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Tripartite Collaboration among Government, Digital Technology Platform, and Manufacturing Enterprises: Evolutionary Game Model

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Abstract: To solve the problems of economic growth and environmental pollution in China, it is crucial for local governments, as the responsible body for environmental protection, to rely on digital technology platforms to promote the green transformation of manufacturing industries, which is conducive to achieving sustainable social development. This study constructs a tripartite evolutionary game model and simulates and analyzes the influencing factors of manufacturing enterprises, the government and digital technology platforms. The study found that the critical value of the government subsidies for manufacturing enterprises using digital technology platforms is between 0.2 and 0.5. Manufacturing enterprises as "economic agents" should ensure their own profits and the good operation of their business when using digital technology platforms for green upgrading. The government penalties can improve enterprises' green productivity as tested. This study enriches the research in the field of combining game theory and digital economy. It provides a theoretical reference for behavioral decisions of manufacturing enterprises, the government and digital technology platforms.

Keywords: the digital economy; environmental; green upgrading of manufacturing; evolutionary game model

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1. Introduction

1.1. Background

According to the China Digital Economy Development Report (2022), the scale of China's digital economy reached 45.5 trillion yuan in 2021, accounting for 39.8% of GDP. The scale of the digital economy is expanding, the market demand is expanding, and the contribution to economic growth is increasing. The development of the digital economy will be conducive to promoting industrial structure upgrading, narrowing the gap with developed countries, and seizing the high ground of global economic development [1,2]. China's overall energy consumption increased by 2.9% from 2021 to 2022, reaching 5.4 billion tons of standard coal [3]. China has set a target of reaching peak carbon by 2030 and becoming carbon neutral by 2060 to fight global warming [4,5]. In the face of increasingly serious environmental problems, using the digital economy to encourage greener manufacturing has emerged as a key strategy for solving this issue [6]. Su et al. [7] found that the modernization of the industrial structure is positively impacted by the growth of the digital economy and technological innovation. Kan et al. [8] considered that the digital economy, which supports the modernization of the country's service sector's worldwide value chain against the backdrop of the global economic downturn, is reviving China's economy and providing it new life. Fu [9] argued that there are three effects of digital technology on the upgrading of the manufacturing industry: innovation, resource allocation, and penetration. China must quicken the deep integration of digital technology and manufacturing to move up to the middle and top of the global value chain. Zhao et al. [10] found that the development of China's cities' human capital and technological advancement was considerably aided by the digital economy, which also aided the development of the country's industrial structure. China has established environmental rules and other measures to decrease environmental pollution from the industrial output to attain the goals of carbon peaking and carbon neutrality [11,12].

As an important part of the resource-processing manufacturing industry, petrochemicals hugely impact economic development [13]. The challenging situation of further tightening the environmental restrictions facing the petrochemical industry, the deep integration of digital technology and business, and the application of digital and intelligent technology to remove bottlenecks in enterprise development have all emerged as significant trends in the growth of the petrochemical industry [14]. As a large global oil and gas enterprise, China National Petroleum Corporation (CNPC) has been innovating cloud technology architecture and integrated solutions for the oil and gas business in recent years, actively building and developing a "Dream Cloud" digital technology platform with the core of the digital twin PaaS platform and cross-platform asset lifecycle data management (ALIM) platform. It has strongly promoted the digital transformation and intelligent development of the oil and gas business. For example, the "Dream Cloud" fault prediction technology, Oriental Exploration, is applied in the complex fault block area of the eastern oilfield, and the prediction accuracy is significantly improved. The traditional practice takes 30 min, and AI technology only takes 10 min. "Reduce more than 40% of personnel input, reduce more than 40% of the workload [15]".

With the accelerated pace of green upgrading in manufacturing, the topic of manufacturing upgrading has attracted much attention from scholars at home and abroad. China has a large regional disparity, and implementing different environmental regulations aligns with China's national conditions [16–21]. Enterprise pressure, social environment, and government policies [22] will affect the transformation of manufacturing. Bigerna et al. [23], Jung et al. [24], Gu et al. [25], and some other scholars have focused on optimal government subsidies. Yang et al. [26] constructed a game model based on a management system consisting of the government and two enterprises that produce green products and compete with each other to discover the optimal amount of government subsidies. By constructing an evolutionary game model between manufacturers and remanufacturers, Zhang et al. [27] investigated the optimal subsidy that could lead the system to the ideal state.

The green modernization of the manufacturing sector is now being driven by, supported by, and sourced from the digital economy. Big data, artificial intelligence, the Internet of Things, and other information technologies are being integrated and used by the manufacturing sector, resulting in the development of new technologies, industries, and models for the manufacturing sector in the modern day [28–30]. Kim [31] and Del Giudice [32] claimed that the industrial sector's transition and modernization had been considerably aided by the digital economy with data serving as a crucial output for this transformation. Caputo et al. [33] demonstrated through their study that the rapid development of IoT technologies can also drive manufacturing transformation and upgrading.

The main insights of our research are summarized below.

(1) The government, as an independent object, is added to the model, providing a new perspective for studying the digital economy and the green upgrading of manufacturing enterprises.

(2) With the development of the digital economy, it is difficult to measure digital technology indicators in the process of green upgrading of enterprises, which can be overcome by the evolutionary game model

(3) Through numerical simulations, the effects of the government subsidies, penalties and revenues generated by manufacturing enterprises using digital economy platforms on the evolutionary stability strategy of the system are studied.

1.2. Paper Organization

With the introduction and background of this study already discussed in Section 1, the rest of this study is structured as follows: Section 2—Literature Review; Section 3—Description of the problem and assumptions of the model; Section 4—Evolutionary model analysis of digital technology platforms affecting green upgrading in manufacturing under government regulation; Section 5—Simulation analysis; Section 6—Discussion; Section 7—Conclusions; Section 8—Policy Implications and Limitations.

2. Literature Review

The research related to this paper can be divided into two categories: the first category is environmental regulation and the digital economy; and the second category is the research on the green upgrading of manufacturing enterprises by the digital economy.

2.1. Environmental Regulation and the Digital Economy

The growth of the digital economy is accelerating society's digitalization and presenting businesses with a wealth of new business options. Bukht and Heeks [34] stated that the IT/ICT sector, which creates fundamental digital goods and services, is the foundation of the digital economy. Evangelista et al. [35] discovered that the deployment of digital technologies may effectively improve the efficiency of economic activities and raise the competitiveness of firms, contributing to economic growth.

Relying on the digital economy to assist in improving environmental quality has become a crucial strategy as environmental pollution has become one of the top worries among the general population. Wen et al. [36] discovered that the usage of digital economy technologies could deliver useful information for governmental regulation and can make it easier to apply environmental legislation and upgrade enterprises to be more environmentally friendly. Liu et al. [37] found that by studying data from 286 cities from 2011–2019, the digital economy can improve environmental production efficiency and promote green economic growth. Xiang et al. [38] discovered that the growth of the digital economy can greatly reduce the output of pollutants, demonstrating a "green effect." In the analysis of many industry sectors, the growth of big data, green sustainable development, and information technology all work to advance and transform the industrial structure. Wang et al. [39] reviewed the incentives that governments can employ to encourage businesses to invest in green technologies for sustainable economic development through innovation and investment. Zhao et al. [40] analyzed that the digital economy has a positive, moderating effect on the process of environmental regulation that affects the development of green technology.

2.2. Research on Green Upgrading of the Manufacturing Industry by the Digital Economy

The effects of the digital economy style on the transformation and growth of manufacturing firms have been extensively researched. The challenge has been how to use the digital economy to support the green transformation of the manufacturing sector.

