# Research on Green Innovation of the Tyre Manufacturers in China Based on System Dynamics

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***ABSTRACT***

*In recent years, the green manufacturing is gradually becoming an important force in the development of automobile manufacturing enterprises in China. How to implement green manufacturing engineering through the green innovation is a realistic problem of China's automobile parts manufacturers. In this paper, green innovation system of tyre manufacturers in China has been analyzed from manufacturers, market and government. Furthmore, the model of green innovation of tyre manufacturers based on system dynamics has been established. According to the research data obtained from Cooper Chengshan (Shandong) Tyre Company in China, the dynamic simulation has been performed. With the estimation, related policy implications and measures required to realize the sustainable development of tyre manufacturers in China have been also discussed. The author believes that the green innovation is beneficial to resource saving, energy saving and environmental friendly in automobile manufacturing enterprises.*

## 1.INTRODUCTION

With the rapid development of China's economy and the increasing demand of people for cars, China's auto market has made rapid growth in recent years, tyre industry which is closely associated with the automotive industry is also developing rapidly, and play an increasingly important role in the automotive industry. On the other hand, With the continuous development of science and technology, the new compositions with better performance and more environmental protection has been created and applied to tyre manufacturing, the replacement of tyre is becoming faster and faster, from government to consumers all put forward higher and higher requirements on the tyre performance[1].

The green innovation of tyre manufacturing enterprises (hereinafter referred to as tyre enterprises) mainly refers to the research and development for green tyre [2]. In the increasingly severe environmental deterioration, the green tyre has been increasingly favored by consumers. Therefore, producing high-performance green tyre through green innovation has become the inevitable choice of China's tyre industry, and also the only way to strive for market position and win a competitive advantage. Compared to the tyre manufacturers in Europe,America,Japan and other developed countries, the main reason why China's tyre enterprises is in a passive situation in the international market is the disadvantage in green manufacture. And the gap in green growth is widening.

This article is organized as follows: In the next section, green innovation system model of tyre manufacturers and its simulation process based on practice of Cooper Chengshan Enterprise have been analyzed. Then, related measures of green innovation for tyre manufacturers have been discussed. The author believes that the green innovation is beneficial to resource saving, energy saving and environmental friendly in automobile manufacturing enterprises.

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## 2. THE CONSTRUCTION OF GREEN INNOVATION SYSTEM OF TYRE ENTERPRISES

### *2.1 THE DETERMINATION OF SYSTEM BOUNDARY*

Based on the perspective of tyre enterprises, the system model of green innovation in this paper is mainly composed of tyre enterprises decision-making subsystem/market demand subsystem/policy regulation system. Exogenous variables include: the development of social economy/the integral market development of green tyre and ecological environment etc..

Assumptions are as follows: ① During 2008-2025 the domestic economic situation is basically stable and maintain developing momentum, tyre enterprises can continue normal operation, no force majeure occurs; ② All government regulations and policies are effective; ③ Within a certain period of time, The levels of R & D technology accumulation only depend on how much time that has been spent in implementing green innovation; ④ In the green innovation process of tyre enterprises, its marketing channel has maintained smooth and efficient; ⑤ Tyre enterprises only produce a product every year, its performance and price can represent the average performance and price of all product the year; ⑥ Tyre prices are only associated with the tyre performance.

### *2.2 THE CONSTRUCTION OF GREEN INNOVATION SYSTEM*

#### *2.2.1 THE COMPOSITION OF GREEN INNOVATION SYSTEM*

The main participants of tyre enterprise green innovation system are enterprise/market and government, the relationship between the three participants as shown in Figure 1:

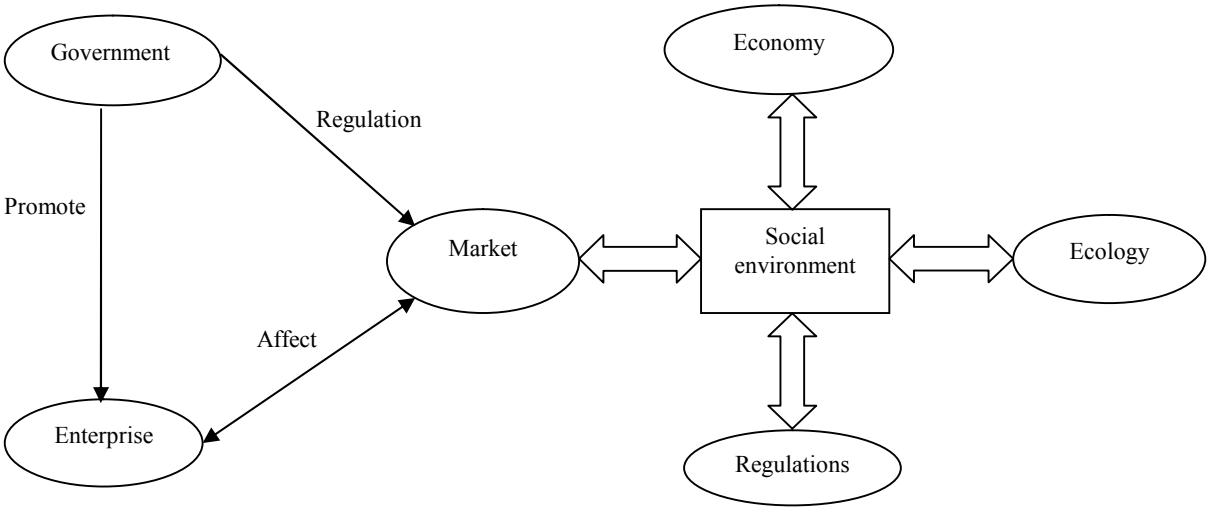


Figure 1. Relationship between the enterprise, government and market.

Tyre enterprise green innovation system is mainly composed of enterprise decision subsystem, market demand subsystem, policy regulation system. Enterprise decision-making subsystem and market demand subsystem act on each other through the relationship of supply and demand;policy regulation system can affect both enterprise decision-making subsystem and market demand subsystem [3].

#### *2.2.2 ANALYSIS OF INFLUENCING FACTORS OF SUBSYSTEM*

The green innovation system of tyre enterprise includes 3 subsystems, as following:

(1) Enterprise decision subsystem: the variables included are enterprise green innovation time (EGIT),enterprise research and development capabilities (ERDC), research funding (RF),expected earnings ratio (EER),etc.,as shown in Table 1.The causality diagram of enterprise decision subsystem has been shown in Figure 2.

(2) Market demand subsystem: the variables included are total growth of green tyres (TGGT), increasing rate of tyre sales (IRTS), enterprise marketing efficiency (EME), etc.,as shown in Table 1.The causality diagram of market demand subsystem has been shown in Figure 3.

(3) Policy regulation subsystem: the variables included are tyre export environment (TEE), green tyre development environment (GTDE), government regulation and control efforts (GRCE), etc,as shown in Table 1.The causality diagram of policy regulation subsystem has been shown in Figure 4.

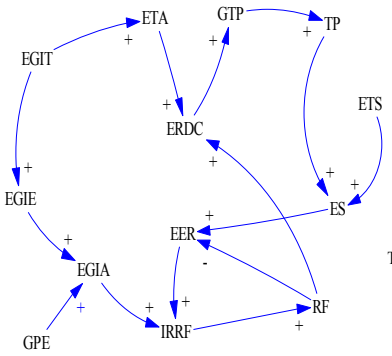


Figure 2. Causality diagram of enterprise decision subsystem.

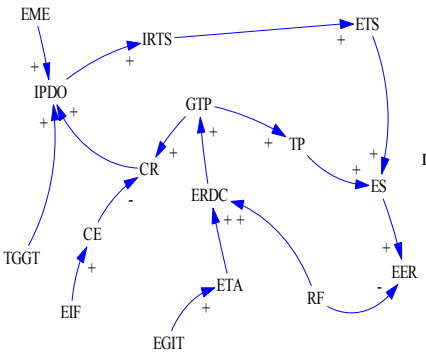


Figure 3. Causality diagram of market demand subsystem.

