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A study on the competition and cooperation relationship of China's photovoltaic supply chain under the policy guidance

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A B S T R A C T

The 531 New Deal has gradually transitioned the photovoltaic market policy from industrial policy to competition policy. This paper considers the two policy orientations of the photovoltaic supply chain: industrial policy and competition policy. Based on differential game theory, the profit models of photovoltaic supply chain entities under the two policy orientations are constructed, and the optimal solutions of each model are solved. The research finds that policy guidance factors affect the strategic choices of photovoltaic supply chain entities; Compared to industrial policies, competition policy orientation can increase the profits of various entities in the photovoltaic supply chain to varying degrees.

1. Introduction

Energy is an important basis for national economic and social development. How to achieve green and sustainable energy development is a research hotspot all over the world. As renewable energy, photovoltaic energy is the focus of attention of all countries. Since the "531" new deal, how to improve the profits of photovoltaic enterprises and realize the healthy development of the photovoltaic industry has become a major problem of the photovoltaic industry (Smith & Margolis, 2019). Changes in government policies and industrial technology iterations have a great impact on the healthy development of the photovoltaic industry. Therefore, under the dual role of government policy orientation and technical shackles, it is of practical significance to study how to optimize the main coordination strategy of photovoltaic industry alliance and realize the value of co-creation of photovoltaic industry (Marsillac, 2012).

Many researchers have conducted research on the collaborative relationship of industrial chains, and existing literature mainly analyzes the collaborative relationship of competition, cooperation, coordination, and other aspects of the supply chain from both theoretical and empirical perspectives. For example, foreign scholars have studied the competitive relationships of enterprises from different perspectives (Nili et al., 2018; Dehghani, 2021; Helveston et al., 2022; Chen & Su,2018). Some domestic scholars have studied the competition or collaborative decision-making issues between entities in the photovoltaic supply chain industry from the perspectives of government policy (Matinfard et al., 2022), fuzzy evaluation (Hu et al., 2023), dual competition (Chen & Su, 2017), social welfare (Chen & Su, 2019), and collaboration (Chen & Su, 2016). Some studies have also used methods such as supply chain models (Zhao et al., 2023), differential game models (Hu & Wu, 2024), and evolution models (Liu et al., 2022) to study the interrelationships between enterprises. A few scholars have studied the competitive relationship of the energy industry. Studying supply chain coordination in the presence of uncertain yield and

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demand (Xie et al., 2017). We have conducted relevant research on the costs (Helveston et al., 2022), policies (Chen & Su, 2018), and cases (Besiou & Van Wassenhove, 2016; Caravella et al., 2024) of competition in the photovoltaic supply chain. Some studies have also studied coordination and competitive decision-making issues in the supply chain from the green supply chain (Jian et al., 2021; Heydari, 2021), equity theory (Kang et al., 2021; Wang et al., 2021) and other perspectives.

In the past, scholars and experts have done in-depth research on the cooperation or coordination relationship of industrial alliance and analyzed the impact of various factors on the coordination relationship of the industrial supply chain. The research of scholars provides a useful reference for this paper to study the subject coordination strategy of photovoltaic industry alliance. However, most scholars only study the cooperation or coordination relationship of industrial alliance, and there are few comparative studies on the cooperation and coordination relationship of industrial alliance. At the same time, few scholars analyze the coordination strategy of photovoltaic industry chain alliance from the perspective of government policy orientation; In addition, this paper further refines the competition cooperation relationship studied by experts and scholars into three types: horizontal cooperation under vertical collaboration, vertical coordination and horizontal competition under vertical collaboration, and analyzes the collaborative strategy tendency of photovoltaic industry chain alliance subjects under different policy guidance. Based on this, this paper constructs the profit game model of alliance subjects under two different policy orientations of industrial policy and competition policy, obtains the optimal profit of each subject, and analyzes the optimal coordination strategy of photovoltaic industry chain alliance under different policy orientations through empirical research.

2. Model Building

2.1 Collaborative strategy model of photovoltaic industry chain alliance under the guidance of industrial policy

2.1.1 Hypothetical conditions

Considering the limited rationality of the cooperative subjects of photovoltaic industry alliance, this chapter selects the differential game model to study the optimal cooperative strategy among the subjects of photovoltaic industry alliance. Based on the main object of this paper is the collaborative innovation subject of photovoltaic industry alliance, this chapter only studies three collaborative strategies: vertical coordination, horizontal cooperation and horizontal competition. In order to simplify the model, this paper only considers the chain alliance model composed of one silicon wafer manufacturing enterprise and multiple photovoltaic system manufacturing enterprises. For the photovoltaic manufacturing enterprises in the alliance, the following assumptions are made according to the actual situation:

Assumption 1: Technological innovation factors. Technological innovation factors are used to measure the technological innovation degree of photovoltaic manufacturing enterprises at all levels under the promotion of government industrial policies. Let R_g be the technological innovation degree of photovoltaic silicon wafer manufacturing enterprises under the guidance of industrial policy; R_{fi} represents the technological innovation degree of the i photovoltaic system manufacturing enterprise under the industrial policy, where, $0 \le R_g \le 1$ 、 $0 \le R_{fi} \le 1$.

Assumption 2: Innovation cost. Let C be the innovation cost of collaborative innovation of photovoltaic industry alliance, and C_{Rg} denotes the cost of technological innovation of photovoltaic silicon wafer manufacturing enterprises. Also let C_{Rfi} be the cost of technological innovation of the i photovoltaic system manufacturing enterprise, since C_R includes the cost paid by the scientific research institute, so $C > C_{Rg} + \sum_{i=1}^{n} C_{Rf_i}$. According to the cost model（Ghosh & Shah, 2012), this paper constructs the photovoltaic industry collaborative innovation alliance, and the enterprise subject innovation cost function is as follows:： $C_{Rg} = \frac{1}{2} hR_g$, $C_{Rfi} = \frac{1}{2} hR_{fi}$, where h is the innovation cost coefficient.

Assumption 3: Production cost. Photovoltaic manufacturing enterprises at all levels need to pay a certain production cost when producing products, and technological innovation factors will reduce the production cost. Let $(1-R_g)C_g$ be the cost of photovoltaic silicon wafer manufacturing enterprises when producing silicon wafers and $(1-R_{f_i})C_{fi}$ represents the non-raw material cost (such as processing process cost) of the i photovoltaic system manufacturer when producing the photovoltaic system.

Assumption 4: PV product price. Let W be the wholesale price of silicon wafers sold by photovoltaic silicon wafer manufacturing enterprises. However, since the collaborative innovation of photovoltaic industry alliance is mainly reflected in the upstream common technology, the upstream silicon wafer manufacturing enterprises of photovoltaic industry have a collaborative income subsidy coefficient for the collaboration of downstream photovoltaic system manufacturing enterprises, which is reflected in the wholesale price of silicon wafers, The upstream PV wafer manufacturing enterprise has a discount coefficient λ for the downstream PV system manufacturing enterprise, that is, the wholesale price of silicon wafer sold by the final PV wafer manufacturing enterprise is λW ; P represents the price of a photovoltaic system sold by a photovoltaic system manufacturer. Regulation $0 \le \lambda \le 1$, $\lambda W \ge C_g + R_g$, $P \ge \lambda\alpha W + C_{fi} + R_{fi}$.

Assumption 5: Market size and sales volume. There is a maximum capacity in the photovoltaic market, and α represents the market scale of the photovoltaic system. Due to the instability of the market, β is used to represent the elasticity coefficient of demand price. S_i represents the sales quantity of the i photovoltaic system manufacturing enterprise before technological innovation, and q_i represents the sales quantity of the i photovoltaic system manufacturing enterprise after technological innovation. As the number of products sold by photovoltaic system manufacturing enterprises is affected by technology, the higher the degree of technological innovation, the greater the sales volume. Therefore, we use $q_i = (1 + R_{fi}) S_i$ to represent the actual sales volume after technological innovation. Finally, Q represents the total sales of all photovoltaic systems in the photovoltaic market, $Q = \sum_{i=1}^{n} q_i$.

