A Game Analysis of Corporate Recycling and Government Regulation: A Currency Form Replacement Perspective

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Abstract. To achieve the “double carbon” goal, enterprises actively engage in recycling and reusing waste products. This approach not only alleviates the dual problems of resource shortage and environmental pollution but also effectively reduces carbon emissions. This paper establishes a two-party evolutionary game model involving “enterprise-government” under limited rationality. Building on this model, the influence of different money forms on recycling entities and regulatory models at different times is considered. The results indicate five evolutionarily stable and balanced strategies correspond to each stage of different currency forms, explained through cost, income, and information transparency dimensions. Finally, according to the characteristics of E-CNY, the paper proposes that the system can achieve an ideal win–win state for both parties. This conclusion recommends the further exploration of the deep application of modern information technology in the field of waste recycling.

Keywords: Waste recycling; Government regulation; Monetary form; “Dual-carbon” goal

1 Introduction

Now that the "dual carbon" goal has entered the practical stage, the academic community has offered suggestions from the perspectives of improving the system, accelerating the transformation of enterprises, promoting technological innovation, and building carbon trading markets[1][2].

With the rise of new generation digital technologies such as mobile Internet and artificial intelligence, Supervision has evolved from the early manual on-site supervision to the digital real-time supervision relying on big data platforms, and the form of enterprise transactions has been upgraded from cash to E-CNY.

The change of payment instruments has improved the security and traceability of corporate recycling activities. The E-CNY provides a new feasible path to effectively curb the bad trading behavior of recycling enterprises, promote the recycling of waste products, and achieve the goal of "double carbon". Legal digital currency not only enhances the convenience of enterprise transactions[3], but also effectively promotes the transformation of government supervision mode from understanding customers to understanding data, and finally forms a data-centered supervision mode to help the government discover and track illegal fund

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flows[4].

this paper explains the influence of various currency forms on the decision-making processes of enterprise recovery and government supervision. The timeline is divided into the traditional paper era, the mobile payment era and the digital era. Adopting a game perspective, the paper explores the changes in decision-making from three key dimensions: cost, benefit, and information transparency.

2 Model Hypothesis

In the context of game theory, the regulatory entity (government) and the recycling entity (enterprise) are bounded rational economic agents. Both the government and the manufacturer engage in two mixed strategies. These mixed strategies are defined as follows: X = {supervision, no supervision} = (x, 1-x), Y={recycling, no recycling}= (y, 1-y); x denotes the probability of government regulation, and y denotes the probability of enterprise recycling.

I denotes enterprise recovery cost, Cg denotes government supervision cost, W denotes government rewards for enterprises participating in recycling, H denotes environmental benefits for the government, F denotes penalty for enterprises that fail to recycle relevant waste and cause environmental pollution, and Ce denotes the additional cost of the government for participating in environmental governance in the later stage.

In alignment with the research conducted by Chen Wanting et al. [5], to comprehensively depict the closed-loop supply chain, certain cost parameters are considered. Specifically, C1 denotes the cost of manufacturing new products by the enterprise through recycling waste products, C2 denotes the cost of manufacturing new products by the enterprise through new raw materials, P denotes the price of new products, and Q denotes the market demand. The profits of new products under the two different cost scenarios are as follows: $\pi_1 = (P-C_1)\,Q$, $\pi_2 = (P-C_2)Q$, $\pi_1 - \pi_2 - I$ represents the premium income of the enterprise participating in recycling. ($C_1 < C_2$, $\pi_1 > \pi_2$)

3 Revenue Analysis of Game Model

In the context of the game theory and the aforementioned assumptions, the expected return matrix for the game players can be obtained, as presented in Table 1.

