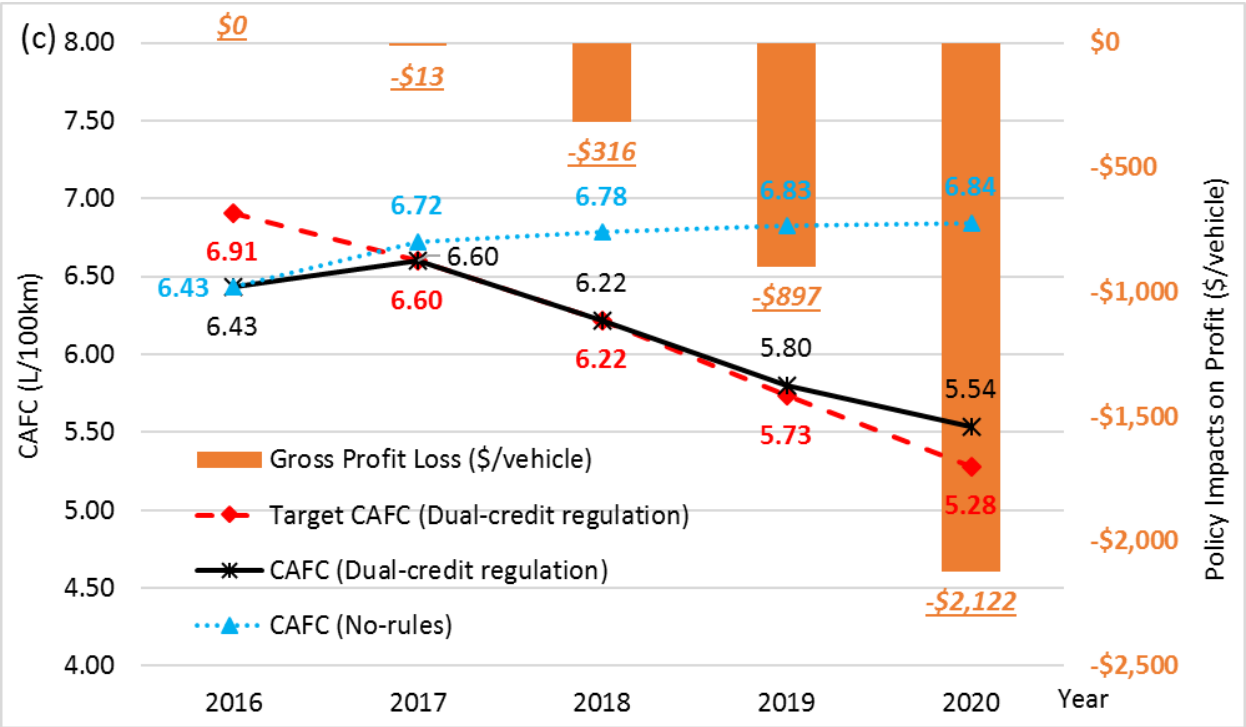


Fig. 1. (a) PEV sales by vehicle type in 2016-2020 in the Dual-credit scenario; (b) Total PEV sales volume by vehicle type in 2016-2020; (c) Target CAFCs, actual CAFCs, and policy impact on profits in 2016-2020.

4.2. Comparison of Dual-credit, CAFC-only, NEV-only scenarios

Although it is believed that the dual-credit policy will drive PEV sales growth in China (Ou et al., 2017), it is worth asking if the policy is the best design for promoting PEV sales. In this section, three vehicle policies - dual-credit policy, CAFC-credit rules, and NEV-credit rules - are compared to find out how the market will evolve under different policy constraints. In the CAFC-only scenario, the actual CAFC of the vehicle industry should be no higher than the corresponding target CAFC in each year from 2017 to 2020. In the NEV-only scenario, the ratio of the produced PEVs to the CVs should be no smaller than the NEV required minimum ratio in each year from 2017 to 2020.

Surprisingly, the dual-credit policy is not the policy that motivates the greatest PEV sales. Instead, the CAFC-credit rules are found more effective at promoting PEV sales. As shown in Fig.

2(a), the PEV market is estimated to be approximately 2.81 million units in 2020 when it complies to the CAFC-credit rules, 20.5% larger than the PEV market under the dual-credit policy.

On the other hand, the dual-credit policy encourages more BEVs in the market than any other policies in this study, as shown in Fig. 2(a). By year 2020, the annual sales of BEVs will increase to approximately 1.44 million units in the dual-credit scenario, which are 0.19 million more than in the CAFC-credit scenario, or 0.92 million more than in the NEV-only scenario. When it comes to the NEV-credit rules, though the rules drive the PEV sales growth to some extent, the sales performance is totally shadowed by the achievements by the dual-credit policy or the CAFC-credit rules.

If the objective of the CAFC-credit rules is to reduce the market's total fuel consumption, stimulate production of fuel-efficient CVs, this purpose is not helped by the addition of the NEV-credit rules, as suggested by literature (Wang, 2017) and confirmed by the NEOCC simulation results. The NEOCC model estimates that the sales share of CV-Low vehicles in 2020 decreases from 4.39% in the CAFC-only scenario to 2.9% in the dual-credit scenario. Not only that, the market share of PHEVs in 2020 decreases from 7.26% in the CAFC-only scenario to 4.14% in the dual-credit scenario. Given the much more generous credits for BEVs, the industry may choose to focus more on the BEV market and use the NEV credits from BEV production to meet both the NEV and CAFC (through the one-way NEV-to-CAFC conversion) targets. As shown by results, the market share of BEVs in 2020 increases from 5.86% in the CAFC-only scenario to 6.76% in the dual-credit scenario.