Assumption 6: Government industrial policy subsidies. To protect the growth of the photovoltaic industry, the government provides industrial capital subsidies to all enterprise entities in the photovoltaic industry collaborative innovation alliance. Let M_g be the industrial policy subsidies given by the government to photovoltaic silicon wafer manufacturing enterprises and photovoltaic system manufacturing enterprises. According to the above assumptions, the market sales volume is affected by the demand price elasticity. It can be known that the total sales volume of all photovoltaic system manufacturers in the market is $Q = \alpha - \beta P$, then $P = \frac{1}{\beta}\alpha - \frac{1}{\beta}Q$, known $Q = \sum_{i=1}^{n} q_i$, then $P = \frac{1}{\beta}\alpha - \frac{1}{\beta}\sum_{i=1}^{n} q_i$; The total sales volume of photovoltaic silicon wafer manufacturing enterprises is $kQ = k\sum_{i=1}^{n} q_i$. Therefore, the expected profits of photovoltaic silicon wafer manufacturing enterprise and the i photovoltaic system manufacturing enterprise can be obtained as follows:

$$\prod_G(W \quad q_i) = (\lambda W - (1 - R_g)C_g)kQ - C_{Rg} + M_g = (\lambda W - (1 - R_g)C_g)k\sum_{i=1}^{n} q_i - \frac{1}{2}hR_g + M_g$$

$$\prod_{Fi}(W \quad q_i) = (P - k\lambda W - (1 - R_{f_i})C_{fi})q_i - C_{Rfi} + M_g$$

$$= (\frac{1}{\beta}\alpha - \frac{1}{\beta}\sum_{i=1}^{n} q_i - k\lambda W - (1 - R_{f_i})C_{fi})q_i - \frac{1}{2}hR_{fi} + M_g$$

3. Model Solving and Analysis

3.1 Solution of Vertical Cooperation and Horizontal Competition Model

In the photovoltaic industry collaborative innovation alliance, horizontal competition under vertical coordination refers to the formation of collaboration between primary photovoltaic silicon wafer manufacturing enterprises and secondary photovoltaic system manufacturing enterprises, which will sell their silicon wafer products to secondary photovoltaic system manufacturing enterprises at a certain discount. However, to obtain more shares and achieve high profit income, secondary photovoltaic system manufacturing enterprises will form competition. Appropriate competition is conducive to promoting the value creation of photovoltaic system manufacturing enterprises in the photovoltaic industry alliance. There will be sales competition and profit competition among photovoltaic system manufacturing enterprises. The competition among photovoltaic system manufacturing enterprises and the impact of key factors on the optimal profit of manufacturing enterprises under the competitive situation are analyzed by solving the optimal profit. The first-order derivative function and second-order derivative function of the expected profit of the i photovoltaic system manufacturing enterprise with respect to q_i are respectively:

$$\frac{\partial \prod_{Fi}(W \quad q_i)}{\partial q_i} = (\frac{1}{\beta}\alpha - \frac{1}{\beta}\sum_{i=1}^{n} q_i - k\lambda W - (1 - R_{f_i})C_{fi}) - \frac{1}{\beta}q_i$$

$$\frac{\partial^2 \prod_{Fi}(W \quad q_i)}{\partial q_i^2} = -\frac{2}{\beta} \prec 0$$

Therefore, the optimal profits of the photovoltaic silicon wafer manufacturing enterprise and the i photovoltaic system manufacturing enterprise can be obtained as follows (see the appendix for the specific certification process):

$$\prod_G(W^* \quad q_i^*) = \frac{1}{\frac{4}{\beta}n(n+1)}\left(n\left(\frac{1}{\beta}\alpha - k(1 - R_g)C_g\right) - \sum_{i=1}^{n}(1 - R_{f_i})C_{fi}\right)^2 - \frac{1}{2}hR_g + M_g$$

$$\prod_{Fi}\left(W^* \quad q_i^*\right)=\beta\left(\frac{\frac{1}{\beta}\alpha-k(1-R_g)C_g}{2(n+1)}+\frac{2n+1}{2n(n+1)}\sum_{i=1}^{n}(1-R_{f_i})C_{fi}-(1-R_{f_i})C_{fi}\right)^2-\frac{1}{2}hR_{fi}+M_g$$

Observation 1: It can be seen from W^* and $q^*_i(W)$ that under the guidance of the government's industrial policy, the optimal wholesale price of photovoltaic silicon wafer manufacturing enterprises increases with the increase of silicon wafer cost; It decreases with the increase of marginal cost of photovoltaic system manufacturing enterprises; With the increase of technological innovation; Due to the collaborative innovation of the industrial alliance, the optimal wholesale price decreases with the increase of the silicon price discount coefficient (collaborative income subsidy coefficient) given by the photovoltaic silicon wafer manufacturing enterprise to the photovoltaic system manufacturing enterprise.

Observation 2: It can be seen from W^*, $q^*_i(W)$ and $q_i=(1+R_{fi})S_i$ that the optimal retail volume and optimal silicon wafer procurement volume of photovoltaic system manufacturing enterprises decrease with the increase of silicon wafer cost of photovoltaic silicon wafer manufacturing enterprises; With the increase of price elasticity coefficient; With the improvement of technological innovation of photovoltaic system manufacturing enterprises.

Observation 3: From the optimal profits of photovoltaic silicon wafer manufacturing enterprises and the i photovoltaic system manufacturing enterprises, it can be seen that the greater the technological innovation, the greater the optimal retail volume of photovoltaic system manufacturing enterprises, the richer the government's industrial policy subsidies, and the greater the optimal profits of photovoltaic silicon wafer manufacturing enterprises and photovoltaic system manufacturing enterprises.

3.2 Solution of Vertical Cooperation and Horizontal Cooperation Model

Vertical collaboration and horizontal cooperation refer to the vertical collaborative innovation between photovoltaic silicon wafer manufacturing enterprises and photovoltaic system manufacturing enterprises, and the horizontal cooperation industrialization between photovoltaic system manufacturing enterprises. By establishing the cooperation model of each photovoltaic system manufacturing enterprise under the industrial policy guidance and horizontal cooperation relationship, and analyzing the optimal income of all photovoltaic system manufacturing enterprises under the horizontal cooperation situation, the expected profits of photovoltaic silicon wafer manufacturing enterprises and all photovoltaic system manufacturing enterprises can be established as follows:

$$\prod_G(W \quad q_i)=(\lambda W-(1-R_g)C_g)kQ-C_{Rg}+M_g=(\lambda W-(1-R_g)C_g)k\sum_{i=1}^{n}q_i-\frac{1}{2}hR_g+M_g.$$

$$\sum\prod_{Fi}(W \quad q_i)=\sum_{i=1}^{n}((P-k\lambda W-(1-R_{f_i})C_{f_i})q_i-C_{Rf_i}+M_g)=\sum_{i=1}^{n}((\frac{1}{\beta}\alpha-\frac{1}{\beta}\sum_{i=1}^{n}q_i-k\lambda W-(1-R_{f_i})C_{f_i})q_i-\frac{1}{2}hR_{fi}+M_g).$$

According to the solution, the optimal profit of photovoltaic silicon wafer manufacturing enterprise, the i photovoltaic system manufacturing enterprise and the collaborative innovation alliance of the whole photovoltaic industry is:

$$\prod_G\left(W^* \quad q_i^*\right)=\frac{\beta}{8}\left(\frac{1}{\beta}\alpha-k(1-R_g)C_g-(1-R_{f_i})C_{f_i}\right)^2-\frac{1}{2}hR_g+M_g$$

$$\prod_{Fi}\left(W^* \quad q_i^*\right)=\frac{\beta}{16n}\left(\frac{1}{\beta}\alpha-k(1-R_g)C_g-(1-R_{f_i})C_{f_i}\right)^2-\frac{1}{2}hR_{fi}+M_g$$

$$\prod(W \quad q_i)=\prod_G(W \quad q_i)+\sum_{i=1}^{n}\prod_{Fi}(W \quad q_i)=\frac{3\beta}{16}\left(\frac{1}{\beta}\alpha-k(1-R_g)C_g-(1-R_{f_i})C_{f_i}\right)^2-\frac{1}{2}h\sum_{i=1}^{n}R_{fi}-\frac{1}{2}hR_g+nM_g$$

Observation 4: It can be seen from q_i^* that under the government's industrial policy subsidies, the optimal sales volume and optimal silicon wafer procurement volume of photovoltaic system decrease with the increase of silicon wafer wholesale price; It decreases with the increase of marginal cost of photovoltaic system; With the increase of technological innovation; With the increase of government industrial policy funds; With the increase of the number of photovoltaic system manufacturing enterprises, it gradually decreases.