Table 1. Government and Enterprise Income Matrix

		Enterprise	
		Recovery(y)	No recycle$(1-y)$
Government	Supervision(x)	$H-C_g-W$ π_1+W-I	$F-C_g-C_e$ π_2-F
	No supervision$(1-x)$	H π_1-I	$-C_e$ π_2

3.1 Analysis of government revenue

Average returns when governments choose regulatory strategies are as follows:

$$E_1 = y(H - C_g - W) + (1 - y)(F - C_g - C_e)$$

Average returns when governments choose non-regulatory strategies are as follows:

$$E_2 = yH + (1 - y)(-C_e)$$

Average government revenue is given by the following:

$$\bar{E}_g = xE_1 + (1 - x)E_2$$

The government chooses to regulate the dynamic equation of replication as follows:

$$F(x) = \frac{d_x}{d_t} = x(E_1 - \bar{E}_g) = x(1 - x)[(1 - y)F - yW - C_g]$$

3.2 Analysis of enterprise income

Average returns when companies choose a recycling strategy are as follows:

$$E_3 = x(\pi_1 + W - I) + (1 - x)(\pi_1 - I)$$

Average revenue when a firm chooses a non-recycling strategy is as follows:

$$E_4 = x(\pi_2 - F) + (1 - x)\pi_2$$

Average corporate income is given by the following:

$$\bar{E}_f = yE_3 + (1 - y)E_4$$

The replication dynamic equation that the enterprise chooses to recycle is as follows:

$$F(y) = \frac{d_y}{d_t} = y(E_3 - \bar{E}_f) = y(1 - y)(xF + xW + \pi_1 - \pi_2 - I)$$

The two-dimensional system is obtained as follows:

$$\begin{cases} F(x) = x(1 - x)[(1 - y)F - yW - C_g] \\ F(y) = y(1 - y)(xF + xW + \pi_1 - \pi_2 - I) \end{cases}$$

3.3 Stability analysis of model equilibrium points

According to the aforementioned replication dynamic equation, five local equilibrium points of the two-dimensional system are obtained: (0,0), (0,1), (1,0), (1,1), and (x^*, y^*). $x^* = \frac{\pi_2 - \pi_1 + I}{W + F}, y^* = \frac{F - C_g}{W + F}$ only holds true when $x^*, y^* \epsilon [0,1]$ is $0 \leq \pi_2 - \pi_1 + I \leq W + F$ and $F - C_g \geq 0$. To analyze the local stability of equilibrium points using the Friedman decision method, the Jacobi matrix (J) is crucial. If both $Det(J) > 0$ and $Tr(J) < 0$ satisfy the determinant, where $Det(J) = a_{11}a_{22} - a_{12}a_{21}, Tr(J) = a_{11} + a_{22}$, the equilibrium point can be considered to have stability. This Jacobi matrix (J) is presented as follows:

$$J = \begin{bmatrix} \frac{\partial_{F(x)}}{\partial_x} & \frac{\partial_{F(x)}}{\partial_y} \\ \frac{\partial_{F(y)}}{\partial_x} & \frac{\partial_{F(y)}}{\partial_y} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

$$= \begin{bmatrix} (2x - 1)(C_g - F + yF + yW) & x(x - 1)(F + W) \\ y(-F - W)(y - 1) & (2y - 1)(\pi_2 - \pi_1 + I - xF - xW) \end{bmatrix}$$

4 Evolutionary Equilibrium Analysis Under Currency form Replacement

This section will analyze the behavior changes of the game parties under different currency forms from three dimensions: cost, premium return and transaction information transparency.

(1) $C_g - F > 0, 0 < W + F < I - \pi_1 + \pi_2$ denotes the paper cash era with high cost and low premium return. Equilibrium points is presented in Table 2.

