



The impact of policy mixes on new energy vehicle diffusion in China

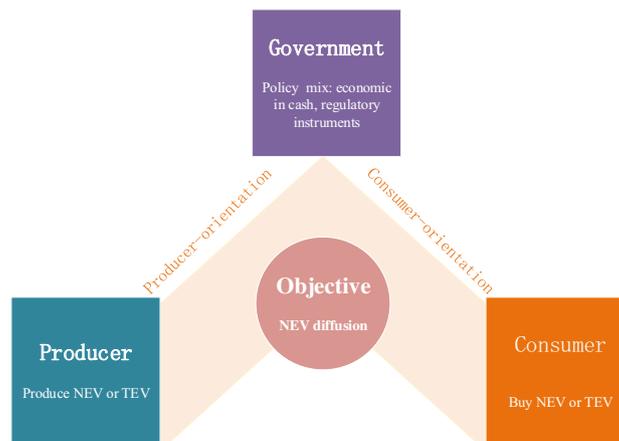
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Abstract

The Chinese government has instituted a number of policies to actively promote the diffusion of new energy vehicles (NEVs). There is widespread consensus that policy mixes can drive NEV diffusion effectively. To verify this consensus, we construct a two-dimensional framework of NEV policy instruments: producer-orientation versus consumer-orientation instruments, economic in cash versus regulatory instruments and classify NEV policy mixes. Then, we analyse the impact of policy mixes on NEV diffusion among enterprises and consumers by building an evolutionary game model. And according to the concept of stable area in the evolutionary game, we propose a definition of policy effect. The results show: (1) Policy mixes can reduce the saddle point of the auto market game and accelerate the spread of NEVs. In the early stages of the NEV industry, the government should take the policy mix strategy with four policies, and economic in cash instrument should be the main policy. (2) Policy mixes composed of producer-orientation and consumer-orientation instruments have a synergy or complementarity to promote NEV diffusion effectively. (3) With the increasing rate of NEV production and consumption, the government should adopt policy mixes mainly composed of regulatory instruments and rather than economic instruments.

Graphical abstract



Keywords Policy mixes · New energy vehicles diffusion · Policy effect · Evolutionary game

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Introduction

With the continuous and steady growth of Chinese motor vehicle ownership, motor vehicle pollution has become one of the main sources of air pollution in China. Moreover, increasing demand for automobile fuel has intensified energy security issues (Zhang et al. 2013). Although oil can be replaced by biodiesel (Marousek et al. 2012), and biodiesel has proven to be economically feasible (Marousek et al. 2015), the development of new energy vehicles (NEVs) is undoubtedly preferable. Ma et al. (2017) found that technology is still a bottleneck factor in the NEV industry, and technological progress has a greater impact on the diffusion of NEVs than economic subsidy policies. However, due to the existence of technological innovation externalities, the diffusion rate of NEVs among the two groups of automobile manufacturers and consumers is low. In order to stimulate and accelerate the diffusion of NEVs, the government needs to guide companies and consumers through subsidies, taxes and other policy instruments.

China is more interested in using NEVs to alleviate environmental pollution and energy crises than other countries. From 2010 to 2018, China's NEV sales increased from 0.72 million to 125.62 million, making it the country with the largest sales of NEVs in the world (Li et al. 2019). The rapid spread of NEVs in China has a lot to do with government policy incentives. The Chinese government has implemented a series of policies, such as subsidies, taxes and traffic management, especially "measures for the parallel administration of the average fuel consumption and NEV credit of passenger vehicle enterprises" (dual-credit policy), which means cash by trade in the market (Li et al. 2018). And these policies bring much more positive effects, such as improving the technology, reducing the production cost and customer cost (Fan and Dong 2018) and influencing consumer preference (Levay et al. 2017). However, policy instruments often appear in the form of policy mixes in the real economy. In this article, we focus on two questions: How does policy mix affect corporate production decisions and consumer purchasing decisions? And how can we quantify the effectiveness of policy mixes on promoting NEV diffusion?

We make three contributions to the policy mix research. First, we construct a quadruple policy instruments typology—producer-orientation versus consumer-orientation instruments, economic in cash versus regulatory instruments. Second, we define the concept of policy effect (PE), which is measured by the stable area. Namely, PE is equal to the stable area with policy interference minus the stable area without policy interference. Third, we build an evolutionary game model to quantify the impact of policy mixes on NEV diffusion among enterprises and consumers.

Previous studies focused on quantitative evaluations of a single policy. We conduct quantitative evaluation studies on policy mixes, including the complementary and synergistic effects of different policies. And the results show that: (1) Policy mixes can reduce the saddle point of the auto market game and accelerate the spread of NEVs. In the early stages of the NEV industry, the government should take the policy mix strategy including four policies, and economic in cash policy should be the main policy. (2) Policy mixes composed of producer-orientation and consumer-orientation instruments have a synergy or complementarity to promote NEV diffusion effectively. And the policy mix composed of the same type of policies (several policies belonging to producer-oriented policies or consumer-oriented policies) is generally complementary, while the policy mix composed of producer-oriented tools and consumer-oriented tools is generally synergistic. (3) With increasing NEV production and consumption, the government should adopt policy mixes mainly composed of regulatory instruments, and the policy mixes should shift from focusing on economic instruments to regulatory instruments.

The rest of the article is organized as follows. Section 2 reviews the relevant literature. Section 3 provides a framework for classifying NEV policy instruments and policy mixes and discusses the impact on the diffusion of NEVs. Section 4 builds up the evolutionary game model of NEV diffusion. Section 5 is the model analysis, and in Sect. 6 simulations and verifications are given. In the last section, conclusions are drawn and policy recommendations provided.

Literature review

Policy mixes

The number of theoretical and empirical studies on policy mixes is growing. Theoretical research mainly focuses on the reconceptualization of the framework of policy mixes. Magro and Wilson (2013) argued policy mixes come in four forms: rationales mixes, domains mixes, instrument mixes and multi governance mixes. Instrument mixes are the core of policy mixes (Rogge and Reichardt 2016). Flanagan et al. (2011) provided definitions of policy mix tensions and interactions. DelRío (2014) provided definitions of four kinds of interactions between policy instruments but did not conduct in-depth quantitative verification research. Some scholars mainly focus on quantifying the effects of policy mixes. Lathan and Feldman (2015) assessed the effect of multilevel innovation policy mixes, and found policies are complementary. Fabrizi et al. (2018) studied the impact of policy mixes on environmental innovation and found regulation policies and research network policies have a complementary effect.

Guerzoni and Raiteri (2015) studied the policy mixes on innovation activity from the demand-side and supply-side, and a synergetic effect of policy mix was found.

There are few empirical studies on policy mixes, which has affected the further development of policy mixing (Schmidt and Sewerin 2019). We focus on quantifying the impact of policy mixes on the diffusion of NEVs. Our research addresses the gap described by Xu and Su (2016) and verifies the definition of the types of positive interaction provided by DelRío (2014) in the area of NEVs.

Government policies and NEV diffusion

Existing research on NEV policy can be divided into two categories: textual analysis and empirical studies. And empirical studies include two aspects: one is about the policy effects of NEV diffusion, and the other concerns the impact of policies on consumer preference.

Textual analysis focuses on content analysis and comparison analysis of NEV policies. Gong et al. (2013) summarized the policies and demonstration activities concerning NEVs in China and found the Chinese technology policies could promote NEV production and demonstration policies could promote NEV commercialization. Zhang and Bai (2017) provided a policy dependency mapping method to analyse NEV policies on the national, regional and provincial levels, and found multi-government policies have different impacts on the adoption of NEVs. Xu and Su (2016) summarized 22 types of policy instruments and proposed a framework of NEV policy tools to analyse them. These studies are mostly conceptual research on NEV policies. This article will extend the classification of policy mixes concerning NEVs and empirically study the effect of policy mixes on the NEV industry.

To evaluate the impact of policies on NEV diffusion, econometrics, game, system dynamics and other methods are used in empirical studies. Bastin et al. (2010) found the policies of technology-push and market-pull have a positive influence on stimulating diffusion of the new technologies in the NEV industry in Brazil. Langbroek et al. (2016) studied the side effects of policies and found the free parking subsidy and free charging subsidy have a positive influence on NEV diffusion among consumers, and the influence is different in consumers at different stages. Ma et al. (2017) also studied the effect of policy instruments, including purchase subsidies, tax policies and traffic restriction policies. Kong et al. (2020) used the system dynamics method and found that China's elimination of car purchase subsidies will reduce the sales of NEVs by 40%. Melton et al. (2017) provided a new framework method of the policy report card to assess plug-in electric vehicle policies, including demand-side and supply-side policies. Wang et al. (2017) studied the effects of policies on the two sides of NEV adoption.

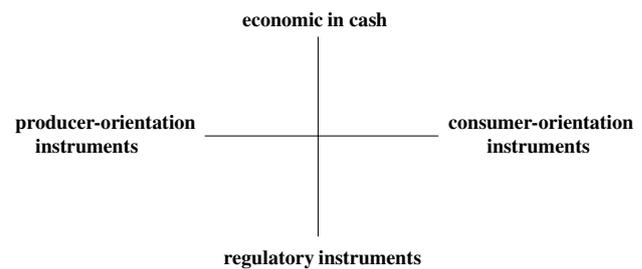


Fig. 1 A quadruple policy instrument typology

The production-oriented policy measures aimed at stimulating technological progress are the model developing award and the manufacturing award. And the consumer-oriented policy measures aimed at improving the purchasing motivation are tax exemption, license fees, charging discounts, etc. Referencing the agent-based models, Silvia et al. (2016) found that hybrid policy mixes were the most effective way to promote the adoption of electric vehicles. Guan et al. (2016) used stochastic evolutionary game method to study the impact of government support policies on the diffusion of NEV among consumers, and the results showed that the support policies can reduce the life cycle cost of NEVs and improve the performance of NEVs. A substitution effect between dual-credit policies and subsidies was found (Li et al. 2018). Fan et al. (2018) used the evolutionary game method to analyse the effects of policies on NEV diffusion among enterprises and consumers. They found it is more effective to pull the market by enterprise subsidy than consumer subsidy.