The NEV-credit rules stipulate the PEV required minimum ratios to the industry. Because BEV scores (S_{BEV}) are larger than PHEV score (S_{PHEV}) in the NEV-credit rules, the number of BEVs need to meet the PEV required minimum ratio is smaller than that of PHEVs. This partially

explains the result as in Fig 2 (a) that the PEV sales are surprisingly lower (big reduction in PHEV sales and small increase in BEV sales) in the dual-credit scenario than in the CAFC-only scenario.

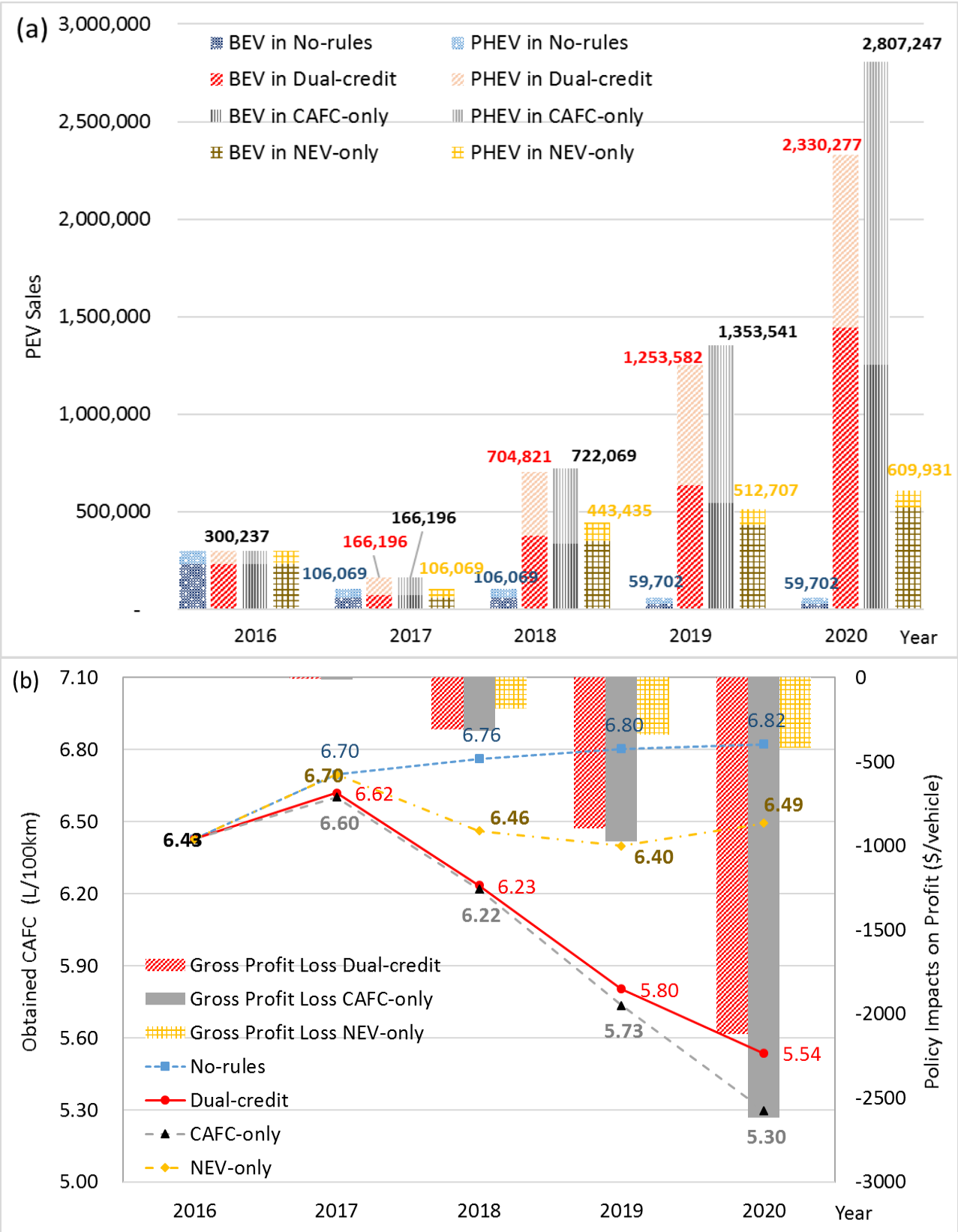
One concern is that the convenience of using PEV multipliers and the NEV-to-CAFC conversion credits to achieve CAFC compliance may discourage production of efficient CVs (as showed previously) and encourage sales of more profitable gas guzzlers. In the model results, the 2020 market, the sales of CV-High (inefficient CVs) increase about 6.89% more in the dual-credit policy than they are in the CAFC-only scenario.