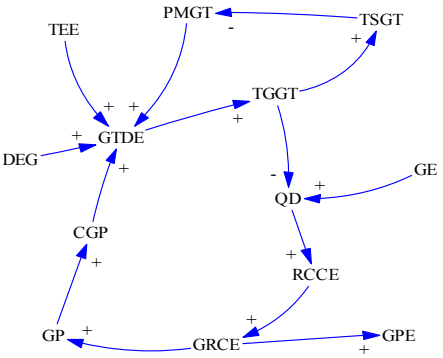


Figure 4. Causality diagram of policy regulation subsystem.

### *2.2.3 THE CONSTRUCTION OF GREEN INNOVATION SYSTEM*

On the basis of the structure of construction of green innovation system, the causality diagram of tyre enterprises green innovation system has been determined, as shown in Figure 5.

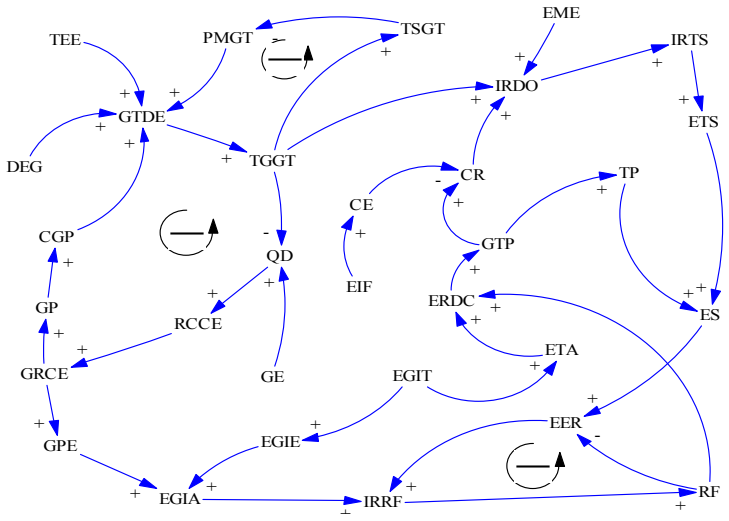


Figure 5. Causality diagram of tyre enterprise green innovation system.

## 3. SIMULATION

### *3.1 THE CONSTRUCTION OF SYSTEM DYNAMICS MODEL*

According to the causality diagram of tyre enterprise green innovation system, the stock and flow diagram of tyre enterprise green innovation system, describing the relationship of delivery, control and feedback in the system, has been illustrated in Figure 6.

### *3.2 SYSTEM SIMULATION*

#### *3.2.1 VARIABLES OF GREEN INNOVATION SYSTEM*

Green innovation system model of tyre enterprises, which includes variables such as state variables, rate variables and auxiliary variables, and constants, has been established. There are 40 variables, including 3 state variables, 3 rate variables, 27 auxiliary variables and 7 constants in the model of system, as illustrated in Table 1.