The digital economy has no fundamental meaning in academia. From the perspective of core components, Bukht and Heeks [34] believes that digital technology is the main component of the digital economy. The digital economy is crucial for the green upgrading of manufacturing firms, from the growth of the digital technology economy to digital technology applications. With the advancement of information technology and the subsequent global technological revolution, new paradigms transcend the "first information sector" and the "second information sector", and thus the concept of the digital economy was born, as proposed by Bowman [41]. The growth of the digital economy offers crucial technology assistance for the creation of new products [42], numerical control over production [43], administration of the manufacturing process, and enterprise collaboration. Sturgeon [44] and Chryssolouris et al. [45] point out that with the digital economy as a background, digital manufacturing has become a very promising set of technologies to reduce product development time and cost, meet customization needs, improve product quality, and respond to the market faster. Wang [46] stated that digital manufacturing enables computers and related technologies to control the entire production process. Kim et al. [47] suggested that the impact of the digital economy on manufacturing can be better illustrated in "Industry 4.0", where digitalization can reshape manufacturing into a highly interconnected yet complex dynamic system. Kurfess et al. [48] argued that the digital economy provides powerful tools for industrial development to create leaner, more profitable, and data-driven manufacturing processes.

2.3. Motivations and Contributions

Table 1 compares with recent major studies. The main contributions to the literature on the green upgrading of manufacturing enterprises of this paper are as follows:

Table 1. Comparisons with main recent research.

Paper	Government Subsidy	Government Penalty	Manufacturing Enterprises	Digital Economy	Model Type
Jung et al. [24]	√		√		Supply chain
Gu et al. [25]	√		√		Supply chain
Yang et al. [26]	√		√		Evolutionary game
Wen et al. [36]		√		√	Empirical analysis
Wang et al. [39]	√		√		Empirical analysis
Zhao et al. [40]		√		√	Empirical analysis
Kim et al. [47]			√	√	Empirical analysis
Yang et al. [49]		√		√	Evolutionary game
Gao et al. [50]			√	√	Evolutionary game
Mondal et al. [51]			√		Supply chain
Our paper	√	√	√	√	Evolutionary game

Firstly, this paper considers the effects of government subsidies and penalties, analyzes the dynamic change process of strategic choices of each game subject and the evolutionary stability of the system under different values, and verifies the validity of the evolutionary stability analysis by parameter assignment. Additionally, it provides theoretical references for the future development of manufacturing enterprises, the government and digital technology platforms.

Secondly, the research on the relationship between the digital economy and enterprise green upgrading started late and mostly focused on theoretical studies. This paper adds the government as an independent party of the game into the model, which provides a new perspective for studying the digital economy and the green upgrading of manufacturing enterprises. It makes up for the shortage of relevant theoretical studies.

Lastly, by adding the government as an independent individual to the evolutionary model, it provides better suggestions for formulating the government's future policy strategy to support the green transformation of enterprises by analyzing the subsidies and penalties of government supplementation.

3. Description of the Problem and Assumptions of the Model

The evolutionary game model between "manufacturing enterprises and government digital technology platforms" is constructed to study the influence of behavioral interactions among three game subjects and examine the evolutionary steady state of the system in various situations and the key variables that influence this state. The tripartite evolutionary game model described in this research is based on the traditional evolutionary game mode. Game theory is a classical theory used to study strategic conflict and rivalry among stakeholders or the choice of strategy in the face of a situation. Evolutionary game models commonly use differential equations to describe the evolution of strategies and are deterministic evolutionary models. Since differential equations are mathematically analytic in nature, replicating dynamic equations is one of the most commonly used decision mechanisms in evolutionary games [52]. Therefore, the model in this paper refers to the approach of Samuelson. The basic assumptions and structure are described below [53]. Figure 1 shows the relationship between each game subject.

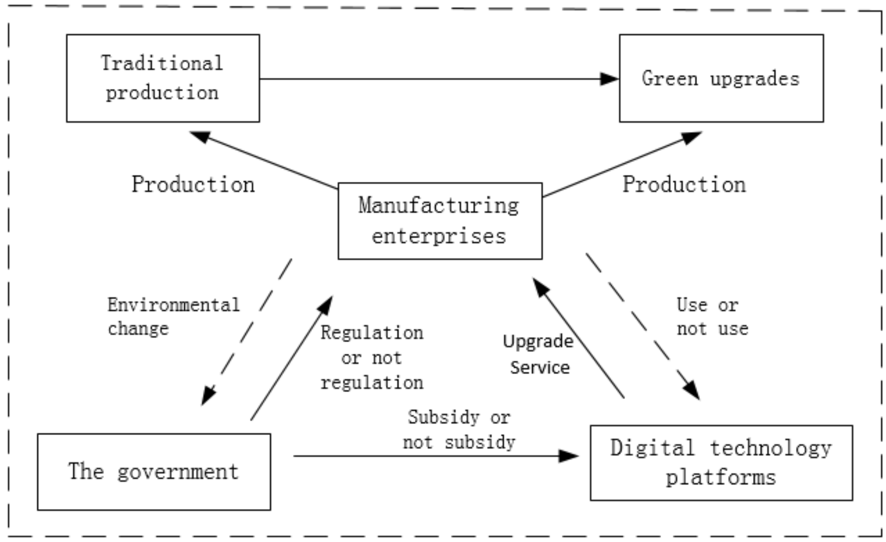

Figure 1. Strategic relationship of each game subject.

Hypothesis 1. *Manufacturing enterprises as the main body of production: in the process of enterprises operating the digital technology platform strategy that include "use" and "not use", respectively, their probability becomes x and $1 - x$ ($0 \leq x \leq 1$). When manufacturing enterprises use optimization services on digital platforms, their service improves and leads to an increase in revenue. The government benefits from environmental changes due to the manufacturing enterprises' upgrades, and digital technology platforms providing such upgrade services gain an increase in revenue as a result of the manufacturing enterprises' use of the process.*

Hypothesis 2. *Local governments are responsible for environmental protection; the government can make incentive and penalty policies in the process of environmental governance according to the actual needs. Government "regulation" strategy and "no regulation" strategy are y and $1 - y$ ($0 \leq y \leq 1$). In the process of the government regulating manufacturing enterprises, subsidies and incentive measures can be provided to enterprises that "use" digital technology platforms to enhance their services and transformation. For enterprises that do "not use" the platforms, the government can punish them through government regulations. Notwithstanding, manufacturing enterprises that "use" a digital technology platform for their upgrading will bring environmental change benefits to the government.*

Hypothesis 3. *The "upgrade services" strategy and "no upgrade services" strategy of the digital technology platform are z and $1 - z$ ($0 \leq z \leq 1$), respectively. In the process of upgrading the service of the digital technology platform, the government will subsidize the platform to promote enterprise R&D, and the government will benefit. These benefits include economic and social gains.*

Hypothesis 4. *The government, manufacturing enterprises and digital technology platforms are all finite rationals in the evolutionary game model. Meanwhile, these three players are randomly matched and are repeated games.*

Hypothesis 5. *In the tripartite evolutionary model, the basis net incomes of manufacturing enterprises before green upgrades are denoted π_2. Basis net incomes of the manufacturing enterprises, the government, and digital technology platforms green upgrades are represented as π_1, π_3, and π_4, respectively. π_5 denotes the manufacturing enterprises using the upgrade of service digital technology platforms to increase the income, π_6 means digital technology platforms increase the income, π_7 is potential benefits for the government, and π_8 is environmental change benefits. c_1*

represents the costs of manufacturing enterprises for green upgrades, while c_2 represents the cost of manufacturing enterprises without the upgrades. Moreover, c_3 and c_4 express the cost of the government to regulation and management. c_5 denotes the costs of digital technology platforms. s_1 and s_2 denote the government subsidies for manufacturing enterprises and digital technology platforms. Meanwhile, government penalties are denoted as g_1, and opportunity costs of the manufacturing enterprises are g_2. The sources of gains for each stakeholder in the green upgrade are shown in Table 2.

