Verification of Green Reform and Government Policy Decisions of Manufacturing Firms Based on Evolutionary Game

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***Abstract*—The primary concern right now in terms of global green development is cutting carbon emissions. The Chinese government wants to fully decrease carbon peak across by 2030 and to achieve carbon neutrality by 2060. Reducing emissions from industry is a critical issue because it is one of the largest producers of carbon emissions. However, the requirement to lower emissions in the industrial sector will surely cost more, increase costs, and even result in losses, thus an increasing number of businesses are still reluctant to implement reforms. The Chinese government has introduced a number of policies to encourage green growth as much as possible since it recognizes the challenges faced by businesses. Seeing the above problem, we propose in our study the derivation and prediction using an evolutionary game model, which analyzes the degree of influence between multiple variables. Research shows that in the current situation, irrespective of government policy choices, manufacturing companies are opting for green manufacturing is the best way forward. It offers a solid theoretical foundation for government and business decision-making.**

***Keywords*—green manufacturing, evolutionary game, manufacturing development, decision making, carbon neutral**

I. Introduction

As the manufacturing sector has grown rapidly, environmental issues it has caused have progressively risen to the forefront of people's minds. China should be more aware of the environmental issues caused by industry as a major producer. However, some businesses are unable to meet the government's standards as a result of inadequate execution or excessive sunk costs as environmental protection laws increase in severity. The government wants to regulate the manufacturing sector to reduce environmental pollution, but it doesn't want to do so at the expense of manufacturing earnings. The majority of Chinese manufacturers today are also aware of the demand and value of environmental protection. A study by Kubokawa and Saito demonstrates that there are numerous steps that can be performed to enhance the manufacturing sector (Kubokawa *et al.*, 2000).

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Numerous factors affect how corporations adopt government policies in the manufacturing sector. If manufacturing companies alter their procedures, there will be substantial additional expenditures. Environmental legislation might not increase businesses' profitability (Zhou *et al.* 2021). Therefore, we use an evolutionary game model that models the search for balance in the game. The different elements that impact government and business revenue can be balanced by this model.

This paper uses an evolutionary game to examine whether manufacturing enterprises comply with environmental protection rules and regulations and the relationship between the gains and losses experienced by both sides. Some studies that employ numerous data analyses to address these issues have some limitations, however, that are significantly impacted by things like limited data. Evolutionary games continue to offer us a good solution. In Section 2, we will undertake a literature review to determine the challenges governments and businesses have in adopting green development and to pinpoint the most important variables influencing business decisions and governmental regulations. A theoretical foundation for our variable selection is also provided by the analysis of various articles. Evolutionary games are also used in numerous decision-making processes. As a result, in Section 3, we develop and offer logical answers for a number of significant influencing elements using the evolutionary game model. The study's conclusions are presented in the final section, along with the parties' choices of actions, and its inadequacies are examined.

II. Literature Review

An evolutionary game theory approach is used to examine the interaction between government incentives, fines, and the synergistic emission reduction benefits for businesses participating in green supply chains (Liu *et al.* 2022). Businesses benefit from improved reputations when the government asks green suppliers to embrace new environmental rules. Government policy subsidies and incentives can also benefit new energy companies, while on the other side, these intangible reputational gains frequently translate into real financial gains (Cheng

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et al. 2022). A sustainable supplier development program also aids in boosting client satisfaction for the business, which boosts sales performance even more (Fan *et al.*, 2021). The country's improved environmental reputation has had a major and positive impact on worldwide import and export trade, and governments have gained good reputation points as a result of important environmental accomplishments (Fan *et al.* 2021, Zhang *et al.*, 2021). However, the implementation of new environmental policies will eventually result in increased financial costs for governments and businesses. When developing a green city, the government spends much more on labor and cleaning supplies, and businesses increase manufacturing costs when engaging in green production and processing (Yan *et al.*, 2021, Ramon *et al.*, 2021).

In order to save money, many companies often do not fully implement green programs or are unable to carry out environmental measures due to their industrial structure, which then results in environmental taxes or pollution fines (Du *et al.*, 2020). As a result, when the government implements environmental rules, companies must decide whether they should pay penalties, pay taxes or invest in new technologies, environmental equipment and other capital expenditures (Lyu *et al.*, 2022). When enacting rules, the government can frequently generate income via corporate environmental taxes and fines for company infractions of environmental laws (Shen *et al.*, 2022). However, when businesses voluntarily adopt green production objectives without reference to any government environmental control rules, they frequently experience significant positive reputation gains and are exempt from paying fines, even though they must incur higher disposal costs. In contrast, the government suffers significant negative reputation revenue losses (Li *et al.*, 2021). Companies can frequently save a significant amount on disposal costs by forgoing energy-saving production at this time, but their reputation may suffer as a result (Cooper *et al.*, 2018). It tends to decrease investment and import/export trade for the nation or region when both the government's and the company's reputations are severely impacted. In order to make decisions, businesses frequently need to consider the advantages and disadvantages (Xie and Wu, 2021; Ramandi and Bafruei, 2020). One study also examined the impact of government policies in Thailand and found that government policy solutions in the steel sector have had a broad driving effect on steel recycling manufacturing companies (Amirhossein *et al.*, 2022). Both altruistic preferences and government subsidies are crucial in manufacturing recycling systems, and in AP improving eco-design to make systems greener comes at the cost of lost profits for manufacturers, which needs to be supported by government subsidies (Siqi *et al.*, 2022). Some papers examined specific subsidies to maximize their incentive effect on companies, while considering the crowding-out effect of government subsidies on business investment in innovation (Zhanchi *et al.*, 2022).

