

## Article

# The Influence of Low Carbon Emission Engine on the Life Cycle of Automotive Products: A Case Study of Three-Cylinder Models in the Chinese Market

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**Abstract:** There is a development trend for fuel vehicles to adopt low-carbon emission engines. The sales of cars with low-carbon three-cylinder engines in the Chinese market have declined. Is the life cycle of automotive products with three-cylinder engines entering a recession stage? In order to achieve this research objective, which is to investigate whether assembling a three-cylinder engine affects the life cycle of an automotive product, this paper constructs an ecological theory-based approach to measuring the life cycle of automotive products. First, the logistic model is used to measure the intrinsic growth rate, internal inhibition coefficient, and theoretical upper limit of product sales scale before and after the automotive products are equipped with three-cylinder engines. In the second stage, the Lotka–Volterra model is used to calculate the intrinsic growth rate, internal inhibition coefficient, theoretical upper limit, and symbiosis coefficient of the sales scale of the products before and after the three-cylinder engine, taking the Chinese automobile manufacturing enterprises as an example for empirical analysis. The research results show that the selection of three-cylinder engine for automotive products will not lead to the product life cycle entering the recession period ahead of time.

**Keywords:** three-cylinder engine; logistic model; Lotka–Volterra model; life cycle assessment; automobile manufacturing enterprise



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## 1. Introduction

### 1.1. Emission Reduction of Automotive Products

In China, environmentally friendly vehicles are the current development trend [1]. However, the public has a process of accepting low-emission and new energy vehicles. Scholars also focus on the research on the industry's supporting facilities [2], sales, and supply chain of low emission and new energy vehicles [3–7]. The comprehensive method is applied to relevant research [8,9]. Comprehensive entropy analysis [10] and fuzzy set analysis [11] are used in this issue. When the acceptance of low-carbon emission vehicles in the automobile market is a gradual process, scholars have focused on the market performance of low-carbon emission vehicles [12–18]. There is a lack of innovation in low carbon emission vehicles in China, and relevant industries and innovation policies should be strengthened [19]. In the future, the low-carbon-emission automobile industry will be more dependent on the market environment [20]. Low carbon vehicles are of great significance for realizing the harmonious development between man and nature [21–23]. However, during the operation of low-carbon vehicles such as new energy vehicles and electric vehicles, carbon emissions are transferred to power plants. If the environmental protection problems in the power generation process cannot be solved, carbon emissions will still exist [24–28].

### *1.2. Development and Characteristics of Three-Cylinder Engine in China's Automobile Market*

With the increasingly severe global environmental problems, China has promulgated a series of fuel consumption restrictions and regulations for motor vehicles in recent years. In 2017, China's five ministries and commissions jointly issued the measures for the parallel management of the average fuel consumption of passenger vehicle enterprises and new energy vehicle credits (hereinafter referred to as the "Dual-Credit management measures"). China's energy-saving and environmental protection policies have promoted the development process of small engine displacement. Under the new technical conditions, three-cylinder engines have emerged. Under the conditions of meeting fuel consumption, power, and smooth-going characteristics, the number of models equipped with three-cylinder engines is increasing. However, Chinese consumers have always been skeptical of three-cylinder engines, and car jitter, cheap in price, and weak power have always been the labels of three-cylinder engines.

Before 2015, the three-cylinder engine models in China's passenger car market were mainly concentrated on self-owned brand mini cars. With the development of China's passenger car market, the market scale of traditional fuel mini cars has decreased year by year, and the three-cylinder locomotive models sold in China's passenger car market have gradually decreased. With the tightening of energy-saving laws and regulations for motor vehicles, mainstream automobile brands have gradually launched three-cylinder engine models since 2015 in order to meet the energy-saving requirements. It can be seen from the number of three-cylinder locomotives and the number of brands over the years that this trend is becoming more and more obvious.

On 16 March 2015, the entire Peugeot 408 was replaced with a 1.2T three-cylinder engine, the first mainstream-branded three-cylinder model to be launched in the Chinese passenger car market in the new era. In July of the same year, Ford Focus launched a 1.0T three-cylinder engine model, and Citroen c4l launched a 1.2t three-cylinder engine model. Over time, the luxury brand BMW, the joint venture brands Buick, Chevrolet, and Honda, and the independent brands Geely and Lynkco have successively launched three-cylinder locomotive products. By the third quarter of 2021, 24 brands have launched more than 80 models equipped with three-cylinder engines.

Although the number of corporate brands and models equipped with three-cylinder engines has been increasing, the sales of three-cylinder models have not always increased but reached a peak in sales in 2019, with 1.253 million units sold for the year, accounting for 6.1% of the domestic passenger car market. Even in the highest sales year, the share of three-cylinder engines is still at a low level, and as of the most recent first three quarters of 2021, the share of sales of three-cylinder models fell to 3.0%, less than half of that of 2019 [29].

In the global trend of small engine displacement, the three-cylinder engine in the Chinese automobile market has yet to be widely accepted by consumers. The first three-cylinder engine products in the Chinese automobile market were applied to minicars, such as Xiali, Alto, QQ, etc., and they were negatively labeled by consumers as cheap, poorly powered, jittery, and low-end due to the technical level and the positioning of the products as minicars at that time. Even with the development of the level of technology, now the three-cylinder engine in power, noise, and energy-saving has surpassed the then four-cylinder engine, but the impression of the product of the three-cylinder machine is still stuck in many negative comments. On the other hand, China has made great efforts to develop new energy vehicles and has implemented the dual-credit policy. In the selection of energy-saving technology routes, a new energy path has been added. Taking into account such factors as R & D expenditure, sales volume, and energy-saving level, enterprises will focus more on the research and development of new energy technologies. Under this influence, the product strategies of the independent enterprise and the joint venture have different emphases. Because the joint venture mostly sells a set of power assemblies to the global market, it needs to consider the global market as a whole. Therefore, the joint venture brand is more active in promoting three-cylinder engine products. The independent

enterprise focuses on the Chinese market, and the R & D and marketing models invested in new energy technologies are significantly more than those of the joint venture.

Since 2015, many passenger car enterprises in China's market have launched products equipped with three-cylinder engines on products with different positionings. Overall, the joint venture brands are more keen to launch three-cylinder engine products, on the one hand, because the joint venture brands are forced to meet fuel consumption targets for energy-saving regulations; but on the other hand, it can also be seen that the reserves of the joint venture brand in terms of engine technology should be ahead of the independent brand, and the joint venture brand will quickly launch three-cylinder engine products according to market changes. In terms of the sales proportion of three-cylinder engines, the performance of American brands and independent brands is obviously better than that of other brands. At present, the German brand with the largest proportion in the passenger car market is not eager to launch three-cylinder engines. Only three-cylinder locomotives under the BMW brand are on sale, and the cumulative sales volume of three-cylinder engines of German brand in the first three quarters of 2021 only accounts for 10.6%. In terms of vehicle type, enterprises are more willing to give priority to the promotion of three-cylinder engine products in cars. Most of the first models of various brands are cars, and SUV users pay more attention to vehicle power factors. In terms of the first equipped model, in addition to Ford and General Motors, the first three-cylinder engine products of other brands mostly choose the next core model. On the one hand, it is necessary to minimize the impact on the sales of core models, and on the other hand, the sales volume should not be too small, otherwise there is no scale advantage.