In terms of the impact of policies on consumer preferences, Zhang et al. (2013) studied the impact of policies on the preference for NEV adoption and found that policies moderate the relation between four attributes, including financial benefits, performance of vehicle, environmental awareness and psychological needs and NEV diffusion among consumers. Ewing (2000) used a discrete choice experiment to study the impact of policies on consumer preferences for NEVs and found attributes of NEVs can be influenced by the policies. For example, economic instruments and vehicle technology policies can affect the vehicle performance and cost, and transportation policies can also affect commuting costs.

In summary, previous studies have focused on the study of various single policy, and lacked a quantification of the joint role of multiple policy tools. Therefore, from the perspective of policy mixes, we construct a policy mix framework and propose a new quadruple policy instrument typology. Secondly, we use evolutionary game theory to define the policy effect and quantify the impact of policy mixes on the diffusion of NEVs.

Table 1 Classification of NEVs policy instruments

Classification of policy instruments	Form of policy instruments	Function
<i>1 Producer-orientation instruments</i>		
1.1 Economic in cash (P_{ES})	R&D subsidy, R&D tax credit, equipment imports tax credit, etc	Reduce the production cost
1.2 Regulatory instruments (P_{EM})	Dual-credit policy	Impact on the profits of the enterprise
<i>2 Consumer-orientation instruments</i>		
2.1 Economic in cash (C_{ES})	Purchase subsidy, the vehicle purchase tax and travel tax, etc	Reduce the purchase cost
2.2 Regulatory instruments (C_{EM})	Traffic management policy (license plate numbers, parking fees, etc.)	Affect the consumer preference

Table 2 Classifications of the policy mixes of the NEV policy instruments

Type of policy mix	Form of policy mix	Stakeholders	The types of interaction
<i>No policy mix</i>			
No policy instrument	(1) –	–	–
Only one policy instrument	(2) P_{ES} (3) P_{EM}	Automobile enterprises	–
	(4) P_{CS} (5) P_{CM}	Consumers	–
<i>Policy mix</i>			
Only two policy instruments	(6) (P_{ES}, P_{EM})	Automobile enterprises	Complementarity ^a or Synergy ^b
	(7) (P_{CS}, P_{CM})	Consumers	
	(8) (P_{ES}, P_{CS})	Automobile enterprises and consumers	
	(9) (P_{ES}, P_{CM})		
	(10) (P_{EM}, P_{CS})		
	(11) (P_{EM}, P_{CM})		
Only three policy instruments	(12) (P_{ES}, P_{EM}, P_{CS})	Automobile enterprises and consumers	
	(13) (P_{ES}, P_{EM}, P_{CM})		
	(14) (P_{ES}, P_{CS}, P_{CM})		
	(15) (P_{EM}, P_{CS}, P_{CM})		
All instruments	(16) ($P_{ES}, P_{EM}, P_{CS}, P_{CM}$)	Automobile enterprises and consumers	

^aSee Del Río (2014) “Full complementarity: X adds fully to the effect of Y in the combination: $X + Y = 2$ ”. P273^bSee Del Río (2014) “Synergy: Adding X to Y magnifies the impact of the combination: $X + Y > 2$ ”. P273

A framework of NEV policy mixes

A new quadruple policy instrument typology

In this paper, the diffusion of NEVs includes the diffusion of NEVs on the supply-side (producers) and the demand-side (consumers). Governments use policy mixes to promote the diffusion of NEVs from the supply and demand-sides. Therefore, we provide a new quadruple policy instrument typology, as shown in Fig. 1, which divides the NEV policy tools into two dimensions: producer-orientation and consumer-orientation, economic in cash and regulatory instruments. Producer-orientation instruments aim at inducing the behavior of producers by a set of measures which can reduce

costs and improve performance (Xu et al. 2016). Consumer-orientation instruments aim at inducing the behavior of consumers by a set of measures which can reduce purchasing cost and induce change in consumer behavior (Xu et al. 2016). Economic and regulatory policy instruments are conventional typologies (Borrás and Edquist 2013). Generally, economic instruments include in cash or in kind. Economic instruments in cash provide positive incentives (or disincentives) to support innovation activities. Regulatory instruments, which use legal tools to regulate the action of stakeholders by government, are compulsory in nature, such as laws, rules, directives, etc. Regulatory instruments are also measured in cash as the stakeholders will enjoy a premium by complying, but non-compliance may come with a penalty.

According to the above quadruple policy instrument typology (Fig. 1), the classification of NEV policy instruments is shown in Table 1.

NEV policy mixes

A policy mix is defined as a combination that includes at least two or more policy instruments (Borrás and Edquist 2013). DelRío (2014) defined four types of interaction of policy mix: strong conflict, weak conflict, full complementarity and synergy. The first two are negative interactions, and the latter two are positive.

According to the quadruple policy instrument typology, the NEV policies are divided into five types of policy mix. The types composed of zero policies and only one policy instrument are included in our research, and they are the control group for the policy mix. Table 2 shows the classifications of the policy mixes of the NEV policy instruments.

The evolutionary game model of NEV diffusion

Evolutionary game theory refers to the process in which each player learns slowly and finally reaches equilibrium by replicating a dynamic mechanism under the premise of bounded rationality. Evolutionary stability strategy (Smith and Price 1973) and imitative dynamics (Taylor and Jonker 1978) are the core basic concepts of evolutionary game theory. They represent the stable state and the dynamic convergence process toward the stable state of evolutionary game theory. Under the influence of policy mixes, enterprises and consumers will constantly imitate and learn the behavior of the dominant group (the group that may obtain higher income by choosing an NEV strategy) and improve their own strategies. This method is suitable for the dynamic change process of enterprises and consumers in the selection of NEVs.

Based on the evolutionary game model of NEV diffusion among enterprises and consumers (Fan and Dong 2018), we consider four policy factors. Based on R&D subsidies and purchase subsidy policy, regulatory instruments affecting enterprises' green production earnings and consumer preferences are added. Then, an evolutionary game model of NEV diffusion from a policy mix perspective is constructed. The evolutionary game method is mainly divided into three steps: (1) Propose research hypotheses and establish the payoff matrix and the game model of both producers and consumers according to relevant parameters, as detailed in Part 4. (2) Use the replication dynamic equation to solve the equilibrium point of the evolutionary game and analyse the effect of policy mixes through the change of the effective stability area, as detailed in Part 5. (3) The theoretical inference of the fifth

part is verified by numerical simulation based on specific cases.

The assumptions and related parameters considered are as follows.

Assumptions

There are two groups in the market: automobile enterprises and consumers. Each company has two strategies: produce NEVs or TEVs (tradition engine vehicles). Each consumer has two strategies: buy a NEV or a TEV. And the consumer can only choose one type of consumption at a time.

Consumer-oriented regulatory instruments will affect consumers' consumption preferences. Policies such as free green license plates and no traffic restrictions will increase consumers' preference to buy NEVs. However, policies such as license plate restriction for TEVs will reduce consumers' preference to buy TEVs.

The sum of cash comprising economic instruments and regulatory instruments to enterprises cannot exceed their cost, and the sum of cash to consumers cannot exceed half of the price of NEVs. Consumer-oriented regulatory instruments affect consumer preferences, and the preference factor for buying TEVs cannot be less than zero.

Parameters

(1) Non-policy parameter

Π_1 : represents the unit profit of NEVs corresponding to produce NEVs strategy.

Π_2 : represents the unit profit of TEVs corresponding to produce TEVs strategy.

p_1 : represents the price of NEVs corresponding to produce NEVs strategy.

p_2 : represents the price of TEVs corresponding to produce TEVs strategy.

c_1 : represents the unit cost of NEVs for enterprises corresponding to produce NEVs strategy.

c_2 : represents the unit cost of TEVs for enterprises corresponding to produce TEVs strategy.

x : represents the percent of enterprises with producing NEVs strategy.

$1 - x$: represents the percent of enterprises with producing TEVs strategy.

y : represents the percent of consumers with NEVs consumption.

$1 - y$: represents the percent of consumers with TEVs consumption.

U_1 : represents one unit of the consumer surplus with buying NEVs strategy.

U_2 : represents one unit of the consumer surplus with buying TEVs strategy.

σ_1 : represents the preference factor of NEVs consumers based on vehicles performance and environmental awareness.

σ_2 : represents the preference factor of TEVs consumers based on vehicles performance and environmental awareness.

δ_1 : represents the environmental utility of a NEV.

δ_2 : represents the environmental utility of a TEV, and $\delta_1 > \delta_2$.

τ_1 : represents the price sensitive factor of NEVs consumers.

τ_2 : represents the price sensitive factor of TEVs consumers.

(2) Policy parameter

w_1 : represents the amount of cash incentives to enterprises for producing NEVs

w_2 : represents the amount of cash incentives to consumers for buying a NEV, and $w_2 = s_1 + s_2$.

s_1 : represents the amount of cash incentives for price of NEV from the central government and local government.

s_2 : represents the amount of cash incentives for purchasing tax of a NEV, and $s_2 = \frac{p_1}{1+17\%} \times 10\%$.