Next, we will use the pertinent models to justify the aforementioned concepts in order to make them easier to understand.

III. MODEL

Based on the aforementioned literature review we provide an example of how the strategic decisions made by businesses and governments affect the advantages in the context of reality. In order to encourage green manufacturing, the government offers tax benefits, but in the context of the energy transition, businesses can gain market share by being green and cutting back on harmful emissions (Liu *et al.*, 2021). Tax subsidies and other financial incentives can also help to encourage the execution of policy (Zhao *et al.*, 2016). From this, we construct a straightforward two-sided game matrix with the parameters shown below, with the variables x and y standing for the chance of selecting a strategy to identify the evolutionary stable strategy (ESS).

Our final choice of parameters is shown in Table I. A variety of factors were considered when selecting parameters. According to the previous literature review, we can see that the government has a certain role to play in encouraging manufacturing companies to undertake green development. In many cases, the government's strategic direction can determine whether a business is undertaking green manufacturing or not. What we can ascertain is that the development of enterprises, which must be revenue-oriented, will incur many additional costs in green manufacturing reforms and there may also be trial and error costs for new products. In all cases, companies also have to weigh up the increased revenue and the intangible reputation etc. that comes with green manufacturing. We have drawn on a wide range of literature and have thus chosen to look at the areas of revenue, reputation, additional production costs, income, etc., which have a greater impact on governments and companies.

TABLE I. SYMBOL DESCRIPTION

Symbols	Description
RB	Corporate revenue
RG	Government Benefits
r	Reputation gains
ci	Additional production costs
t	Additional taxes
e	Policies to bring foreign trade
f	Fines
a	government subsidies

TABLE II. GAME STRATEGY MATRIX OF STAKEHOLDERS

		Enterprise	
		Green manufacturing(x)	Traditional manufacturing($1-x$)
Government	green policies(y)	$(RB+r-ci+a,\ RG-t+e)$	$(RB-f, RG+f)$
	no green policies($1-y$)	$(RB+r-ci, RG-r)$	(RB, RG)

At Table II, the government and the enterprise both have two options, and since neither side knows which options the other will choose, we can infer the following

conclusion based on the information presented above. The gain for the company is x when it chooses green manufacturing; the gain for the company is (1-x) when it chooses traditional manufacturing. Likewise, when the government decides to pursue green policies, its advantage is y; when it decides against adopting green policies, its gain is (1-y). Following the aforementioned, we arrive to the equation.

$$UB1 = y(RB + r - ci + a) + (1-y)(RB + r - ci) \quad (1)$$

$$UB2 = y(RB - f) + (1-y)(RB) \quad (2)$$

$$UG1 = x(RG - t + e) + (1-x)(RG + f) \quad (3)$$

$$UG2 = x(RG - r) + (1-x)RG \quad (4)$$

We then derive the replicator dynamic equations from Eq. (1)–(4)

$$f(x) = \frac{dx}{dt} = x(1-x)\left[y(a+f) + r - ci\right] \quad (5)$$

$$f(y) = \frac{dy}{dt} = y(1-y)\left[x(r - t + e) + f(1-x)\right] \quad (6)$$

Solve for 5 points as (0,0) (0,1) (1,1) (1,0) $(\frac{f}{t-r-e+f}, \frac{ci-r}{a+f})$ and find the Jacobian matrix according to Eq. (5) and (6).

$$J = \begin{bmatrix} -x\left[r - ci + y(a+f)\right] - \\ (x-1)\left[r - ci + y(a+f)\right] & -x(a+f)(x-1) \\ -y(y-1)(e-f+r-t) & (y-1)\left[f(x-1) - x(e+r-t)\right] \\ & +y\left[f(x-1) - x(e+r-t)\right] \end{bmatrix} \quad (7)$$