Observation 5: It can be seen from $\prod_G(W \quad q_i)$, $\prod_{Fi}(W \quad q_i)$ and $\prod(W \quad q_i)$ that the main profits of photovoltaic industry collaborative innovation alliance and the overall profits of the alliance increase with the increase of government industrial subsidy funds; It decreases with the increase of silicon wafer cost and marginal cost of photovoltaic system; With the increase of technological innovation; At the same time, the profits of photovoltaic system manufacturing enterprises decrease with the increase of the number of manufacturing enterprises; The total profit of the whole photovoltaic industry collaborative innovation alliance increases with the increase of demand elasticity coefficient.

3.3 Solution of Global Coordination Model

The overall coordination of the photovoltaic industry collaborative innovation alliance refers to the establishment of a dynamic balance relationship between the photovoltaic silicon wafer manufacturing enterprise and the photovoltaic system manufacturing enterprise. Since the photovoltaic silicon wafer manufacturing enterprise and the photovoltaic system manufacturing enterprise belong to the upstream and downstream relationship, the photovoltaic silicon wafer manufacturing enterprise and each photovoltaic system manufacturing enterprise can reach a coordination state, so as to maximize the interests of photovoltaic manufacturing enterprises. By establishing the coordination model of photovoltaic system manufacturing enterprises under the coordination mechanism, this paper analyzes the impact of government industrial policy subsidies and technological innovation on the coordination strategy of photovoltaic alliance subjects under the coordination mechanism. A new revenue cost sharing contract is introduced into the photovoltaic industry collaborative innovation alliance to coordinate the relationship between upstream and downstream manufacturing enterprises and distribute the total sales profit of all manufacturing enterprises according to a certain proportion. It is assumed that the profit cost distribution ratios of photovoltaic silicon wafer manufacturing enterprises and photovoltaic system manufacturing enterprises are θ and $1-\theta$ respectively. Then the expected profits of the photovoltaic silicon wafer manufacturing enterprise and the i photovoltaic system manufacturing enterprise can be expressed as:

$$\prod_G(W \quad q_i)=\sum_{i=1}^{n}\left((\lambda W-(1-R_g)C_g)kq_i+\frac{-\frac{1}{2}hR_g+M_g}{n}\right)$$

$$\prod_{Fi}(W \quad q_i)=(\frac{1}{\beta}\alpha-\frac{1}{\beta}\sum_{i=1}^{n}q_i-k\lambda W-(1-R_{fi})C_{fi})q_i-\frac{1}{2}hR_{fi}+M_g$$

The total profit function of photovoltaic silicon wafer manufacturing enterprises and all photovoltaic system manufacturing enterprises is:

$$\prod(W \quad q_i)=\prod_G(W \quad q_i)+\sum_{i=1}^{n}\prod_{Fi}(W \quad q_i)=\sum_{i=1}^{n}\left(\begin{array}{l}\left(\frac{1}{\beta}\alpha-\frac{1}{\beta}\sum_{i=1}^{n}q_i-k(1-R_g)C_g-(1-R_{fi})C_{fi}\right)q_i\\+\frac{-\frac{1}{2}hR_g+(n+1)M_g}{n}-\frac{1}{2}hR_{fi}\end{array}\right)$$

Through the solution, the expected profits of photovoltaic silicon wafer manufacturing enterprises, all photovoltaic system manufacturing enterprises and the total profits of photovoltaic industry collaborative innovation alliance are as follows:

$$\prod_G(W \quad q_i)=\theta\left(\begin{array}{l}\frac{\beta}{4}\left(\frac{1}{\beta}\alpha-k(1-R_g)C_g-(1-R_{fi})C_{fi}\right)^2\\-\frac{1}{2}hR_g+(n+1)M_g-\frac{1}{2}h\sum_{i=1}^{n}R_{fi}\end{array}\right)$$

$$\prod_{Fi}(W \quad q_i)=\frac{R_{fi}}{\sum_{i=1}^{n}R_{fi}}(1-\theta)\left(\begin{array}{l}\frac{\beta}{4}\left(\frac{1}{\beta}\alpha-k(1-R_g)C_g-(1-R_{fi})C_{fi}\right)^2\\-\frac{1}{2}hR_g+(n+1)M_g-\frac{1}{2}h\sum_{i=1}^{n}R_{fi}\end{array}\right)$$

$$\prod(W \quad q_i)=\frac{\beta}{4}\left(\frac{1}{\beta}\alpha-k(1-R_g)C_g-(1-R_{fi})C_{fi}\right)^2-\frac{1}{2}hR_g+(n+1)M_g-\frac{1}{2}h\sum_{i=1}^{n}R_{fi}$$

Observation 6: It can be seen from q_i^* that under the guidance of the government's industrial policy, the optimal sales volume and optimal silicon wafer procurement volume of photovoltaic system decrease with the increase of silicon wafer wholesale price, marginal cost and photovoltaic system manufacturing enterprises, and increase with the improvement of technological innovation.

Observation 7: It can be seen from $\prod_G(W \quad q_i)$, $\prod_{Fi}(W \quad q_i)$ and $\prod(W \quad q_i)$ that under the revenue cost sharing contract, the optimal profits of photovoltaic silicon wafer manufacturing enterprises and photovoltaic system manufacturing enterprises are affected by the capital subsidies of government industrial policies and the degree of technological innovation of each manufacturing enterprise, and increase with the increase of government industrial capital subsidies; With the improvement of technological innovation; It decreases with the increase of silicon wafer cost and marginal cost of photovoltaic system; The total profit of the whole alliance increases with the increase of demand elasticity coefficient.

4. Case Analysis

According to the relevant data in the 2019 Research Report on the development of China's photovoltaic industry, the analysis report of photovoltaic solar energy industry and other internal reports. Through analysis and sorting, the cost data and scale data of China's photovoltaic industry from 2010 to 2019 are obtained, of which the polycrystalline silicon cost and non-polycrystalline silicon cost data from 2013 to 2017 are the prediction data. The data are shown in Table 1.