γ_1 : represents the amount of reward of regulation instruments to enterprises corresponding to produce NEVs strategy.

γ_2 : represents the amount of fine of regulation instruments to enterprises corresponding to produce TEVs strategy, and $r_2 = \beta\gamma_1$.

α_1 : represents the coefficient of preference factor of NEVs consumers influenced by regulation instruments.

α_2 : represents the coefficient of preference factor of TEVs consumers influenced by regulation instruments, and $\alpha_2 = \theta\alpha_1, 1 \leq \theta \leq \frac{1}{\alpha_1}$.

Corporate profits

Based on the above parameters and assumptions, the corporate profit is obtained by the formula below.

When there is no policy for automobile enterprises, the firm profit is shown by Eq. (1) and Eq. (2).

$$\Pi_1 = p_1 - c_1 \tag{1}$$

$$\Pi_2 = p_2 - c_2 \tag{2}$$

When there is only one policy of economic in cash for automobile enterprises, the firm profit is shown by Eq. (3).

$$\Pi'_{1ES} = p_1 - c_1 + w_1 \tag{3}$$

Table 3 Payoff matrix of evolutionary game when there is zero policy

Enterprise	Consumer	
	Buy NEVs (y)	Buy TEVs (1 - y)
Produce NEVs (x)	$p_1 - c_1, \sigma_1\delta_1 - \tau_1p_1$	$-c_1, 0$
Produce TEVs (1 - x)	$-c_2, 0$	$p_2 - c_2, \sigma_2\delta_2 - \tau_2p_2$

Table 4 Payoff matrix of evolutionary game when there is one policy

Enterprise	Consumer	
	Buy NEVs (y)	Buy TEVs (1 - y)
Produce NEVs (x)	$p_1 - c_1 + w_1, \sigma_1\delta_1 - \tau_1p_1 - c_1$	0
Produce TEVs (1 - x)	$-c_2, 0$	$p_2 - c_2, \sigma_2\delta_2 - \tau_2p_2$

When there is only one regulatory policy for automobile enterprises, the firm profit is shown by Eq. (4) and (5).

$$\Pi'_{1EM} = p_1 - c_1 + \gamma_1 \tag{4}$$

$$\Pi'_{2EM} = p_2 - c_2 - \beta\gamma_1 \tag{5}$$

When there is a policy mix combined of economic and regulatory instruments for automobile enterprises, the firm profits are shown by Eq. (6).

$$\Pi'_{1ESM} = p_1 - c_1 + w_1 + \gamma_1 \tag{6}$$

Consumer surplus

Based on the above parameters and assumptions, the consumer surplus is obtained by the formula below:

When there is no policy for consumers, the consumer surplus is shown by Eq. (7) and (8).

$$U_1 = \sigma_1\delta_1 - \tau_1p_1 \tag{7}$$

$$U_2 = \sigma_2\delta_2 - \tau_2p_2 \tag{8}$$

When there is only one policy of economic in cash for consumers, the consumer surplus is shown by Eq. (9).

$$U'_{1cs} = \sigma_1\delta_1 - \tau_1(p_1 - w_2) \tag{9}$$

When there is only one regulatory policy for consumers, the consumer surplus is shown by Eq. (10) and (11).

$$U'_{1CM} = (1 + \alpha_1)\sigma_1\delta_1 - \tau_1p_1 \tag{10}$$

$$U'_{2CM} = (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2 \tag{11}$$

Table 5 Payoff matrix of evolutionary game when there is a policy mix (two policies)

Enterprise	Consumer	
	Buy NEVs (y)	Buy TEVs ($1 - y$)
Produce NEVs (x)	$p_1 - c_1 + w_1, (1 + \alpha_1)\sigma_1\delta_1 - \tau_1p_1$	$-c_1, 0$
Produce TEVs ($1 - x$)	$-c_2, 0$	$p_2 - c_2, (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2$

Table 6 Payoff matrix of evolutionary game when there is a policy mix (three policies)

Enterprise	Consumer	
	Buy NEVs (y)	Buy TEVs ($1 - y$)
Produce NEVs (x)	$p_1 - c_1 + w_1, (1 + \alpha_1)\sigma_1\delta_1 - \tau_1(p_1 - w_2)$	$-c_1, 0$
Produce TEVs ($1 - x$)	$-c_2, 0$	$p_2 - c_2, (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2$

Table 7 Payoff matrix of evolutionary game considering policy mix (four policies)

Enterprise	Consumer	
	Buy NEVs (y)	Buy TEVs ($1 - y$)
Produce NEVs (x)	$p_1 - c_1 + w_1 + \gamma_1, (1 + \alpha_1)\sigma_1\delta_1 - \tau_1(p_1 - w_2)$	$-c_1 + w_1 + \gamma_1, 0$
Produce TEVs ($1 - x$)	$-c_2 - \beta\gamma_1, 0$	$p_2 - c_2 - \beta\gamma_1, (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2$

When there is a policy mix combined of economic and regulatory instruments for consumers, the consumer surplus is shown by Eq. (12).

$$U'_{ICSM} = (1 + \alpha_1)\sigma_1\delta_1 - \tau_1(p_1 - w_2) \tag{12}$$

(5) There is a policy mix which combines four policies, for example policy mix ($P_{ES}, P_{EM}, P_{CS}, P_{CM}$), namely $w_1 \neq 0, \alpha_1 \neq 0, \gamma_1 \neq 0, w_2 \neq 0$, the corresponding payoff matrix is shown in Table 7.

The evolutionary game model

Based on the above analysis, the evolutionary game matrix of NEV diffusion between enterprises and consumers under the five kinds of policy mix are established as shown below:

- (1) There is zero policy, namely $w_1 = \gamma_1 = w_2 = \alpha_1 = 0$, the corresponding payoff matrix is shown in Table 3.
- (2) There is only one policy, for example policy of P_{ES} , namely $w_1 \neq 0, \gamma_1 = w_2 = \alpha_1 = 0$, the corresponding payoff matrix is shown in Table 4. The same meth can be used to compute P_{EM}, P_{CS} and P_{CM} .
- (3) There is a policy mix which combines only two policies, for example policy mix (P_{ES}, P_{CM}), namely $w_1 \neq 0, \alpha_1 \neq 0, \gamma_1 = w_2 = 0$, the corresponding paff matrix is shown in Table 5. The same method can be used to compute (P_{ES}, P_{EM}), (P_{CS}, P_{CM}), (P_{ES}, P_{CS}), (P_{EM}, P_{CS}) and (P_{EM}, P_{CM}).
- (4) There is a policy mix which combines only three policies, for example policy mix (P_{ES}, P_{CS}, P_{CM}), namely $w_1 \neq 0, \alpha_1 \neq 0, w_2 \neq 0, \gamma_1 = 0$, the corresponding payoff matrix is shown in Table 6 The same method can be used to compute (P_{ES}, P_{EM}, P_{CS}), (P_{ES}, P_{EM}, P_{CM}) and (P_{EM}, P_{CS}, P_{CM}).

Model analysis

The existence of an equilibrium solution

Based on the payoff matrix of the evolutionary game, we calculate the duplicated dynamic equation of enterprise benefits and consumer benefits under the five kinds of policy mix which contain 16 scenarios. In the groups composed of rationally bounded players, the production strategy or consumption strategy with higher income than the average level will be gradually adopted by more players, thus the proportion of players adopting various strategies in the groups will change. In the process of replicating the dynamic mechanism of slowly learning, the adoption of strategies by both sides of NEV diffusion will gradually tend to form five evolutionary game equilibrium points. We take the fifth type (scenario 16) for example, it is shown below:

Type 5 (scenario 16): There is a policy mix combining four policies.

$$\begin{aligned} \frac{dx}{dt} &= x(u_{1e} - \bar{u}_e) = x(1 - x)(u_{1e} - u_{2e}) \\ &= x(1 - x)((p_1 + p_2)y + w_1 + (1 + \beta)\gamma_1 - c_1 + c_2 - p_2) \end{aligned} \tag{13}$$