Comparing the PIP in the markets under dual-credit policy or NEV-credit rules, the market will lose $2,619 per vehicle in NEOCC simulation under the CAFC-credit rules, which is the cruelest policy among the three scenarios to the Chinese vehicle industry. With the CAFC-credit rules, the industry has to give up more profitable vehicles and produce as many fuel-efficient vehicles as possible to meet the target CAFCs. However, under the dual-credit policy, the market needs to produce more BEVs to generate some NEV credits to make up for the deficit in CAFC credits. Unfortunately, no matter what policy is imposed to the market, the industry profits will be "cut down" in the NEOCC simulations. Fig. 2(b) shows that the industry profit will be reduced by about $416 per vehicle by 2020 in the NEV-only scenario, which leads to the least amount among these three policy scenarios. Again, this does not mean the industry will actually "lose" money, but only indicates the policy effects. The policy may in the real world motivate R&D investments and lead to technology breakthroughs, resulting the positive policy effect on the industrial profits, but that's beyond the scope of this paper.

In a nutshell, the dual-credit policy is a hybrid policy of the CAFC-credit rules and NEV-credit rules, which leads to fewer PEVs, but more BEVs, in the market. In addition, the actual CAFCs achieved by the dual-credit policy are higher than those achieved by the CAFC-credit rules during

years 2018-2020, as shown in Fig. 2(b). Starting in 2019 when both the CAFC-credit rules and NEV-credit rules are put into effect, the disparity increases between CAFC in compliance with the dual-credit policy and CAFC in compliance with the CAFC-credit rules.

Fig. 2(c) shows the achieved CAFC/NEV credits in different scenarios. The deficit of the CAFC/NEV credits increases yearly, and is at approximately 38.13 million in 2020 in the no-rules scenario. In order to obtain the highest profits in the dual-credit scenario, the ideal situation is that all CAFC/NEV credits are fully used. Therefore, as shown in Fig. 2(c), the sum of the CAFC-credits and NEV-credits is precisely zero in every year. The NEV credits are all used to make up the deficit of the CAFC credits in the dual-credit scenario. Additionally, comparing the CAFC-only and NEV-only scenarios, the NEV credits are always positive in the CAFC-only scenario and the CAFC credits are always negative in the NEV-only scenario. Therefore, considering the difficulty meeting the required minimum ratios in the NEV-credit rules, it is much harder to meet the target CAFCs for the vehicle industry.


(a)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
-
PEV Sales
BEV in No-rules
BEV in Dual-credit
BEV in CAFC-only
BEV in NEV-only
PHEV in No-rules
PHEV in Dual-credit
PHEV in CAFC-only
PHEV in NEV-only
300,237
106,069
166,196
166,196
106,069
106,069
704,821
722,069
443,435
59,702
1,253,582
1,353,541
512,707
59,702
2,330,277
2,807,247
609,931
2016
2017
2018
2019
2020
Year
(b)
7.10
6.80
6.50
6.20
5.90
5.60
5.30
5.00
Obtained CAFC (L/100km)
0
-500
-1000
-1500
-2000
-2500
-3000
Policy Impacts on Profit ($/vehicle)
6.43
6.70
6.70
6.62
6.60
6.76
6.46
6.23
6.22
6.80
6.40
5.80
5.73
6.82
6.49
5.54
5.30
Gross Profit Loss Dual-credit
Gross Profit Loss CAFC-only
Gross Profit Loss NEV-only
No-rules
Dual-credit
CAFC-only
NEV-only
2016
2017
2018
2019
2020
Year