Table 1
Cost and scale data of China's photovoltaic industry from 2010 to 2019

particular year	Polysilicon cost	Non polysilicon cost	PV module market scale（GW）
2010	0.38	2.47	10.8
2011	0.32	2.08	21
2012	0.29	1.76	23
2013	0.26	1.17	27.4
2014	0.23	1.09	35.6
2015	0.2	1.01	45.8
2016	0.18	0.93	53.7
2017	0.16	0.85	75
2018	0.13	0.77	84.3
2019	0.08	0.69	98.6

This paper studies the photovoltaic system industry based on power station construction. According to the 2019 Research Report on the development of China's photovoltaic industry, each photovoltaic system used for power station construction needs 72 silicon chips. The power of each photovoltaic system is about 24W and the conversion rate is 19.2%, so the power generated by each photovoltaic system is about 4.608w. The marginal cost and silicon chip cost of each photovoltaic system are calculated according to this; And this paper stipulates that there is one photovoltaic silicon wafer manufacturing enterprise and five photovoltaic system manufacturing enterprises. Based on the relative static analysis, it is assumed that the marginal cost of five photovoltaic system manufacturing enterprises is the average value and the average value + 2, + 4, - 2, - 4; At the same time, due to the large market demand range of photovoltaic system, the price demand elasticity coefficient is specified as 100 in this paper; Photovoltaic silicon wafer manufacturing enterprises and each photovoltaic system manufacturing enterprise have different degrees of technological innovation in the photovoltaic industry. The assumed conditions in this paper agree that the technological innovation degree of the enterprise is between 0-1, and the intermediate technological innovation degree is specified as 0.5. As the photovoltaic silicon wafer manufacturing enterprise is in a non-competitive state as an upstream enterprise, the technological innovation degree of the photovoltaic silicon wafer manufacturing enterprise is set as 0.5, Photovoltaic system manufacturing enterprises are in horizontal competition. In order to reflect the impact of different degrees of technological innovation on the optimal profits of photovoltaic system manufacturing enterprises, it is set that the technological innovation degrees of photovoltaic system manufacturing enterprises are different and fluctuate up and down around the intermediate technological innovation degree, The technological innovation degree of other photovoltaic system manufacturing enterprises is 0.3, 0.4, 0.5, 0.6 and 0.7 respectively, and the technological innovation cost coefficient is set to 500; In this paper, the government industrial fund subsidy is introduced as the industrial protection for manufacturing enterprises. The highest competitive reward given to photovoltaic product manufacturing enterprises is increasing year by year. From 2010, the reward is 2 million, increasing by 500000 year by year. Due to the construction of photovoltaic industry innovation alliance, the wholesale discount coefficient of silicon wafer given by upstream photovoltaic silicon wafer manufacturing enterprises to downstream photovoltaic system manufacturing enterprises is 0.8. There are five photovoltaic system manufacturing enterprises, accounting for 1% of the national photovoltaic system market. Based on this data, the relevant data required in this paper are calculated as shown in Table 2 (two decimal places are reserved).

Table 2
Product parameters of China's photovoltaic industry from 2010 to 2019 (yuan / W, yuan, GW)

Project parameters	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
C_g	0.38	0.32	0.29	0.26	0.23	0.2	0.18	0.16	0.13	0.08
C_{f1}	815.49	686.09	579.93	384.18	357.64	331.09	304.55	278.01	251.47	224.93
C_{f2}	817.49	688.09	581.93	386.18	359.64	333.09	306.55	280.01	253.47	226.93
C_{f3}	819.49	690.09	583.93	388.18	361.64	335.09	308.55	282.01	255.47	228.93
C_{f4}	821.49	692.09	585.93	390.18	363.64	337.09	310.55	284.01	257.47	230.93
C_{f5}	823.49	694.09	587.93	392.18	365.64	339.09	312.55	286.01	259.47	232.93
α	325520.83	632957.18	693238.81	825858.41	1073013.12	1380449.46	1618561.92	2260561.34	2540870.95	2971884.65
B_f	2000000	2500000	3000000	3500000	4000000	4500000	5000000	5500000	6000000	6500000

According to the data in Table 2, the optimal parameters of vertical coordination and horizontal competition of the photovoltaic industry under the guidance of industrial policy can be calculated, as shown in Table 3.

Table 3
Optimal parameters of alliance enterprises in the case of vertical collaboration and horizontal competition (pieces and Yuan)

Project parameters		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Vertical coordination and horizontal competition	$\prod_{F1}$	2589719.36	15755707.21	22349977.98	39214773.28	69594633.59	119509868.70	168126023.64	336216747.85	429733013.15	594038849.69
	$\prod_{F2}$	4469409.87	21118634.70	27668955.26	43801676.70	75312720.79	126455759.11	175684573.68	345962583.67	439649104.35	604406447.53
	$\prod_{F3}$	7659297.82	27430296.14	33677305.66	48719393.29	81340074.88	133696206.83	183521170.18	355999698.82	449848410.64	615062056.29
	$\prod_{F4}$	12178762.91	34706965.79	40388755.38	53976951.33	87685087.12	141238966.10	191642930.38	366334573.54	460336775.24	626010882.16
	$\prod_{F5}$	18047280.81	42965013.92	47817126.64	59583475.08	94356244.78	149091887.18	200057067.51	376973784.06	471120137.38	637258227.37
	$\prod_{G}$	172353988.64	751611318.15	924652567.85	1361699794.70	2326316990.15	3883118259.37	5363845895.02	10524988263.33	13326512675.38	18269286366.36
	$\prod$	217298459.41	893587935.92	1096554688.77	1606996064.37	2734605751.31	4553110947.29	6282877660.42	12306475651.28	15577200116.14	21346062829.40
Vertical collaboration and horizontal cooperation	$\prod_{F1}$	10915640.52	45099605.32	56072746.39	83106401.35	141065474.61	234529395.19	323639495.47	632993774.94	801565045.44	1098632455.43
	$\prod_{F2}$	11460150.91	46089064.58	57001904.21	83850630.63	141971774.86	235612811.86	324808256.90	634484637.13	803076059.03	1100206437.29
	$\prod_{F3}$	12023632.67	47095856.72	57945755.31	84606377.75	142891602.55	236712403.60	325995182.65	635999727.00	804613782.33	1101811153.89
	$\prod_{F4}$	12606328.03	48120185.16	58904471.26	85373755.58	143825062.56	237828267.33	327200361.70	637539125.55	806178288.39	1103446670.30
	$\prod_{F5}$	13208480.44	49162254.54	59878224.85	86152878.15	144772261.00	238960501.19	328423884.20	639102914.98	807769651.44	1105113052.80
	$\prod_{G}$	102237451.69	448459692.20	552458678.08	814564902.54	1392917150.47	2326625160.96	3214952951.53	6310498395.03	7992138948.35	10959612663.92
	$\prod$	162451684.25	684026658.52	842261780.10	1237654946.00	2107443326.04	3510268540.13	4845020132.45	9490618574.64	12015341774.99	16468822433.65
Overall coordination	$\prod_{F1}$	4079513.34	17412847.38	21444808.44	31548087.46	53795213.78	89688001.38	123838188.54	242745533.57	307358930.82	421348321.49
	$\prod_{F2}$	5439351.13	23217129.84	28593077.92	42064116.61	71726951.70	119584001.84	165117584.72	323660711.43	409811907.76	561797761.99
	$\prod_{F3}$	6799188.91	29021412.30	35741347.40	52580145.76	89658689.63	149480002.30	206396980.90	404575889.28	512264884.69	702247202.49
	$\prod_{F4}$	8159026.69	34825694.76	42889616.88	63096174.92	107590427.56	179376002.76	247676377.08	485491067.14	614717861.63	842696642.99
	$\prod_{F5}$	9518864.47	40629977.22	50037886.36	73612204.07	125522165.48	209272003.22	288955773.26	566406244.99	717170838.57	983146083.49
	$\prod_{G}$	178478708.84	761812072.90	938210369.18	1380228826.27	2353540602.79	3923850060.42	5417920748.56	10620117093.65	13446953223.23	18433989065.39
	$\prod$	212474653.38	906919134.41	1116917106.17	1643129555.08	2801834050.94	4671250071.93	6449905653.05	12642996540.06	16008277646.70	21945225077.84

It can be seen from the data in Table 3 that the profits of photovoltaic system manufacturing enterprises increased year by year from 2010 to 2019, mainly because the sales volume of photovoltaic systems increased year by year, but it was not unrelated to the industrial policy subsidies given by the government and the marginal cost of photovoltaic systems. The increase of government industrial policy subsidies and the reduction of marginal cost of photovoltaic system assembly increased the profits of photovoltaic manufacturing enterprises. At the same time, the profits of photovoltaic silicon wafer manufacturing enterprises are also increasing year by year, and the cost of silicon is also decreasing year by year. The rise of the wholesale price of silicon wafer is the main reason for the profit growth of photovoltaic silicon wafer manufacturing enterprises. The total profit of the photovoltaic industry collaborative innovation alliance has significantly increased year by year, thanks to the cooperation between the upstream and downstream enterprise entities of the alliance. At the same time, horizontal competition has promoted the silicon procurement and sales of photovoltaic system manufacturing enterprises. The increase of silicon procurement has promoted the profit of photovoltaic silicon manufacturing enterprises, to promote the profit of the whole alliance.