Table 8 The saddle points of the evolutionary game under 16 scenarios

Classification of Policy mix	Scenarios	Policy mix forms	Saddle points	
<i>No policy mix</i>				
Zero policy	(1)	0	$x_1^* = \frac{U_2}{U_1+U_2}$	$y_1^* = \frac{c_1-c_2+p_2}{p_1+p_2}$
Only one policy	(2)	P_{ES}	$x_2^* = \frac{U_2}{U_1+U_2}$	$y_2^* = y_{ES} = \frac{-w_1+c_1-c_2+p_2}{p_1+p_2}$
	(3)	P_{EM}	$x_3^* = \frac{U_2}{U_1+U_2}$	$y_3^* = y_{EM} = \frac{-(1+\beta)\gamma_1+c_1-c_2+p_2}{p_1+p_2}$
	(4)	P_{CS}	$x_4^* = x_{CS}^* = \frac{U_2}{U'_{1cs}+U_2}$	$y_4^* = \frac{c_1-c_2+p_2}{p_1+p_2}$
	(5)	P_{CM}	$x_5^* = x_{CM}^* = \frac{U'_{2CM}}{U'_{1CM}+U'_{2CM}}$	$y_5^* = \frac{c_1-c_2+p_2}{p_1+p_2}$
<i>Policy mix:</i>				
Only two policies	(6)	(P_{ES}, P_{EM})	$x_6^* = \frac{U_2}{U_1+U_2}$	$y_6^* = y_{ESM} = \frac{-w_1-(1+\beta)\gamma_1+c_1-c_2+p_2}{p_1+p_2}$
	(7)	(P_{CS}, P_{CM})	$x_7^* = x_{CSM}^* = \frac{U'_{2CM}}{U'_{1CSM}+U'_{2CM}}$	$y_7^* = \frac{c_1-c_2+p_2}{p_1+p_2}$
	(8)	(P_{ES}, P_{CS})	$x_8^* = \frac{U_2}{U'_{1cs}+U_2}$	$y_8^* = \frac{-w_1+c_1-c_2+p_2}{p_1+p_2}$
	(9)	(P_{ES}, P_{CM})	$x_9^* = \frac{U'_{2CM}}{U'_{1CM}+U'_{2CM}}$	$y_9^* = \frac{-w_1+c_1-c_2+p_2}{p_1+p_2}$
	(10)	(P_{EM}, P_{CS})	$x_{10}^* = \frac{U_2}{U'_{1cs}+U_2}$	$y_{10}^* = \frac{-(1+\beta)\gamma_1+c_1-c_2+p_2}{p_1+p_2}$
	(11)	(P_{EM}, P_{CM})	$x_{11}^* = \frac{U'_{2CM}}{U'_{1CM}+U'_{2CM}}$	$y_{11}^* = \frac{-(1+\beta)\gamma_1+c_1-c_2+p_2}{p_1+p_2}$
Only three policies	(12)	(P_{ES}, P_{EM}, P_{CS})	$x_{12}^* = \frac{U_2}{U'_{1cs}+U_2}$	$y_{12}^* = \frac{-w_1-(1+\beta)\gamma_1+c_1-c_2+p_2}{p_1+p_2}$
	(13)	(P_{ES}, P_{EM}, P_{CM})	$x_{13}^* = \frac{U'_{2CM}}{U'_{1CM}+U'_{2CM}}$	$y_{13}^* = \frac{-w_1-(1+\beta)\gamma_1+c_1-c_2+p_2}{p_1+p_2}$
	(14)	(P_{ES}, P_{CS}, P_{CM})	$x_{14}^* = \frac{U'_{2CM}}{U'_{1CSM}+U'_{2CM}}$	$y_{14}^* = \frac{-w_1+c_1-c_2+p_2}{p_1+p_2}$
	(15)	(P_{EM}, P_{CS}, P_{CM})	$x_{15}^* = \frac{U'_{2CM}}{U'_{1CSM}+U'_{2CM}}$	$y_{15}^* = \frac{-(1+\beta)\gamma_1+c_1-c_2+p_2}{p_1+p_2}$
All (four policies)	(16)	$(P_{ES}, P_{EM}, P_{CS}, P_{CM})$	$x_{16}^* = \frac{U'_{2CM}}{U'_{1CSM}+U'_{2CM}}$	$y_{16}^* = \frac{-w_1-(1+\beta)\gamma_1+c_1-c_2+p_2}{p_1+p_2}$

Table 9 The result of the stability of the evolutionary equilibrium point (16th scenarios)

stationary point	Det (J)	Tr (J)	Result
$x = y = 0$	+	-	Ineffective ESS
$x = 1, y = 0$	+	+	Unstable equilibrium
$x = 0, y = 1$	+	+	Unstable equilibrium
$x = 1, y = 1$	+	-	Effective ESS
$x = \frac{U'_{2CM}}{U'_{1CSM}+U'_{2CM}},$ $y = \frac{-w_1-(1+\beta)\gamma_1+c_1-c_2+p_2}{p_1+p_2}$	-	0	Saddle point

According to $\frac{dx}{dt} = 0, \frac{dy}{dt} = 0$, then we can get five evolutionary game equilibria in the plane $D (D = \{(x, y)|0 \leq x \leq 1, 0 \leq y \leq 1\})$, namely $(0, 0), (0, 1), (1, 0), (1, 1)$ and $(\frac{U'_{2CM}}{U'_{1CSM}+U'_{2CM}}, \frac{-w_1-(1+\beta)\gamma_1+c_1-c_2+p_2}{p_1+p_2})$.

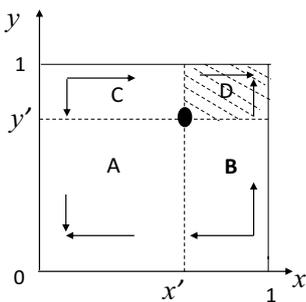
The other 15 scenarios can be calculated in the same way. Finally, we get evolutionary game equilibria of five kinds of policy mix, 16 scenarios. The saddle points of the evolutionary game under 16 scenarios are shown in Table 8.

Equilibrium analysis of the model of NEV diffusion

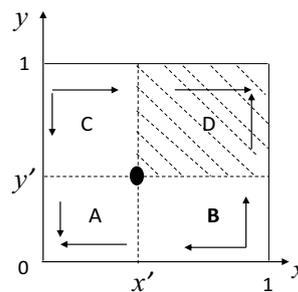
Definition 1: only if both x and y are able to achieve 1 in the diffusion process, namely enterprises tend to choose the NEV production strategy, and consumers tend to choose the buy NEV strategy, stationary point $(1, 1)$ is an effective evolutionarily stable strategy (ESS), and the diffusion of NEVs is considered effective (Fan and Dong 2018).

$$\begin{aligned} \frac{dy}{dt} &= y(u_{1c} - \bar{u}_c) = y(1-y)(u_{1c} - u_{2c}) \\ &= y(1-y)(x((1+\alpha_1)\sigma_1\delta_1 - \tau_1(p_1 - w_2)) \\ &\quad + (1-\theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2) - (1-\theta\alpha_1)\sigma_2\delta_2 + \tau_2p_2 \end{aligned} \tag{14}$$

Fig. 2 The evolutionary phase graph of both players in the NEVs diffusion game



(a) scenarios 1 (zero policy)



(b) scenarios 16(policy mix with all policies)

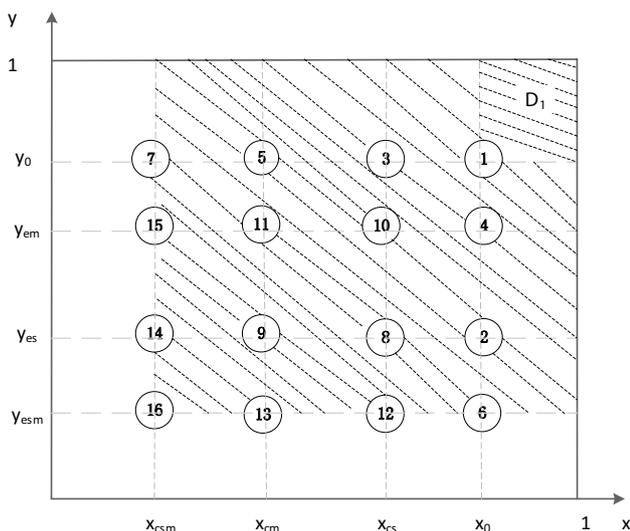


Fig. 3 Dynamic saddle point diagram of NEV diffusion game under different scenarios

According to Eq. (13) and (14), the corresponding Jacobian matrix is obtained as shown in Eq. (15).

$$J = \begin{bmatrix} (1 - 2x)((p_1 + p_2)y + w_1 + (1 + \beta)\gamma_1 - c_1 + c_2 - p_2) & x(1 - x)(p_1 + p_2) \\ y(1 - y)(U'_{1CSM} + U'_{2CM}) & (1 - 2y)(x(U'_{1CSM} + U'_{2CM}) - U'_{2CM}) \end{bmatrix} \quad (15)$$

According to the definition of effective diffusion of NEVs (Fan and Dong 2018) as shown in definition 1, the result of the stability of the evolutionary equilibrium point is shown in Table 9, and the evolutionary phase graph of both players in the NEV diffusion game is shown in

Fig. 2b. The saddle point (x', y') divides the evolutionary phase graph into four domains: A $(x < x', y < y')$, B $(x > x', y < y')$, C $(x < x', y > y')$, D $(x > x', y > y')$, as shown in Fig. 2b.

So:

- (1) When $x < x', y < y'$, the initial state belongs to A, then the state point $(0, 0)$ is an evolutionarily stable state (ESS), but it is ineffective. Namely, enterprises tend to choose the TEV production strategy, and consumers tend to choose the buy TEVs strategy. In this condition, the diffusion of NEVs has failed.
- (2) When $x > x', y < y'$, the initial state belongs to B, the state point $(1, 0)$ is an unstable equilibrium. It will evolve to saddle point (x', y') . Namely, enterprises may tend to choose the NEV production strategy and also may tend to choose the TEV production strategy, and consumers may tend to choose the buy TEVs strategy. In this condition, the diffusion of NEVs is unstable.
- (3) When $x < x', y > y'$, the initial state belongs to C, the state point $(0, 1)$ is an unstable equilibrium. It will evolve to saddle point (x', y') . Namely, enterprises may tend to choose the TEV production strategy, and con-

sumers may tend to choose the buy NEVs strategy and also may tend to choose the buy TEVs strategy. In this condition, the diffusion of NEVs is unstable.

- (4) When $x > x', y > y'$, the initial state belongs to D, then the state point $(1, 1)$ is an evolutionarily stable state

(ESS), moreover it is effective. Namely, enterprises tend to choose the NEV production strategy, and consumers tend to choose the buy NEVs strategy. In this condition, NEVs spread effectively among enterprises and consumers. Thus, the $D(x > x', y > y')$ is the effective stable area of evolution game of NEV diffusion.