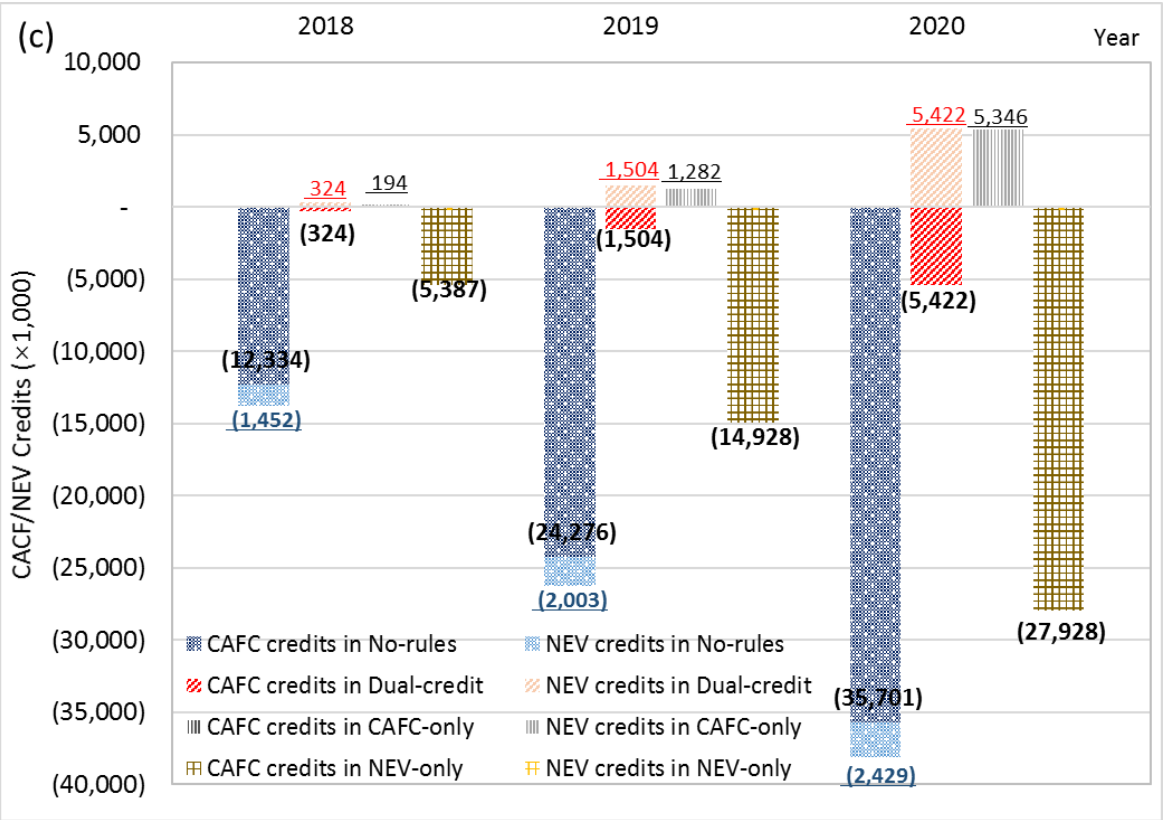


Fig. 2. (a) PEV sales in 2016-2020 from scenarios: no-rules, Dual-credit, CAFC-only, and NEV-only; (b) actual CAFCs and policy impact on profits in 2016-2020 from scenarios: no-rules, Dual-credit, CAFC-only, and NEV-only: (c) CAFC/NEV credits obtained in 2018-2020 from scenarios: no-rules, Dual-credit, CAFC-only, and NEV-only (numbers with the underscore are the NEV credits).

4.3. BEV Credits in the Dual-credit Policy

In the dual-credit policy, how sensitive are the PEV sales or the market share with the BEV scores and CAFC multipliers? What if we modify the BEV scores in calculating the NEV credits or the CAFC multiplier in calculating the CAFC credits in the dual-credit policy? In order to analyze the internal relations of the equations in the dual-credit policy, three scenarios are discussed in this section: “80%BEV-NEV Dual-credit,” “40%BEV-NEV Dual-credit,” and “50%PHEV-CAFC Dual-credit.” In the “80%BEV-NEV Dual-credit” scenario, the modified dual-credit policy has 20% reduction of the BEV’s NEV scores. In the “40%BEV-NEV Dual-credit” scenario, the modified dual-credit policy has 60% reduction of the BEV’s NEV scores. In the

“50%PHEV-CAFC Dual-credit” scenario, the modified dual-credit policy reduces the PHEV CAFC multiplier to half.

Fig. 3 presents the market responses to the three scenarios. The no-rules scenario and the dual-credit scenario work as benchmarks in comparisons. Comparing “80%BEV-NEV Dual-credit” and “40%BEV-NEV Dual-credit,” it shows that smaller BEV’s NEV scores leads to an increase of PEV sales, but results in a smaller market share and fewer units of BEVs. The increase of PEV sales is attributed to the rapid growth of PHEV units, as shown in Fig. 3(a), since more PEVs are needed to satisfy the NEV credit requirement when BEVs (and PEVs overall) receives fewer credits. Additionally, the smaller BEV’s NEV scores reduce the actual CAFC from 5.48 L/100km in 2020 in the “80%BEV-NEV Dual-credit” scenario to 5.40 L/100km in 2020 in the ‘40%BEV-NEV Dual-credit” scenario. In the CV segment, the decrease of the BEV’s NEV score leads to a growth in the CV-Low vehicles, as shown in Fig. 3(b). This is because, instead of producing BEVs to gain NEV credits and lower CAFC, the vehicle industry finds it is easier to produce more PHEVs to gain NEV credits, and produce more CV-Low vehicles in order to lower the CAFC when the BEV’s NEV scores are smaller.

Considering the “50%PHEV-CAFC Dual-credit” scenario, the projected units of PEVs are much less than they are in other scenarios, however, both the market share and units of BEVs are larger than they are in other scenarios, as shown in Fig. 3. This is because the decrease of PHEV CAFC multiplier motivates the auto firms to obtain the CAFC or NEV credits by other means: producing more BEVs, or producing more CV-Low vehicles. In contrast to having the CV-Low vehicles, producing/importing the BEVs with greater CAFC multipliers is a better option under the CAFC-credit rules, let alone BEVs also supply NEV credits under the NEV-credit rules. Therefore, the market share of CV-Low vehicles increases in “50%PHEV-CAFC Dual-credit”

more than it is in the dual-credit scenario, but the growth of the BEV sales is much more impressive in this comparison.