China's new energy vehicles are experiencing rapid development. In November 2020, the general office of the State Council issued the new energy vehicle industry development plan (2021–2035) (hereinafter referred to as the Plan) [30]. According to the Plan, by 2025, the sales volume of new energy vehicles will reach about 20% of the total sales volume of new vehicles. By 2035, pure electric vehicles will become the mainstream of newly sold vehicles, and vehicles in the public sector will be fully electrified. As one of the new energy types, plug-in hybrid vehicles can not only meet the requirements of new energy vehicles but also eliminate the mileage anxiety of consumers, and they are gradually being accepted by the market. The proportion of three-cylinder engines used in plug-in hybrid vehicles is significantly higher than that in traditional fuel vehicles. New energy vehicle users focus more on indicators such as driving range and total power of the power system. The number of engine cylinders is no longer the focus of consumers. Many three-cylinder plug-in hybrid models are sold under the ideal Geely and Lynkco brands. In 2021, Lincoln, Land Rover, and other luxury brands also launched new energy models equipped with three-cylinder locomotives.

### *1.3. Automobile Energy Saving and Emission Reduction Measures*

In order to cope with the increasingly serious energy shortage and environmental pollution, various regions and countries have promulgated corresponding environmental protection laws to guide major automobile enterprises to further reduce fuel consumption. Energy saving and environmental protection are the inevitable choices for the sustainable and healthy development of China's automobiles in the future. At present, the energy-saving and emission reduction of automobiles can be realized by developing new energy vehicles, lightening automobiles, improving engine combustion and other technologies. In the environment of energy saving and emission reduction, the miniaturization of the engine, which has gradually become the mainstream, becomes active.

The new energy electric vehicle is a comprehensive product of cutting-edge achievements in electric power, automobiles, chemistry, automatic control, computers, new materials, new energy, and other technologies. From the perspective of environmental protection, electric vehicles produce almost zero pollution; there is no doubt that it is feasible to use electric vehicles to make up for the defects of original fuel vehicles that pollute the environment and consume energy. However, up to now, there are still many problems that need to

be solved gradually; the construction of social supporting resources, such as charging piles, needs to be popularized and improved. Most car companies do not take this option, with the most important reason being that the research and development cycle is too long and the development costs are too high.

Generally speaking, the heavier the vehicle, the higher the fuel consumption. The research report shows that the fuel consumption will be reduced by 8% for every 10% reduction in the weight of the vehicle. In 2018, the average fuel consumption of Chinese passenger cars was 5.8 L/100 km, which is 9% less than the target of reaching 5 L/100 km by 2020. In other words, the vehicle weight needs to be reduced by 11.2% to meet the requirements. According to the statistics of the Ministry of Industry and Information Technology of China [29], the average weight of passenger cars in China is 1456 kg, so the average weight of vehicles needs to be reduced by 163 kg to reach the emission standard of 5 L/100 km. In the automobile manufacturing industry, according to statistics, the manufacturing cost can be increased by CNY 319 per 33 kg of weight reduction, and the reverse price weight ratio is 9.7 CNY/kg. In this way, the production cost of each vehicle is about CNY 1581. Dealing with the contradiction between a vehicle lightweight, cost, and safety is thus an important part of the design and development of various automobile manufacturers with fierce competition. The process of automobile lightweighting does not simply involve reducing some materials or replacing steel with aluminum, instead, it requires long-term research and development of automobile enterprises and overall optimization of the whole vehicle structure. Therefore, it is still a long-term technical way to achieve the goal of energy saving and emission reduction through the realization of vehicle lightweight.

Improving the engine technology has a great impact on the fuel economy and power performance of the automobile engine. At present, the strategies to improve engine technology can be roughly divided into the adoption of turbocharging technology, direct injection technology, stratified combustion technology, and continuous variable valve timing technology. Taking the turbocharging technology widely used in the market as an example, the performance of the three-cylinder turbocharged engine is better than that of the four-cylinder turbocharged engine. But the current turbocharged technology is urgently needed to solve the problem of turbo lag, the impact of which can be reduced by the operating characteristics of the three-cylinder engine. There will be no problems such as exhaust interference or small turbine lag because the exhaust pulse of the three-cylinder engine is continuous. In terms of engine performance, it is well known that for the same displacement, the smaller the number of cylinders, the larger the cylinder volume. At the same time, the larger the stroke and cylinder diameter, the larger the torque at low speed.

In terms of engine power, the three-cylinder engine has a large power rise, small friction loss, a simple structure, less mechanical friction surface, and high thermal efficiency. At present, research on the three-cylinder engine mainly focuses on the mechanical technology of the engine [31–33].

#### *1.4. Product Life Cycle*

Raymond Vernon proposed the product life cycle (PLC) theory. Product life cycle refers to the market life of a product. According to Vernon, product life cycle refers to the marketing life of a new product from entering the market to being eliminated by the market. The product life cycle can generally be divided into four stages: the formation stage of the product, the growth stage of the product, the mature stage of the product, and the decline stage of the product [34]. Life-cycle theory provides managers with a range of parameters, indicators, and tools to assess the signs of transition from one stage to the next [35]. Miller and Friesen proposed a 5-stage model: Birth Phase, Growth Phase, Maturity Phase, Revival Phase, and Decline Phase [36]. In recent years, life cycle research has undergone new development. It is found that the impact of different financing channels on innovation varies with different stages of the life cycle and the advancement of the life cycle, and the overall performance weakens [37]. Investment fluctuations have

different effects on technological innovation of products with different life cycles [38]. Trade credit can be used as a sustainable resource in the life cycle [39]. Different life cycles need to implement corresponding management concepts, management strategies [40], and management culture [41]. The development of new technologies [42,43] and new economic models [44] also puts forward new tasks for life cycle research.

Through the research of previous research results, we find that there are some problems in the current research as follows: (1) the research on low-carbon emission vehicles is mainly focused on new energy vehicles, and the attention on the improvement of low-carbon emission fuel vehicle engines is not high. (2) The research on the three-cylinder engine for automobiles mainly focuses on the technical level, and the research on the connection between the use of the three-cylinder engine and the life cycle of the product is not enough. (3) There are few studies on the life cycle of automotive products from the perspective of ecology and population dynamics.

The logistic model and the Lotka–Volterra model are constructed to analyze the evolution direction of the interaction mechanism between the three-cylinder engine automotive products and the total product volume of the enterprise. This paper deeply analyzes the development history of three-cylinder passenger cars in China and explores the future development trend of three-cylinder engines [45]. (The sample data for this article is selected from the data website of the relevant industry associations, “home of car owners”, <https://xl.16888.com/brand.html>, accessed on 1 August 2022) The research structure and steps of this paper are shown in the following figure.