Then, using the same method, we can get the stability of the evolutionary equilibrium points with the five kinds of policy mix in the 16 scenarios. Based on Table 8, the dynamic saddle point diagram in all scenarios is shown in Fig. 3.

According to the above analysis, the first inference is obtained.

Inference 1: Only if the initial state both x and y belong to the effective stable area D , can the initial state point (x, y) be successfully evolved to the stationary point $(1, 1)$. Namely, enterprises prioritize the NEV production strategy, and consumers prefer the buy NEVs strategy in the diffusion process. Then the diffusion of NEVs is considered effective. The function of the effective stable area D is determined by the saddle point (x', y') , as shown in Eq. (16).

$$f(x, y) = (1 - x') \times (1 - y') \tag{16}$$

It is well known that the effective stable area is influenced by NEV policies, and this can be seen from Fig. 3. So, the definition of policy effect (PE) is measured by the variation range of the stable area. It is equal to the stable area with policy interference minus the stable area without policy interference.

Policy effect analysis

Type 1: (scenario 1)

When there is no NEV policy, function (16) can be rewritten as Eq. (17). It is a stable area (D_1) without policy intervention. Type 1 (scenario 1) is the base case.

$$f(x, y) = (1 - x') \times (1 - y') = \left(1 - \frac{\sigma_2\delta_2 - \tau_2p_2}{\sigma_1\delta_1 - \tau_1p_1 + \sigma_2\delta_2 - \tau_2p_2}\right) \times \left(1 - \frac{c_1 - c_2 + p_2}{p_1 + p_2}\right) \tag{17}$$

Type 2 (scenarios 2–5)

When there is only one NEV policy, for example, the economic in cash policy for enterprises, function (16) can be rewritten as Eq. (18), then its differential coefficient is obtained, as shown in Eq. (19).

$$f_{w_1}(x, y) = (1 - x') \times (1 - y') = \left(1 - \frac{\sigma_2\delta_2 - \tau_2p_2}{\sigma_1\delta_1 - \tau_1p_1 + \sigma_2\delta_2 - \tau_2p_2}\right) \times \left(1 - \frac{-w_1 + c_1 - c_2 + p_2}{p_1 + p_2}\right) \tag{18}$$

$$f'_{w_1}(x, y) = \left(1 - \frac{\sigma_2\delta_2 - \tau_2p_2}{\sigma_1\delta_1 - \tau_1p_1 + \sigma_2\delta_2 - \tau_2p_2}\right) \times \frac{1}{p_1 + p_2} > 0 \tag{19}$$

Therefore, $f_{w_1}(x, y)$ is a monotone increasing function of economic subsidy coefficient (w_1) for enterprises. For the saddle point, the horizontal ordinate remains unchanged, and the longitudinal coordinate moves downward, then the stable area D_2 is bigger than D_1 . This means the probability of NEV diffusion increases.

Using the same computing method, similar results are obtained with the other three scenarios, such as P_{ES} , P_{EM} , P_{CM} . Then the second inference is obtained.

Inference 2: If sales price, production cost and consumer preferences remain unchanged, the effective stable area $D-1$ ¹ influenced by a single policy is larger than the area D_1 influenced by zero policy. The single policy effect is the difference, namely it equals $D-1$ minus D_1 .

Type 3 (scenarios 6–11)

On the condition that a policy mix contains only two NEV policies, for example, the economic in cash policy for enterprises and regulatory instruments for consumers, function (16) can be rewritten as Eq. (20). Then two partial differential functions are obtained as Eq. (21) and Eq. (22).

$$f_{w_1, \alpha_1}(x, y) = (1 - x') \times (1 - y') = \left(1 - \frac{(1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2}{(1 + \alpha_1)\sigma_1\delta_1 - \tau_1p_1 + (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2}\right) \times \left(1 - \frac{-w_1 + c_1 - c_2 + p_2}{p_1 + p_2}\right) \tag{20}$$

$$f'_{w_1}(x, y) = \left(1 - \frac{(1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2}{(1 + \alpha_1)\sigma_1\delta_1 - \tau_1p_1 + (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2}\right) \times \frac{1}{p_1 + p_2} > 0 \tag{21}$$

$$f'_{\alpha_1}(x, y) = \left(1 - \frac{-w_1 + c_1 - c_2 + p_2}{p_1 + p_2}\right) \times \frac{\theta\sigma_2\delta_2 U'_{1CM} + \sigma_1\delta_1 U'_{1CM}}{(U'_{1CM} + U'_{2CM})^2} > 0 \tag{22}$$

¹ $D-1$: the effective stable area influenced by single policy, such as D_2, D_3, D_4, D_5 .

$f_{w_1, \alpha_1}(x, y)$ is a monotone increasing function of economic subsidy coefficient (w_1) for enterprises, moreover it is also a monotone increasing function of consumer preference factor (α_1). For the saddle point, the horizontal ordinate moves to the left, and the longitudinal coordinate moves downward, then the stable area D_9 is bigger than D_2 (or D_4). This means the probability of NEV diffusion increases.

Using the same computing method, similar results are obtained for the other five scenarios, such as policy mix $(P_{ES}, P_{EM}), (P_{CS}, P_{CM}), (P_{ES}, P_{CS}), (P_{EM}, P_{CS})$ and (P_{EM}, P_{CM}) . Then, we get the third inference.

Inference 3: When sales price, production cost and consumer preference remain unchanged, the effective stable area $D-2^2$ influenced by a policy mix with two policies is larger than the area $D-1$ influenced by the corresponding single policy. If its policy effect is larger than the sum of the corresponding single policy effects of two policy instruments, the policy mix is in synergy. If its policy effect is equal to the sum of the corresponding single policy effects of two policy instruments, the policy mix is fully complementary.

Type 4 (scenarios 12–15)

In this case, when there is a policy mix combining three policies, for example, the economic in cash policy both for enterprises and consumers, and regulatory instruments for consumers, function (16) can be rewritten as Eq. (23). Three partial differential functions are obtained as shown in Eq. (24), Eq. (25) and (26).

$$f_{w_1, w_2, \alpha_1}(x, y) = (1 - x') \times (1 - y') = \left(1 - \frac{(1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2}{(1 + \alpha_1)\sigma_1\delta_1 - \tau_1(p_1 - w_2) + (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2} \right) \times \left(1 - \frac{-w_1 + c_1 - c_2 + p_2}{p_1 + p_2} \right) \tag{23}$$

$$f'_{w_1}(x, y) = \left(1 - \frac{(1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2}{(1 + \alpha_1)\sigma_1\delta_1 - \tau_1(p_1 - w_2) + (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2} \right) \times \frac{1}{p_1 + p_2} > 0 \tag{24}$$

$$f'_{w_2}(x, y) = \frac{\tau_1((1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2)}{((1 + \alpha_1)\sigma_1\delta_1 - \tau_1p_1 + \tau_1w_2 + (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2)^2} \times \frac{w_1 - c_1 + c_2 + p_1}{p_1 + p_2} > 0 \tag{25}$$

$$f'_{\alpha_1}(x, y) = \frac{\sigma_1\delta_1((1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2) + \theta\alpha_2\delta_2(1 + \alpha_1)\sigma_1\delta_1 - \tau_1(p_1 - w_2)}{((1 + \alpha_1)\sigma_1\delta_1 - \tau_1p_1 + \tau_1w_2 + (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2p_2)^2} \times \frac{w_1 - c_1 + c_2 + p_1}{p_1 + p_2} > 0 \tag{26}$$

$f_{w_1, w_2, \alpha_1}(x, y)$ is a monotone increasing function of economic subsidy coefficient (w_1) for enterprises, and economic subsidy coefficient (w_2) for consumers. Moreover, it is also a monotone increasing function of consumer preference factor (α_1). For the saddle point, the horizontal ordinate moves to the left, and the longitudinal coordinate moves downward, then the stable area D_{14} is bigger than D_7 (D_8 or D_9). This means the probability of NEV diffusion increases.

Using the same computing method, similar results are obtained for the other three scenarios. The fourth inference is obtained.

Inference 4: If sales price, production cost and consumer preference remain unchanged, the effective stable area $D-3^3$ influenced by policy mixes with three policies is larger than the area $D-2$ influenced by the corresponding policy mixes with two policies. Moreover, its policy effect is no less than the sum of the corresponding three single policy effects.

Type 5 (scenario 16)

When there is a policy mix combining all types of policies, namely economic in cash and regulatory instruments both for enterprises and consumers, function (16) can be rewritten as Eq. (27), then four partial differential functions are obtained, as in Eq. (28), Eq. (29), Eq. (30) and Eq. (31).

² D-2: the effective stable area influenced by a policy mix of two policies, such as $D_6, D_7, D_8, D_9, D_{10}, D_{11}$.