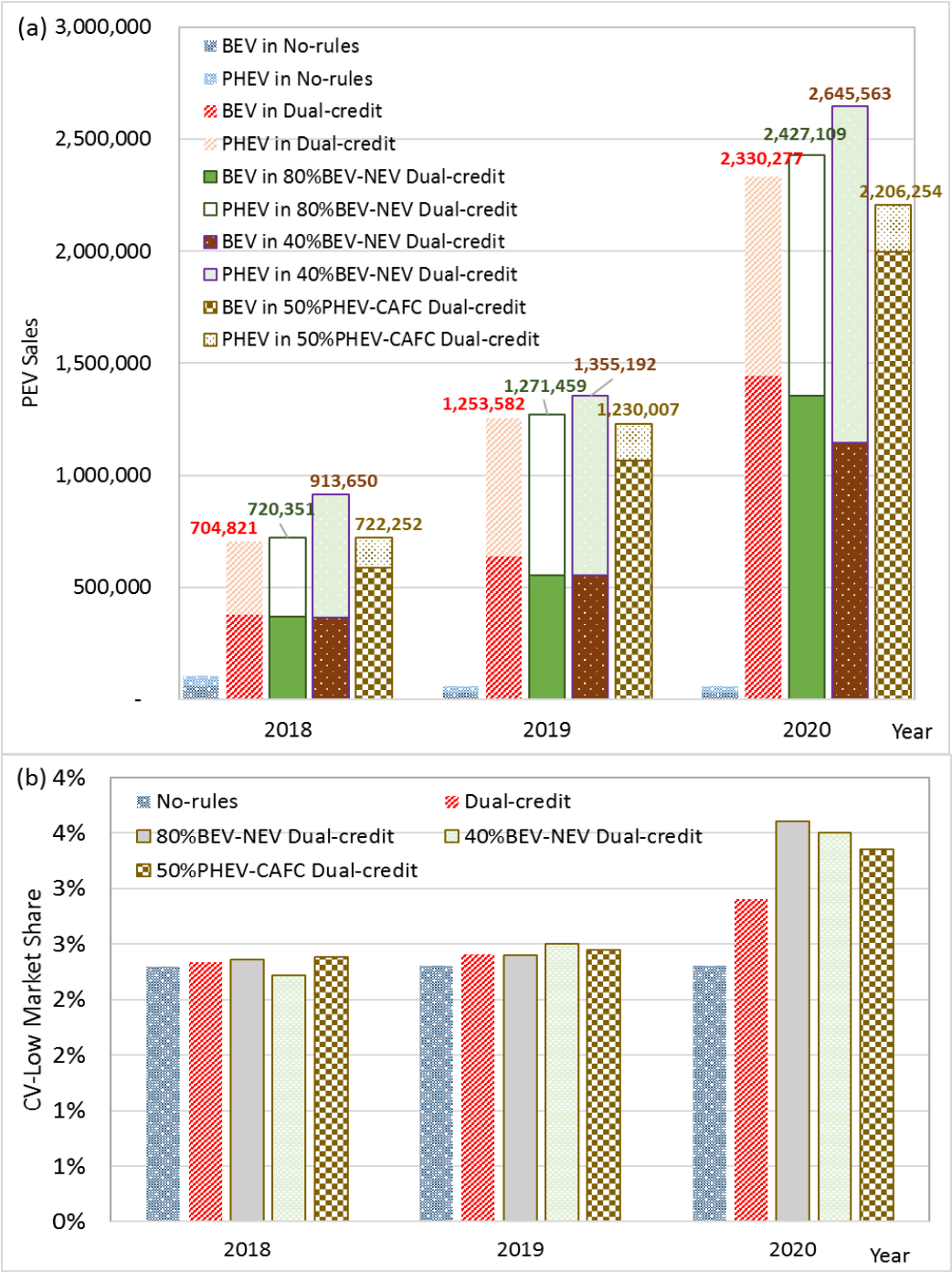


Fig. 3. (a) PEV sales in 2018-2020 from scenarios: no-rules, Dual-credit, 80%BEV-NEV dual-credit, 40%BEV-NEV Dual-credit, and 50%PHEV-CAFC Dual-credit; (b) CV-Low market shares in 2018-2020 from scenarios: no-rules, Dual-credit, 80%BEV-NEV Dual-credit, 40%BEV-NEV Dual-credit, and 50%PHEV-CAFC Dual-credit.

4.4. Role of Fuel-efficient CVs Under the Dual-credit Policy

Under the dual-credit policy, whether the low fuel consumption CVs are able to contribute the vehicle industry to meet the CAFC criteria and the NEV required minimum ratios? In the NEOCC model, the incremental cost of improving CV fuel-efficient (FE incremental cost) ($/MPG) are defaulted as $272/MPG for sedan CVs and $368/MPG for SUV CVs respectively, which values are based on the estimations form the U.S. market (National Research Council, 2011). Lower FE incremental cost promotes the price competitiveness of CVs, which means the costs of R&D or production to adopt the fuel-efficient technologies into the CVs are reduced; and in order to achieve more profits, the OEMs are more likely to increase the market share of CV-Low (fuel-efficient) vehicles instead of PEVs, if relatively more money is need to invest into the PEV segment to meet the requirements by the dual-credit policy.

To evaluate the influences of the CV fuel-efficient technology costs, FE upgrade multiplier, which is the ratio of the FE incremental cost over the defaulted FE incremental cost, is used in the analysis. For example, when the FE upgrade multiplier equals 0.5, the scenario is with the FE incremental cost at $136/MPG for sedan CVs and $184/MPG for SUV CVs. Thus, the smaller the FE upgrade multiplier is, the lower FE incremental costs are, and the cheaper prices of the CV-Low vehicles will be.