As shown in Figure 1, this paper uses the logistic model to analyze the growth mechanism of automobile products and judges the impact of low-carbon engines on the development of automobile products through comparative studies. Then, this paper uses the Lotka–Volterra model to evaluate the impact of automobile products on the total sales of enterprise products and judges the impact of low-carbon engines on the overall development of automobile products through comparative research.

Research process	Step 1	Step 2	Step 3	Step 4
Research contents	Automobile product growth mechanism	Influence of low carbon engine on product growth	Influence of a single product on the total amount of automobile products	Influence of low carbon engine products on total automobile products
Research methods	Logistic model	Logistic model With and without method	Lotka–Volterra model	Lotka–Volterra model With and without method

Figure 1. Research structure and steps.

## 2. Data and Methods

### 2.1. Population Dynamics

#### (1) Single population growth mechanism.

The development of any population will be restricted by its own growth capacity and resource environment, and species will follow the law of life cycle. In this paper, the automotive products sold by the automobile manufacturing enterprises are regarded as the automobile product population, and the automotive products are studied using the population number. Likewise, the development of populations in a socioeconomic system should not grow indefinitely. If an automobile market is regarded as an ecosystem, the

cars of different brands can be regarded as populations. The population model can be well applied here. The model is as follows [46,47]:

$$g_1(t) = \frac{dN_1(t)}{dt} = \alpha_1 N_1 \left( 1 - \frac{N_1}{K_1} \right) \quad (1)$$

$g_1(t)$  is the growth rate of sales volume of automotive products in T stage.

$N_1(t)$  is the population size of automotive products in  $t$  period.

$K_1$  is the largest automobile product population.

$\alpha_1$  is the intrinsic growth rate of the automobile product population.

$\left( 1 - \frac{N_1}{K_1} \right)$  is the growth retardation factor of the automobile product population.

The metering model is as follows:

$$\begin{aligned} \text{because: } & dN_1(t) \approx \Delta N_1(t), \Delta N_1(t) = N_1(t) - N_1(t-1), dt \approx \Delta t = t - (t-1) = 1. \\ \text{therefore: } & g_1(t) \approx \Delta N(t) = \alpha_1 N_1(t-1) + \gamma_1 N_1^2(t-1) \end{aligned} \quad (2)$$

Among them, generally  $\alpha_1 > 0$  represents the synergy within an automotive product group, and is called the internal synergy coefficient. When  $\alpha_1 > 1$ , the internal synergy effect of automotive products is significant.

Set  $\gamma_1 = -\frac{\alpha_1}{K_1}$ , generally,  $\gamma_1 < 0$ , which is used to express the competition effect within the automobile product population, which is called the internal competition coefficient or the population density inhibition coefficient of the automobile product population.

(2) Interaction mechanism of two species.

Automobile manufacturing enterprises share their own resources with other enterprises while sharing various resources of other enterprises. A healthy ecosystem can effectively promote the sharing of various innovation and operational resources among enterprises. In the same way, the internal relationship model of automobile product population 2 (P2) can be obtained.

$$g_2(t) = \frac{dN_2(t)}{dt} = \alpha_2 N_2 \left( 1 - \frac{N_2}{K_2} \right) \quad (3)$$

The following model explains the effect of population P2 on population P1.

$$g_1(t) = \frac{dN_1(t)}{dt} = \alpha_1 N_1 \left( 1 - \frac{N_1}{K_1} + \frac{\beta_{12} N_2}{K_2} \right) \quad (4)$$

$\beta_{12}$  indicates the effect of population 2 on population 1 (when  $\beta_{12} > 0$ , synergistic effect; when  $\beta_{12} < 0$ , competitive effect). The following population dynamics system expresses the effect of population p1 on population P2.

$$g_2(t) = \frac{dN_2(t)}{dt} = \alpha_2 N_2 \left( 1 - \frac{N_2}{K_2} + \frac{\beta_{21} N_1}{K_1} \right) \quad (5)$$

$\beta_{21}$  is the influence factor of population 1 to population 2. The dynamic system composed of population P1 and population P2 is:

$$\begin{cases} g_1(t) = \frac{dN_1(t)}{dt} = \alpha_1 N_1 \left( 1 - \frac{N_1}{K_1} + \frac{\beta_{12} N_2}{K_2} \right) \\ g_2(t) = \frac{dN_2(t)}{dt} = \alpha_2 N_2 \left( 1 - \frac{N_2}{K_2} + \frac{\beta_{21} N_1}{K_1} \right) \end{cases} \quad (6)$$

Considering two or more entities in the ecosystem competing and symbiotic at the same time [48], the system can show a symbiotic relationship of product populations [49–51]. Relevant studies have shown that the symbiotic mechanism of automotive products is suitable for analysis with population dynamics [52–54].

## 2.2. Sample Introduction

The models selected in this paper are mainly the best-selling models launched by joint ventures in the Chinese market, at least those that used to be best-selling. The model samples selected in the study are shown in the following table.

As shown in Table 1, six main models from six Sino–foreign joint ventures were selected for research. The comprehensive fuel consumption refers to the comprehensive fuel consumption (L) of a vehicle running 100 km published by the Ministry of Industry and Information Technology. These six models were once popular products in China’s passenger car market. However, in recent years, these models have encountered sales difficulties, and the sales volume has dropped significantly.

**Table 1.** Three-cylinder engine models and their emissions.

Product Model	Developing Enterprise	Engine Displacement	Comprehensive Fuel Consumption (L)	Time of Market Launch
Focus	CA-Ford	1.0 T	5.4	July-2015
408	Dongfeng Peugeot	1.2 T	5.2	March-2015
C4L	Dongfeng Citroen	1.2 T	5.4	July-2015
Encore	SAIC Buick	1.0 T	5.5	July-2019
Crider	GAC Honda	1.0 T	5.5	September-2018
Malibu	SAIC Chevrolet	1.3 T	5.9	January-2019

Take the Chang’an Ford Focus model, for example, which finally received a new generation in November 2018, nearly seven years after the previous generation was launched (in April 2012, the third generation Focus was launched in the Chinese market). Compared with its competitors, the Nissan Sylphy, which is one of the representative models in the current A-class car market, carried out model replacements in 2012 and 2016, respectively. At the 2019 Shanghai auto show, the latest generation of Nissan Sylphy products with a 12 mm longer wheelbase was officially released, and the update frequency was much higher than that of the Focus.