³ D-3: the effective stable area influenced by a policy mix of three policies, such as $D_{12}, D_{13}, D_{14}, D_{15}$.

$$\begin{aligned}
 f_{w_1, \gamma_1, w_2, \alpha_1}(x, y) &= (1 - x') \times (1 - y') \\
 &= \left(1 - \frac{(1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2 p_2}{(1 + \alpha_1)\sigma_1\delta_1 - \tau_1(p_1 - w_2) + (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2 p_2} \right) \times \left(1 - \frac{-w_1 - (1 + \beta)\gamma_1 + c_1 - c_2 + p_2}{p_1 + p_2} \right) \\
 &= \frac{(1 + \alpha_1)\sigma_1\delta_1 - \tau_1 p_1 + \tau_1 w_2}{(1 + \alpha_1)\sigma_1\delta_1 - \tau_1 p_1 + \tau_1 w_2 + (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2 p_2} \times \frac{w_1 + (1 + \beta)\gamma_1 - c_1 + c_2 + p_1}{p_1 + p_2} \quad (27)
 \end{aligned}$$

$$f'_{w_1}(x, y) = \left(1 - \frac{(1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2 p_2}{(1 + \alpha_1)\sigma_1\delta_1 - \tau_1(p_1 - w_2) + (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2 p_2} \right) \times \frac{1}{p_1 + p_2} > 0 \quad (28)$$

$$f'_{\gamma_1}(x, y) = \left(1 - \frac{(1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2 p_2}{(1 + \alpha_1)\sigma_1\delta_1 - \tau_1(p_1 - w_2) + (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2 p_2} \right) \times \frac{1 + \beta}{p_1 + p_2} > 0 \quad (29)$$

$$f'_{w_2}(x, y) = \frac{\tau_1((1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2 p_2)}{((1 + \alpha_1)\sigma_1\delta_1 - \tau_1 p_1 + \tau_1 w_2 + (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2 p_2)^2} \times \frac{w_1 + (1 + \beta)\gamma_1 - c_1 + c_2 + p_1}{p_1 + p_2} > 0 \quad (30)$$

$$f'_{\alpha_1}(x, y) = \frac{\sigma_1\delta_1((1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2 p_2) + \theta\sigma_2\delta_2(1 + \alpha_1)\sigma_1\delta_1 - \tau_1(p_1 - w_2)}{((1 + \alpha_1)\sigma_1\delta_1 - \tau_1 p_1 + \tau_1 w_2 + (1 - \theta\alpha_1)\sigma_2\delta_2 - \tau_2 p_2)^2} \times \frac{w_1 + (1 + \beta)\gamma_1 - c_1 + c_2 + p_1}{p_1 + p_2} > 0 \quad (31)$$

$f_{w_1, \gamma_1, w_2, \alpha_1}(x, y)$ is a monotone increasing function of economic subsidy coefficient (w_1), and extra cost (γ_1) for enterprises, economic subsidy coefficient (w_2) for consumers, consumer preference factor (α_1). For the saddle point, the horizontal ordinate moves to the left and the longitudinal coordinate moves downward, then the stable area D_{16} is bigger than D_{14} (D_{12} or D_{13} or D_{15}), which means the probability of NEV diffusion increases. The fifth inference is obtained.

Inference 5: When sales price, production cost and consumer preference remain unchanged, the effective stable area $D-4^4$ influenced by a policy mix with four policies is larger than the area $D-3$ influenced by the corresponding policy mixes with three policies. Besides, its policy effect is larger than the sum of the corresponding single policy effects of four policy instruments.

Simulation analysis

Our research takes the NEV BYD E6 and the TEV M6 as examples to simulate and verify the above inferences.

Data

The data were obtained from the official websites,⁵ and the case researched by Fan and Dong (2018). In China, the profit of the mainstream automobile enterprise is about 10%. According to the above analysis, give the unit of the first part parameters is *wanyuan* (CNY), $p_1 = 33.98$, $p_2 = 33.98$, $c_1 = 25$, $c_2 = 5.54$, $w_1 = 19.46$, $w_2 = 8.68$, $\gamma_1 = 0.5$. And the second part parameters are given $\delta_1 = 50$, $\delta_2 = 40$, $\tau_1 = 1$, $\tau_2 = 1$, $\sigma_1 = 1.2$, $\sigma_2 = 1$, $\alpha_1 = 0.15$, $\theta = 1$, $\beta = 0.8$. According to the consumer surplus formulas (7)–(12), then $U_1 = 26.02$, $U_2 = 27.1$, $U'_{1CS} = 34.7$, $U'_{1CM} = 35.02$, $U'_{2CM} = 21.11$, $U'_{1CSM} = 43.7$.

⁴ $D-4$: the effective stable area influenced by a policy mix of four policies, such as D_{16} .

⁵ <http://www.d1ev.com/>, <http://www.bydauto.com.cn>, <http://www.shanghai.gov.cn/>, <http://cafenev.miit-eidc.org.cn>

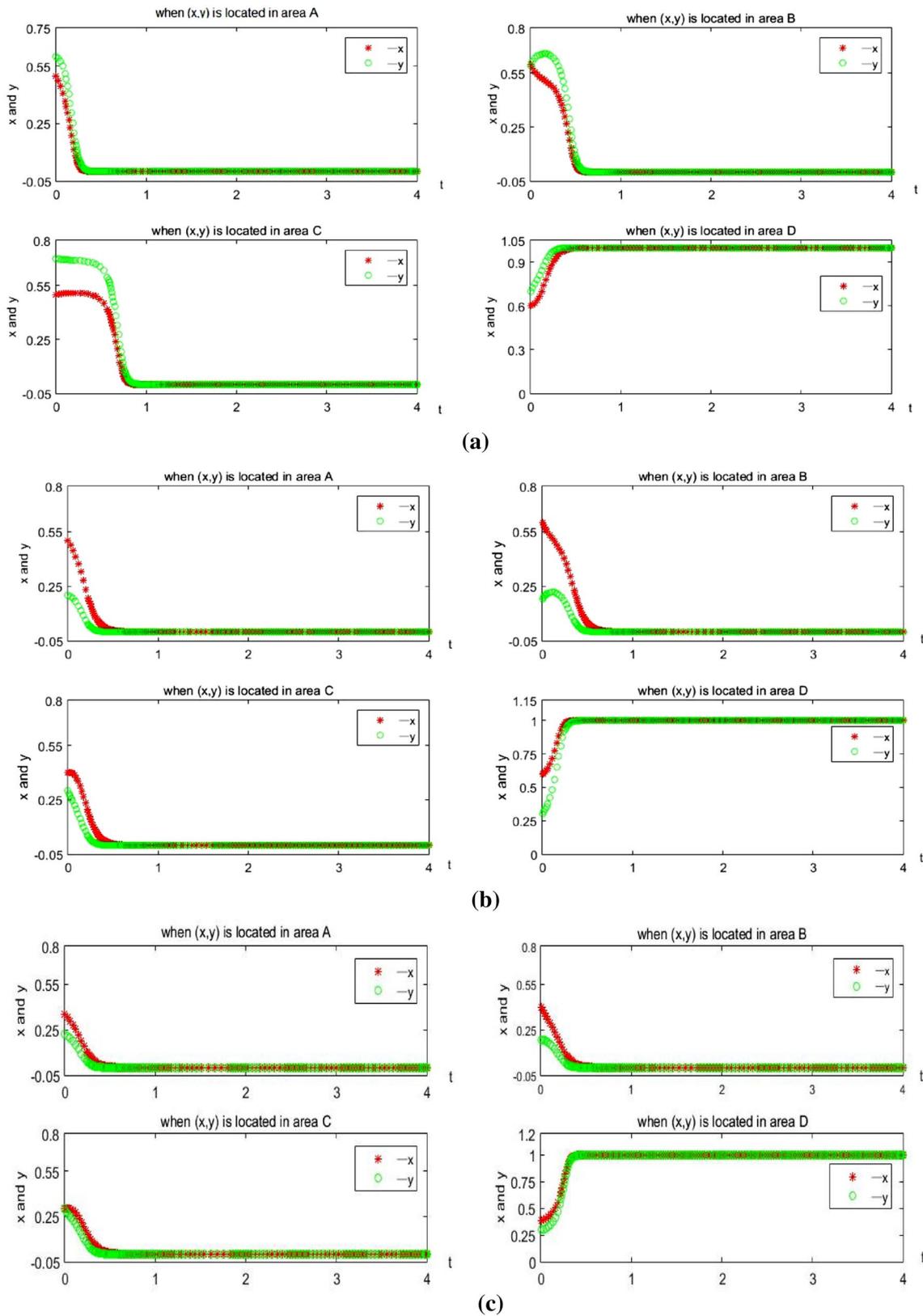


Fig. 4 **a** Type 1: when the saddle point $x=0.51, y=0.69$, **b** Type 2: when the saddle point $x=0.51, y=0.28$, **c** Type 3: when the saddle point $x=0.38, y=0.28$, **d** Type 4: when the saddle point $x=0.33, y=0.28$, **e** Type 5: when the saddle point $x=0.33, y=0.26$