Table 2. Major parameters in the evolutionary game.

Parameters	Definition
x	Manufacturing enterprises choose the strategy of using [54]
y	The government chooses the strategy of regulation [55]
z	Digital technology platforms choose the strategy to upgrade services [56]
π_1	Benefits gained by manufacturing enterprises using digital technology platforms [54]
π_2	Benefits obtained by manufacturing enterprises not using digital technology platforms [55]
π_3	Potential benefits to the government from manufacturing enterprises using digital platforms for green upgrades [56]
π_4	The profit of green upgrading of digital technology platforms [56]
π_5	Manufacturing enterprises use the upgrade of service digital technology platforms for green upgrades to increase income [26]
π_6	After manufacturing enterprises use the digital technology platform, digital technology platforms increase income
π_7	Potential economic and social benefits to the government after the government subsidizes the digital economy platform to upgrade services.
π_8	Under government regulation, manufacturing enterprises use a digital technology platform to bring environmental change benefits to the government
c_1	The cost of equipment and technology for manufacturing enterprises to adopt digital platforms [54]
c_2	Costs to be paid by manufacturing enterprises not using digital technology platforms [55]
c_3	Costs incurred in government regulation of manufacturing enterprises [56]
c_4	The cost of environmental management that the government has to pay when not using digital technology platforms
c_5	Costs incurred for services provided by digital technology platforms
s_1	The government subsidies for manufacturing enterprises using digital technology platforms [56]
s_2	Digital technology platforms receive government subsidies [54]
g_1	Government penalties for not using digital technology platforms [54]
g_2	Opportunity costs incurred by manufacturing enterprises not participating in digital platforms [54]

4. Evolutionary Model Analysis

4.1. Building the Game Model Involving Stakeholders

4.1.1. Scenario with Regulation

Manufacturing enterprises expected payoffs. When manufacturing enterprises choose the “use” strategy, while digital technology platforms choose the “upgrade services” strategy, manufacturing enterprises will receive the benefits gained from using the digital technology platforms π_1, plus increased revenue from using digital platforms that upgrade services to the green upgrade π_5 and the subsidies provided by the government s_1, minus the cost of equipment and technology that manufacturing enterprises have to pay to adopt the digital platforms c_1, means their expected payoffs are equal to $\pi_1 - c_1 + s_1 + \pi_5$. If the digital technology platforms choose the “not upgrade services” strategy and manufacturing enterprises still choose the “use” strategy, then their expected payoffs are equal to $\pi_1 - c_1 + s_1$ when manufacturing enterprises choose the “not use” strategy and digital technology platforms choose the “upgrades services” strategy. Manufacturing enterprises not using digital technology platforms gain π_2, and subsequently, they will pay the cost of not using digital technology platforms c_2, and suffer government fines g_1. Manufacturing enterprises choosing the "not use" strategy in the digital platforms incur opportunity costs g_2, so their expected return is equal to $\pi_2 - c_2 - g_1 - g_2$. The digital technology platforms choosing the "not upgrade services" strategy result in manufacturing enterprises not incurring opportunity costs, and therefore their expected returns are equal to $\pi_2 - c_2 - g_1$.

The government expected payoffs when manufacturing enterprises choose the "use" strategy, while digital technology platforms choose the "upgrade service" strategy. Benefits obtained by manufacturing enterprises not using digital technology platforms π_3, minus the government's management cost c_3, minus the government's subsidy s_1, minus the digital technology platforms to the manufacturing enterprises using these platforms in order to obtain government subsidies s_2, plus potential revenue for the government after the government subsidizes enterprises that upgrade services for digital technology platforms π_7, plus under government regulation, manufacturing enterprises using a digital technology platform to bring environmental change benefits to the government π_8, means their expected return is equal to $\pi_3 - c_3 - s_1 - s_2 + \pi_7 + \pi_8$. If the digital technology platforms choose the "not upgrade services" strategy, the government will not have s_2 generated, so their expected return is equal to $\pi_3 - c_3 - s_1$. When manufacturing enterprises choose a "not use" strategy, this means they rely on not using digital technology platforms. Then, the government in the development of policy and management costs c_3, the government not using digital technology platforms' enterprises that need to pay the cost of environmental management c_4 and will generate digital technology platforms to obtain the government subsidies s_2, plus government-imposed penalties on enterprises not using digital technology platforms, plus potential revenue for the government π_7, means their expected return is equal to $-c_3 - c_4 + g_1 - s_2 + \pi_7$. If the digital technology platforms choose the "not upgrade services", the government will not have subsidies s_2; at this time, their return will be equal to $-c_3 - c_4 + g_1$.

Digital technology platforms expected payoffs when manufacturing enterprises choose the "use" strategy, while digital technology platforms choose the "upgrades services" strategy. The benefits generated by the use of the digital technology platforms π_4, plus the digital technology platforms to obtain government subsidies s_2, minus the costs incurred by the digital technology platforms to provide services c_5, plus digital technology platforms that increase income π_6, are expected to yield a return equal to $s_2 + \pi_4 - c_5 + \pi_6$. If the system's digital technology platforms choose the "not upgrade services" strategy, their expected return equals 0. When manufacturing enterprises choose the "not use" strategy, and digital technology platforms choose the "service upgrades" strategy, then their expected return equals $s_2 + \pi_4 - c_5$. If the digital technology platforms choose the "not upgrade services" strategy, their expected return equals 0.

4.1.2. Scenario without Regulation

Manufacturing enterprises expected payoffs. When manufacturing enterprises choose the "use" strategy, while digital technology platforms choose the "upgrade services" strategy, their expected return is equal to $\pi_1 - c_1 + \pi_5$. If the digital system platforms have the "not service upgrade", and manufacturing enterprises choose the "use" strategy, their expected return is $\pi_1 - c_1$. The expected return when manufacturing enterprises choose the "not use" strategy and the digital technology platforms choose the "upgrade services" or "not upgrade services" strategy, equals $\pi_2 - c_2 - g_2$ and $\pi_2 - c_2$, respectively.

The government expected payoffs. When manufacturing enterprises choose the "use" strategy, and the digital technology platforms choose the "upgrade service" or "not upgrade service" strategy, their expected return equals $\pi_3 - s_2 + \pi_7$ and π_3, respectively. When manufacturing enterprises choose the "not use" strategy, and the digital technology platforms choose the "no upgrade service" or "not upgrade service" strategy, their expected return equals $-c_4 - s_2 + \pi_7$ and $-c_4$, respectively.

Digital technology platforms expected payoffs. When manufacturing enterprises choose the "use" strategy, while digital technology platforms choose the "upgrade services" or "not upgrade services" strategy, their expected return are equal to $s_2 + \pi_4 - c_5 + \pi_6$ and 0, respectively. Their expected return when the manufacturing enterprises choose the "not use" strategy and the digital technology platforms choose the "upgrades services" or "not upgrade services" strategy, equals $s_2 + \pi_4 - c_5$ and 0, respectively.

Presenting the underlying presumptions of the stakeholder game model in the previous section, the benefits matrix of manufacturing enterprises, the government, and digital technology platforms in the corporate brand authenticity upgrades service strategy, can be established, as displayed in Table 3.

Table 3. Benefits matrix for manufacturing enterprises, the government, and digital technology platforms.

