Research on Steel Sales Incentive Mechanism Based on Supply Chain Collaboration

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Abstract: The iron and steel industry plays a pivotal role in China's industrial development, this article builds a closed supply chain of producers, sellers, and consumers for the current situation of steel sales model and existing problems in China. In order to enable steel companies to respond to direct sales and agents in different market changes, under the circumstances of recycling, the incentive mechanism model of principal-agent/direct sales is constructed. Then this article studied the relationship between expected returns of steel producers, market uncertainties, incentive factors, risk aversion factors, and effort costs. The research results have very important practical significance for the development and management of China's steel sales chain.

1. Introduction

The rapid development of the steel industry has accelerated the process of industrialization, urbanization and national defense. Today's steel companies not only need to face fierce competition from their peers but also need to withstand the cruel test of the market.

Patricia Guarnieri proposes a framework-based multi-criteria decision-making approach, MCDA modeling, to help business decision makers select the most appropriate third party with a set of system standards [1]. Majumder and Groenevelt studied the competition caused by the remanufacturing of third-party remanufacturers to replace the initial product [2]. Chi Yunyi studied the incentive problem of closed-loop supply chain based on principal-agent theory and conducted case analysis [3]. Wang Yajie constructed a long-term incentive mechanism model for supply chain financial financing based on principal-agent theory [4]. From the perspective of quality management, Qin Qiong explores the factors affecting the quality of recycled products under asymmetric information conditions and establishes a principal-agent model [5]. Existing research shows that a reasonable incentive mechanism can promote cooperation between members of the supply chain to become more compact and convenient, and the interests tend to be consistent in order to maximize the system benefits.

This paper conducts a detailed study on China's steel sales supply chain model, constructs an incentive mechanism model of principal-agent/direct sales, and proposes a reasonable solution for the sales of steel enterprises by analyzing the game between direct sales and agency.

2. Member Expectation Benefit and Behavior Decision Analysis

Suppose the seller only carries out the sales work, and the steel producer is responsible for the production and has a certain part of the direct sales. The steel sales price is p, the unit cost price is C_m and $\mathrm{p} > C_m$, The steel sales output function is as follows:

$$q_i = a_i + \varepsilon \quad i = 1,2 \tag{1}$$

In the formula (1), q_i represents the result of steel sales efforts, a_i represents the effort variable, a_1 represents the sales effort of steel sellers, a_2 represents the degree of direct sales efforts of steel producers; ε represents the steel market Random factor.

Producers develop agency contracts and production cost functions for sellers and producers based on steel sales are as follows:

$$S(q_1) = \alpha + \beta(p - C_m)q_1 \tag{2}$$

$$S(q_2) = \lambda + \eta(p - C_m)q_2 \tag{3}$$

In the formula (2)-(3), α is the fixed agency fee that the seller receives from the manufacturer, λ is a fixed expenditure in the direct sales process of the manufacturer, β is the revenue that the seller obtains from the manufacturer through agency sales, η is the cost of expenditure generated by the manufacturer through direct sales.

Assuming that the effort cost $C(a_i)$ of the seller and the manufacturer can be equivalent to the monetary cost, this article uses the classic effort cost function. b_i represents the cost factor.

$$C(a_i) = b_i {a_i}^2/2 \tag{4}$$

Producer revenue v can be described as follows:

$$v = (p - C_m)q_1 + (p - C_m)q_2 - S(q_1) - S(q_2) \tag{5}$$

Producer's and seller's actual income (ω_2、ω_1)are as follows:

$$\omega_2 = v - S(q_2) - S(q_1) - C(a_2) \tag{6}$$

$$\omega_1 = S(q_1) - C(a_1) \tag{7}$$

Producer's and seller's deterministic equivalent income are as follows, Ev is the expected income of the producer, Ew is the expected income of the seller, ρ_i indicates absolute risk avoidance.

$$v = Ev - \frac{1}{2}\rho_2\eta^2(p - C_m)^2\delta^2 \tag{8}$$

$$\omega_2 = Ew - \frac{1}{2}\rho_1\beta^2(p - C_m)^2\delta^2 \tag{9}$$

Both producers and sellers use the utility function of absolute risk aversion, ρ_i indicates the absolute risk aversion of the seller and the manufacturer, ω represents the actual revenue of the seller.