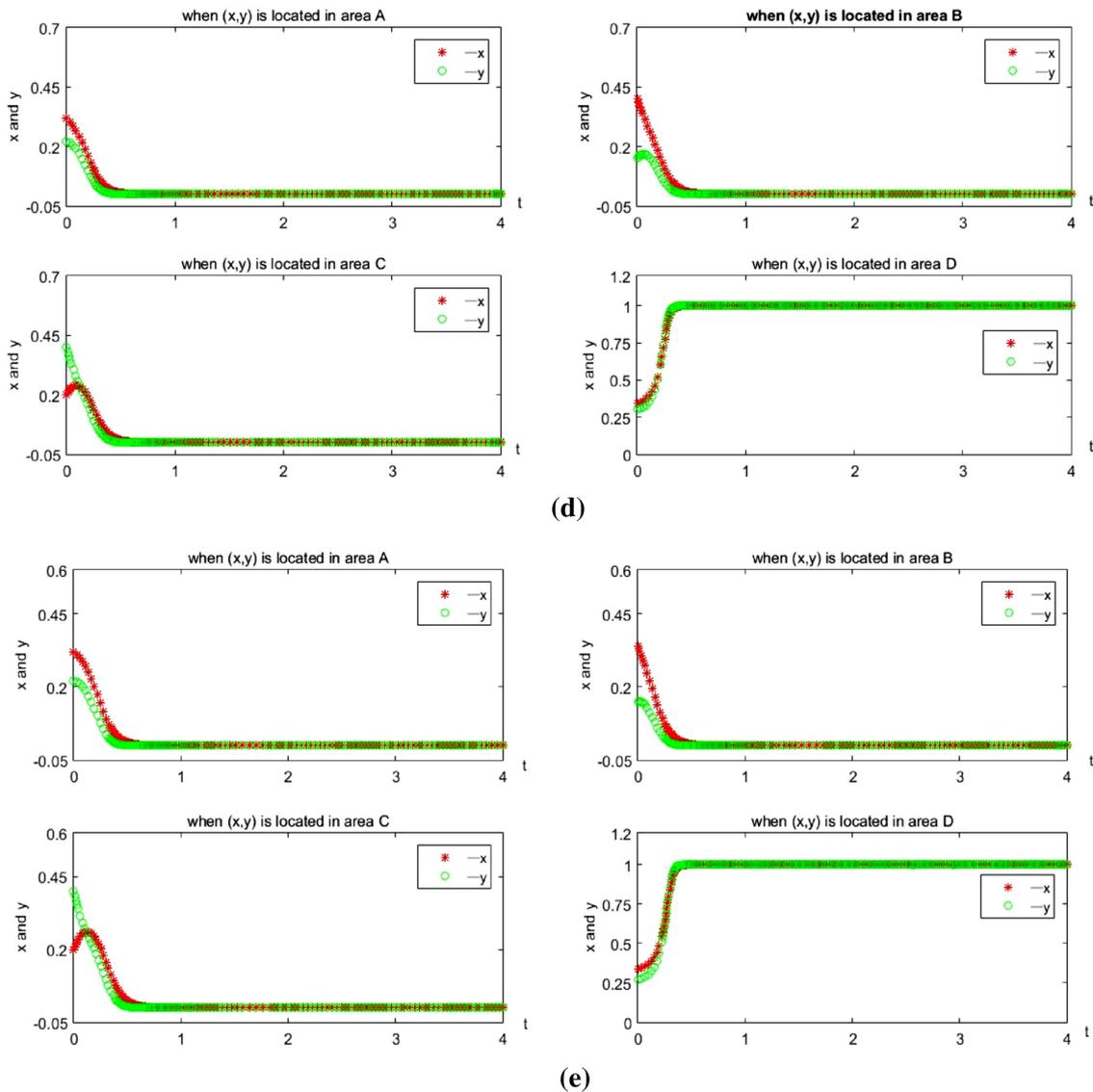


Fig. 4 (continued)

The simulation results of NEV diffusion evolutionary game

We verify the correctness of inference 1 through Matlab simulation according to the saddle point calculation formula of the evolutionary game (Table 8) and the data in Sect. 6.1. Matlab R2015a software was used to obtain the simulation results of NEV diffusion under five types of policy mix, as shown in Fig. 4. The specific analysis is as follows.

(1) Type 1 (scenario 1)

As shown in Fig. 4a, when there is zero policy, the saddle point is $(0.51, 0.69)$, and the effective stable area is D_1 ($x > 0.51, y > 0.69$). Only when the initial state belongs to

D_1 , will it evolve to effective ESS $(1, 1)$. Namely, enterprises are more likely to choose the making NEV E6 strategy and consumers tend to choose the buying NEV E6 strategy, the NEV E6 spreads effectively among enterprises and consumers without policy intervention. When the initial state belongs to the other three areas (A, B and C), TEV M6 will dominate the market, and NEVs cannot spread effectively in the market. So, inference 1 in type 1 is verified.

(2) Type 2 (scenarios 2–5)

As shown in Fig. 4b, when there is only one policy, for example policy of P_{ES} , the saddle point is $(0.51, 0.28)$, the effective stable area is D_2 ($x > 0.51, y > 0.28$), it gets bigger than D_1 . Only when the initial state belongs to D, will it

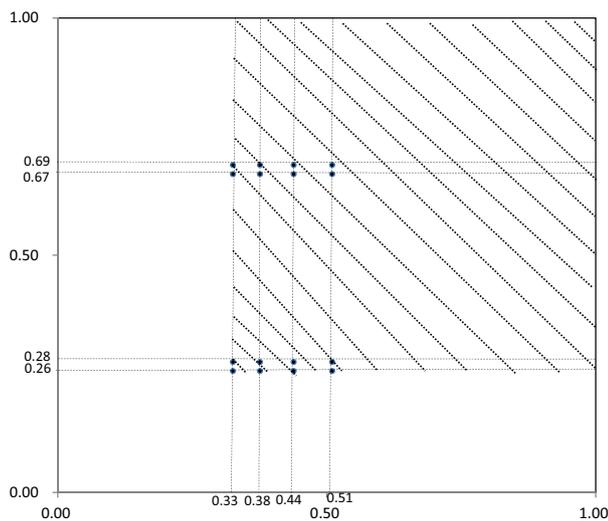


Fig. 5 The graph of saddle point and the effective stable area of numerical simulation

evolve to effective ESS (1, 1). Compared with Fig. 4a, the single policy effectively reduces the starting point of the effective diffusion rate of NEVs among consumer groups. When it belongs to the other three areas (A, B and C), TEV M6 will dominate the market, and NEVs cannot spread effectively in the market. So, inference 1 in type 2 is verified.

(3) Type 3 (scenarios 6–11)

As shown in Fig. 4c, when there is a policy mix which combines only two policies, for example policy mix (P_{ES}, P_{CM}), the saddle point is (0.38, 0.28), the effective stable area is D_9 ($x > 0.38, y > 0.28$), it gets bigger than D_2 . Compared with Fig. 4b, the policy mix effectively reduces the starting point of the effective diffusion rate of NEVs among producer groups. Also, only when the initial state belongs to D, will it evolve to effective ESS (1, 1). When it belongs to the other three areas (A, B and C), TEV M6 will dominate the market, and NEVs cannot spread effectively in the market. So, inference 1 in type 3 is verified.

(4) Type 4 (scenarios 12–15)

As shown in Fig. 4d, when there is a policy mix which combines only three policies, for example policy mix (P_{ES}, P_{CS}, P_{CM}), the saddle point is (0.33, 0.28), the effective stable area is D_{14} ($x > 0.33, y > 0.28$), it gets bigger than D_9 . Compared with Fig. 4c, the policy mix effectively reduces the starting point of the effective diffusion rate of NEVs among producer groups. Only when the initial state belongs to D, will it evolve to effective ESS (1, 1). When it belongs to the other three areas (A, B and C), TEV M6 will dominate the market, and NEVs cannot spread effectively in the market. So, inference 1 in type4 is verified.

Table 10 The results of numerical simulation

Types of policy mix	scenario	Policy mix forms	saddle point (x, y)	the effective stable area	Policy effect (PE)	The types of interaction
<i>No policy mix</i>						
Zero policy	(1)	0	(0.51, 0.69)	$D_1=0.1517$	0.00	–
Only one policy	(2)	P_{ES}	(0.51, 0.28)	$D_2=0.3551$	0.20	–
	(3)	P_{EM}	(0.51, 0.67)	$D_3=0.1611$	0.01	–
	(4)	P_{CS}	(0.44, 0.69)	$D_4=0.1739$	0.02	–
	(5)	P_{CM}	(0.38, 0.69)	$D_5=0.1933$	0.04	–
	<i>Policy mix</i>					
Only two policies	(6)	(P_{ES}, P_{EM})	(0.51, 0.26)	$D_6=0.3645$	0.21	Complementarity
	(7)	(P_{CS}, P_{CM})	(0.33, 0.69)	$D_7=0.2089$	0.06	Complementarity
	(8)	(P_{ES}, P_{CS})	(0.44, 0.28)	$D_8=0.4070$	0.26	Synergy
	(9)	(P_{ES}, P_{CM})	(0.38, 0.28)	$D_9=0.4523$	0.30	Synergy
	(10)	(P_{EM}, P_{CS})	(0.44, 0.67)	$D_{10}=0.1847$	0.03	Complementarity
	(11)	(P_{EM}, P_{CM})	(0.38, 0.67)	$D_{11}=0.2053$	0.05	Complementarity
Only three polices	(12)	(P_{ES}, P_{EM}, P_{CS})	(0.44, 0.26)	$D_{12}=0.4178$	0.27	Synergy
	(13)	(P_{ES}, P_{EM}, P_{CM})	(0.38, 0.26)	$D_{13}=0.4643$	0.31	Synergy
	(14)	(P_{ES}, P_{CS}, P_{CM})	(0.33, 0.28)	$D_{14}=0.4888$	0.34	Synergy
	(15)	(P_{EM}, P_{CS}, P_{CM})	(0.33, 0.67)	$D_{15}=0.2218$	0.07	Complementarity
All polices	(16)	$(P_{ES}, P_{EM}, P_{CS}, P_{CM})$	(0.33, 0.26)	$D_{16}=0.5018$	0.35	Synergy

(5) Type 5 (scenario 16)

As shown in Fig. 4e, when there is a policy mix which combines four policies, for example policy mix $(P_{ES}, P_{EM}, P_{CS}, P_{CM})$, the saddle point is $(0.33, 0.26)$, the effective stable area is D_{16} ($x > 0.33, y > 0.26$), it gets bigger than D_{14} . In addition, only when the initial state belongs to D, will it evolve to effective ESS $(1, 1)$. Compared with Fig. 4d, the policy mix effectively reduces the starting point of the effective diffusion rate of NEVs among consumer groups. And compared with the single policy (Fig. 4b), the policy mix effectively reduces the starting point of the effective diffusion rate of NEVs among producer groups and consumer groups. At this point, the producer group and consumer group of NEVs tend to effectively spread through the starting point of the market rate is relatively low. However, when it belongs to the other three areas (A, B and C), TEV M6 will dominate the market, and NEVs cannot spread effectively in the market. So, inference 1 in type 5 is verified.