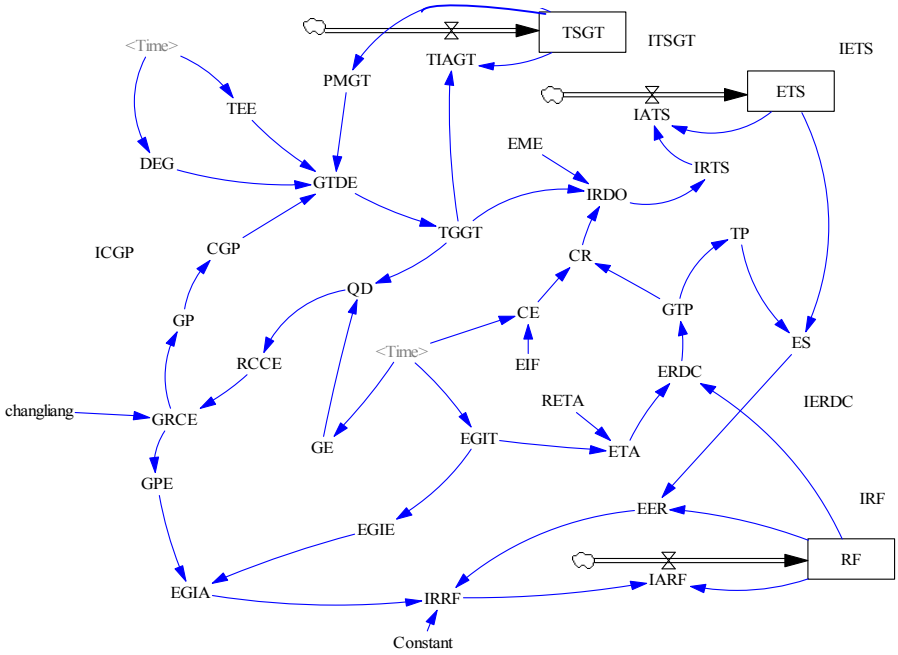


Figure 6. Stock and flow diagram of tyre enterprise green innovation system.

#### *3.2.2 CONSTRUCTION OF EQUATION AND SYSTEM SIMULATION*

According green innovation model and the concrete operation of the enterprise, the relevant equations and parameter values has been determined as follows:

ETA=Constant + Coefficient*EGIT (1)

ERDC=∫ Coefficient*ETA+∫ Coefficient*RF+ IERDC (2)

EGIA=Coefficient*(GPE+EGIE) (3)

EGIE=Constant + Coefficient*EGIT (4)

EGIT=Time□2008 (5)

ETS=∫ IATS+IETS (6)

ES=ETS*TP (7)

CE=Coefficient*[(1□EIF)^(Time□2008)] (8)

CR=Coefficient*□GTP-CE□ (9)

GRCE=Constant + Coefficient*RCCE (10)

GPE=GRCE (11)

QD=GE-TGGT (12)

CGP=∫ Coefficient*GP+ICGP (13)

IARF=Coefficient*EGIA + Coefficient*EER (14)

IARF=IARF*RF (15)

RF=∫ IARF+IRF (16)

EER=ES / RF (17)

GP=Coefficient*GRCE (18)

GTDE=Coefficient*DEG+Coefficient*CGP+Coefficient*PMGT+Coefficient*TEE

TGGT=Coefficient*GTDE (19)

TIAGT=TSGT*TGGT (20)

TSGT=∫ TIAGT+ITSGT (21)

PMGT=Constant□TSGT (22)

RCCE=Coefficient*QD (23)

TP=Coefficient*GTP (24)

GTP=Coefficient*ERDC (25)

IRDO=Coefficient*TGGT +Coefficient*CR (26)

IRTS=IRDO (27)

IATS=ETS*IRTS (28)

DEG [(2008,0.05)-(2025,0.2)],(2008,0.09),(2009,0.092),(2010,0.103),(2011, 0.092), (2012,0.078), (2013,0.075), (2014,0.075),(2015,0.075),(2016,0.075),(2017,0.075),(2018,0.075),(2019,0.075),(2020,0.075),(2021,0.075), (2022,0.075), (2023, 0.075),(2024,0.075),(2025,0.075)] (29)

TEE [(2008,0)-(2025,10)],(2008,8),(2009,9),(2010,6), (2011,4), (2012,3), (2013,4), (2014,5),(2015,6), (2016,7), (2017, 8),(2018,8),(2019,8),(2020,8),(2021,8),(2022,8),(2023,8),(2024,8),(2025,8)] (30)

Where: the variables are illustrated in Table 1.

With an example of Cooper Chengshan Enterprise, the system dynamics simulation software Vensim-PLE has been used to simulate its green innovation activities according to the model in 2008-2025, simulation step is taken as 1 year.