	Manufacturing Enterprises			
Digital technology platforms	x Use		$1-$ x Not-Use	
	The government		The government	
	y Regulation	$1-$ y Not Regulation	y Regulation	$1-$ y Not Regulation
z Upgrade Services	$\pi_1 + \pi_5 - c_1 + s_1$; $\pi_3 - c_3 - s_1 - s_2 + \pi_7 + \pi_8$; $s_2 + \pi_4 - c_5 + \pi_6$	$\pi_1 + \pi_5 - c_1$; $\pi_3 - s_2 + \pi_7$; $s_2 + \pi_4 - c_5 + \pi_6$	$\pi_1 + \pi_5 - c_1$; $\pi_3 - s_2 + \pi_7$; $s_2 + \pi_4 - c_5 + \pi_6$	$\pi_2 - c_2 - g_1 - g_2$; $-c_3 - c_4 + g_1 - s_2 + \pi_7$; $s_2 + \pi_4 - c_5$
$1-$ z Not Upgrade Services	$\pi_1 - c_1 + s_1$; $\pi_3 - c_3 - s_1$; 0	$\pi_1 - c_1$; π_3; 0	$\pi_2 - c_2 - g_1$; $-c_3 - c_4 + g_1$; 0	$\pi_2 - c_2$; $-c_4$; 0

4.2. Equilibrium Analysis of the Three-Way Evolutionary Game of Brand Authenticity

Revenue expectation function construction.

According to the revenue matrix in Table 2, the expected revenue of the three subjects, manufacturing enterprises, the government, and digital technology platforms, is obtained as follows:

(1) The expected return of manufacturing enterprises is V_{11} when they "use", V_{12} when they do "not use", and the average expected return is V_1.

Benefits for manufacturing enterprises

$$V_{11} = yz(\pi_1 - c_1 + s_1 + \pi_5) + y(1-z)(\pi_1 - c_1 + s_1) + (1-y)z(\pi_1 - c_1 + \pi_5) + (1-y)(1-z)(\pi_1 - c_1) \quad (1)$$

$$V_{12} = yz(\pi_2 - c_2 - g_1 - g_2) + y(1-z)(\pi_2 - c_2 - g_1) + (1-y)z(\pi_2 - c_2 - g_2) + (1-y)(1-z)(\pi_2 - c_2) \quad (2)$$

V_1 is the average anticipated returns for manufacturing enterprises.

$$V_1 = xV_{11} + (1-x)V_{12} \quad (3)$$

Taking the proportion of the "use" strategy as an example, the replicated dynamic equation of manufacturing enterprises can be expressed as follows:

$$dx/dt = x(V_{11} - V_1) = -x(1-x)(\pi_1 - c_1 + y(c_2 + g_1 + s_1 - \pi_2 + z\pi_2 - zc_2) + z(c_2 + g_2 - \pi_2)) \quad (4)$$

(2) V_{21} and V_{22} are the expected returns of the government adopting the strategies of "regulation" and "not regulation", and the average expected return is V_2.

Benefits of the government

$$V_{21} = xz(\pi_3 - c_3 - s_1 - s_2 + \pi_7 + \pi_8) + x(1-z)(\pi_3 - c_3 - s_1) + (1-x)z(-c_3 - c_4 + g_1 - s_2 + \pi_7) + (1-x)(1-z)(-c_3 - c_4 + g_1) \quad (5)$$

$$V_{12} = xz(\pi_2 - s_2 + \pi_7) + x(1-z)\pi_3 + (1-x)z(-c_4 - s_2 + \pi_7) - c_4(1-x)(1-z) \quad (6)$$

Similarly, the average income of the government V_2 is

$$V_2 = yV_{21} + (1-y)V_{22} \quad (7)$$

Accordingly, the replicated dynamic equation of the government can be expressed as follows:

$$dy/dt = y(V_{21} - V_2) = y(y-1)[x(-z\pi_3 - z\pi_2 + g_1 + s_1) + c_3 - g_1] \quad (8)$$

(3) The expected return of the digital technology platforms to upgrade service is V_{31}, the expected return of the digital platforms not to upgrade the service is V_{32}, and the average expected return is V_3.

Benefits of digital technology platforms

$$V_{31} = yx(-c_5 + s_2 + \pi_4 + \pi_6) + x(1-y)(-c_5 + s_2 + \pi_4 + \pi_6) + (-c_5 + s_2 + \pi_4)(1-x)y + (1-x)(1-y)(-c_5 + s_2 + \pi_4) \quad (9)$$

$$V_{32} = 0 \quad (10)$$

Finally, the average income of digital technology platforms V_3 is

$$V_3 = zV_{31} + (1-z)V_{32} \quad (11)$$

Similarly, the following replicated dynamic equation can be expressed as

$$dz/dt = z(V_{31} - V_3) = -z(z-1)(-c_5 + s_2 + \pi_4 + \pi_6 x) \quad (12)$$

4.3. Equilibrium Solution

The stakeholders find it challenging to play their best move due to the restricted rationality of manufacturing companies, the government, and digital technology platforms. Hence, it can be said that Equations (4), (8) and (12) represent an evolutionary process. It develops into a three-way replicated dynamic system. Manufacturing companies, the government, and digital technology platforms might be able to invent techniques to maximize benefits as iterations develop, and eventually produce a stable evolutionary strategy (ESS) [55].

$$\begin{cases} F_1 = dx/dt = x(V_{11} - V_1) = -x(1-x)(c_2 - c_1 + \pi_1 - \pi_2 + yg_1 + yg_2 + \pi_5 z + s_1 y) \\ F_2 = dy/dt = y(V_{21} - V_2) = y(y-1)[c_3 - g_1 + g_1 x + s_1 x + \pi_2 xz - \pi_3 xz - \pi_8 xz] \\ F_3 = dz/dt = z(V_{31} - V_3) = -z(z-1)(-c_5 + s_2 + \pi_4 + \pi_6 x) \end{cases} \quad (13)$$

In the dynamical system composed of 3 game subjects, let F(x) = 0, F(y) = 0, F(z) = 0, and it can obtain 8 pure strategy Nash equilibrium points of the system, which are: E1(0,0,0), E2(0,0,1), E3(0,1,0), E4(0,1,1), E5(1,0,0), E6(1,0,1), E7(1,1,0), and E8(1,1,1). All stakeholders adopt a pure strategy in each of these equilibrium points, which constitute the boundary of the domain Ω [56].

Additionally, there is another equilibrium point, E9, in the solution domain:

$$\begin{cases} -x(1-x)(c_2 - c_1 + \pi_1 - \pi_2 + yg_1 + yg_2 + \pi_5 z + s_1 y) = 0 \\ y(y-1)[c_3 - g_1 + g_1 x + s_1 x + \pi_2 xz - \pi_3 xz - \pi_8 xz] = 0 \\ -z(z-1)(-c_5 + s_2 + \pi_4 + \pi_6 x) = 0 \end{cases} \quad (14)$$

where E9 is

$$\begin{cases} x^* = \frac{c_5 - s_2 - \pi_4}{\pi_6} \\ y^* = \frac{c_1 - c_2 + \pi_1 - \pi_2 + z\pi_5}{-(g_1 + g_2 + s_1)} \\ z^* = \frac{xg_1 + xs_1 + c_3 - g_1}{x\pi_3 - x\pi_2 + \pi_8 x} \end{cases} \tag{15}$$

E9 $\in \Omega$; otherwise, it should be abandoned.

4.4. Asymptotic Stability

The replication dynamic equations of the three participating subjects: namely, manufacturing enterprises, the government, and digital technology platforms, all constitute to the three-dimensional replication dynamical system. According to Friedman's replication dynamics system stability analysis method [57], the Jacobian matrix of the three-dimensional replication dynamics system is given as follows:

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial z} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix}$$

$$\begin{bmatrix} \begin{matrix} -(2x-1)(c_2 - c_1 + \pi_1 - \pi_2 \\ +g_1 y + g_2 z + \pi_5 z + s_1 y) \end{matrix} & x(1-x)(g_1 + s_1) & x(1-x)(g_2 + \pi_5) \\ y(y-1)(g_1 + s_1 + \pi_2 z - \pi_3 z - \pi_8 z) & \begin{matrix} (2y+1)(c_3 - g_1 + g_1 x + s_1 x + \\ \pi_2 xz - \pi_3 xz - \pi_8 xz) \end{matrix} & y(y-1)(\pi_2 x - \pi_3 x + \pi_8 x) \\ -\pi_6 z(z-1) & 0 & -(1-2z)(\pi_4 - c_5 + s_2 + \pi_6 x) \end{bmatrix} \tag{16}$$

Then, by including the eight equilibrium points E1–E8 in Equation (16), the Jacobian matrices corresponding to all equilibria can be calculated. The results are shown in Table 4.