In the case of vertical collaboration and horizontal cooperation, the optimal silicon wafer wholesale volume and optimal photovoltaic system sales volume of photovoltaic system manufacturing enterprises are similar to those in the case of horizontal cooperation, which increase with the increase of silicon wafer sales and the annual increase of government industrial policy subsidies; The profits of photovoltaic silicon wafer manufacturing enterprises and photovoltaic system manufacturing enterprises rise.

Under the overall coordination of the alliance, the optimal silicon wafer wholesale volume and optimal photovoltaic system sales volume of photovoltaic system manufacturing enterprises are similar to those under the vertical coordination and horizontal competition, which increases with the sharp increase of silicon wafer sales and the annual increase of government industrial fund subsidies; The profits of photovoltaic silicon wafer manufacturing enterprises and photovoltaic system manufacturing enterprises rise accordingly; The profit of each photovoltaic system manufacturing enterprise increases with the increase of technological innovation. However, through the comparison of horizontal competition and horizontal cooperation, it can be found that the overall profit of the photovoltaic industry collaborative innovation alliance under the overall coordination of the alliance is growing faster and faster with time.

4.1 Collaborative Strategy Model of Photovoltaic Industry Chain Alliance under the Guidance of Competition Policy

4.1.1 Hypothetical Conditions

According to the construction and assumptions of the collaborative strategy model of photovoltaic industry alliance under industrial policy, some assumptions in this section are modified as follows:

Assumptions 1, 2, 3, 4 and 5 are not modified. Modify assumption 6 as follows:

Assumption 6: Government competition policy subsidies. To promote industrial market competitiveness, the government provides competitive capital subsidies to all enterprise entities in the photovoltaic industry collaborative innovation alliance. Use N_g to indicate the competition policy subsidy given by the government to photovoltaic silicon wafer manufacturing enterprises. The amount of subsidy funds that photovoltaic silicon wafer enterprises can obtain is related to the degree of technological innovation, so the competition reward that photovoltaic silicon wafer manufacturing enterprises can obtain is $R_g N_g$; N_F is the competition policy subsidy for photovoltaic system manufacturing enterprises. The competition policy fund subsidy that each photovoltaic system manufacturing enterprise can obtain is determined by the degree of technological innovation of each enterprise. Therefore, the competition policy fund subsidy that each photovoltaic system manufacturing enterprise can obtain is $\frac{R_{fi}}{\sum_{i=1} R_{fi}} N_F$.

According to the above assumptions, the expected profits of the photovoltaic silicon wafer manufacturing enterprise and the i photovoltaic system manufacturing enterprise can be obtained as follows:

$$\prod_G(W \quad q_i) = (\lambda W - (1-R_g)C_g)kQ - C_{Rg} + \mathrm{R}_g N_g = (\lambda W - (1-R_g)C_g)k\sum_{i=1}^{n} q_i - \frac{1}{2}hR_g + \mathrm{R}_g N_g$$

$$\prod_{Fi}(W \quad q_i) = (P - k\lambda W - (1-R_{f_i})C_{fi})q_i - C_{Rfi} + \frac{R_{fi}}{\sum_{i=1} R_{fi}} N_F = (\frac{1}{\beta}\alpha - \frac{1}{\beta}\sum_{i=1}^{n} q_i - k\lambda W - (1-R_{f_i})C_{fi})q_i - \frac{1}{2}hR_{fi} + \frac{R_{fi}}{\sum_{i=1} R_{fi}} N_F$$

4.2 Model Solving and Analysis

4.2.1 Solution of Vertical Cooperation and Horizontal Competition Model

Under the guidance of the government's competition policy, there is also competition among horizontal enterprise subjects in the photovoltaic industry alliance. There will be sales competition and profit competition among photovoltaic system manufacturing enterprises. The competition among photovoltaic system manufacturing enterprises and the impact of key factors on the optimal profit of manufacturing enterprises under the horizontal competition are analyzed by solving the optimal profit. The optimal profit of photovoltaic silicon wafer manufacturing enterprise and the i photovoltaic system manufacturing enterprise can be obtained as follows:

$$\prod_G\left(W^* \quad q_i^*\right)=\frac{1}{\frac{4}{\beta}n(n+1)}\left(n\left(\frac{1}{\beta}\alpha-k(1-R_g)C_g\right)-\sum_{i=1}^{n}(1-R_{f_i})C_{fi}\right)^2-\frac{1}{2}hR_g+\mathrm{R}_gN_g$$

$$\prod_{Fi}\left(W^* \quad q_i^*\right)=\beta\left(\frac{\frac{1}{\beta}\alpha-k(1-R_g)C_g}{2(n+1)}+\frac{2n+1}{2n(n+1)}\sum_{i=1}^{n}(1-R_{f_i})C_{fi}-(1-R_{f_i})C_{fi}\right)^2-\frac{1}{2}hR_{fi}+\frac{R_{fi}}{\sum_{i=1}R_{fi}}N_F$$

Observation 8: From the optimal profits of the photovoltaic silicon wafer manufacturing enterprise and the first photovoltaic system manufacturing enterprise, under the guidance of the government's competition policy, the profits of the enterprise main body of the photovoltaic industry collaborative innovation alliance have a great relationship with the overall value of the alliance, technological innovation factors and competitive capital subsidies. The competitive capital subsidies no longer have the same protective effect as the industrial policy subsidies, The acquisition of competition subsidies is directly linked to the technological innovation degree of the enterprise subject. The greater the technological innovation, the greater the government competition fund subsidy, and the greater the enterprise subject and the overall value of the photovoltaic industry alliance.

4.2.2 Solution of Vertical Cooperation and Horizontal Cooperation Model

By establishing the cooperation model of each photovoltaic system manufacturing enterprise under the guidance of government competition policy and horizontal cooperation relationship, the optimal income of all photovoltaic system manufacturers in the case of horizontal cooperation is analyzed. The optimal profit of photovoltaic silicon wafer manufacturing enterprise, the i photovoltaic system manufacturing enterprise and the collaborative innovation alliance of the whole photovoltaic industry is:

$$\prod{}_G\left(W^* \quad q_i^*\right)=\frac{\beta}{8}\left(\frac{1}{\beta}\alpha-k(1-R_g)C_g-(1-R_{f_i})C_{f_i}\right)^2-\frac{1}{2}hR_g+\mathrm{R}_gN_g$$

$$\prod{}_{Fi}\left(W^* \quad q_i^*\right)=\frac{\beta}{16n}\left(\frac{1}{\beta}\alpha-k(1-R_g)C_g-(1-R_{f_i})C_{f_i}\right)^2-\frac{1}{2}hR_{fi}+\frac{R_{fi}}{\sum_{i=1}R_{fi}}N_F$$

$$\prod(W \quad q_i)=\prod{}_G(W \quad q_i)+\sum_{\mathrm{i}=1}^{\mathrm{n}}\prod{}_{Fi}(W \quad q_i)=\frac{3\beta}{16}\left(\frac{1}{\beta}\alpha-k(1-R_g)C_g-(1-R_{f_i})C_{f_i}\right)^2-\frac{1}{2}h\sum_{i=1}^{n}R_{fi}-\frac{1}{2}hR_g+\mathrm{R}_gN_g+N_F$$

Observation 9: It can be seen from $\prod_G(W \quad q_i)$, $\prod_{Fi}(W \quad q_i)$ and $\prod(W \quad q_i)$ that under the guidance of government competition policy, the main profits of photovoltaic industry collaborative innovation alliance enterprises and the overall profits of the alliance increase with the increase of government competition fund subsidies; It decreases with the increase of silicon wafer cost and marginal cost of photovoltaic system; With the increase of technological innovation; At the same time, the profits of photovoltaic system manufacturing enterprises decrease with the increase of the number of manufacturing enterprises; The total profit of the whole photovoltaic industry collaborative innovation alliance increases with the increase of demand elasticity coefficient.