Lower costs in CV fuel-efficient technology bring more CV-Low vehicles into the market to meet the dual-credit policy requirements. As shown in Fig. 4(a), when the FE incremental costs decrease, more vehicles of the CV-Low sedan and CV-Low SUV are produced by the industry. On the other hand, when the FE incremental costs decrease, the units of PHEVs significantly decrease, however the total units of BEVs do not change much. This is because the industry needs to produce a certain number of PEVs to meet the NEV minimum requirement ratio, and the scores earned by a BEV are much larger than the scores earned by a PHEV, the industry will consider more BEVs

when deciding to reduce production of PEVs. As shown in Fig. 4(b), because of the reduction of PEVs, there are no NEV credits earned any more when the FE upgrade multiplier is smaller than 0.75. At the same time, a large amount of CAFC credits are accumulated since there are more CV-Low vehicles produced when the incremental costs of the fuel-efficient technology decline.

The PIP will reduce when the FE incremental costs decrease, as shown in Fig. 4(c). When the FE upgrade multiplier ranges from 0.25 to 0.75, the gross profit of the industry impacted by the policy loses approximately $139-$220 USD, which is smaller than the loss of $316 USD per vehicle in 2018 under the dual-credit scenario[†]. However, when the FE incremental cost declines further, the PIP grows back. This is because even if the PEVs totally lose their market competitiveness compared with the CV-Low vehicles, the industry still has to internally subsidize more to maintain the PEV numbers enforced by the NEV minimum required ratios. In addition, the actual CAFC gradually reduces as the FE upgrade multiplier decrease, as shown in Fig. 4(c). Therefore, the reduction of the fuel-efficient technology cost will not only make the industry produce more CV-Low vehicles, but will also help to reduce profit losses impacted by the dual-credit policy, which is critical to the OEMs. Notably, the defaulted FE incremental costs adopted in the NEOCC model are assumed at the same level of the U.S. market. If the costs of R&D or production to adopt the fuel-efficient technology are cheaper in the Chinese market than in the U.S. level, there will be more CV-Low vehicles and less PEVs under the dual-credit policy compared with the defaulted dual-credit scenario; on the other hand, if these costs are more expensive in China, the industry will produce more PEVs to meet the requirements by the dual-credit policy, as shown in Fig. 4. If the OEMs want to reduce the profit losses impacted by this new policy, they need to decrease the costs of the fuel-efficient technology in CVs anyhow.

[†] This study assumed that the CAFC-credit rules and NEV-credit rules take effects in 2018 for FE incremental costs analysis, which is applied with a dual-credit scenario. Notably, only CAFC-credit rules are implemented in 2018 according to the official version of the dual-credit policy.