The price of stagnant product renewal is the decline of its sales volume and influence. According to the data, as a benchmark product in the A-class car market, Focus not only achieved excellent performance of monthly sales with more than 30,000 vehicles, but also won the sales champion in the segment market for three consecutive years from 2012 to 2014. With the rise of its competitors and the “lack of ambition” of Focus itself, its sales volume began to decline in 2015. Now, even if the new generation of Focus came out finally, it would be difficult to reproduce the glory of that year. Other models of Chang’an Ford have similar experiences. In terms of cars, the fifth generation Mondeo has been in service for nearly six years since it was launched in August 2013. It has obviously lagged behind in both interior design and technological configuration. The youngest product in the Ford family, the Forester, was launched in December 2014 and received a mid-life facelift in October 2018. As a model with low profit and high sales volume, after the modification, the whole series is only equipped with the controversial three-cylinder engine, and the sales volume also plummeted, even smaller than that in the peak period of one month. In the Chang’an Ford SUV camp, the Kuga and Edge have also entered the end of the product cycle. The development of Chang’an Ford is a microcosm of the development of some Sino–foreign joint ventures. Many people attribute the plight of Chang’an Ford to the three-cylinder engine. However, the actual situation is not necessarily the case, which is also a mystery that this study wants to reveal.

## 2.3. Analysis Results of Logistic Model

This paper first analyzes the growth mechanism and mode of automotive products by using a logistic model, especially comparing the differences between products equipped with three-cylinder engines. This paper attempts to explore whether the adoption of a three-

cylinder engine will significantly change the growth mechanism and mode of products. The research results are shown in the following table.

As shown in Table 2, the effect of dynamic mechanism analysis of a single population logistic model is very good, and most regression effects are very good. The data in the table shows that the upper limit of theoretical sales volume of some models, including Focus, Encore, Crider, and Malibu, is decreasing after the replacement of the low-carbon three-cylinder engine. The Peugeot 408 and C4L saw a rise in the theoretical upper limit of sales.

**Table 2.** Logistic model results of vehicle models and enterprise sales.

Product Model	Before Assembling the Three-Cylinder Engine			After Assembling the Three-Cylinder Engine		
	Intrinsic Growth Rate ( $\alpha_1$ )	Internal Inhibition Coefficient ( $\gamma_1$ )	Theoretical Upper Limit of Sales Volume ( $K_1$ )	Intrinsic Growth Rate ( $\alpha_1$ )	Internal Inhibition Coefficient ( $\gamma_1$ )	Theoretical Upper Limit of Sales Volume ( $K_1$ )
Focus	0.093 (1.529) *	$-3.819 \times 10^{-6}$ (-1.883) *	24,481	0.191 (2.019) **	$-1.346 \times 10^{-5}$ (-2.625) ***	14,205
CA-Ford	0.127 (2.173) **	$-2.378 \times 10^{-6}$ (-2.456) ***	53,707	0.186 (2.091) **	$-3.019 \times 10^{-6}$ (-2.633) ***	61,715
Peugeot 408	0.376 (2.173) ***	$-6.451 \times 10^{-5}$ (-2.456) ***	5825	0.247 (2.532) ***	$-3.388 \times 10^{-5}$ (-3.532) ***	7304
DF-Peugeot	0.234 (2.734) ***	$-8.654 \times 10^{-6}$ (-2.929) ***	27,076	0.164 (1.588) *	$-7.371 \times 10^{-6}$ (-2.296) **	22,364
C4L	0.498 (2.527) ***	$-2.163 \times 10^{-4}$ (-3.533) ***	2305	0.178 (1.114)	$-3.678 \times 10^{-5}$ (-1.353)	4839
DF-citroen	0.316 (2.283) **	$-1.732 \times 10^{-5}$ (-2.951) ***	18,220	0.532 (2.464) **	$-2.200 \times 10^{-5}$ (-2.654) ***	24,167
Encore	0.679 (4.807) ***	$-1.095 \times 10^{-4}$ (-5.347) ***	6204	-0.109 (-0.781)	$-6.559 \times 10^{-5}$ (-2.567) ***	-1668
Saic-buick	0.402 (3.133) ***	$-4.531 \times 10^{-6}$ (-3.454) ***	88,673	0.473 (1.793) *	$-6.084 \times 10^{-6}$ (-2.012) **	71,798
Crider	0.518 (4.058) **	$-4.525 \times 10^{-5}$ (-5.452) ***	11,439	0.118 (0.552)	$-1.444 \times 10^{-5}$ (-0.895)	8169
Ghac	0.718 (5.839) ***	$-1.276 \times 10^{-5}$ (-6.604) ***	56,256	0.948 (3.701) ***	$-1.402 \times 10^{-5}$ (-3.907) ***	67,595
Malibu	0.375 (3.752) ***	$-3.715 \times 10^{-5}$ (-4.431) ***	10,099	0.792 (2.563) ***	$-1.688 \times 10^{-4}$ (-3.168) ***	4698
Saic-chevrolet	0.405 (4.531) ***	$-7.487 \times 10^{-6}$ (-4.880) ***	54,140	0.351 (1.961) **	$-1.135 \times 10^{-5}$ (-2.885) ***	30,927

() *t* value, \* *p* value < 0.1, \*\* *p* value < 0.05, \*\*\* *p* value < 0.01.

After Focus withdrew the three-cylinder engine models, the intrinsic growth rate increased, and the internal inhibition coefficient also increased. The total result is the decline of the theoretical upper limit of sales volume. Interestingly, under the condition that CA-Ford launched the three-cylinder engine version of the Focus, the maximum sales volume of the whole enterprise increased significantly. After the launch of the low-carbon engine vehicle model represented by the Focus, the sales limit of the whole enterprise has increased. It can be preliminarily determined that low-carbon engines may be a power source for enterprises to revitalize new engines.

The performance of the Peugeot 408 is just the opposite to that of the Focus. After the Peugeot 408 model withdrew the three-cylinder engine, the intrinsic growth rate decreased, and the internal inhibition coefficient also decreased. Finally, the theoretical sales limit of the model rose. Meanwhile, the overall sales cap of DF Peugeot decreased.

After the DF Citroen C4L model was equipped with a three-cylinder engine, the theoretical upper limit of automobile sales of this model and the whole enterprise has been significantly increased. Observing its regression model, we can find that the rise of low-carbon engine models and the theoretical sales volume for enterprises is due to the decrease of internal inhibition coefficient.

After Encore installed the low-carbon three-cylinder engine, the theoretical upper limit of sales volume of encore models and SAIC Buick enterprises both decreased. It shows

that for SAIC Buick, the low-carbon three-cylinder engine has not brought a significant improvement in performance to the enterprise. The situation of Crider and Malibu is similar to that of Encore.

The single population analysis shows that most of the models in the sample have not significantly improved the competitiveness of the enterprise and its products after the replacement of the three-cylinder engine and have not significantly improved the theoretical upper limit of the enterprise’s product sales. At the same time, the sales volume of most products did not get out of recession. So, can we conclude that the three-cylinder engine is not conducive to the development of automotive products? In order to answer this question, we need to use the two-species Lotka–Volterra model to further look at the symbiotic mechanism between the three-cylinder locomotive and the overall sales volume of the enterprise from the perspective of population symbiosis.

### 2.4. Lotka–Volterra Model Analysis Results

It is one-sided to study the influence of the three-cylinder engine on the product life cycle only from the perspective of single population growth. In this paper, the Lotka–Volterra model is used to analyze the symbiosis mechanism and interaction mode of the automotive products and the total products of their affiliated enterprises, especially to compare the differences between the products equipped with three-cylinder engines. This paper attempts to explore whether the adoption of the three-cylinder engine will significantly change the symbiosis mechanism and interaction mode between the product and the total product of its affiliated enterprises. The research results are shown in the following table.