4.2.3 Solution of Global Coordination Model

Under the guidance of government competition policy, the revenue cost sharing contract is introduced into the photovoltaic industry collaborative innovation alliance to coordinate the relationship between upstream and downstream manufacturing enterprises and distribute the total sales profit of all manufacturing enterprises according to a certain proportion. The expected profits of photovoltaic silicon wafer manufacturing enterprises, all photovoltaic system manufacturing enterprises and the total profits of photovoltaic industry collaborative innovation alliance can be obtained as follows:

$$\prod{}_G(W \quad q_i)=\theta\begin{pmatrix}\frac{\beta}{4}\left(\frac{1}{\beta}\alpha-k(1-R_g)C_g-(1-R_{fi})C_{fi}\right)^2\\-\frac{1}{2}hR_g+\mathrm{R}_gN_g+N_F-\frac{1}{2}h\sum_{i=1}^{n}R_{fi}\end{pmatrix}$$

$$\prod_{Fi}(W \quad q_i)=\frac{R_{fi}}{\sum_{i=1} R_{fi}}(1-\theta)\left(\begin{array}{l}\frac{\beta}{4}\left(\frac{1}{\beta}\alpha-k(1-R_g)C_g-(1-R_{fi})C_{fi}\right)^2 \\ -\frac{1}{2}hR_g+\mathrm{R}_gN_g+N_F-\frac{1}{2}h\sum_{i=1}^{n}R_{fi}\end{array}\right)$$

$$\prod(W \quad q_i)=\frac{\beta}{4}\left(\frac{1}{\beta}\alpha-k(1-R_g)C_g-(1-R_{fi})C_{fi}\right)^2-\frac{1}{2}hR_g+\mathrm{R}_gN_g+N_F-\frac{1}{2}h\sum_{i=1}^{n}R_{fi}$$

Observation 10: It can be seen from $\prod_G(W \quad q_i)$, $\prod_{Fi}(W \quad q_i)$ and $\prod(W \quad q_i)$ that under the revenue cost sharing contract, the optimal profits of photovoltaic silicon wafer manufacturing enterprises and photovoltaic system manufacturing enterprises are affected by the capital subsidy of government competition policy and the degree of technological innovation of each manufacturing enterprise, and increase with the increase of government competition capital subsidy; With the improvement of technological innovation.

5. Case Analysis

According to the data in Table 2, the optimal profit statement of the alliance in the case of vertical coordination and horizontal competition of the photovoltaic industry under the guidance of government competition policy can be calculated, as shown in Table 4. It can be seen from the data in Table 4 that with the change of time axis, the optimal profits of both silicon wafer manufacturing enterprises and photovoltaic system manufacturing enterprises in the photovoltaic industry alliance are increasing year by year. The reason is that the sales volume of silicon wafer, the sales volume of photovoltaic systems and the subsidy of government competitive funds are increasing year by year. At the same time, according to the comparison of the annual optimal profits of the five photovoltaic system manufacturers, it can be found that with the increase of the degree of technological innovation, the optimal profits are also increasing year by year, indicating that the degree of technological innovation of enterprises is positively correlated with the optimal profits. From the perspective of the total value of the photovoltaic industry collaborative innovation alliance, the value created by the alliance increases year by year with the change of time.

In the case of vertical and horizontal cooperation among the enterprise entities of the photovoltaic industry collaborative innovation alliance, the optimal profits of the enterprise entities of the photovoltaic industry collaborative innovation alliance and the overall optimal profits of the alliance are increasing year by year. With the change of the time axis, the government has invested more and more competitive capital subsidies. At the same time, enterprises with a high degree of technological innovation can allocate more and more competitive capital subsidies, As a result, the optimal profits of the five photovoltaic system manufacturing enterprises gradually increased in the later stage; At the same time, as the photovoltaic silicon wafer manufacturing enterprises are in a noncompetitive state, their revenue gradually increases with the increase of silicon wafer demand of photovoltaic system manufacturing enterprises. Therefore, the overall profit of the alliance is also increasing year by year.

Under the overall coordination of the alliance, it increases with the increase of government competition reward year by year; The profits of photovoltaic silicon wafer manufacturing enterprises and photovoltaic system manufacturing enterprises rise; accordingly, the profit of each photovoltaic system manufacturing enterprise increases with the increase of technological innovation. However, through the comparison of horizontal competition and horizontal cooperation, it can be found that the overall profit of the photovoltaic industry collaborative innovation alliance under the overall coordination of the alliance is growing faster and faster with time. Under the overall coordination of the alliance, the overall value of the photovoltaic industry collaborative innovation alliance in 2019 is the largest.

5.1 Comparison of optimal coordination strategies of photovoltaic Alliance under different policy orientations

Combined with the analysis of the synergy strategy and empirical data of the enterprise entities of the photovoltaic industry alliance under the guidance of industrial policy and competition policy, and considering the optimal profit of the enterprise entities of the alliance and the overall development of the alliance, this paper makes a comparative optimization analysis on the choice of the synergy strategy of the enterprise entities of the alliance under the guidance of industrial policy and competition policy, as shown in Fig. 1 and Fig. 2.

Under the guidance of industrial policy, the collaborative strategy of the enterprise subject of photovoltaic industry collaborative innovation alliance is shown in Fig. 1. For photovoltaic wafer manufacturing enterprises, photovoltaic wafer manufacturing enterprises prefer the overall coordination strategy of the alliance. According to the income cost sharing coefficient under the overall coordination, photovoltaic wafer manufacturing enterprises can obtain more than 80% of the profits; The second cooperation strategy of photovoltaic silicon wafer enterprises is the vertical cooperation and horizontal competition strategy, and its profit is much larger than that in the case of horizontal cooperation.

Table 4
Optimal profit statement of each coordination strategy of alliance enterprise subject under Competition (piece, yuan)