Table 4. Strategic equilibrium points and their eigenvalues.

Equilibrium Point	λ_1	Symbol	λ_2	Symbol	λ_3	Symbol	State
(0,0,0)	$\pi_1 - c_1 - \pi_2 + c_2$	+	$g_1 - c_3$	N	$\pi_4 - c_5 + s_2$	+	Instability point
(1,0,0)	$\pi_1 - c_1 + c_2 - \pi_2$	+	$-s_1 - c_3$	-	$c_5 - s_2 - \pi_4$	-	Instability point
(0,1,0)	$c_2 - c_1 + \pi_1 - \pi_2 - s_1 + g_1$	N	$c_3 - g_1$	N	$\pi_4 - c_5 + s_2$	+	Instability point
(0,0,1)	$c_2 - c_1 + \pi_1 - \pi_2 + \pi_5$	+	$g_1 - c_3$	N	$\pi_4 - c_5 + s_2$	+	Instability point
(1,1,0)	$c_1 - \pi_1 - c_2 + \pi_2 - s_1$	N	$c_3 + s_1$	+	$\pi_4 - c_5 + s_2 + \pi_6$	+	Instability point
(1,0,1)	$c_1 - c_2 - \pi_1 + \pi_2 - g_2 - \pi_5$	-	$\pi_3 - \pi_2 - c_3 - s_1 + \pi_8$	N	$c_5 - \pi_4 - s_2 - \pi_6$	-	Uncertain
(0,1,1)	$c_1 - c_2 + g_1 + g_2 + \pi_1 - \pi_2 + s_1 + \pi_5$	+	$c_3 - g_1$	N	$-s_2 + c_5 - \pi_4$	-	Instability point
(1,1,1)	$c_1 - c_2 - \pi_1 + \pi_2 - g_1 - g_2 - s_1$	-	$c_3 + \pi_2 - \pi_3 + s_1 - \pi_8$	N	$c_5 - s_2 - \pi_4 - \pi_6$	-	Uncertain

In Table 4, The eigenvalue symbol cannot be judged by "N", "+" means the eigenvalue is greater than zero, "-" represents eigenvalues less than zero, λ_1, λ_2, λ_3 are the eigenvalues. The equilibrium points in a three-way game are (1,0,1) and (1,1,1).

For E1(0,0,0), the Jacobian matrix is the following:

$$J_1 = \begin{pmatrix} c_2 - c_1 + \pi_1 - \pi_2 & 0 & 0 \\ 0 & g_1 - c_3 & 0 \\ 0 & 0 & \pi_4 - c_5 + s_2 \end{pmatrix} \tag{17}$$

The eigenvalues of matrix J_1 are $\lambda_1 = \pi_1 - c_1 - \pi_2 + c_2$, $\lambda_2 = g_1 - c_3$, $\lambda_3 = \pi_4 - c_5 + s_2$, respectively. Based on the analysis of the profit purpose of manufacturing enterprises, the revenue of manufacturing enterprises after green upgrading is greater than the cost, so the characteristic value $\lambda_3 = \pi_4 - c_5 + s_2 > 0$ means this equilibrium point is not asymptotically stable.

Analogously, the Jacobian matrix at E2(1,0,0) is the following:

$$J_2 = \begin{pmatrix} c_2 - c_1 + \pi_1 - \pi_2 & 0 & 0 \\ 0 & -s_1 - c_3 & 0 \\ 0 & 0 & \pi_6 - c_5 + s_2 + \pi_4 \end{pmatrix} \quad (18)$$

The eigenvalues of matrix J_2 are $\lambda_1 = c_2 - c_1 + \pi_1 - \pi_2$, $\lambda_2 = -s_1 - c_3$, and $\lambda_3 = c_5 - s_2 - \pi_4$, respectively. As $\lambda_1 = c_2 - c_1 + \pi_1 - \pi_2 > 0$ is based on the analysis of the profit purpose of manufacturing enterprises, this equilibrium point is not asymptotically stable.

The Jacobian matrix J_3 at the equilibrium point E3(0,1,0) is:

$$J_3 = \begin{pmatrix} c_2 - c_1 + \pi_1 - \pi_2 + s_1 + g_1 & 0 & 0 \\ 0 & c_3 - g_1 & 0 \\ 0 & 0 & s_2 - c_5 + \pi_4 \end{pmatrix} \quad (19)$$

The eigenvalues of matrix J_3 are $\lambda_1 = c_2 - c_1 + \pi_1 - \pi_2 - s_1 + g_1$, $\lambda_2 = c_3 - g_1$ and $\lambda_3 = s_2 - c_5 + \pi_4$. Based on the analysis of the profit purpose of the digital technology platforms, $\pi_4 + s_2 - c_5 > 0$, this equilibrium point is not asymptotically stable.

The Jacobian matrix J_4 at the equilibrium point E4(0,0,1) is:

$$J_4 = \begin{pmatrix} c_2 - c_1 + \pi_1 - \pi_2 + \pi_5 & 0 & 0 \\ 0 & -c_3 + g_1 & 0 \\ 0 & 0 & c_5 - s_2 - \pi_4 \end{pmatrix} \quad (20)$$

The eigenvalues of matrix J_4 are $\lambda_1 = c_2 - c_1 + \pi_1 - \pi_2 + \pi_5$, $\lambda_2 = -c_3 + g_1$, and $\lambda_3 = s_2 - c_5 + \pi_4$. Based on the analysis of the profit purpose of manufacturing enterprises, $c_2 - c_1 + \pi_1 - \pi_2 + \pi_5 > 0$, this equilibrium point is not asymptotically stable.

The Jacobian matrix J_5 at the equilibrium point E5(1,1,0) is:

$$J_5 = \begin{pmatrix} c_1 - c_2 - g_1 - \pi_1 + \pi_2 - s_1 & 0 & 0 \\ 0 & c_3 + s_1 & 0 \\ 0 & 0 & \pi_4 - c_5 + s_2 + \pi_6 \end{pmatrix} \quad (21)$$

The eigenvalues of matrix J_5 are $\lambda_1 = c_1 - \pi_1 - c_2 + \pi_2 - s_1$, $\lambda_2 = c_3 + s_1$ and $\lambda_3 = \pi_4 - c_5 + s_2 + \pi_6$.

Based on the analysis of the profit purpose of the digital technology platforms $\pi_4 + s_2 - c_5 + \pi_6 > 0$, this equilibrium point is not asymptotically stable.

The Jacobian matrix J_6 at the equilibrium point E6(1,0,1) is:

$$J_6 = \begin{pmatrix} c_1 - c_2 - \pi_1 + \pi_2 - g_2 - \pi_5 & 0 & 0 \\ 0 & \pi_3 - \pi_2 - c_3 - s_1 + \pi_8 & 0 \\ 0 & 0 & c_5 - \pi_4 - s_2 - \pi_6 \end{pmatrix} \quad (22)$$

The eigenvalues of matrix J_6 are $\lambda_1 = c_1 - c_2 - \pi_1 + \pi_2 - g_2 - \pi_5$, $\lambda_2 = \pi_3 - \pi_2 - c_3 - s_1 + \pi_8$ and $\lambda_3 = c_5 - \pi_4 - s_2 - \pi_6$. When $\pi_3 - \pi_2 - c_3 - s_1 + \pi_8 < 0$, E6(1,0,1) has asymptotic stability.