Table 2. High Regulatory Costs and Low Recovery Premium Returns

equilibrium	Det(J)	symbol	Tr(J)	+/-	Result
(0, 0)	$(C_g - F) * (I - \pi_1 + \pi_2)$	+	$F - C_g - I + \pi_1 - \pi_2$	−	ESS
(0, 1)	$(C_g + W) * (\pi_1 - \pi_2 - I)$	−	$I - C_g - \pi_1 + \pi_2 - W$		Saddle point
(1, 0)	$(C_g - F) * (F - I + \pi_1 - \pi_2 + W)$	−	$C_g - I + \pi_1 - \pi_2 + W$		Saddle point
(1, 1)	$(C_g + W) * (I - F - \pi_1 + \pi_2 - W)$	+	$C_g - F + I - \pi_1 + \pi_2$	+	Instability

In the traditional cash era, characterized by a relatively low level of productivity, lacking a shared information platform. Both supervision cost and recovery cost are large. the equilibrium point (non-regulatory, non-regulatory, non-regulatory), Do not recycle) remains stable.

(2) $C_g - F > 0, 0 < I - \pi_1 + \pi_2 < W + F$ represents the era of cash conversion to electronic payments with high costs and medium premium returns. Equilibrium points is presented in Table 3.

Table 3. High Regulatory Costs and Medium Recovery Premium Returns

equilibrium	Det(J)	symbo l	Tr(J)	+/-	Result
(0, 0)	$(C_g - F) * (I - \pi_1 + \pi_2)$	+	$F - C_g - I + \pi_1 - \pi_2$	−	ESS
(0, 1)	$(C_g + W) * (\pi_1 - \pi_2 - I)$	−	$I - C_g - \pi_1 + \pi_2 - W$	−	Saddle point
(1, 0)	$(C_g - F) * (F - I + \pi_1 - \pi_2 + W)$	+	$C_g - I + \pi_1 - \pi_2 + W$	+	Instability
(1, 1)	$(C_g + W) * (I - F - \pi_1 + \pi_2 - W)$	−	$C_g - F + I - \pi_1 + \pi_2$	+	Saddle point

During the transition from traditional cash to the era of mobile payment. the recycling activities of enterprises are still dominated by cash transactions. Various risks are associated with cash transactions. In addition, the country's management of waste products is not stringent, lacking a well-established recycling system. Consequently, enterprises opt for a non-recycling strategy during this transitional stage. considering the high regulatory costs C_g, the government adopts a non-regulatory strategy. (no regulation, no recycling) remains a stable equilibrium point during this phase.

(3) $C_g - F < 0, 0 < W + F < I - \pi_1 + \pi_2$ represents the mobile payment era with low regulatory costs and low recovery premium income for enterprises. Equilibrium points is presented in Table 4.

Table 4. Low Regulatory Cost and Low Recovery Premium Income

equilibrium	Det(J)	symbol	Tr(J)	+/-	Result
(0, 0)	$(C_g - F) * (I - \pi_1 + \pi_2)$	−	$F - C_g - I + \pi_1 - \pi_2$	−	Saddle point
(0, 1)	$(C_g + W) * (\pi_1 - \pi_2 - I)$	+	$I - C_g - \pi_1 + \pi_2 - W$	+	Instability
(1, 0)	$(C_g - F) * (F - I + \pi_1 - \pi_2 + W)$	+	$C_g - I + \pi_1 - \pi_2 + W$	−	ESS
(1, 1)	$(C_g + W) * (I - F - \pi_1 + \pi_2 - W)$	+	$C_g - F + I - \pi_1 + \pi_2$	+	Instability

In the era of mobile payment, the government can leverage information technology to ascertain the actual recycling practices of enterprises through relevant online electronic transaction information. This approach significantly reduces supervision costs. despite the lower supervision costs, insufficient incentives for enterprise recycling persist. During this stage, the recycling cost for enterprises outweighs the profit difference between the new and recycled products. Accordingly, (supervision, no recycling) is a stable equilibrium point.

(4) $C_g - F > 0, I - \pi_1 + \pi_2 < 0$ represents the era of digital currency conversion from electronic payment characterized by high regulatory costs and high recovery premium returns. Equilibrium points is presented in Table 5.