As shown in Table 3, the regression effect of the LV model is good, which indicates that the two-population LV model is applicable for the study of the symbiosis mechanism of automobile enterprises. In the regression results of the model, there are a few cases where the  $\beta$  coefficient exceeds the boundary of ecological theory. In this case, focus should be on the positive and negative of the coefficient value. In the sample, four brands use three-cylinder engines, which can promote the total sales volume of their enterprises.

Table 3. Lotka–Volterra model results of vehicle models and enterprise sales.

Product Model	Before Assembling the Three-Cylinder Engine				After Assembling the Three-Cylinder Engine			
	$\alpha_1$	$\gamma_1$	$\gamma_2$	$\beta_{12}$	$\alpha_1$	$\gamma_1$	$\gamma_2$	$\beta_{12}$
Focus	0.100 (1.638) *	$-1.832 \times 10^{-7}$ (-0.054)	$-2.132 \times 10^{-6}$ (-1.355)	-0.719	0.170 (1.672) *	$-1.957 \times 10^{-5}$ (-1.599) *	$1.694 \times 10^{-6}$ (0.550)	0.232
CA-Ford	0.103 (1.560) *	$-3.075 \times 10^{-6}$ (-2.333) **	$2.254 \times 10^{-6}$ (0.781)	11.875	0.221 (2.533) ***	$-9.468 \times 10^{-6}$ (-3.425) ***	$2.687 \times 10^{-5}$ (2.574) ***	1.060
Peugeot 408	0.328 (3.078) ***	$-7.950 \times 10^{-5}$ (-4.863) ***	$7.827 \times 10^{-6}$ (2.470) **	0.375	0.177 (1.165)	$-3.365 \times 10^{-5}$ (-3.491) ***	$2.632 \times 10^{-6}$ (0.607)	0.046
DF-Peugeot	0.186 (1.962) *	$-1.183 \times 10^{-5}$ (-2.955) ***	$2.157 \times 10^{-5}$ (1.172)	0.479	0.026 (0.235)	$-8.382 \times 10^{-6}$ (-2.721) ***	$2.750 \times 10^{-5}$ (2.988) ***	5.621
C4L	0.516 (2.604) ***	$1.549 \times 10^{-5}$ (0.478)	$-2.505 \times 10^{-5}$ (-2.527) ***	-0.921	0.730 (3.085) ***	$-1.057 \times 10^{-4}$ (-1.195)	$-2.235 \times 10^{-5}$ (-1.704) *	-0.446
DF-Citroen	0.523 (2.420) **	$-2.756 \times 10^{-5}$ (-2.707) ***	$2.886 \times 10^{-5}$ (0.944)	-1.838	0.437 (2.700) ***	$-3.008 \times 10^{-5}$ (-2.791) ***	$8.119 \times 10^{-5}$ (1.406)	1.280
Encore	0.797 (4.083) ***	$-1.086 \times 10^{-4}$ (-5.288) ***	$-1.441 \times 10^{-6}$ (-0.875)	-0.188	-0.668 (-1.859) *	$-4.787 \times 10^{-5}$ (-1.772) *	$7.566 \times 10^{-6}$ (1.680) *	-0.723
Saic-buick	0.472 (3.381) ***	$-4.555 \times 10^{-6}$ (-3.485) ***	$-1.387 \times 10^{-5}$ (-1.247)	-0.215	0.382 (1.523) *	$-5.989 \times 10^{-6}$ (-1.975) **	$3.916 \times 10^{-5}$ (0.926)	-1.430
Crider	-0.028 (-0.116)	$-3.462 \times 10^{-5}$ (-3.882) ***	$8.732 \times 10^{-6}$ (2.599) ***	-23.739	0.644 (1.523) *	$-1.085 \times 10^{-5}$ (-0.672)	$-8.251 \times 10^{-6}$ (-1.436)	-0.861
Ghac	1.058 (6.498) ***	$-1.373 \times 10^{-5}$ (-7.435) ***	$-3.025 \times 10^{-5}$ (-2.967) ***	0.023	0.947 (3.647) ***	$-1.407 \times 10^{-5}$ (-3.776) ***	$4.621 \times 10^{-7}$ (0.056)	0.029

Table 3. Cont.

Product Model	Before Assembling the Three-Cylinder Engine				After Assembling the Three-Cylinder Engine			
	$\alpha_1$	$\gamma_1$	$\gamma_2$	$\beta_{12}$	$\alpha_1$	$\gamma_1$	$\gamma_2$	$\beta_{12}$
Malibu	0.577 (3.137) ***	$-4.148 \times 10^{-5}$ (-4.617) ***	$-3.250 \times 10^{-6}$ (-1.306)	-0.327	0.791 (2.521) **	$-1.597 \times 10^{-4}$ (-2.537) **	$-1.462 \times 10^{-6}$ (-0.278)	-0.070
Saic-chevrolet	0.446 (3.967) ***	$-7.671 \times 10^{-6}$ (-4.887) ***	$-3.795 \times 10^{-6}$ (-0.604)	-0.118	0.382 (2.027) *	$-1.013 \times 10^{-5}$ (-2.254) **	$-1.746 \times 10^{-5}$ (-0.581)	-0.226

() *t* value, \* *p* value < 0.1, \*\* *p* value < 0.05, \*\*\* *p* value < 0.01.

The Focus and CA-Ford are mutually beneficial in the symbiotic relationship of automotive products. Before assembling the low-carbon three-cylinder engine, Chang'an Ford's product line had a competitive relationship with the Focus. After assembling the low-carbon three-cylinder engine, Chang'an Ford's product line has a synergistic symbiotic relationship with Focus. This shows that the low-carbon product engine has effectively changed the product symbiosis mechanism within Ford and optimized the product ecosystem. At the same time, Chang'an Ford's performance in the Chinese market is not satisfactory. The main reason is not that it uses a three-cylinder engine. Chang'an Ford should not attribute the decline in product market competitiveness and market share in recent years to the use of three-cylinder engines. Products, such as 408, C4L, Crider, and others, can still achieve the synergy effect on the total product volume of the enterprise after using the three-cylinder engine. Among them, 408 and Focus are two-way collaborative relationships with the sum of the product lines of the affiliated enterprises. After the adoption of the three-cylinder engine, Encore and Malibu have formed a competitive relationship with their affiliated enterprises. However, before adopting the three-cylinder engine, Encore and Malibu also formed a competitive relationship with their affiliated enterprises. The use of a three-cylinder engine intensifies this internal competitive relationship.

It can be seen that the low-carbon three-cylinder engine has no significant impact on the life cycle decline of automotive products. On the contrary, most of the research sample products have a positive impact on the total sales volume of the products and enterprises after they are replaced with three-cylinder engines. The decline in market competition of some automobile enterprises and their mainstream products cannot be simply attributed to the three-cylinder engine but to the deep-seated operation problems faced by the enterprises, which should be analyzed in depth. For example, whether there are problems in the development strategy, product development, and research and development investment of the enterprise should be analyzed.