The Jacobian matrix J_7 at the equilibrium point E7(0,1,1) is:

$$J_7 = \begin{pmatrix} c_2 - c_1 + g_1 + g_2 + \pi_1 - \pi_2 + s_1 + \pi_5 & 0 & 0 \\ 0 & c_3 - g_1 & 0 \\ 0 & 0 & -s_2 + c_5 - \pi_4 \end{pmatrix} \quad (23)$$

The eigenvalues of matrix J_7 are $\lambda_1 = c_1 - c_2 + g_1 + g_2 + \pi_1 - \pi_2 + s_1 + \pi_5$, $\lambda_2 = c_3 - g_1$ and $\lambda_3 = -s_2 + c_5 - \pi_4$.

As $\lambda_2 = c_1 - c_2 + g_1 + g_2 + \pi_1 - \pi_2 + s_1 + \pi_5 > 0$, this equilibrium point is not asymptotically stable.

The Jacobian matrix J_8 at the equilibrium point E8(1,1,1) is:

$$J_8 = \begin{pmatrix} c_1 - c_2 - \pi_1 + \pi_2 - g_1 - g_2 - s_1 & 0 & 0 \\ 0 & c_3 + \pi_2 - \pi_3 + s_1 - \pi_8 & 0 \\ 0 & 0 & c_5 - s_2 - \pi_4 - \pi_6 \end{pmatrix} \quad (24)$$

The eigenvalues of matrix J_8 are $\lambda_1 = c_1 - c_2 - \pi_1 + \pi_2 - g_1 - g_2 - s_1$, $\lambda_2 = c_3 + \pi_2 - \pi_3 + s_1 - \pi_8$ and $\lambda_3 = c_5 - s_2 - \pi_4 - \pi_6$.

According to the judgmental criterion, E8(1,1,1) is a sink when $c_3 + \pi_2 - \pi_3 + s_1 - \pi_8 < 0$.

4.5. Game Scenario

Based on the results described in Section 4.4, there are two possible game scenarios for green business upgrading.

Scenario 1: When $\pi_3 - \pi_2 - c_3 - s_1 + \pi_8 < 0$, there is the equilibrium point E6(1,0,1). In this case, manufacturing enterprises choose the strategy of "participating in digital technology platforms for green upgrading", and the government chooses the strategy of "not regulation". In turn, digital technology platforms choose the "upgrade services". This combination of strategies is an ESS.

Scenario 2: When $c_3 + \pi_2 - \pi_3 + s_1 - \pi_8 < 0$, there is the equilibrium point E8(1,1,1). In this case, manufacturing enterprises choose the strategy of "participating in the digital technology platforms for green upgrading", the government chooses the strategy of "regulation", and digital technology platforms choose to "upgrade services". This strategy's combination is an ESS.

5. Simulation Analysis

For the analysis of two states, E6(1,0,1) (scenario 1) and E8(1,1,1) (scenario 2) are ideal for the system to verify the validity of the evolutionary stability analysis in this paper, and to verify the impact of different manufacturing enterprises' subsidies, digital technology platforms' subsidies, and the government penalties on the evolutionary results. Numerical simulations are performed using Matlab2016b software. The parameter assignment method and the interaction between the parameters in the two cases are assigned. All the variables that emerged in the case study are listed in Table 5.

Table 5. The relevant data used in the case study.

Parameters	π_1	π_2	π_3	π_4	π_5	π_6	π_8	c_1	c_2	c_3	c_5	s_1	s_2	g_1	g_2
Array 1 value	0.9	0.6	1.0	0.3	0.2	0.1	0.05	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.1
Array2 value	0.9	0.6	1.2	0.3	0.2	0.1	0.05	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.1

In order to test the validity of the evolutionary stability analysis of the system, array 1 and array 2 were substituted into the model for simulation; the initial strategy probabilities of the game subjects manufacturing enterprises, the government, and digital technology platforms are taken as (0.3, 0.3, 0.3), (0.4, 0.4, 0.4), (0.5, 0.5, 0.5), and the results are shown in Figures 2 and 3.

From Figures 2 and 3, the system eventually evolves into E8(1,1,1) under the condition of array 1, and E6(1,0,1) under the condition of array 2. The results of the system evolution stability analysis in this research are supported by the simulation analysis. For manufacturing companies, the government, and digital technology platforms, the model is reliable and offers useful, practical advice. In order to eliminate the influence of the initial probability values on the system evolution, the initial strategy probabilities of the game subjects' manufacturing enterprises, the government, and digital technology platforms, are taken as 0.3, 0.3, and 0.3, respectively, and the influence of π_1, s_1, and g_1 on the system evolution results are studied.

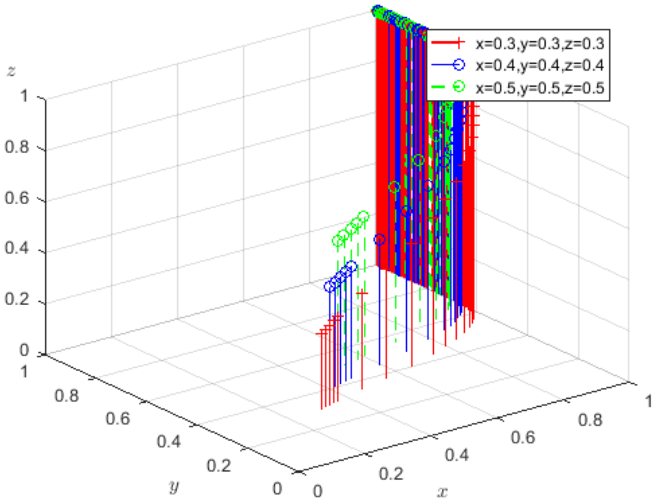

Figure 2. Simulation of the evolutionary game under array 1 (x manufacturing enterprises, y the government, z digital technology platforms).

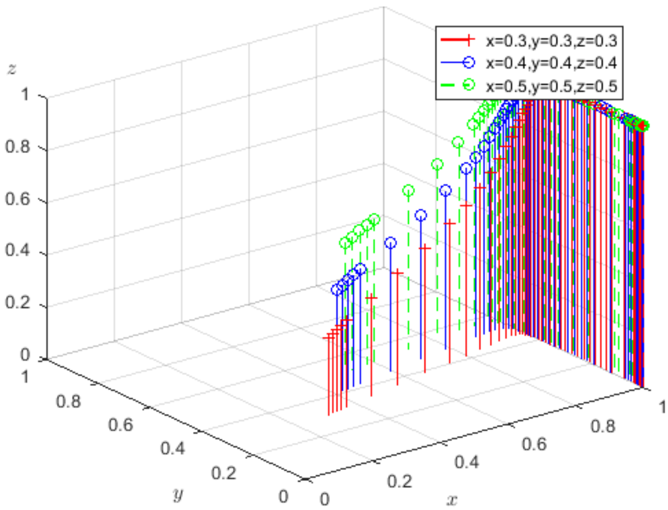

Figure 3. Simulation of the evolutionary game under array 2 (x manufacturing enterprises, y the government, z digital technology platforms).

5.1. The Government Subsidy Intensity for Manufacturing Enterprises s_1

In order to study the influence of change of the government subsidy on the system evolution under E8(1,1,1) and E6(1,0,1), the values of s_1 are 0.2, 0.5, and 0.8, respectively, under the condition that other parameters are certain. The simulation results are shown in Figures 4 and 5. As seen from Figure 4, the change of the government subsidy s_1 does not affect the evolutionary stability point of the system, because in E8(1,1,1), the government chooses the "regulation" strategy; therefore, the government subsidy does not affect the strategy choice of manufacturing enterprises and digital technology platforms at this time.