Table 5. High Regulatory Costs and High Recovery Premium Returns

equilibrium	Det(J)	symbol	Tr(J)	+/-	Result
(0, 0)	$(C_g - F) * (I - \pi_1 + \pi_2)$	−	$F - C_g - I + \pi_1 - \pi_2$		Saddle point
(0, 1)	$(C_g + W) * (\pi_1 - \pi_2 - I)$	+	$I - C_g - \pi_1 + \pi_2 - W$	−	ESS
(1, 0)	$(C_g - F) * (F - I + \pi_1 - \pi_2 + W)$	+	$C_g - I + \pi_1 - \pi_2 + W$	+	Instability
(1, 1)	$(C_g + W) * (I - F - \pi_1 + \pi_2 - W)$	−	$C_g - F + I - \pi_1 + \pi_2$		Saddle point

During the transition from electronic payment to the era of E-CNY, the development of non-cash payment methods, with electronic payment as the primary means and digital yuan as a supplementary form, brings traceability in the purchase information of buyers of waste products. This advancement enables enterprises to easily and quickly estimate the recycling price of waste products based on relevant information. High transparency of information constrains enterprise behavior, and there is no need for government to supervise the cost of consumption. (unregulated, recycled) is a stable equilibrium point for this transition phase.

(5) $C_g - F < 0, I - \pi_1 + \pi_2 < 0$ represents the era of currency digitization with low regulatory costs and high premium returns for enterprises. Equilibrium points is presented in Table 6.

Table 6. Low Regulatory Costs and High Recovery Premium Returns

equilibrium	Det(J)	symbol	Tr(J)	+/-	Result
(0, 0)	$(C_g - F) * (I - \pi_1 + \pi_2)$	+	$F - C_g - I + \pi_1 - \pi_2$	+	Instability
(0, 1)	$(C_g + W) * (\pi_1 - \pi_2 - I)$	+	$I - C_g - \pi_1 + \pi_2 - W$	−	ESS
(1, 0)	$(C_g - F) * (F - I + \pi_1 - \pi_2 + W)$	−	$C_g - I + \pi_1 - \pi_2 + W$	+	Saddle point
(1, 1)	$(C_g + W) * (I - F - \pi_1 + \pi_2 - W)$	−	$C_g - F + I - \pi_1 + \pi_2$	−	Saddle point

In the era of E-CNY, leveraging its centralized management mode, the traceability function of blockchain technology can be used to more accurately monitor the recycling information of enterprises. Under various constraints, enterprises are incentivized to reduce unethical behaviors such as waste abandonment, where the government possesses mature regulatory means and low regulatory costs, it is inclined to adopt a non-regulatory strategy. (no regulation, recycling) is a stable equilibrium point at this stage.

(6) $C_g - F < 0, 0 < I - \pi_1 + \pi_2 < W + F$ represents the combination of low cost and medium recovery premium income. Equilibrium points is presented in Table 7.

Table 7. Low Regulatory Costs and Medium Recovery Premium Returns

equilibrium	Det(J)	symbol	Tr(J)	+/-	Result
(0, 0)	$(C_g - F) * (I - \pi_1 + \pi_2)$	$-$	$F - C_g - I + \pi_1 - \pi_2$	+	Saddle point
(0, 1)	$(C_g + W) * (\pi_1 - \pi_2 - I)$	$-$	$I - C_g - \pi_1 + \pi_2 - W$		Saddle point
(1, 0)	$(C_g - F) * (F - I + \pi_1 - \pi_2 + W)$	$-$	$C_g - I + \pi_1 - \pi_2 + W$		Saddle point
(1, 1)	$(C_g + W) * (I - F - \pi_1 + \pi_2 - W)$	$-$	$C_g - F + I - \pi_1 + \pi_2$	$-$	Saddle point
$(\frac{\pi_2-\pi_1+I}{W+F}, \frac{F-C_g}{W+F})$	$\frac{(C_g + W)(F - C_g)}{F + W} * \frac{(F - I + \pi_1 - \pi_2 + W)(I - \pi_1 + \pi_2}{F + W}$	+	0		centre point

The system exhibits only stable limit cycles without stable equilibrium points, and the evolution trajectory of the two players in the game follows a periodic closed loop denoted by (x^*, y^*). The result of the evolutionary game suggests that both the government and the enterprise choose mixed strategies, leading to limited analytical insights.