$$u = -e^{-\omega\rho_i} \tag{10}$$

The best incentives that producers provide to vendors need to be constrained by incentive compatibility constraints. u_1 is the seller's own retained earnings level, u_2 is the producer's own direct retained earnings level. Vendor and manufacturer incentive compatibility constraints are as follows:

$$\alpha + \beta(p - C_m)a_1 - b_1{a_1}^2/2 - \frac{1}{2}\rho_1\beta^2(p - C_m)^2\delta^2 \geq u_1 \tag{11}$$

$$\lambda + \eta(p - C_m)a_2 - b_2{a_2}^2/2 - \frac{1}{2}\rho_2\eta^2(p - C_m)^2\delta^2 \geq u_2 \tag{12}$$

$$a_1 \in arg\max_{\delta_1} \omega = \alpha + \beta(p - C_m)a_1 - b_1{a_1}^2/2 - \frac{1}{2}\rho_1\beta^2(p - C_m)^2\delta^2 \tag{13}$$

$$a_2 \in arg\max_{\delta_2} v = \lambda + \eta(p - C_m)a_2 - b_2{a_2}^2/2 - \frac{1}{2}\rho_2\eta^2(p - C_m)^2\delta^2 \tag{14}$$

The vendor and manufacturer decision models are as follow:

$$\max_{\delta_1}\omega = \alpha + \beta(p - C_m)a_1 - b_1{a_1}^2/2 - \frac{1}{2}\rho_1\beta^2(p - C_m)^2\delta^2 \tag{15}$$

$$\max_{\beta,\eta} Ev = (1-\beta)(p-C_m)q_1 + (1-\eta)(p-C_m)q_2 - \lambda - \alpha \tag{16}$$

3. Commission-agent / direct marketing incentive model Literature References

3.1 Commission-agent/direct marketing incentive model under the condition of information symmetry

When the information of the producer and the seller, as well as the producer and the market, are symmetrical, Manufacturer and vendor incentive compatibility constraints do not exist. The manufacturer's decision model can be expressed as follows:

$$\max_{\beta,\eta} Ev = (1-\beta)(p-C_m)a_1 + (1-\eta)(p-C_m)a_2 - \alpha - \lambda \tag{17}$$

$$\alpha + \beta(p-C_m)a_1 - b_1{a_1}^2/2 - \frac{1}{2}\rho_1\beta^2(p-C_m)^2\delta^2 \geq u_1 \tag{18}$$

$$\lambda + \eta(p-C_m)a_2 - b_2{a_2}^2/2 - \frac{1}{2}\rho_2\eta^2(p-C_m)^2\delta^2 \geq u_2 \tag{19}$$

In the case of information symmetry, the constraint (18)(19) is established.

$$a_1^* = \frac{p-C_m}{b_1} \quad a_2^* = \frac{p-C_m}{b_2} \quad \beta^* = 0 \;\; \eta^* = 0 \tag{20}$$

Bring formula (20) into formula (17):

$$\alpha^* = u_1 + \frac{(p-C_m)^2}{2b_1} \quad \lambda^* = u_2 + \frac{(p-C_m)^2}{2b_2} \tag{21}$$

Bring formula (18) into formula (14), Manufacturers expected revenue is as follows:

$$E_v^* = \frac{(p-C_m)^2}{2b_1} + \frac{(p-C_m)^2}{2b_2} - u_1 - u_2 \tag{22}$$

3.2 Commission-agent/direct sales incentive mechanism model under asymmetric information

In fact, the situation in which the information of the producer and the seller is symmetrical is basically non-existent. Under these circumstances, the manufacturer's decision model can be expressed as follows:

$$\max_{\beta,\eta} Ev = (1-\beta)(p-C_m)q_1 + (1-\eta)(p-C_m)q_2 - \lambda - \alpha - b_2{a_2}^2/2 - \frac{1}{2}\rho_2\eta^2(p-C_m)^2\delta^2 \tag{23}$$

$$a_1 \in arg\max_{\delta_1} \omega = \alpha + \beta(p-C_m)a_1 - b_1{a_1}^2/2 - \frac{1}{2}\rho_1\beta^2(p-C_m)^2\delta^2 \tag{24}$$

$$a_2 \in arg\max_{\delta_2} v = \lambda + \eta(p-C_m)a_2 - b_2{a_2}^2/2 - \frac{1}{2}\rho_2\eta^2(p-C_m)^2\delta^2 \tag{25}$$

$$\alpha + \beta(p-C_m)a_1 - b_1{a_1}^2/2 - \frac{1}{2}\rho_1\beta^2(p-C_m)^2\delta^2 \geq u_1 \tag{26}$$

$$\lambda + \eta(p-C_m)a_2 - b_2{a_2}^2/2 - \frac{1}{2}\rho_2\eta^2(p-C_m)^2\delta^2 \geq u_2 \tag{27}$$

After a series of calculations, manufacturers expected revenue is as follows:

$$Ev^{as} = \frac{(p-C_m)^2}{2b_1(1+b_1\rho_1\delta^2)} + \frac{(p-C_m)^2}{2b_2(1+b_2\rho_2\delta^2)} - u_1 - u_2 \tag{28}$$

3.3 Comparative analysis of two different information type models

According to the above model, after a series of calculations, the algebraic formula of each decision factor in two different information cases is obtained. As shown in Table 1.