In E6(1,0,1), as seen from Figure 5, the critical value of the government subsidy to enterprises s_1 is between 0.2 and 0.5. When the government subsidy to enterprises is greater than this critical value, manufacturing enterprises, the government, and digital technology platforms will eventually choose the "use", "not regulation" and "upgrade service" strategy, respectively. When the government subsidies to enterprises are less than this threshold, manufacturing enterprises, the government, and digital technology platforms will eventually choose the "use", "regulation", and "upgrade service" strategy, respectively, and the evolutionary stability point of the system is E8(1,1,1).

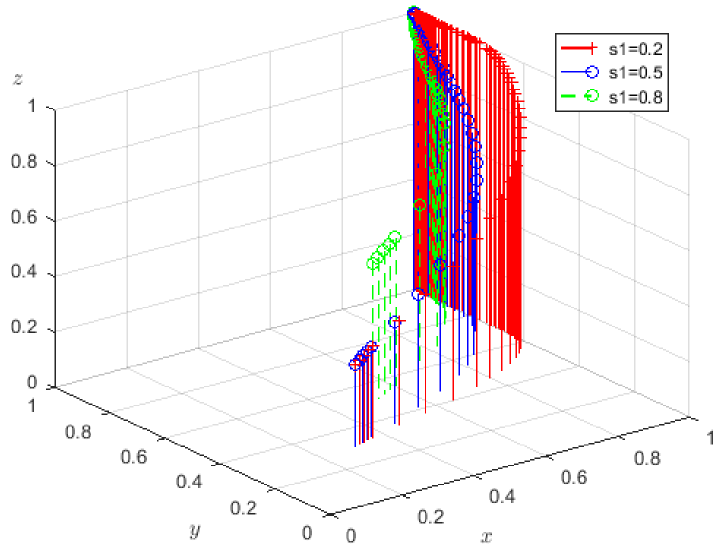

Figure 4. Effect of the government subsidy to enterprises s_1 change on evolutionary results under array 1 (x manufacturing enterprises, y the government, z digital technology platforms).

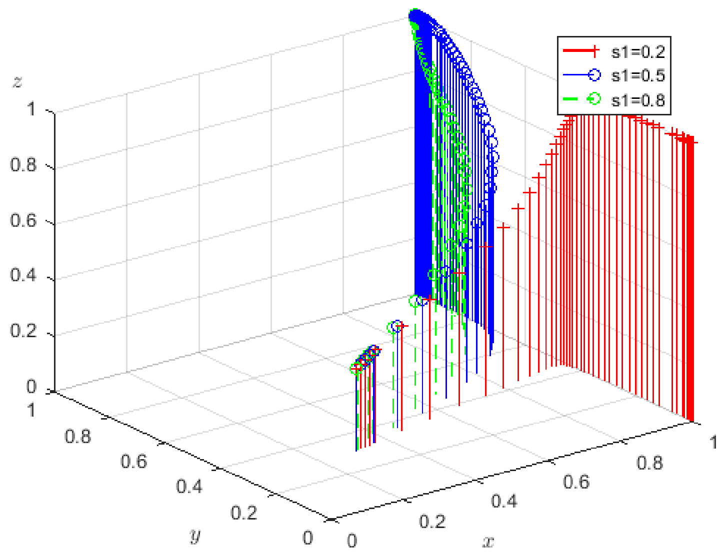

Figure 5. Effect of the government subsidy to enterprises s_1 on the evolutionary results under array 2 (x manufacturing enterprises, y the government, z digital technology platforms).

5.2. The Impact of Digital Technology Platforms on Manufacturing Enterprises π_1

In order to determine the impact of the change of digital technology platforms on the green upgrade of enterprises on the system evolution results, the values of π1 were made to be 0.3, 0.6, and 0.9 under the condition that the other parameters are certain. The simulation results are shown in Figures 6 and 7. As seen in Figure 6, in the process of using digital technology platforms in manufacturing, π1 has no impact on the outcome because it is profitable for manufacturing enterprises. Therefore, manufacturing enterprises, the government and digital technology platforms will eventually choose to participate in digital technology platforms, regulation and upgrading services. At this point, the system's evolutionary stability point is E8(1,1,1).

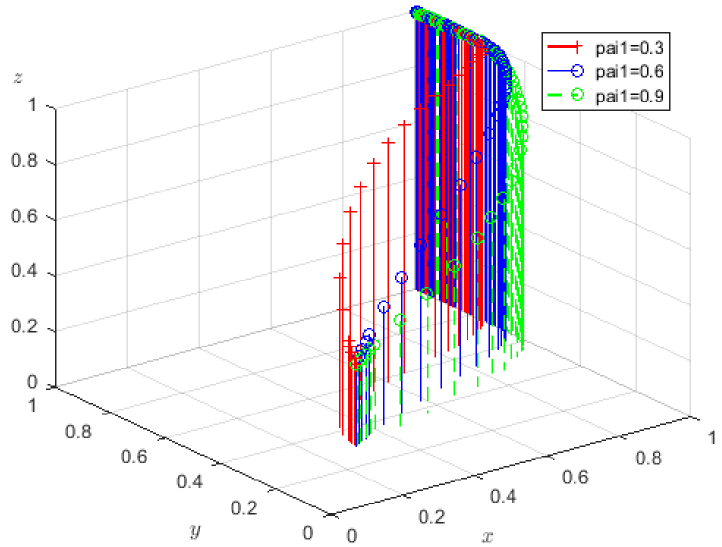

Figure 6. Effect of benefits gained by manufacturing enterprises using digital technology platforms $\pi 1$ on evolutionary results under array 1 (x manufacturing enterprises, y the government, z digital technology platforms).

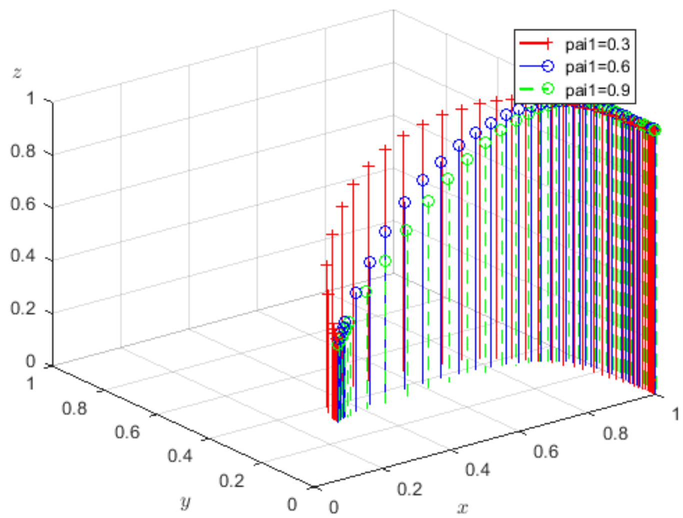

Figure 7. Effect of benefits gained by manufacturing enterprises using digital technology platforms $\pi 1$ on evolutionary results under array 2 (x manufacturing enterprises, y the government, z digital technology platforms).

As seen in Figure 7, the benefits of using digital technology platforms by manufacturing enterprises do not affect the evolutionary stability point of the system. This is because even if the government chooses the "not regulation" strategy, the manufacturing enterprises are profitable in using digital technology platforms to promote the green upgrading of the enterprises; they will choose the "use" strategy at this time.