### 3. Results and Discussion

#### 3.1. Results

In this paper, the theory and models of ecology and population dynamics are applied to the life cycle analysis of automotive products, and the impact of three-cylinder engines on the product life cycle is compared. In the study, the sales volume of the sample enterprises is regarded as the size of the population, and the sales data of the sample automotive products are analyzed by constructing a two-stage logistic model and a Lotka–Volterra model. Based on the study of population dynamics growth mechanisms, the different life cycles of automobile enterprises are discussed. The article focuses on the analysis of the impact of the new low-carbon three-cylinder engine on the product life cycle. The results show that the three-cylinder engine with low carbon emissions has no significant effect on the life cycle decline of automotive products. On the contrary, most of the research sample products have a positive impact on the total sales volume of the products and enterprises after they are replaced with three-cylinder engines. The decline in market competition of some automobile enterprises and their mainstream products cannot be simply attributed to the three-cylinder engine, but the deep-seated operational problems faced by the enterprises should be analyzed in depth.

### 3.2. Discussion

Compared with traditional research on product life cycle measurement, the biggest characteristic of this paper is that it returns to the theory and method of ecological research and discusses product life cycle measurement based on the methods of ecology and population dynamics. Life cycle theory comes from ecological research. Compared with the traditional research on low-carbon emission vehicles [6–10], this paper studies the three-cylinder engine from the perspective of consumer market selection, expanding the field and perspective of low-carbon emission vehicle research.

Compared with the current research on consumer acceptance of the low-carbon emission vehicle market [12–18], this paper conducts the research on market acceptance from the perspective of symbiosis of the enterprise product population. This method uses the objective data index of sales volume and develops the thinking of related research. Compared with the traditional three-cylinder engine research [29–31], this paper carries out quantitative analysis from the perspective of product life cycle, expanding the field and perspective of three-cylinder engine research.

### 3.3. Management Enlightenment

Before new energy vehicles such as hybrid electric vehicles and pure electric vehicles are fully popularized, low-carbon environmental protection engines with small displacement are a good transition product. When developing automotive products, enterprises should not only grasp the future technical requirements of the products, but also pay attention to the current market acceptance of new energy and low-carbon environmental protection engines.

#### (1) Prospect of the low carbon environmental protection engine.

In September 2020, the Chinese government proposed at the 75th United Nations General Assembly that “China will enhance its national independent contribution, adopt more powerful policies and measures, strive to reach the peak of carbon emissions by 2030, and strive to achieve carbon neutrality by 2060.” It can be predicted that the relevant regulatory requirements for energy conservation and emissions of motor vehicles will be consistent with the action plan of carbon peaking and carbon neutralization. At the same time, with the continuous progress of engine technology, the technical parameters of the three-cylinder engine in terms of power level, fuel consumption index, and NVH will have better performance, which will create mature conditions for the large-scale application of the three-cylinder engine. As more and more countries around the world announce that they will stop selling traditional fuel vehicles in the future, all major automobile enterprises have also announced plans to stop selling traditional fuel vehicles. With the progress of technology, the new energy products made by three-cylinder engines in combination with new energy technologies will certainly achieve greater development in the future.

The three-cylinder engine has many advantages: its simple structure, light weight and small lateral size; while reducing weight and cost, it also provides more space for the layout of the engine compartment and is more suitable for application in hybrid vehicles. Moreover, the smaller the number of cylinders of the engine with the same displacement, the lower the fuel consumption.

The number of cylinders in the engine has grown from a single cylinder to 12 cylinders or more. Now, with the progress of science and technology and the improvement of the national environmental protection policy, the number of cylinders in the engine has gradually returned to three. After so many years of technological precipitation, the technology of automobile manufacturing enterprises has become more and more mature. Today, with the growing awareness of environmental protection, energy saving and emission reduction are tests for major automobile enterprises. Compared with the development of new energy vehicles, the reduction of vehicle weight, and the adoption of four-cylinder small displacement models, the three-cylinder engine has many advantages, such as lower cost, shorter R & D cycle, and higher combustion efficiency compared with the displacement. Therefore, we also have reason to believe that with the maturity of the three-cylinder

engine technology, its market recognition will continue to improve, and it will become an increasingly mainstream presence in the field of internal combustion engines before the arrival of the pure electric era.

(2) Market strategy of low carbon emission vehicles.

The practice of China's passenger car market shows that many enterprises have successfully used three-cylinder low-carbon engines in the development of new products. The product development of these enterprises has their own characteristics, and the market strategy hits the mark. First of all, automobile manufacturers need to promote three-cylinder engine products in a gradual and orderly manner. In the modification of one type of vehicle, try to introduce some models with three-cylinder engines. At the initial stage of using the three-cylinder engine, we are not in a hurry for success; instead, we sow more tolerance and patience for the market and consumers and correctly face the psychological adaptation process of consumers. Secondly, the enterprise effectively provides high-quality three-cylinder engine products. At the same time, it is necessary to pay attention to the price strategy of new products and make appropriate concessions to consumers. Third, enterprises do their jobs in marketing, advertising, and product promotion.

(3) Policy recommendations.

The government encourages automobile manufacturers to develop and provide low-carbon fuel vehicles through relevant regulatory measures and incentive policies. This policy can be regarded as a transitional policy before the full popularization of new energy vehicles. Government departments should increase the transparency of relevant information and publish relevant performance indicators and carbon emission data of low-carbon three-cylinder engines in a timely manner. This measure can enable the public to obtain more comprehensive engine data and reduce the asymmetry of information about three-cylinder engines. Promoting international cooperation on three-cylinder low carbon emission engines can be achieved through relevant policies.

#### 4. Conclusions

The purpose of this paper is to explore whether assembling a three-cylinder engine will affect the life cycle of automotive products. In short, after assembling the three-cylinder engine, whether the automotive products will enter the recession period of the life cycle ahead of time is unclear. In order to achieve this research goal, this paper constructs a measurement method for the automotive product life cycle based on ecological theory. This method should be able to reflect the impact of the low-carbon three-cylinder engine on the life cycle of the automobile brand. This research has achieved the above research objectives by empirical analysis showing that the three-cylinder engine with low carbon emissions has no significant impact on the life cycle decline of automotive products.

The research highlights of this paper are as follows: (1) the logistic model and Lotka–Volterra model based on population dynamics theory are developed to measure the product life cycle. (2) The logistic model is used to calculate the intrinsic growth rate, internal inhibition coefficient, and theoretical upper limit of sales volume of automotive products. A comparison is made between the situations before and after assembling the three-cylinder engine to study the life cycle change of the product. (3) The Lotka–Volterra model is used to calculate the overall symbiotic relationship between automotive products and enterprise products. To study the life cycle change of the product, we compared the situation before and after assembling the three-cylinder engine.