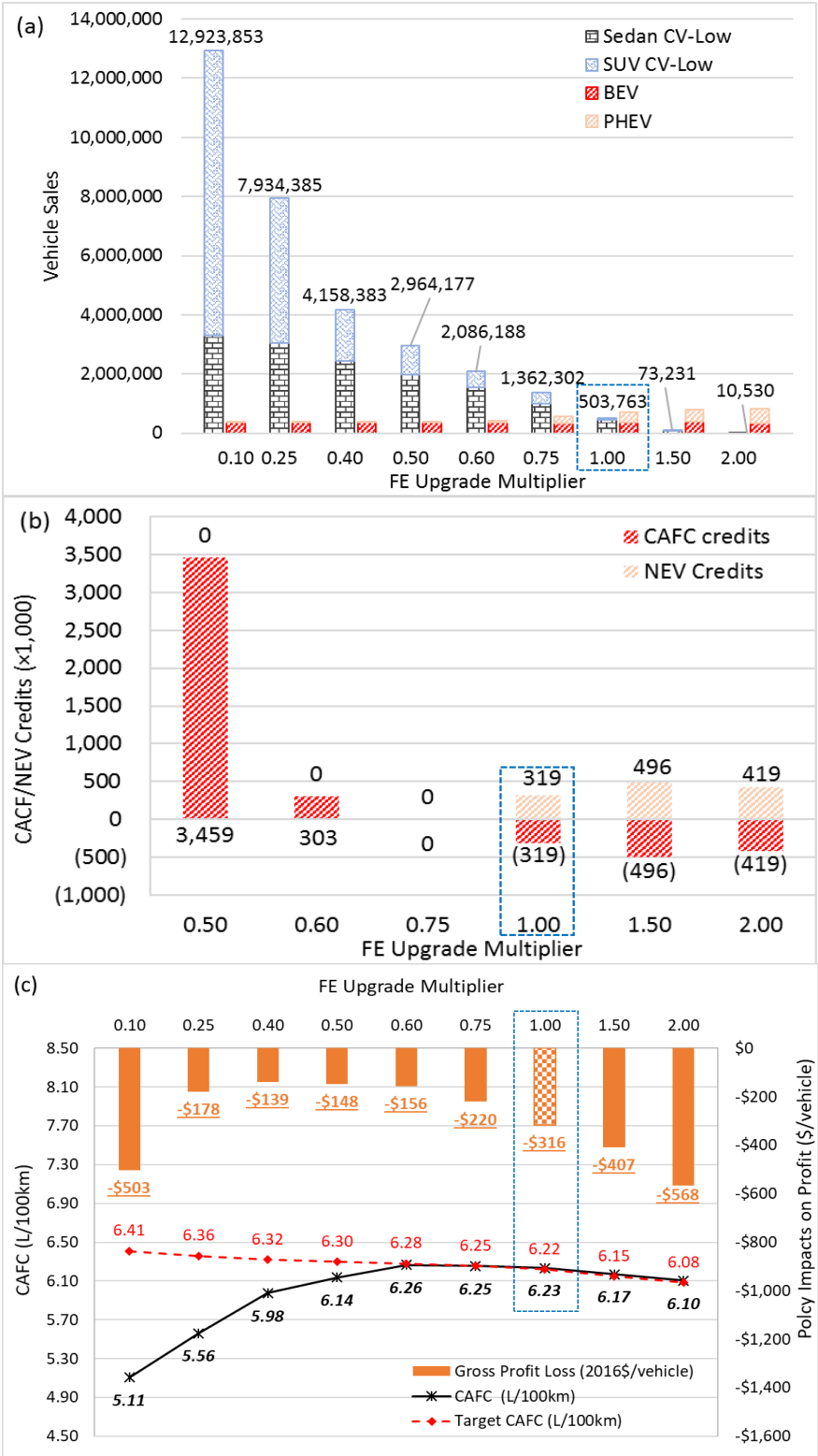


Fig. 4. (a) CV-Low sales and PEV sales (numbers are total units of CV-Low); (b) CAFC credits and NEV credits (numbers with the underscore are the NEV credits); (c) actual CAFCs, and policy impact on profits by the CV-FC upgrade multiplier. (All scenarios are simulated at year 2018, and the dual-credit regulation (CAFC-credit rules + NEV-credit rules) is assumed to take effects in 2018)

5. Conclusions and Future Work

By simulating the policy scenarios in the NEOCC model, this study quantified and compared the impacts of vehicle policies on the Chinese vehicle market. In the NEOCC model, 15 different types of vehicles are assumed. With the CARTAC database, the vehicle sales and performance metrics are estimated to ensure the reliability of the model calibration. In this study, seven policy scenarios (no-rules, dual-credit, CAFC-only, NEV-only, 80%BEV-NEV dual-credit, 40%BEV-NEV dual-credit, and 50%PHEV-CAFC dual-credit) in 2016-2020, and the sensitivity analysis of the FE incremental costs are discussed.

By comparing the vehicle markets with the dual-credit policy and other policy constraints, this paper presents the market dynamics insights that are expected to inform stakeholders involved with transportation electrification. Key observations are:

- The dual-credit policy plays a significant role in the vehicle industry. According to the NEOCC simulation, the PEV sales market will rapidly grow with annual sales of over 2 million units by 2020 if the policy is strictly complied with, but compared with the benchmark - no-rules scenario, the policy impacts on vehicle industry profits could reach to $2,122 per vehicle in 2020.
- When the dual-credit policy is enacted, simulation shows that the BEV-350 sedan will be the most popular among PEV models, followed by the SUV PHEV. In general, BEV sedans with long electric ranges will be more popular than other PEV models.
- Comparing impacts of the CAFC-credit rules on the market, the dual-credit policy is less capable of driving the PEV sales; however, the dual-credit policy promotes more BEVs in the market.

- Under the dual-credit policy, NEV credits are often used to make up the CAFC credits deficit. It is easier for the vehicle industry to meet the NEV required minimum ratios than to meet the CAFC targets under this scenario in NEOCC.
- Compared with the CAFC-credit rules, more BEVs will be produced through compliance with the dual-credit policy, while more units of high fuel-consumption and profitable vehicles are also expected. Thus, the difference between the actual CAFC and target CAFC becomes greater by year in the dual-credit scenario.
- PEV sales and market shares are sensitive to the multipliers in the CAFC-credit rules and NEV-credit rules. The smaller BEV's NEV scores are, the greater PEV sales will be; the smaller PHEV's CAFC multipliers are, the greater BEV sales and low fuel-consumption vehicles sales will be.
- Incremental costs of promoting fuel-efficient technology in CVs are critical to influence the impacts from the dual-credit policy: smaller FE incremental costs are, more units of CV-Low vehicles and less PHEVs are produced, while the NEV minimum requirement ratios ensure the small changes of BEV units.
- Facing the impacts under the dual-credit policy, the reduction of the fuel-efficient technology costs with more CV-Low vehicles will relieve the profit loss stress of the industry.

In general, by applying the hypothesis of profit maximization, this study calculates the policy impacts on industrial profit, projects the potential impacts, and discusses the vehicle market evolution under different policy constraints. However, profit maximization in a particular year might be economic "short-termism" that ignores potential vehicle industry measures for long-term goals (Laverty, 1996). For example, instead of transferring or trading, the vehicle industry might, as a precaution, bank the extra CAFC/NEV credits and carry forward for future use to achieve

maximum net present values in the long-term. The study assumes that the vehicle industry would strictly abide by the dual-credit policy, yet it is very possible for the vehicle industry may opt to pay the penalties after considering the opportunity costs. What is more, in order to simplify the computation in the model, the market sizes and technology levels in 2017-2020 are assumed to remain unchanged from 2016 levels in the study, which should be dynamically interactive with the industry supply-side and consumer demand-side. Therefore, more work is needed to improve the policy analysis, and the next version of NEOCC model will consider those problems in the future.