5.3. The Government's Punishment of Manufacturing Enterprises g_1

The government penalty, as seen in Figure 8, will affect the evolution rate. That is, under E8(1,1,1), along with the increase of government punishment, manufacturing enterprises, and the government, digital technology platforms will eventually choose the "use", "regulation", and "upgrade service" strategy, respectively, and at this time, the evolutionary stability point of the system is E8(1,1,1). The government penalties can force enterprises to green upgrade, proving the existence of Porter's hypothesis [58]. From Figure 9, in E6(1,0,1), the change of the government penalty g_1 to enterprises does not affect the evolutionary stability point of the system, and at this time, the evolutionary stability point of the system is E6(1,0,1).

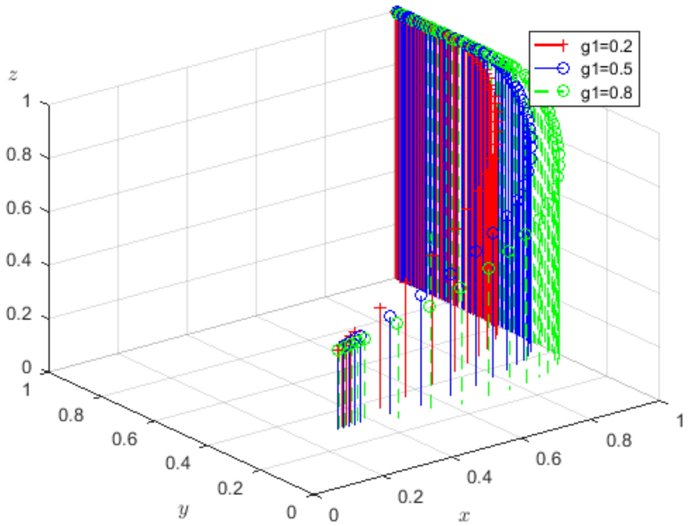

Figure 8. Effect of the government's punishment of manufacturing enterprises g_1 on evolutionary results under array 1 (x manufacturing enterprises, y the government, z digital technology platforms).

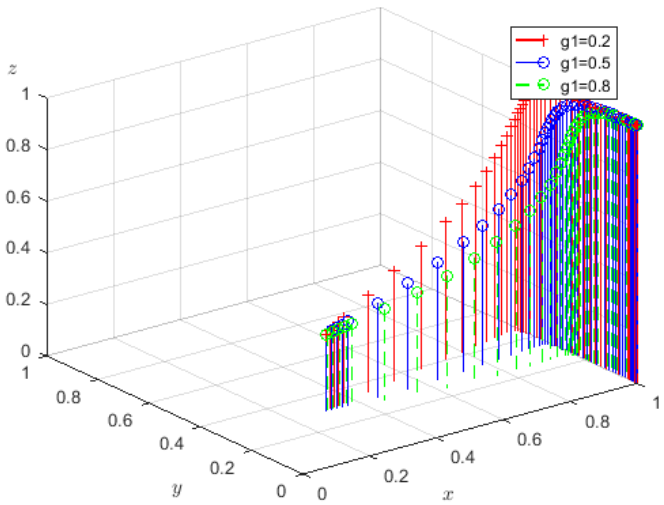

Figure 9. Effect of the government's punishment of manufacturing enterprises g_1 on evolutionary results under array 2 (x manufacturing enterprises, y the government, z digital technology platforms).

6. Discussion

The numerical simulations above show that there are two strategic combinations in the evolutionary process, which are E6(1,0,1) (scenario 1) and E8(1,1,1) (scenario 2).

Firstly, government subsidies help to encourage manufacturing enterprises to provide green transformation [59–62]. Advanced technologies are receiving increased attention in every sector of industry. Technology development cannot be separated from strong financial support, and the core of revenue intervention policy is to provide economic compensation for environmental benefits. The best way to promote and direct green innovation is to strengthen financial and taxation support measures. The degree of resource limitations on green manufacturing is reduced at the source by preferential policies, such as boosting R&D subsidies for businesses to carry out green improvements.

Secondly, the benign operation of manufacturing enterprises should be ensured in the process of transformation [51,63,64]. Operating profitability is the main source of corporate profitability, the basis for the development of other profitability, and the guarantee for a series of corporate upgrading activities, such as expanding production and accelerating circulation. If an enterprise wants to develop further, the first thing to improve is operating profitability.

Finally, we will improve the environmental tax incentive mechanism that forces enterprises to go green. The environmental protection tax is an important part of greening the tax system [65]. The environmental protection tax should be introduced as a precursor to gradually adjust the structure of the environmental protection tax system, improve the environmental protection tax system, improve the transparency of taxation, and implement the government penalties along with the government subsidy incentives to help enterprises achieve green upgrading.

7. Conclusions

To achieve the goal of carbon neutrality and carbon peaking, this paper analyzes how digital technology platforms can promote green upgrading in manufacturing using evolutionary games, and draws the following conclusions:

Firstly, when the government chooses the subsidy strategy under E8(1,1,1), different subsidy strengths will change the final stable state of the system. When government subsidies to manufacturing enterprises are small, government spending is in a reasonable range and does not affect the government's strategy choice; therefore, the system evolves to E8(1,1,1). When the government subsidizes enterprises significantly, it will affect the evolutionary stability point, E6(1,0,1), of the government's strategy choice system.

Secondly, manufacturing enterprises should ensure that profits are in the process of green upgrading, which makes them run benignly. The influence of digital technology platforms on a manufacturing enterprise $\pi 1$ changes from 0.3 to 0.8 without affecting the evolutionary stability point of the system. The green upgrading of enterprises needs to increase the cost of enterprises, and gradually shift to the direction of low energy consumption, low carbon, et cetera, thus creating the premise of ensuring the benefits of enterprises.

Thirdly, the government's punishment can force enterprises to green upgrade. As the government's penalty g1 for manufacturing enterprises increases from 0.2 to 0.8, manufacturing enterprises will choose green upgrading. By penalizing manufacturing enterprises that do not use digital technology platforms, the government can encourage the manufacturing industry to choose digital technology platforms to play the incentive mechanism of taxation and promote green upgrading.

8. Policy Implications and Limitations

8.1. Policy Implications

On the basis of the previously mentioned conclusions, recommendations are made for the three game themes' pursuit of sustainable development in the areas of economics, society, and environments.

Firstly, adhering to the policy orientation of environmental regulation and providing full play to the positive effect of environmental regulation on the green upgrading of enterprises. Technology development cannot be separated from strong financial support, and the core of revenue intervention policy is to provide economic compensation for environmental benefits. The best way to promote and direct green innovation is to strengthen financial and taxation support measures. The degree of resource limitations on green manufacturing is reduced at the source by preferential policies, such as boosting R&D subsidies for businesses to carry out green improvements. Research and development for green products, as well as clean manufacturing, ought to be prioritized when allocating funding for environmental legislation.

Secondly, from an enterprise's point of view, digital transformation should be implemented gradually to prevent dangers to the company that are brought on by a lack of funding as a result of a thorough implementation. Enterprises should combine their strengths, invest more in and promote scientific research, provide high-priority data security, and improve training for digital talent. At the same time, the digital technology platforms should actively carry out platform construction management to provide a better development environment for manufacturing enterprises.

Thirdly, enhancing the environmental protection tax incentive system so that it encourages businesses to go green. The greening of the tax system includes a significant contribution from the environmental protection tax. To help businesses upgrade to a greener way of doing things, the government should implement the environmental protection tax as a first step in gradually changing the structure of the environmental protection tax system, improving it, increasing tax transparency, and putting in place government penalties and incentives.

8.2. Limitations

There are also more limitations to this study that need research: firstly, the connection between digital technology platforms and green manufacturing upgrades should be investigated first. Secondly, there is a chance that the parameters used and the settings made in this study will not accurately reflect the situation, as it is in reality. In order to better support green development and regional economic growth, future research can examine green upgrading from the standpoint of the organizational management system dynamics of digital technology, manufacturing businesses, the government, and the public sector.

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