The advantage of the method recommended in this paper is that it reflects the impact of three-cylinder engine products on the sales of automotive products through objective data. This research avoids the subjective interference brought by market research, interviews, and other methods. At the same time, the data for this method is relatively easy to obtain, and the model operation is relatively simple. The model developed in this paper can not only better measure the life cycle of automotive products but also focus on analyzing the population dynamic characteristics of automotive products in the declining stage. Therefore, the two-stage logistic model and Lotka–Volterra model in this paper can provide

support for scientific decision-making in enterprises. The main shortcomings of this study are that the sample size of the study is relatively small, the time span of the study is relatively short, and the data type in the study is relatively singular. In future studies, the author will expand the sample size, data span, and variable types of the study.

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## References

1. Kendall, M. Fuel cell development for New Energy Vehicles (NEVs) and clean air in China. *Prog. Nat. Sci. Mater. Int.* **2018**, *28*, 113–120. [[CrossRef](#)]
2. Tan, R.P.; Lin, B.Q. Are people willing to support the construction of charging facilities in China? *Energy Policy* **2020**, *143*, 111604. [[CrossRef](#)]
3. Jahangir, H.; Gougheri, S.S.; Vatandoust, B.; Golkar, M.A.; Golkar, M.A.; Ahmadian, A.; Hajizadeh, A. A novel cross-case electric vehicle demand modeling based on 3D convolutional generative adversarial networks. *IEEE Trans. Power Syst.* **2022**, *37*, 1173–1183. [[CrossRef](#)]
4. Jahangir, H.; Gougheri, S.S.; Vatandoust, B.; Golkar, M.A.; Ahmadian, A.; Hajizadeh, A. Plug-in electric vehicle behavior modeling in energy market: A novel deep learning-based approach with clustering technique. *IEEE Trans. Smart Grid* **2020**, *11*, 4738–4748. [[CrossRef](#)]
5. Jahangir, H.; Tayarani, H.; Ahmadian, A.; Golkar, M.A.; Miret, J.; Tayarani, M.; Gao, H.O. Charging demand of plug-in electric vehicles: Forecasting travel behavior based on a novel rough artificial neural network approach. *J. Clean. Prod.* **2019**, *229*, 1029–1044. [[CrossRef](#)]
6. He, L.Y.; Pei, L.L.; Yang, Y.H. An optimised grey buffer operator for forecasting the production and sales of new energy vehicles in China. *Sci. Total Environ.* **2020**, *704*, 135321. [[CrossRef](#)]
7. Yan, Q.Y.; Zhang, M.J.; Li, W.; Qin, G.Y. Risk assessment of new energy vehicle supply chain based on variable weight theory and cloud model: A case study in China. *Sustainability* **2020**, *12*, 3150. [[CrossRef](#)]
8. Tang, B.; Tang, J.; Liu, Y.; Zeng, F. Comprehensive evaluation and application of GIS insulation condition part 1: Selection and optimization of insulation condition comprehensive evaluation index based on multi-source information fusion. *IEEE Access* **2019**, *7*, 88254–88263. [[CrossRef](#)]
9. Egbue, O.; Long, S. Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. *Energy Policy* **2012**, *48*, 717–729. [[CrossRef](#)]
10. Ma, Y.; Shi, T.; Zhang, W.; Hao, Y.; Huang, J.; Lin, Y. Comprehensive policy evaluation of NEV development in China, Japan, the United States, and Germany based on the AHP-EW model. *J. Clean. Prod.* **2019**, *214*, 389–402. [[CrossRef](#)]
11. Qiu, S.; Wang, W.; Wang, K.C. A comprehensive system for AASHTO PP67-10 based asphalt surfaced pavement cracking evaluation. *Can. J. Civ. Eng.* **2016**, *43*, 260–269. [[CrossRef](#)]
12. Trencher, G.; Edianto, A. Drivers and barriers to the adoption of fuel cell passenger vehicles and buses in Germany. *Energies* **2021**, *14*, 833. [[CrossRef](#)]
13. Lashari, Z.; Ko, J.; Jang, J. Consumers' intention to purchase electric vehicles: Influences of user attitude and perception. *Sustainability* **2021**, *13*, 6778. [[CrossRef](#)]
14. Hao, Y.; Dong, X.Y.; Deng, Y.X.; Li, L.X.; Ma, Y. What influences personal purchases of new energy vehicles in China? An empirical study based on a survey of Chinese citizens. *J. Renew. Sustain. Energy* **2016**, *8*, 065904. [[CrossRef](#)]
15. Du, Z.; Lin, B. How oil price changes affect car use and purchase decisions? Survey evidence from Chinese cities. *Energy Policy* **2017**, *111*, 68–74. [[CrossRef](#)]
16. Luo, G.; Weng, J.-H.; Zhang, Q.; Hao, Y. A reexamination of the existence of environmental Kuznets curve for CO<sub>2</sub> emissions: Evidence from G20 countries. *Nat. Hazards* **2017**, *85*, 1023–1042. [[CrossRef](#)]
17. Gong, B.G.; Liu, R.; Zhang, X.Q. Market acceptability assessment of electric vehicles based on an improved stochastic multicriteria acceptability analysis-evidential reasoning approach. *J. Clean. Prod.* **2020**, *269*, 121990. [[CrossRef](#)]
18. Lin, B.Q.; Shi, L. Identify and bridge the intention-behavior gap in new energy vehicles consumption: Based on a new measurement method. *Sustain. Prod. Consum.* **2022**, *31*, 432–447. [[CrossRef](#)]