Project parameters		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Vertical coordination and horizontal competition	$\prod_{F1}$	1789719.36	14755707.21	21149977.98	37814773.28	67994633.59	117709868.70	166126023.64	334016747.85	427333013.15	591438849.69
	$\prod_{F2}$	4069409.87	20618634.70	27068955.26	43101676.70	74512720.79	125555759.11	174684573.68	344862583.67	438449104.35	603106447.53
	$\prod_{F3}$	7659297.82	27430296.14	33677305.66	48719393.29	81340074.88	133696206.83	183521170.18	355999698.82	449848410.64	615062056.29
	$\prod_{F4}$	12578762.91	35206965.79	40988755.38	54676951.33	88485087.12	142138966.10	192642930.38	367434573.54	461536775.24	627310882.16
	$\prod_{F5}$	18847280.81	43965013.92	49017126.64	60983475.08	95956244.78	150891887.18	202057067.51	379173784.06	473520137.38	639858227.37
	$\prod_{G}$	172353988.64	751611318.15	924652567.85	1361699794.70	2326316990.15	3883118259.37	5363845895.02	10524988263.33	13326512675.38	18269286366.36
	$\prod$	217298459.41	893587935.92	1096554688.77	1606996064.37	2734605751.31	4553110947.29	6282877660.42	12306475651.28	15577200116.14	21346062829.40
Vertical collaboration and horizontal cooperation	$\prod_{F1}$	10115640.52	44099605.32	54872746.39	81706401.35	139465474.61	232729395.19	321639495.47	630793774.94	799165045.44	1096032455.43
	$\prod_{F2}$	11060150.91	45589064.58	56401904.21	83150630.63	141171774.86	234712811.86	323808256.90	633384637.13	801876059.03	1098906437.29
	$\prod_{F3}$	12023632.67	47095856.72	57945755.31	84606377.75	142891602.55	236712403.60	325995182.65	635999727.00	804613782.33	1101811153.89
	$\prod_{F4}$	13006328.03	48620185.16	59504471.26	86073755.58	144625062.56	238728267.33	328200361.70	638639125.55	807378288.39	1104746670.30
	$\prod_{F5}$	14008480.44	50162254.54	61078224.85	87552878.15	146372261.00	240760501.19	330423884.20	641302914.98	810169651.44	1107713052.80
	$\prod_{G}$	102237451.69	448459692.20	552458678.08	814564902.54	1392917150.47	2326625160.96	3214952951.53	6310498395.03	7992138948.35	10959612663.92
	$\prod$	162451684.25	684026658.52	842261780.10	1237654946.00	2107443326.04	3510268540.13	4845020132.45	9490618574.64	12015341774.99	16468822433.65
Overall coordination	$\prod_{F1}$	4079513.34	17412847.38	21444808.44	31548087.46	53795213.78	89688001.38	123838188.54	242745533.57	307358930.82	421348321.49
	$\prod_{F2}$	5439351.13	23217129.84	28593077.92	42064116.61	71726951.70	119584001.84	165117584.72	323660711.43	409811907.76	561797761.99
	$\prod_{F3}$	6799188.91	29021412.30	35741347.40	52580145.76	89658689.63	149480002.30	206396980.90	404575889.28	512264884.69	702247202.49
	$\prod_{F4}$	8159026.69	34825694.76	42889616.88	63096174.92	107590427.56	179376002.76	247676377.08	485491067.14	614717861.63	842696642.99
	$\prod_{F5}$	9518864.47	40629977.22	50037886.36	73612204.07	125522165.48	209272003.22	288955773.26	566406244.99	717170838.57	983146083.49
	$\prod_{G}$	178478708.84	761812072.90	938210369.18	1380228826.27	2353540602.79	3923850060.42	5417920748.56	10620117093.65	13446953223.23	18433989065.39
	$\prod$	212474653.38	906919134.41	1116917106.17	1643129555.08	2801834050.94	4671250071.93	6449905653.05	12642996540.06	16008277646.70	21945225077.84

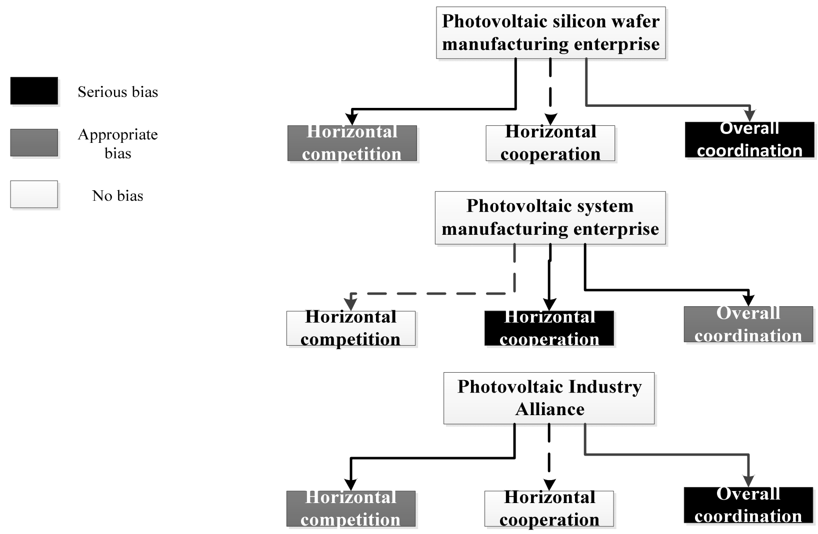

Fig. 1. Coordination strategy of enterprise entities of photovoltaic industry alliance under the guidance of industrial policy

Photovoltaic system manufacturing enterprises prefer to choose vertical collaboration and horizontal cooperation strategy. Whether it is horizontal competition or overall coordination, most of the profits are ultimately obtained by photovoltaic silicon wafer manufacturing enterprises, and photovoltaic system manufacturing enterprises can only obtain less profits. However, in the case of horizontal cooperation, photovoltaic system manufacturing enterprises can obtain more optimal profits. For the overall value of the alliance, the photovoltaic industry alliance is more inclined to the overall coordination strategy. According to the comparison of the overall alliance profits under the three coordination situations, it is found that the profits of the photovoltaic industry alliance under the overall coordination are the best, followed by the profits under the vertical coordination and horizontal competition strategy.

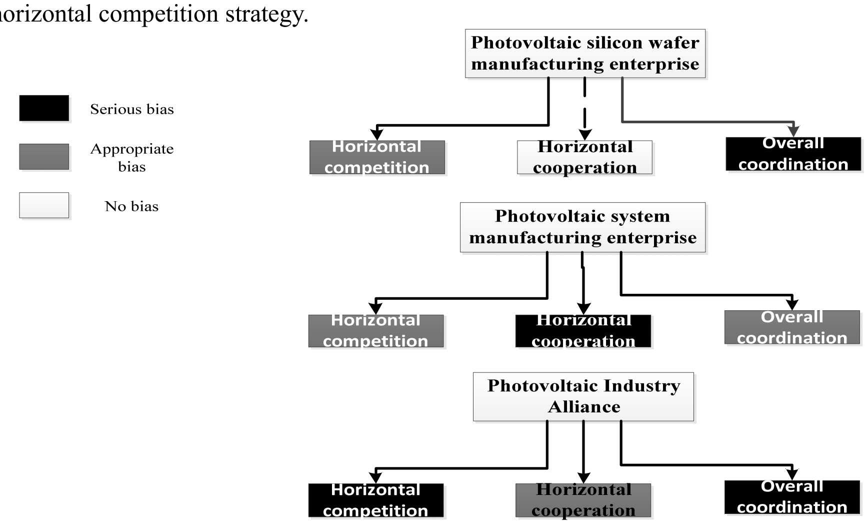

Fig. 2. coordination strategy of enterprise entities of photovoltaic industry alliance under the guidance of competition policy

Under the guidance of competition policy, the collaborative strategy of the enterprise subject of photovoltaic industry collaborative innovation alliance is shown in Fig. 2. The coordination strategy selected by photovoltaic silicon wafer manufacturing enterprises is like that under the guidance of industrial policy, and they are more inclined to the overall coordination strategy of the alliance and the vertical coordination and horizontal competition strategy. Although PV system manufacturing enterprises prefer to choose vertical collaboration and horizontal cooperation strategy, through the comparison of the optimal profits of PV system manufacturing enterprises under competition policy and industrial policy, the optimal profits under the guidance of competition policy increase to varying degrees. Therefore, PV system manufacturing enterprises will moderately prefer horizontal competition and overall coordination strategy. PV industry alliance is more inclined to vertical coordination, horizontal competition and overall coordination strategy. The overall profit of the alliance under these two coordination methods is much greater than that under horizontal cooperation.