Simulation results of policy effect of NEVs diffusion

The simulation results of specific cases are used to verify the correctness of inferences 2 to 5 in Part 5, and the policy effects under the five types of policy mix are analyzed. According to the saddle point calculation formula of the evolutionary game (Table 8), the effective stability area function (Formula 16), and the definition of policy effect and data in Part 6.1, the equilibrium points and policy effects under five kinds of policy mix are calculated, as shown in Fig. 5 and Table 10. The concrete analysis is as follows.

The NEV E6 spreads freely in the market without policy intervention. The saddle point position is $(0.51, 0.69)$, and the corresponding effective stable area D_1 is 0.1517. The area D_1 is the base stable state space.

The NEV E6 diffuses under the influence of a single policy which contains four scenarios, from 2 to 5. The saddle points are $(0.51, 0.28)$, $(0.51, 0.67)$, $(0.44, 0.69)$, $(0.38, 0.69)$, and the corresponding effective stable areas are $D_2=0.3551, D_3=0.1611, D_4=0.1739$ and $D_5=0.1933$. And $D_2 > D_5 > D_4 > D_3 > D_1$. In addition, the corresponding policy effects are $PE_2=0.20, PE_3=0.01, PE_4=0.02, PE_5=0.04$. Among the four policies, the policy of economic in cash for enterprises is the most effective, followed by consumer-oriented regulation instruments and purchase subsidy policy, while the regulatory policy for enterprises is the least effective. Therefore, inference 2 is verified.

The NEV E6 diffuses under the influence of policy mixes combining only two policies, the corresponding scenarios are from 6 to 11. Then the saddle points are $(0.51, 0.26)$, $(0.33, 0.69)$, $(0.44, 0.28)$, $(0.38, 0.28)$, $(0.44, 0.67)$ and $(0.38, 0.67)$. And the corresponding effective stable areas are $D_6=0.3645, D_7=0.2089, D_8=0.4070, D_9=0.4523, D_{10}=0.1847,$

$D_{11}=0.2053$. And $D_9 > D_8 > D_6 > D_7 > D_{11} > D_{10}$. They are all larger than the area influenced by the corresponding single policy. Their policy effects are 0.21, 0.06, 0.26, 0.30, 0.03 and 0.05, respectively. These policy mixes, such as $(P_{ES}, P_{EM}), (P_{CS}, P_{CM}), (P_{EM}, P_{CS})$ and (P_{EM}, P_{CM}) belong to the type of full complementarity because their effect equals to the sum of the effects of the corresponding single policy tool. The two policy mixes, such as (P_{ES}, P_{CS}) and (P_{ES}, P_{CM}) belong to the type of synergy because their policy effects are larger than the sum of the effects of the corresponding single policy instruments. In addition, among the six policy mixes, the policy mix of (P_{ES}, P_{CM}) is the most effective, and the policy mix of (P_{EM}, P_{CS}) is the least effective. Therefore, inference 3 is verified.

The NEV E6 diffuses under the influence of policy mixes combining only three policies, the corresponding scenarios are from 12 to 15. The saddle points are $(0.44, 0.26)$, $(0.38, 0.26)$, $(0.33, 0.28)$ and $(0.33, 0.67)$. The corresponding effective stable areas are $D_{12}=0.4178, D_{13}=0.4643, D_{14}=0.4888, D_{15}=0.2218$. And $D_{14} > D_{13} > D_{12} > D_{15}$. Their policy effects are 0.27, 0.31, 0.34 and 0.07, respectively. They are larger than the effects of the policy mixes combining the corresponding two policies, and no lower than the sum of the effects of the corresponding three single policy instruments. These policy mixes, such as $(P_{ES}, P_{EM}, P_{CS}), (P_{ES}, P_{EM}, P_{CM})$ and (P_{ES}, P_{CS}, P_{CM}) , belong to the type of synergy. The policy mix of (P_{EM}, P_{CS}, P_{CM}) belongs to the type of full complementarity. In addition, among the four policy mixes, the effect of the policy mix of (P_{ES}, P_{CS}, P_{CM}) is the most effective, and it is the smallest for the policy mix of (P_{EM}, P_{CS}, P_{CM}) . Therefore, inference 4 is verified.

The NEV E6 diffuses under the influence of policy mixes combining all four policies. The saddle point is $(0.33, 0.26)$. The corresponding effective stable area is 0.5018, and the policy effect is 0.35. And $D_{16} > D_{14} > D_{13} > D_{12} > D_{15}$. Moreover, $PE_{16} > PE_2 + PE_3 + PE_4 + PE_5$. So, the policy mix of $(P_{ES}, P_{EM}, P_{CS}, P_{CM})$ belongs to the type of synergy. It is more effective than others in promoting the diffusion of NEV E6. Therefore, inference 5 is verified.

In sum, the five inferences are all obtained and verified. Comparing the policy effects under all policy scenarios, the results are shown as Eq. (32).

$$PE_{16} > PE_{14} > PE_{13} > PE_9 > PE_{12} > PE_8 > PE_6 > PE_2 > PE_{15} > PE_7 > PE_{11} > PE_5 > PE_{10} > PE_4 > PE_3 \tag{32}$$

Conclusions and policy implications

Different from previous studies on the effect of a single policy or multiple single policies, we focus on the impact of policy mixes on the diffusion of NEVs. First, we propose

a new policy mix framework of NEV policy instruments: producer-orientation vs. consumer-orientation instruments, economic in cash vs. regulatory instruments, and this framework can serve as a reference for quantitative research. Then, by referring to the concept of the stable area in evolutionary game theory, we propose a definition of policy effect. That is, the effect of policy mixes on the diffusion of NEVs through the difference of the effective stable area under two types of policy mix. Based on the evolutionary game method, the quantitative theoretical derivation and simulation verification of the effects of policy mixes are carried out. Our research conclusions have important reference significance for the government to follow corresponding policy mix strategies at different stages of NEV diffusion. And the following conclusions can be drawn.

1. In the initial stage without policy, due to the existence of negative externalities, the production desire of manufacturers of NEVs and the consumption desire of consumers are relatively low. NEVs cannot be effectively and rapidly spread at this stage, unless with policy intervention or combining other measures. This is consistent with the results of other research (Fan and Dong 2018). Therefore, the government should adopt a diversified policy mix strategy, comprehensively using producer-oriented and consumer-oriented economic in cash policies and regulatory policies, and the policy mixes should be dominated by economic in cash policies.
2. Of single policies, producer-oriented economic in cash policy plays the greatest role, which is consistent with the research of Fan and Dong (2018). We further find that the effect of the consumer-oriented regulatory policy is greater than the purchase subsidy policy. The study of Kong et al. (2020) confirms the positive role of the two policies on NEV diffusion, but they did not analyse the joint effect of the two policies. We have studied it and found that the policy mix composed of the same type of policies (several policies belonging to producer-oriented policies or consumer-oriented policies) is generally complementary, while the policy mix composed of producer-oriented tools and consumer-oriented tools is generally synergistic. According to the characteristics of various policies, the government should comprehensively consider the market subjects of supply and demand, and reasonably match the economic in cash policies and regulatory policies. Only in this way can the policy mixes give full play to its complementary or synergistic effect and effectively promote NEV diffusion.
3. Compared with a single policy, a policy mix can effectively accelerate the diffusion of NEVs. The saddle point and the stable area of NEV diffusion are both influenced dramatically by NEV policies. Different policy mixes

have different impacts on the diffusion of NEVs. With increasing production and consumption, the government should adopt policy mixes mainly composed of regulatory instruments. At this stage, the policy mixes should shift from focusing on using economy in cash instruments to regulatory instruments.

Therefore, some suggestions are proposed for government, as follows.

Governments should adopt different policy mixes at the different stages of NEV diffusion. (1) In the early stages of NEV diffusion, the government should implement a variety of policy mixes which include both producer-orientation and consumer-orientation instruments and maximize the synergy and complementarity between policy tools. At this stage, the producer-oriented and consumer-oriented economy in cash instruments in the policy mixes are essential, such as research and development subsidies, innovative products of car bonus, purchase subsidies, etc. And the policy mixes should encourage enterprises to carry out technological innovation and promote the diffusion of new NEV technologies. (2) With the increase of the diffusion rate of NEVs, when NEVs achieve a certain market share, the government should consider the administrative cost and policy effect, and gradually reduce the intensity of policy mixes. In the policy mixes, the regulatory instruments should then take priority, such as the carbon emission trading policies, traffic restriction policies, green license plate policies and so on. And government can regulate and constrain the behavior of the market players, such as enterprises and consumers, and promote the diffusion of NEVs.

There are some limitations in our research. Firstly, we do not consider assigning specific values to all NEV policies, such as green license plates and traffic restrictions, which were quantified according to the same qualitative variable. Secondly, we use the deterministic evolutionary game method. We focus on studying the impact of policy mixes on NEV diffusion and do not consider the fluctuations caused by random factors or major emergencies such as COVID-19 on the impact of policy mixes and the diffusion of NEVs. Thirdly, this article is a validation of policy mix practice, so we also do not take the optimal range of policy parameters into account. In future, more factors will be introduced to make the model more realistic. And we will also pay attention to the research on parameter collocation optimization of policy mixes.

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