19. Liu, L.; Zhang, T.; Avrin, A.P.; Wang, X. Is China's industrial policy effective? An empirical study of the new energy vehicles industry. *Technol. Soc.* **2020**, *63*, 101356. [CrossRef]
20. Wang, D.; Li, Y. Measuring the policy effectiveness of China's new-energy vehicle industry and its differential impact on supply and demand markets. *Sustainability* **2022**, *14*, 8215. [CrossRef]
21. Dillman, K.J.; Arnadottir, A.; Heinonen, J.; Czepkiewicz, M.; Daviosdottir, B. Review and meta-analysis of EVs: Embodied emissions and environmental breakeven. *Sustainability* **2020**, *12*, 9390. [CrossRef]
22. Onat, N.C.; Aboushaqrah, N.N.M.; Kucukvar, M.; Tarlochan, F.; Hamouda, A.M. From sustainability assessment to sustainability management for policy development: The case for electric vehicles. *Energy Convers. Manag.* **2020**, *216*, 16.
23. Ahmadi, P. Environmental impacts and behavioral drivers of deep decarbonization for transportation through electric vehicles. *J. Clean. Prod.* **2019**, *225*, 1209–1219. [CrossRef]
24. Dranka, G.G.; Ferreira, P. Electric vehicles and biofuels synergies in the Brazilian energy system. *Energies* **2020**, *13*, 4423. [CrossRef]
25. Gan, Y.; Lu, Z.; He, X.; Hao, C.; Wang, Y.; Cai, H.; Wang, M.; Elgowainy, A.; Przesmitzki, S.; Bouchard, J. Provincial greenhouse gas emissions of gasoline and plug-in electric vehicles in China: Comparison from the consumption-based electricity perspective. *Environ. Sci. Technol.* **2021**, *55*, 6944–6956. [CrossRef]
26. Hou, F.; Chen, X.; Chen, X.; Yang, F.; Ma, Z.; Zhang, S.; Liu, C.; Zhao, Y.; Guo, F. Comprehensive analysis method of determining global long-term GHG mitigation potential of passenger battery electric vehicles. *J. Clean. Prod.* **2021**, *289*, 125137. [CrossRef]
27. Petrovic, D.T.; Pesic, D.R.; Petrovic, M.M.; Mijailovic, R.M. ELECTRIC CARS are they solution to reduce CO2 emission? *Therm. Sci.* **2020**, *24*, 2879–2889. [CrossRef]
28. Kim, S.; Pelton, R.E.O.; Smith, T.M.; Lee, J.; Jeon, J.; Suh, K. Environmental implications of the national power roadmap with policy directives for battery electric vehicles (BEVs). *Sustainability* **2019**, *11*, 6657. [CrossRef]
29. Yang, L.; Guo, D. Current situation and development analysis of three-cylinder engine passenger cars in China. *Automob. Accessories* **2021**, *23*, 62–63. (In Chinese)
30. General Office of the State Council of the People's Republic of China, New Energy Vehicle Industry Development Plan (2021–2035). Available online: [https://www.gov.cn/zhengce/content/2020-11/02/content\\_5556716.htm](https://www.gov.cn/zhengce/content/2020-11/02/content_5556716.htm) (accessed on 20 October 2020).
31. Saravanan, S.; Durai, K.P.; Sundaram, I.M. Comparison of combustion characteristics of an automotive CRDI engine with conventional HCV engine. *Int. J. Oil Gas Coal Technol.* **2019**, *21*, 390–405. [CrossRef]
32. Liu, X.A.; Shangguan, W.B.; Lv, Z.P.; Ahmed, W.; Zhu, W. A study on optimization method of a powertrain mounting system with a three-cylinder engine. *J. Mech. Eng. Sci.* **2017**, *231*, 2235–2252. [CrossRef]
33. McGhee, M.; Wang, Z.M.; Bech, A.; Shayler, P.J.; Witt, D. The effects of cylinder deactivation on the thermal behavior and fuel economy of a three-cylinder direct injection spark ignition gasoline engine. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2019**, *233*, 2838–2849. [CrossRef]
34. Vernon, R. International investment and international trade in the product cycle. *Q. J. Econ.* **1966**, *80*, 190–207. [CrossRef]
35. Jawahar, I.M.; Laughlin, G.L.M. Toward a descriptive stakeholder theory: An organizational life cycle approach. *Acad. Manag. Rev.* **2001**, *26*, 397–414. [CrossRef]
36. Miller, D.; Friesen, P.H. A longitudinal study of the corporate life cycle. *Manag. Sci.* **1984**, *30*, 1161–1183. [CrossRef]
37. Ling, S.; Han, G.; An, D.; Akhmedov, A.; Wang, H.; Li, H.; Hunter, W.C. The effects of financing channels on enterprise innovation and life cycle in Chinese a-share listed companies: An empirical analysis. *Sustainability* **2020**, *12*, 6704. [CrossRef]
38. Li, M.M.; Hao, Z.X.; Luan, M.; Li, H.B.; Cao, G.K. The impact of innovation investment volatility on technological innovation of enterprises in different life cycles. *Math. Probl. Eng.* **2021**, *2021*, 2442071. [CrossRef]
39. Canto-Cuevas, F.-J.; Palacín-Sánchez, M.-J.; Di Pietro, F. Trade credit as a sustainable resource during an SME's life cycle. *Sustainability* **2019**, *11*, 670. [CrossRef]
40. Jing, S.W.; Yang, Y.R.; Ho, Z.P.; Yan, J.N.; Huang, H.T. The development of a frame model for management strategies selection using fuzzy proximity. *Clust. Comput.* **2017**, *20*, 141–153. [CrossRef]
41. Belak, J. Management and governance: Organizational culture in relation to enterprise life cycle. *Kybernetes* **2016**, *45*, 680–698. [CrossRef]
42. Rashid, A.; Masood, T.; Erkoyuncu, J.A.; Tjahjono, B.; Khan, N.; Shami, M.U.D. Enterprise systems' life cycle in pursuit of resilient smart factory for emerging aircraft industry: A synthesis of critical success factors' (CSFs), theory, knowledge gaps, and implications. *Enterp. Inf. Syst.* **2018**, *12*, 96–136. [CrossRef]
43. Ma, D.J. Comprehensive decision analysis of industry 4.0 virtual enterprises considering the personalized customization model of product life cycle. *J. Sens.* **2022**, *2022*, 1175565. [CrossRef]
44. Ma, S.Z.; Liang, Q.H. Industry competition, life cycle and export performance of China's cross-border e-commerce enterprises. *Int. J. Technol. Manag.* **2021**, *87*, 171–204. [CrossRef]
45. Statistics of Automobile Sales in China. Available online: <http://xl.16888.com/brand.html> (accessed on 1 August 2022).
46. Verhulst, P.F. Notice sur la loi que la population suit dans son accroissement. *Corresp. Math. Phys.* **1838**, *10*, 113–121.
47. Cox, D.R. The regression analysis of binary sequences. *J. R. Stat. Soc. Ser. B* **1958**, *20*, 215–242. [CrossRef]
48. Volterra, V. Fluctuations in the abundance of a species considered mathematically. *Nature* **1926**, *118*, 558–560. [CrossRef]
49. Zhang, G.; McAdams, D.A.; Shankar, V.; Darani, M.M. Technology evolution prediction using Lotka-Volterra Equations. *J. Mech. Des.* **2018**, *140*, 61–101. [CrossRef]
50. Modis, T. Technological forecasting at the stock market. *Technol. Forecast. Soc. Change* **1999**, *62*, 173–202. [CrossRef]

51. Chang, C.; Ku, C.; Ho, H. Fuzzy multi-choice goal programming for supplier selection. *Int. J. Oper. Res. Inf. Syst.* **2010**, *1*, 28–52. [[CrossRef](#)]
52. Wang, S.Y.; Chen, W.M.; Wu, X.L. Competition analysis on industry populations based on a three-dimensional lotka–Volterra model. *Discret. Dyn. Nat. Soc.* **2021**, *2021*, 9935127. [[CrossRef](#)]
53. Wang, S.Y.; Chen, W.M.; Liu, Y. Collaborative product portfolio design based on the approach of multi choice goal programming. *Math. Probl. Eng.* **2021**, *2021*, 6678533.
54. Wu, X.L.; Wang, S.Y.; Liu, Y.Z.; Ling, J.; Yu, X. Competition equilibrium analysis of China’s luxury car market based on three-dimensional grey lotka–Volterra model. *Complexity* **2021**, *2021*, 7566653. [[CrossRef](#)]