6. Conclusion

This paper studies the collaborative strategy of photovoltaic industry chain alliance under the guidance of industrial policy and competition policy. Through the construction of profit model and actual case analysis, the following conclusions are drawn:

(1) Under the guidance of industrial policy, photovoltaic silicon wafer manufacturing enterprises prefer the overall coordination strategy of the alliance. The second coordination strategy is the vertical coordination and horizontal competition strategy; Photovoltaic system manufacturing enterprises prefer to choose vertical cooperation and horizontal cooperation strategy; The photovoltaic industry alliance is more inclined to the overall coordination strategy, followed by the vertical coordination and horizontal competition strategy.

(2) Under the guidance of competition policy, the cooperation strategy selected by photovoltaic silicon wafer manufacturing enterprises is similar to that under the guidance of industrial policy, which is more inclined to the overall coordination strategy of the alliance and the vertical cooperation and horizontal competition strategy; Although PV system manufacturing enterprises prefer to choose vertical collaboration and horizontal cooperation strategy, they moderately prefer horizontal competition and overall coordination strategy; PV industry alliance is more inclined to vertical coordination, horizontal competition and overall coordination strategy.

(3) Through the comparison between industrial policy orientation and competition policy orientation, it is found that under the guidance of competition policy, the optimal profits of each subject of photovoltaic industry chain alliance increase in varying degrees.

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Appendix：

$$\frac{\partial\prod_{Fi}(W \quad q_i)}{\partial q_i}=(\frac{1}{\beta}\alpha-\frac{1}{\beta}\sum_{i=1}^{n}q_i-k\lambda W-(1-R_{f_i})C_{fi})-\frac{1}{\beta}q_i$$

$$\frac{\partial^2\prod_{Fi}(W \quad q_i)}{\partial q_i^2}=-\frac{2}{\beta}\prec 0$$

令 $\frac{\partial\prod_{Fi}(W \quad q_i)}{\partial q_i}=0$； The reaction function can be obtained:

$$q_i=\frac{(\frac{1}{\beta}\alpha-\frac{1}{\beta}\sum_{l\neq i}q_l-k\lambda W-(1-R_{f_i})C_{fi})}{\frac{2}{\beta}}$$

Similarly, we can obtain: $q_j=\frac{(\frac{1}{\beta}\alpha-\frac{1}{\beta}\sum_{l\neq j}q_l-k\lambda W-(1-R_{fj})C_{fj})}{\frac{2}{\beta}}$ 。

Order q_i-q_j , we can get: $q_j=q_i-\beta((1-R_{fj})C_{fj}-(1-R_{f_i})C_{fi})$ ， Put $j=1,2,\cdots,i-1,i+1,\cdots,n$ into the reaction function and we get:

$$\sum_{l\neq i}q_l=q_1+q_2+\cdots+q_{i-1}+q_{i+1}+\cdots+q_n$$
$$=(n-1)q_i-\beta(\sum_{j\neq i}(1-R_{fj})C_{fj}-(n-1)R_{f_i}C_{fi})$$

Therefore, the following can be obtained:

$$q_i=\frac{(\frac{1}{\beta}\alpha-\frac{1}{\beta}\sum_{l\neq i}q_l-k\lambda W-(1-R_{f_i})C_{fi})}{\frac{2}{\beta}}$$

$$\frac{2}{\beta}q_i=\frac{1}{\beta}\alpha-\frac{1}{\beta}(n-1)q_i+\sum_{j\neq i}(1-R_{fj})C_{fj}-(n-1)(1-R_{f_i})C_{fi}-k\lambda W-(1-R_{f_i})C_{fi}$$

$$\frac{1}{\beta}(n+1)q_i=\frac{1}{\beta}\alpha+\sum_{j\neq i}(1-R_{fj})C_{fj}-n(1-R_{f_i})C_{fi}-k\lambda W$$

From the above formula: $q^*_i(W)=\frac{\frac{1}{\beta}\alpha+\sum_{j\neq i}(1-R_{fj})C_{fj}-n(1-R_{f_i})C_{fi}-k\lambda W}{\frac{1}{\beta}(n+1)}$ ， so

$$\sum_{i=1}^{n}q^*_i(W)=\frac{n\left(\frac{1}{\beta}\alpha-k\lambda W\right)-\sum_{i=1}^{n}(1-R_{f_i})C_{fi}}{\frac{1}{\beta}(n+1)}$$

Substituting $\sum_{i=1}^{n}q^*_i(W)$ into the expected profit function of photovoltaic silicon wafer manufacturing enterprises, we can get:

$$\prod_G\left(W \quad q^*_i(W)\right) = (\lambda W - (1-R_g)C_g)k\sum_{i=1}^{n} q_i - \frac{1}{2}hR_g + M_g$$

$$= (\lambda W - (1-R_g)C_g)k\left(\frac{n\left(\frac{1}{\beta}\alpha - k\lambda W\right) - \sum_{i=1}^{n}(1-R_{f_i})C_{fi}}{\frac{1}{\beta}(n+1)}\right) - \frac{1}{2}hR_g + M_g$$

The first-order derivative function and the second-order derivative function of the expected profit of the photovoltaic silicon wafer manufacturing enterprise with respect to W are as follows:

$$\frac{\partial\prod_G\left(W \quad q^*_i(W)\right)}{\partial W} = \frac{\lambda k}{\frac{1}{\beta}(n+1)}\left(n\left(\frac{1}{\beta}\alpha - k\lambda W\right) - \sum_{i=1}^{n}(1-R_{f_i})C_{fi} - nk(\lambda W - (1-R_g)C_g)\right)$$

$$\frac{\partial^2\prod_G\left(W \quad q^*_i(W)\right)}{\partial W^2} = \frac{-2nk^2\lambda^2}{\frac{1}{\beta}(n+1)} \prec 0$$

The first derivative function of the profit function of photovoltaic silicon wafer manufacturing enterprises $\frac{\partial\prod_G\left(W \quad q^*_i(W)\right)}{\partial W} = 0$,

The optimal wholesale price of silicon wafer can be obtained as follows:

$$W^* = \frac{n\left(\frac{1}{\beta}\alpha + k(1-R_g)C_g\right) - \sum_{i=1}^{n}(1-R_{f_i})C_{fi}}{2nk\lambda}$$

By substituting W^* into $q^*_i(W)$, the optimal sales volume of the i photovoltaic system manufacturing enterprise can be obtained as follows:

$$q^*_i(W) = \beta\left(\frac{\frac{1}{\beta}\alpha + k(1-R_g)C_g}{2(n+1)} + \frac{2n+1}{2n(n+1)}\sum_{i=1}^{n}(1-R_{f_i})C_{fi} - (1-R_{f_i})C_{fi}\right)$$

Then there are:

$$\sum_{i=1}^{n} q^*_i\left(W^*\right) = \frac{1}{\frac{2}{\beta}(n+1)}\left(n\left(\frac{1}{\beta}\alpha - k(1-R_g)C_g\right) - \sum_{i=1}^{n}(1-R_{f_i})C_{fi}\right)$$

Therefore, it can be seen that the optimal profit of photovoltaic silicon wafer manufacturing enterprise and the i photovoltaic system manufacturing enterprise is:

$$\prod_G\left(W^* \quad q^*_i\right) = \frac{1}{\frac{4}{\beta}n(n+1)}\left(n\left(\frac{1}{\beta}\alpha - k(1-R_g)C_g\right) - \sum_{i=1}^{n}(1-R_{f_i})C_{fi}\right)^2 - \frac{1}{2}hR_g + M_g$$

$$\prod_{Fi}\left(W^* \quad q^*_i\right) = \beta\left(\frac{\frac{1}{\beta}\alpha - k(1-R_g)C_g}{2(n+1)} + \frac{2n+1}{2n(n+1)}\sum_{i=1}^{n}(1-R_{f_i})C_{fi} - (1-R_{f_i})C_{fi}\right)^2 - \frac{1}{2}hR_{fi} + M_g$$