The simulation time is from 2008 to 2025, the time step is set to 1 years (as shown in Figure 7). According to the green innovation system model of tyre enterprise, the initial value of the model and parameter estimation has been determined firstly. Then, the system dynamics simulation software Vensim-PLE has been used to simulate the green innovation activities of Cooper Chengshan Enterprise in 2008-2025. And the simulation results of main variables in the model are as follows.

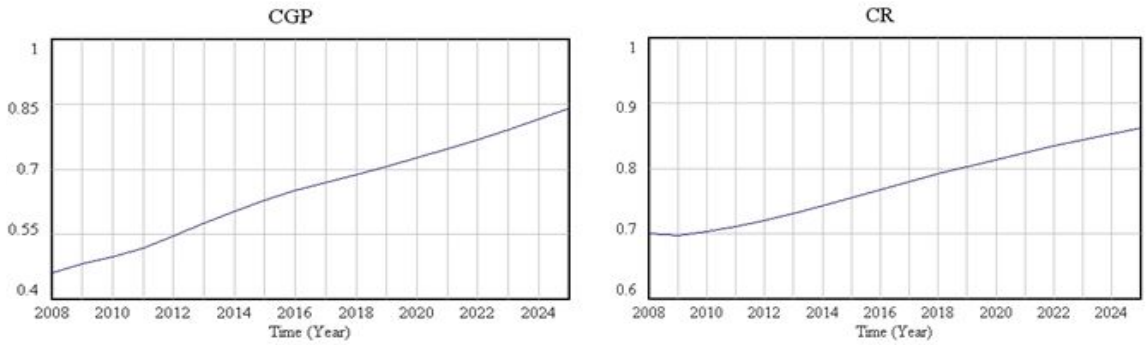


Figure 7. Simulation results of consumer green preferences and green tyre performance customer evaluation in 2008-2025.

As shown in Figure 7, consumer green preferences increases steadily over time, growth rate is relatively stable, its graphic basically likes a straight line; customer evaluation increases steadily over time, which means that customer satisfaction on the quality of tyre is gradually increasing.

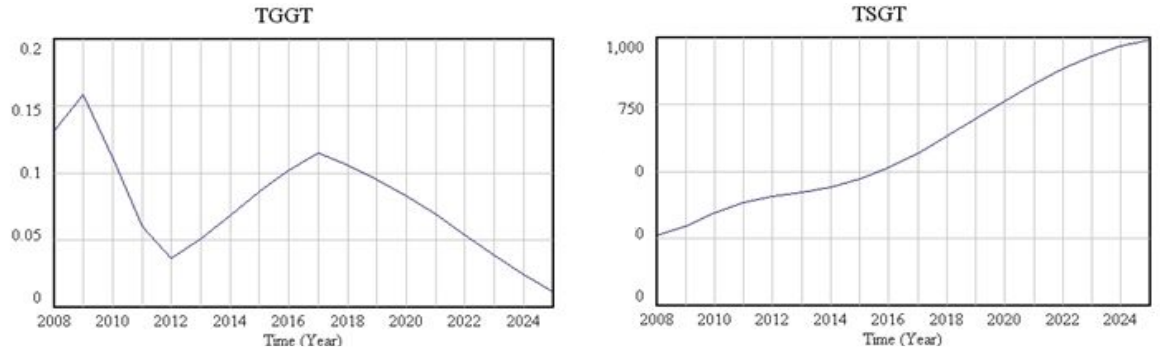


Figure 8. Simulation results of the total growth rate and total sales of green tyre in 2008-2025.

As shown in Figure 8, the graphic of total growth of green tyres waves all the time, it is relatively high in the initial stage, then mainly because the tyre export environment is not good, its value greatly reduces, since the tyre enterprises begin to pay attention to the green innovation, its growth rate begins to rise slowly again; Total sales of green tyre also changes with the total growth rate of green tyre.