TABLE III. CALCULATE RESULTS OF EVOLUTIONARY GAMES BETWEEN ENTERPRISE AND GOVERNMENT

Point	det J	tr J
(0,0)	$f(r-ci)$	$r-ci$
(0,1)	$-f$	$a-ci+f+r$
(1,1)	$t-r-e$	$ci-a-f-r$
(1,0)	$(ci-r)(e+r-t)$	$ci-r$
(x*,y*)	$\frac{-\left[f\left(\frac{f}{e-f+r-t}+1\right)-\frac{f(e+r-t)}{e-f+r-t}\right](ci-r)}{a+f} - f\left(\frac{f}{e-f+r-t}+1\right)(ci-r)\left(\frac{ci-r}{a+f}-1\right)$	$-\frac{f(a+f)\left(\frac{f}{e-f+r-t}+1\right)}{e-f+r-t}$

We substituted each of the five points into the Jacobi matrix and obtained the results shown in Table III

The parameters are scaled correctly using current policies, the literature review in Section II, and analysis to provide the results shown below.

TABLE IV. LOCAL STABILITY ANALYSIS RESULTS OF EVOLUTIONARY GAMES BETWEEN ENTERPRISE AND GOVERNMENT

Point	det J	tr J	Stability
(0,0)	+	+	Unstable point
(0,1)	-	-	Unstable point
(1,1)	+	-	ESS
(1,0)	+	-	ESS
(x*,y*)	-	+	Saddle point

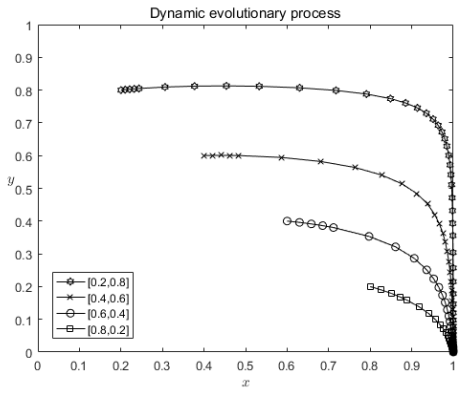

Figure 1. Dynamic evolutionary process

We can infer from Table IV and Fig. 1, that the evolutionary stable strategy (ESS) point is (1,1) (1,0). This demonstrates that companies will always select green production, regardless of what the government does. Along with lowering the cost and increasing influence, this will also considerably improve the government's reputation. It is true that adopting green policies has many drawbacks for governments, which can result in significant cost increases, and that it is not always the best option just in terms of the benefits. Though it is not clear from the benefits alone, it is also a means to fulfill the expanding energy needs of various regions, lower global energy consumption from an international standpoint (Khan *et al.*, 2022), and also boost the nation's influence in the globe. As a result, we think that enterprises should unquestionably pick green production. The government should adopt a higher viewpoint and forgo a certain amount of monetary gain in order to obtain greater intangible benefits.

IV. CONCLUSION

With a focus on the influence and significance of policy changes on corporate green manufacturing, our study primarily examines the game situation between governmental green policies and enterprise green manufacturing through an evolutionary game model. Governments are currently faced with a dilemma, and it is particularly difficult to balance business revenues with green environmental development. Our research is to

some extent helping companies and the government to analyze the impact of the benefits of the decision. It provides a theoretical basis in the decision-making choices of both sides, and also validates the rationality of China's future orientation in the continued promotion of green manufacturing.

By evolutionary game model in comparison to the prior circumstance, we draw the following conclusion.

1. The government can urge enterprises to implement green manufacturing. By supporting green manufacturing enterprises to a certain extent with policies that can make the green economy flourish, there is a very far-reaching impact.

2. Through model calculations, we can learn that appropriate green policies make it inevitable for companies to choose green manufacturing. This can help the government gain a better national and international reputation in terms of environmental protection in addition to lowering costs and increasing influence to some extent. The benefits alone do not fully measure this.

3. Through the evolutionary game of various green policies, so that as businesses balance the benefits and drawbacks, they increasingly choose to green production. Our study of the changing dynamics between manufacturing companies and the government's environmental strategy is important because it will help establish a green economy, normalize green manufacturing, and provide the groundwork for future carbon neutrality objectives.

Finally, this study demonstrates the necessity of governmental policies in addition to provide a basis for enterprises to select their strategies. However, there are some restrictions in some special cases because of the few variables that are taken into account in our evolutionary game model. For instance, it is impossible to precisely estimate the costs and benefits of both parties, and some of the information mentioned in the Section 2 maybe influence the decision between different game equilibria. These elements necessitate the inevitable defect in our evolutionary game model. Additionally, we also have a small sample size. However, we will keep expanding the sample size of the experiment, improving the model, and maximize the usability of the results.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Shengan Yu conducted the research and calculate the data. Hang Zhou collate the literature review, analysis the influence factors. Kai Wu collated this research, analysis the development.

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