Table 1 Three Scheme comparing Comparison of decision factors and producers' income in two information environments

Information Type	a_1^*	a_2^*	β^*	η^*	Ev^*
symmetry	$\frac{p-C_m}{b_1}$	$\frac{p-C_m}{b_2}$	0	0	$\frac{(p-C_m)^2}{2b_1}+\frac{(p-C_m)^2}{2b_2}-u_1-u_2$
asymmetry	$\frac{\beta(p-C_m)}{b_1}$	$\frac{\beta(p-C_m)}{b_2}$	$\beta^{as}=\frac{1}{1+b_1\rho_1\delta^2}$	$\eta^{as}=\frac{1}{1+b_2\rho_2\delta^2}$	$\frac{(p-C_m)^2}{2b_1(1+b_1\rho_1\delta^2)}+\frac{(p-C_m)^2}{2b_2(1+b_2\rho_2\delta^2)}-u_1-u_2$

Through comparative analysis, we get the following conclusions.

1) When information is asymmetrical, the excitation coefficient β,η decreases as the risk avoidance factor ρ_i and the cost coefficients b_i increase. When the risk aversion factor of the seller and the manufacturer is too high, the manufacturer should abandon the incentive and choose to sign a fixed payment contract with the seller. And manufacturers also need to abandon the direct sales business and hand over all sales of steel to the seller.

2) When information is asymmetrical, the excitation coefficient β,η is negatively correlated with the market uncertainty factor δ_i^2. When δ_i^2 tends to infinity, means that the sales market is extremely pessimistic, manufacturers cannot predict market conditions. In order to maintain their own profits, producers should choose to sign a fixed payment contract with the seller, and they should abandon the direct sales business and transfer all sales to the dealer.

3) When information is asymmetrical, the expected return of the producer is negatively correlated with the risk aversion factor ρ_i, the cost coefficient b_i and the market uncertainty δ_i^2 factor.

4) Use θ to indicate the relative incentive strength between steel seller sales and producer direct sales: $\theta=\beta^{as}/\eta^{as}$. Deriving the risk avoidance factor ρ_i by the relative excitation strength θ, we find that the relative incentive intensity is positively correlated with the risk aversion factor. So when the risk evasion factor of the seller increases, the manufacturer should appropriately consider the direct selling business, reduce the proportion of the expected profit of the seller's agent, and reduce the sales incentive coefficient β of the high seller to maximize its own benefits. Deriving the effort cost coefficient by relative excitation intensity θ, we find that the relative incentive intensity is negatively correlated with the seller's sales effort cost coefficient and positively correlated with the manufacturer's direct sales effort cost coefficient. So when considering the incentive level, manufacturers should increase their investment in direct sales to producers and reduce the incentive coefficient for sellers. Deriving market uncertainties by relative excitation intensity θ, we find that the relative incentive intensity is negatively correlated with the uncertainty of the steel sales market. The higher the market uncertainty, the lower the incentive level for the seller.

4. Case study

The case is based on the Hexi Branch of Jiugang Group. The cost that the producer needs to pay is equal to the expected return of the producer under the symmetry of the information minus the expected return of the producer under the information asymmetry.

$$\Delta v=Ev^*-Ev^{as}=\frac{(p-C_m)^2}{2b_1}\left(1-\frac{1}{1+b_1\rho_1\delta^2}\right)+\frac{(p-C_m)^2}{2b_2}\left(1-\frac{1}{1+b_2\rho_2\delta^2}\right) \quad (29)$$