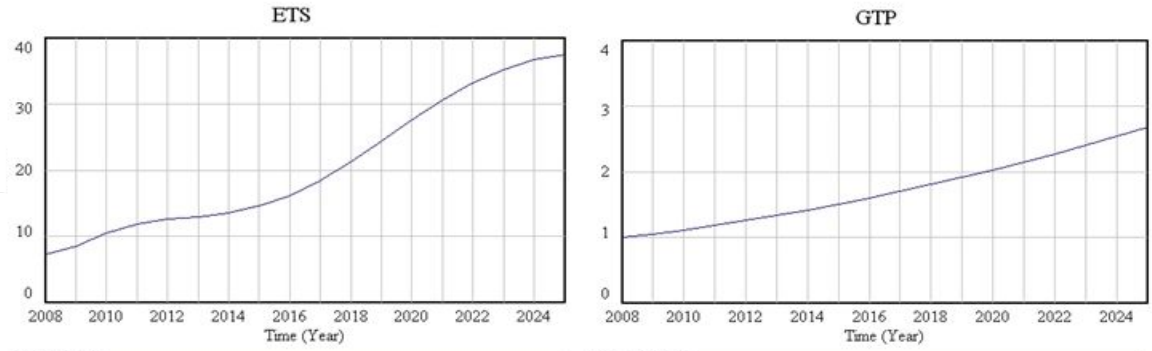


Figure 9. Simulation results of the total sales of enterprise and green tyre performance in 2008-2025.

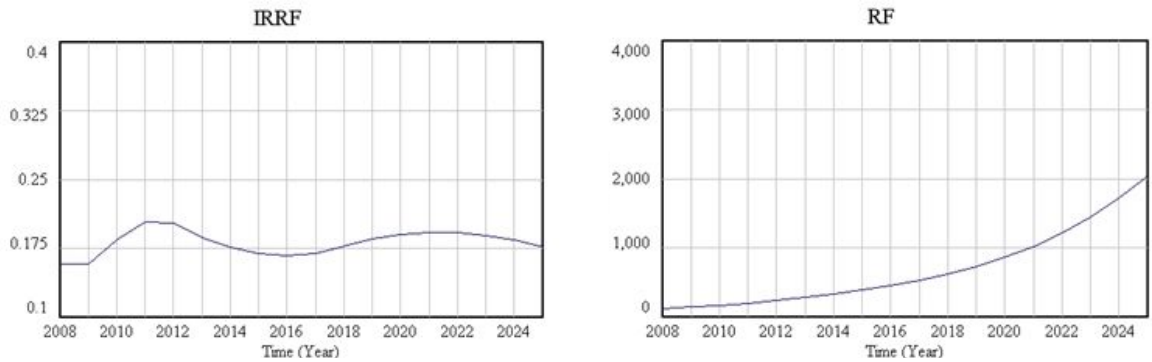


Figure 10. Simulation results of research funding and the increased rate of research funding in 2008-2025.

As shown in Figure 10, the increased rate of research funding waves all the time, but it is basically maintained at 17.5%, which means that the enterprise has maintained a relatively high R & D investment; Research funding has continued to rise since 2008, the rising rate is basically stable.

### *3.3 MODEL CHECKING*

Through the use of Vensim PLE Software, this paper has completed the Unit check and the Reality check of the model, then selects the data of Cooper Chengshan Enterprise in 2008-2012 for history matching, the simulation result is basically consistent with the actual situation, the relative error is 4.8% ~ 10.2%, fitting accuracy of the model is relatively high.

## 4. THE GREEN INNOVATION STRATEGY OF TYRE MANUFACTURERS

### *4.1 STRENGTHEN THE SUPPORT FROM GOVERNMENT POLICY*

Our country should formulate a complete set of laws and regulations and strictly carry out according to the domestic current situation of the development of green tyre. On the one hand, use binding force of laws and regulations to accelerate industrial upgrading, economic restructuring, to realize green, low-carbon, cycle development and improve the quality and efficiency of development; On the other hand, improve the incentive mechanism, and support policies, programs, funds and other areas for green innovation of tyre enterprises according to the actual development situation and problems.