It is evident that the transaction media in different currency forms impact the stable and equilibrium strategies of enterprises and governments across the dimensions of cost, net income of enterprises, and transparency of transaction information. Fig 1 shows the evolution of the equilibrium point.

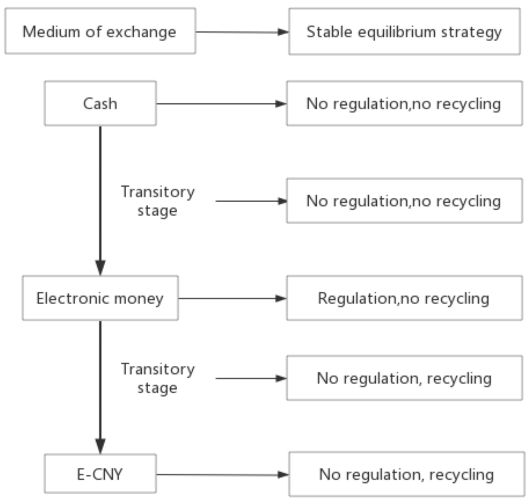

Fig 1 Evolution of Stable Equilibrium Strategy Under Currency Form Replacement

5 Numerical Simulation Analysis

This section draws upon relevant parameters from the China Renewable Resources Recycling Industry Development Report (2022). Additionally, numerical simulations, referenced from [6], The dynamic evolutionary path graph of both entities is derived through simulation, with distinct initial values [x,y] set to detect the stability of the evolutionary path. M1, M2, M3, M4, and M5 indicate that the initial values [x,y] are [0.1,0.9], [0.3,0.7], [0.9,0.1], respectively. Assuming that the time period is [0,100], the parameter values of each experiment scenario are presented in Table 8.

Table 8. Parameter assignment table in different situations

Argument	C_g	I	C_1	C_2	F	W	H	Q
Scenario (1)	4	10	3.4	3.5	3	4	12	20
Scenario (2)	4	9	3.25	3.6	3	4	12	20
Scenario (3)	2	10	3.4	3.5	3	4	12	20
Scenario (4)	4	8	3.1	3.7	3	4	12	20
Scenario (5)	2	8	3.1	3.7	3	4	12	20
Scenario (6)	2	9	3.25	3.6	3	4	12	20

In Fig 2 and Fig 3, While the evolution paths of the two scenarios differ, both converge to the system's equilibrium point at (0,0). Considering the five initial strategies, regulators initially opt for a certain proportion of regulatory strategies. However, influenced by high regulatory costs, the government gradually shifts toward non-regulatory strategies. In an environment lacking supervision, neither business owners nor the objective has the motivation to recover, leading enterprises to choose non-recycling strategies to capture the recovery premium income.