Similarly, the additional cost of the producer, agency cost of manufacturer, direct selling cost of the manufacturer can be shown as follows:

$$Ev_{\text{Direct}}{}^{*} - Ev_{\text{Direct}}{}^{as} = \frac{(p-C_m)^2}{2b_2}\left(1-\frac{1}{1+b_2\rho_2\delta^2}\right) \quad (30)$$

$$Ev_{\text{Agency}}{}^{*} - Ev_{\text{Agency}}{}^{as} = \frac{(p-C_m)^2}{2b_1}\left(1-\frac{1}{1+b_1\rho_2\delta^2}\right) \quad (31)$$

$$Ev^{as} = \frac{(p-C_m)^2}{2b_1(1+b_1\rho_1\delta^2)} + \frac{(p-C_m)^2}{2b_2(1+b_2\rho_2\delta^2)} - u_1 - u_2 \quad (32)$$

4.1 Analysis of the relationship between risk aversion factor and cost and benefit

When studying the relationship between the risk aversion factor of the seller and the cost and benefit, the risk evading factor of the seller's producer is taken as a single independent variable.

1) ρ_1=0.015,0.025,0.035,0.045,0.055, According to the manufacturer's agency cost formula, the calculation results are as follows:

Table 2 Agency costs and expected benefits for two different sheets of steel (RMB)

ρ_1		0.015	0.025	0.035	0.045	0.055
Plate	Δv	19728.26	30250.00	39212.96	46939.66	53669.35
	Ev^{as}	111793.48	90750.00	72824.08	57370.68	43911.30
Rebar	Δv	35713.04	54760.00	70985.18	84972.41	97154.84
	Ev^{as}	202373.92	164380.00	131829.63	103855.18	79490.32

Based on the tabular data, we can derive the relationship between the vendor risk aversion factor and the cost, also the relationship between the vendor risk aversion factor and the expected return.

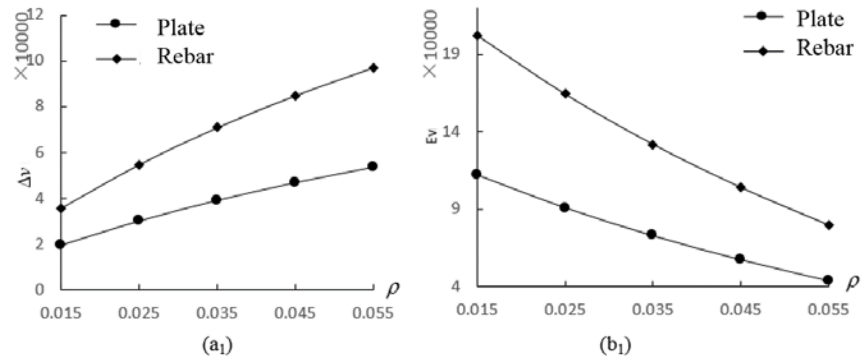

Fig. 1 Relationship between vendor risk aversion factor and producer agent cost (a1) and expected return (b1)

The figure shows that the expected return of the manufacturer's sales of steel products through the seller is a decreasing relationship with the risk aversion factor of the seller, and the greater the risk aversion factor of the seller, the less the profit the producer receives from the seller. In this case, the manufacturer needs to appropriately increase the incentive level for the seller to increase its own revenue. This is consistent with the conclusion in 3.3.

2) ρ_2 =0.01,0.02,0.03,0.04,0.05, According to the manufacturer's direct cost formula, the calculation results are as follows:

Table 3 Direct selling costs for two different sheets of steel and expected direct sales (RMB)

ρ_2		0.01	0.02	0.03	0.04	0.05
Plate	Δv	13750.00	25208.33	34903.85	43214.29	50416.67
	Ev^{as}	123750.00	100833.34	81442.30	64821.42	50416.67
Rebar	Δv	24890.91	45633.33	63184.62	78228.57	91266.67
	Ev^{as}	224018.18	182533.34	147430.76	117342.86	91266.67

Based on the tabular data, we can derive the relationship between the vendor risk aversion factor and the cost, also the relationship between the vendor risk aversion factor and the expected return.

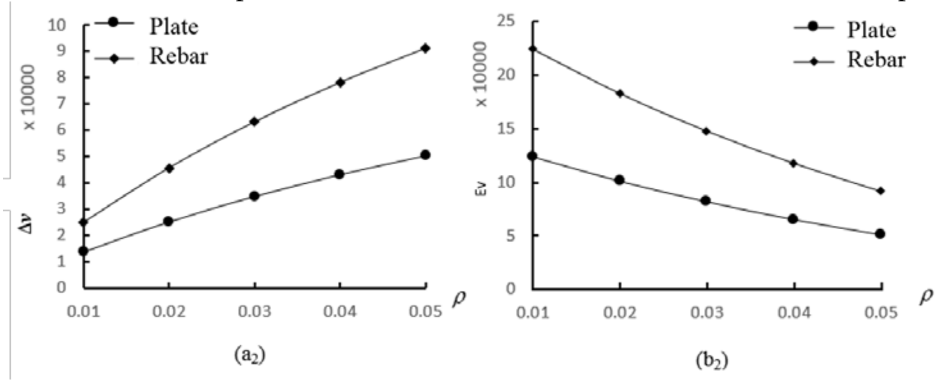

Fig. 2 Relationship between producer risk aversion factor and producer direct selling cost (a2) and expected return (b2)