### *4.2 CHANGE THE INNOVATION MODE OF ENTERPRISE*

China’s tyre enterprises lack R & D strength because of generally small scale, therefore, enterprises should actively build green R & D alliances to continuously improve product performance, and also pay attention to the construction of enterprise marketing network, thus enhancing the competitiveness of China's tyre industry in the global tyre industry.

### *4.3 CHANGE THE CONCEPT OF GREEN CONSUMPTION*

Although Chinese consumers have significantly increased consumer awareness of green in recent years, most consumers lack awareness of the green tyre causing the green tyre in the domestic market share is still not high. Therefore, the government should make full use of various media and publicity, and actively promote the popularization of green products and green tyre knowledge.

## 5. CONCLUSION

With green innovation system model of tyre enterprises and simulating, the behavior of green innovation in tyre enterprises based on the theory of dynamical systems has been analyzed. Furthermore, corresponding countermeasures have been taken to promote the green innovation of China tyre enterprises. It is helpful for China's tyre enterprises to innovate their green manufacture system.

## REFERENCES

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**APPENDIX 1:**

Table 1. Variables of green innovation system of tyre manufacturer.

| Serial number | Name | Abbreviation | Property |
|---|---|---|---|
| 1 | Total sales of green tyres | TSGT | State variable |
| 2 | Enterprise tyre sales | ETS | State variable |
| 3 | Research funding | RF | State variable |
| 4 | Total growth of green tyres | TGGT | Rate variable |
| 5 | Increasing rate of tyre sales | IRTS | Rate variable |
| 6 | Increasing rate of dealer order | IRDO | Rate variable |
| 7 | Increasing rate of research funding | IRRF | Rate variable |
| 8 | Enterprise technological accumulation | ETA | Auxiliary variable |
| 9 | Enterprise research and development capabilities | ERDC | Auxiliary variable |
| 10 | Enterprise green innovation awareness | EGIA | Auxiliary variable |
| 11 | Enterprise green innovation environment | EGIE | Auxiliary variable |
| 12 | Enterprise green innovation time | EGIT | Auxiliary variable |
| 13 | Enterprise sales | ES | Auxiliary variable |
| 14 | Domestic economic growth | DEG | Auxiliary variable |
| 15 | Customer expectations | CE | Auxiliary variable |
| 16 | Customer reviews | CR | Auxiliary variable |
| 17 | Government expectations | GE | Auxiliary variable |
| 18 | Government regulation and control efforts | GRCE | Auxiliary variable |
| 19 | Government promotion efforts | GPE | Auxiliary variable |
| 20 | Quantity deviation | QD | Auxiliary variable |
| 21 | Consumer green preference | CGP | Auxiliary variable |
| 22 | Increasing amount of research funding | IARF | Auxiliary variable |
| 23 | Expected Earnings Ratio | EER | Auxiliary variable |
| 24 | Green Propaganda | GP | Auxiliary variable |
| 25 | Green tyre development environment | GTDE | Auxiliary variable |
| 26 | Total increasing amount of green tyre | TIAGT | Auxiliary variable |
| 27 | Potential market for green tyres | PMGT | Auxiliary variable |
| 28 | Regulation and control changing efforts | RCCE | Auxiliary variable |
| 29 | Tyre prices | TP | Auxiliary variable |
| 30 | Tyre export environment | TEE | Auxiliary variable |
| 31 | Green tyre performance | GTP | Auxiliary variable |
| 32 | Increasing amount of tyre sales | IATS | Auxiliary variable |
| 33 | Time | T | Auxiliary variable |
| 34 | Initial value of Enterprise Research and development capabilities | IERDC | Constant |
| 35 | Initial value of enterprise tyre sales | IETS | Constant |
| 36 | Initial value of consumer green preference | ICGP | Constant |
| 37 | Initial value of research funding | IRF | Constant |
| 38 | Initial value of Total sales of green tyres | ITSGT | Constant |
| 39 | Enterprise marketing efficiency | EME | Constant |
| 40 | Expected increasing factor | EIF | Constant |