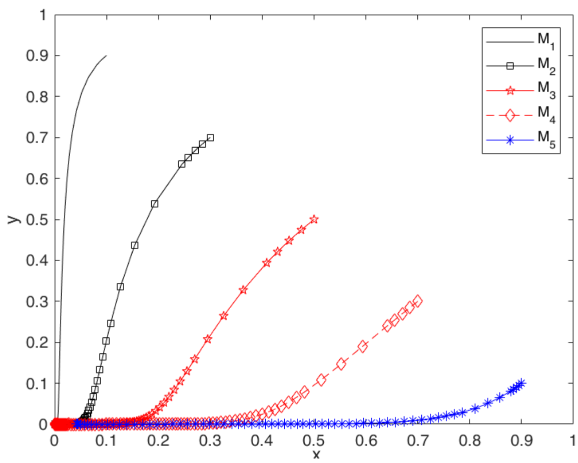

Fig 2. High Regulatory Costs and Low Recovery Premium Returns

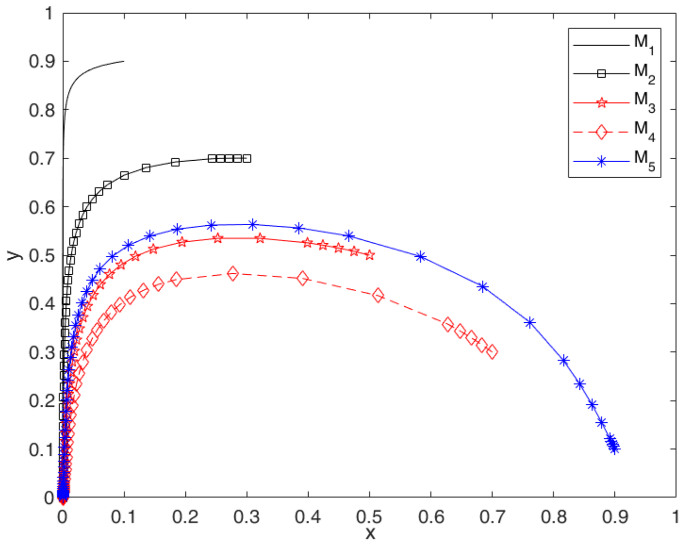

Fig 3. High Regulatory Costs and Medium Recovery Premium Returns

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Fig 5. High Regulatory Costs and High Recovery Premium Returns

Fig 4, The evolution path of different initial values [x,y] toward the final evolutionary stability strategy (1,0) exhibits slight variations. In contrast to M1–M4, the regulatory group's proportion decreases initially and then increases continuously toward 1. M5 highlights that when the proportion of enterprise recycling strategy is below 10%, the government rapidly escalates supervision until comprehensive oversight is achieved.