Future research should pay attention to impacts caused by cost increases in PEV or fuel-efficient technology production, the influence fuel prices have on policy implementation, the potential penalties, and CAFC/NEV credit prices, which are all critical in evaluating PEV market growth.

6. Acknowledgements

The authors would like to thank the Aramco Services Company for their generous financial support for this study. The authors are solely responsible for the views expressed in this study.

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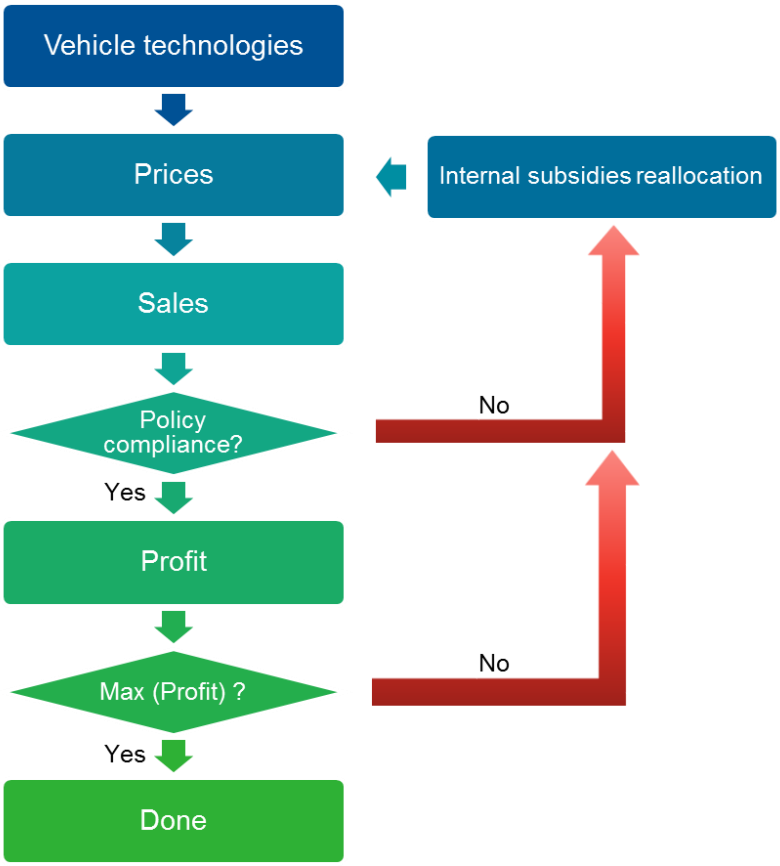
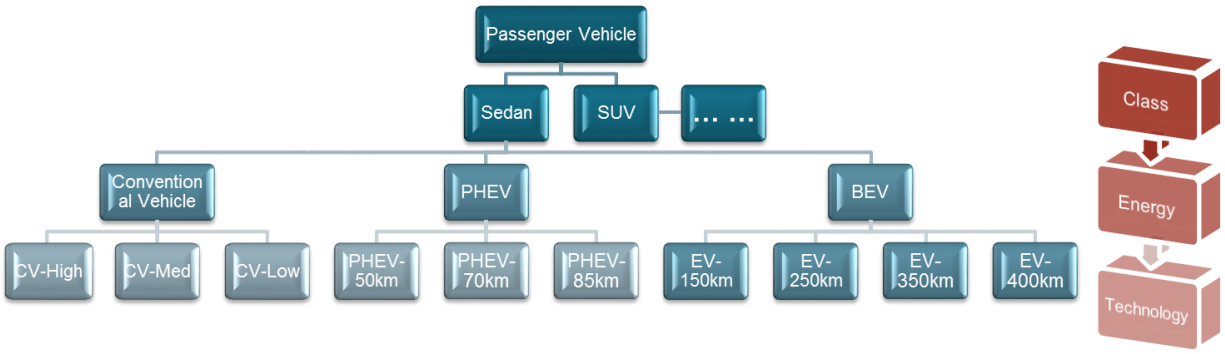
Appendix

The NEOCC model was developed by Oak Ridge National Laboratory to simulate the automotive industry's compliance scenarios under the dual-credit policy or other vehicle energy policies. This model is calibrated to 2016 sales, prices, and vehicle fuel economies of the China automotive market, with data support by the CATARC. NEOCC maximizes industry profits by optimizing internal subsidies for PEVs and efficient conventional vehicles, subject to the policy compliance constraints, as shown by Appendix Fig. a which describes the calculation method.



Appendix Fig. a. Logic flow chart of the NEOCC.

NEOCC takes into account: PEV sales share and sales-weighted average fuel consumption requirements, incremental cost of fuel efficiency, range limitation of battery electric vehicles, charging infrastructure, consumer choice and central and local government subsidies, and other monetary or nonmonetary incentives for PEVs. The discrete choice model is adopted as the methodology for computing the vehicle's market sales, and the structure is shown in Appendix Fig. b. The NEOCC can be used to analyze the potential compliance strategies and profit impacts, including pricing strategies, technology challenges, government subsidy, and infrastructure needs. It can also be used to assess the potential impact on gasoline vehicles and gasoline demand.



Appendix Fig. b. Structure of discrete choice model in the NEOCC.