The figure shows that the relationship between the expected return of the manufacturer's direct sales of steel products and the manufacturer's risk aversion factor is a decreasing relationship, and the greater the manufacturer's risk aversion factor, the less profit the producer receives. In this case, manufacturers need to appropriately increase the incentive level for sellers, reduce the proportion of direct sales and direct investment, to protect their own income. This is consistent with the conclusion in 3.3.

4.2 Analysis of the relationship between market uncertainty and producer cost and benefit

When analyzing the relationship between market uncertainties and producer costs and returns, the market uncertainty is analyzed as a single variable. $\rho_1=\rho_2$ =0.2, $\delta^2=10,20,30,40,50$. The calculation results are as follows:

Table 4 The result of producer cost and expected return (RMB)

δ^2		10	20	30	40	50
Plate	Δv	50416.67	86428.57	113437.50	134444.44	151250.00
	Ev^{as}	201666.67	129642.86	75625.00	33611.12	0
Rebar	Δv	91266.67	156457.14	205350.00	243377.78	273800.00
	Ev^{as}	365066.67	234685.72	136900.00	60844.44	0

Based on the tabular data, we can derive the relationship between market uncertainties and producer costs and returns.

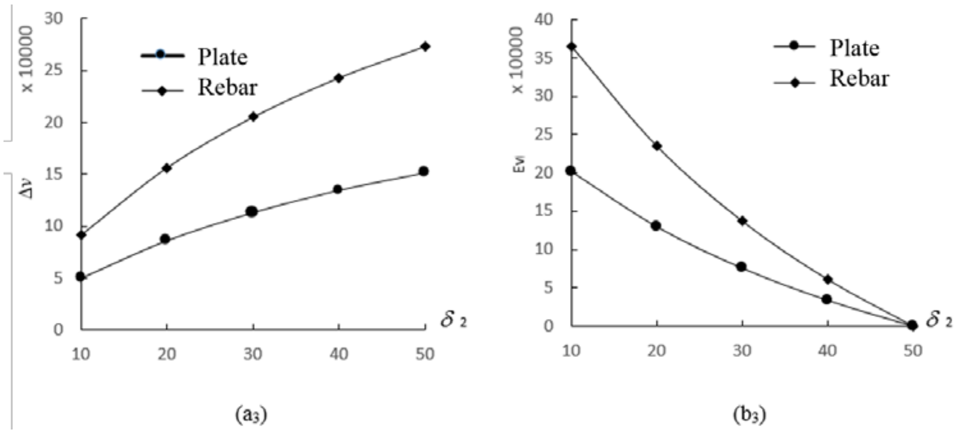

Fig. 3 The relationship between market uncertainties and producer costs (a3) and returns (b3).

The figure shows that the relationship between the expected return of the producer and the uncertainty of the steel sales market is a monotonous decreasing relationship. In the case of increased market uncertainty, producers need to work harder to maintain direct sales. This is consistent with the conclusion in 3.3.

5. Conclusion

This paper studies the steel sales incentive mechanism of the entrusted agent in the closed supply chain, the incentive problems between producers and sellers, and the marketing relationship between the market and the producers. By analyzing the game between direct sales and agents, manufacturers have the following strategies for direct sales and agents based on market conditions: (1) When the market uncertainty is large, the manufacturer should appropriately abandon part of the direct sales business, hand it over to the seller, and sign a fixed contract with the seller. (2) When the seller's risk aversion factor is large, the manufacturer should increase the incentive level for the seller, increase the cost of direct sales, and increase the sales share of the direct sales. (3) When the manufacturer's risk aversion factor is large but the impact on direct sales is small, the manufacturer should increase the cost of direct sales; when the manufacturer's risk aversion factor is too large, the manufacturer should abandon the direct sales business and hand over the business to sales.

In addition, the article does not consider the transportation, storage costs, and secondary use of steel in the direct sales process of the manufacturer. These aspects can be improved in future research.

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