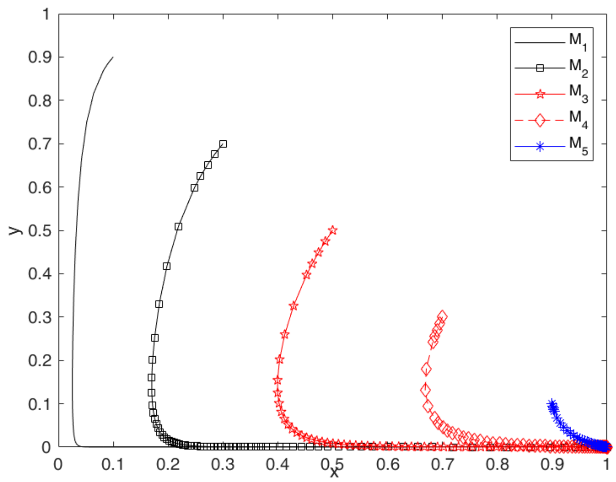

Fig 4. Low Regulatory Costs and Low Recovery Premium Returns

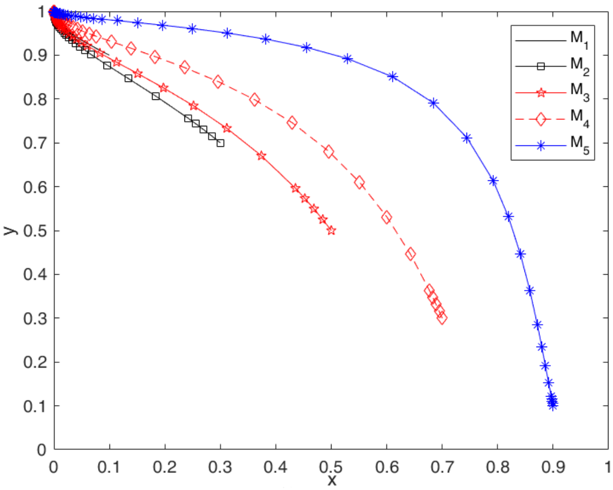

Fig 5. High Regulatory Costs and High Recovery Premium Returns

In Fig 5 and Fig 6, both scenarios exhibit almost identical evolution paths, and the system evolution equilibrium point is (0,1). When the initial value of y is small, such as M4–M5, the y value experiences a rapid increase, followed by a simultaneous decrease in the x value and an increase in the y value, ultimately reaching the stable equilibrium point (0,1). Importantly, According to the analysis provided, only Fig. 6, labeled “low cost - high income,” represents a win–win state.

In Fig 7, In scenarios involving bounded rationality, both parties constantly adjust their strategies based on considerations of their interests. The calculations reveal that the system undergoes periodic closed-loop movement around the coordinates [0.286, 0.143]. However, the evolutionarily stable strategy is not achieved in this process.

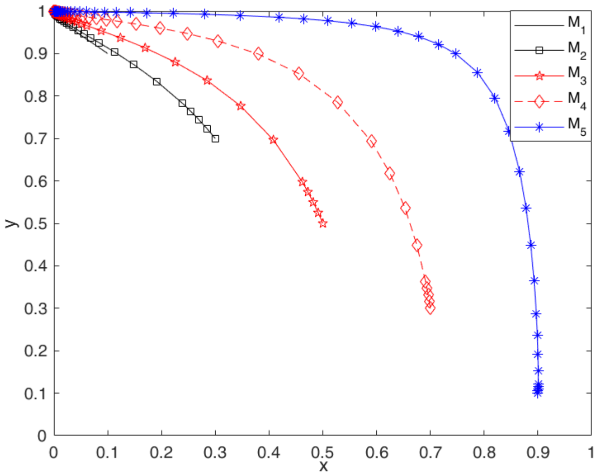

Fig 6. Low Regulatory Costs and High Recovery Premium Returns

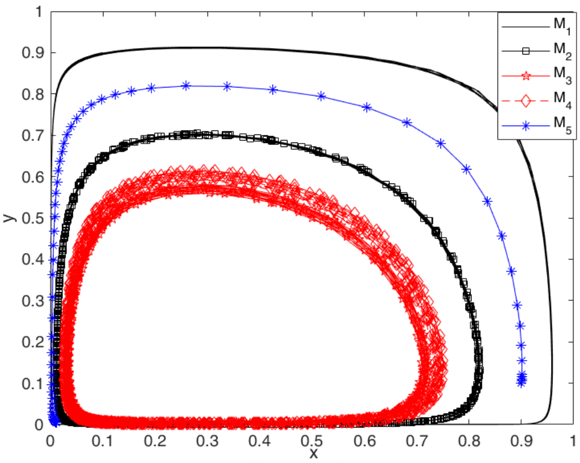

Fig 7. High Regulatory Costs and Medium Recovery Premium Returns

7 Conclusions and Suggestions

Under the background of currency form change, the stable equilibrium point of the game between the regulatory parties of enterprise recycling behavior is constantly evolving. in the E-CNY era to be fully entered, the government should establish a digital supervision system to maintain a stable and balanced strategy of (non-supervision, recycling) and promote the application of digital reform.

Furthermore, exploring the deep application of modern information technology in various links in the field of enterprise recycling is crucial. It is essential to promote innovation in core technologies that support and integrate E-CNY, blockchain, and other technologies in the governance of the recycling field. In addition, efforts should be made to accelerate the popularization of the application of E-CNY in various links in the field of recycling, supervise the circulation of E-CNY in the entire chain with digital supervision, and constantly strengthen the deep application of big data in the field of recycling.

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