

Low carbon transport for petroleum products: A pipeline pricing optimization perspective

Renfu Tu^{1*}, Rui Qiu^{1,2}, Yingqi Jiao¹, Qi Liao¹, Ning Xu¹, Jian Du¹, Yongtu Liang^{1*}

1 Beijing Key Laboratory of Urban Oil and Gas Distribution Technology, China University of Petroleum-Beijing, Fuxue Road No.18, Changping District, Beijing 102249, PR China

2 School of Business, Society and Engineering, Mälardalen University, Västerås 721 23, Sweden
(Corresponding Author: turenfu@foxmail.com, liangyt21st@163.com)

ABSTRACT

The pipeline is a low-carbon and economical transportation mode in the downstream supply chain of petroleum products. At present, due to the lack of research on multi-product pipeline pricing strategies, the unreasonable pricing strategy has resulted in low utilization of pipeline capacity. This phenomenon causes the problem of high energy consumption of petroleum products transportation. Therefore, this paper aims to improve pipeline turnover and promote the low-carbon transportation market from the perspective of pipeline pricing optimization. We propose an integrated framework for multi-product pipelines, coupling the pricing strategy and logistics optimization model. This framework is used to simulate the pricing behavior of the pipeline carrier and the corresponding logistics planning behavior of the oil shipper. We simulate and display 10 pipeline pricing schemes for two regions in China with distinctly different logistics structures, and analyze the benefits of the new strategy in both economic and environmental terms. The results show that the well-performing schemes can increase pipeline carriers' revenue by 11.41 million CNY per month, significantly improve the competitive advantage of long-distance pipelines, and reduce carbon emissions by 272 tons. In turn, recommendations for policymakers are provided at four levels. In conclusion, the new pricing strategy will help reverse the disadvantageous situation of the pipeline in the competitive market and promote the petroleum product logistics industry to reduce carbon emissions.

Keywords: Multi-product pipeline, pricing strategy, low carbon, multi-scheme analysis, policy recommendations

NONMENCLATURE

Abbreviations

MP-PIP	The multi-product pipeline
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OS	Oil shipper
PC	Pipeline carrier
PipeChina	National Oil and Gas Pipeline Network Company
PPLOM	Petroleum product logistics optimization model

1. INTRODUCTION

In the context of energy conservation and emission reduction, although renewable energy sources such as biomass, hydrogen, and geothermal energy have made development in recent years, petroleum products are still the mainstay of primary energy consumption at present, accounting for nearly one-third of the total. And, such a situation will continue to maintain for a long time. To meet the market demand, the oil shipper usually chooses the transportation mode, including pipeline, rail, ship, and truck, based on the logistics cost as the judging indicator [1]. These modes are collectively referred to as carriers and compete with each other. The shipper and carrier together constitute the downstream supply chain of petroleum products. The pipeline has the characteristics of high volume and continuity in the transportation process, and is also the mode with the lowest carbon emissions [2]. Under the combined influence of unreasonable pipeline pricing and the lack of decarbonized transportation, the capacity utilization of multi-product pipelines is reduced, and cannot adapt to the new situation in the future.

Until 2020, in China, oil shippers have a monopoly in the market and pipelines are their subsidiary facilities. This also meant that shippers would give preference to the multi-product pipeline (MP-PIP) when choosing a transportation mode, as there were no transportation costs to be paid within the companies. However, in an attempt to improve infrastructure utilization and reduce carbon emissions, the Chinese government has undertaken a deepening reform of its oil and gas storage

and transportation facilities by establishing the National Oil and Gas Pipeline Network Company (PipeChina), which reorganized pipeline assets and made them independent of the original oil shippers [3]. Starting in 2020, pipelines have gradually opened up a new mode of fairness and openness, participating in the market as a third-party vehicle.

Due to the lack of experience in market-based pipeline operation, PipeChina simply adopted transportation price per unit turnover as the charge for MP-PIP transportation. After a period of operation, the competitiveness of pipelines relative to other modes was greatly reduced, and the pipeline carrier's revenue was significantly reduced. In order to reverse the unfavorable situation and increase the market share of pipelines, it is obvious to develop a new pricing strategy. At the same time, pipeline transportation has a higher energy utilization rate compared to other modes. In other words, the increase in pipeline market share will help to transform the downstream logistics of petroleum products into a low-carbon one.

Based on the above context, the objectives of this study are as follows.

- 1) Improving the economic efficiency of pipeline carriers.
- 2) Quantifying emission reductions from petroleum product transportation.
- 3) Proposing a new pricing strategy for MP-PIP in China.

2. LITERATURE REVIEW

Pricing strategy is a key component of the logistics industry. The transport price is usually an important factor influencing the judgment of the shipper, but also the most difficult factor for the carrier to determine. In the petroleum product distribution system, carriers are required to consider both cost reimbursement and shippers' ability to accept prices, thus making pricing strategies characterized by a two-way decision. Traditionally, pricing strategies include cost-plus, target revenue, and marginal cost pricing [4]. This paper focuses on promoting the decarbonization of the transportation market for petroleum products from the perspective of MP-PIP pricing strategy based on PPLM.

In terms of pipeline transportation, pricing policies in Europe and America have come a long way after more than a decade of development. The North American natural gas market, consisting mainly of the United States and Canada, is the largest energy market in the world. The U.S. has established a third-party route system with legislation mandating that pipeline operators be open to all shippers. Pipeline pricing laws are cost-oriented and priced through reasonable pipeline

transportation costs, including historical costs of pipelines and related facilities, depreciation of assets, required benefits, operating and maintenance expenses, and income taxes from central and local governments. The U.S. strictly controls pipeline prices to prevent unreasonable costs from entering into transmission costs and to create a level playing field in the market. On this basis, Canada has established corresponding incentive mechanisms to ensure that all parties enjoy the benefits of pipeline transportation improvements while providing appropriate protection for transportation cost increases beyond their control [5]. In Europe, the cap pricing mechanism in pipeline transportation is an improvement on the base cost of service method. Pipeline companies adjust price changes over a certain period (typically 3 years) through a cap pricing formula [6]. In theory, the increase in the price of pipeline transportation is equal to the expected annual increase in operating costs minus the expected increase in productivity. Whereas the original pipeline price was determined by the cost-of-service method, the cap pricing method is used to limit the level of pipeline transportation prices over a certain period. Cap pricing is an incentive that helps pipeline companies increase productivity and reduce costs. Pipeline transportation rates are primarily based on an "import/export" rate structure, with the shipper side paying an import capacity charge, an export capacity charge, and a pipeline capacity or usage charge from import to export [7]. Accordingly, the Chinese government, aiming to improve the pricing mechanism for natural gas pipeline transportation, enhance the scientific, standardization, and transparency of pricing, and strengthen the price regulation of natural monopoly links, formulated the Measures for Administration of Prices of Natural Gas Pipeline Transportation (for Interim Implementation) and the Measures for Supervision and Examination of Pricing Costs of Natural Gas Pipeline Transportation (for Interim Implementation) in 2021 [8]. The documents stipulate that pipeline transportation prices shall be set by the government following the "permitted cost plus reasonable revenue" method, that is, the permitted revenue shall be determined by approving the permitted cost and regulating the permitted revenue, and the pipeline transportation rate shall be approved. But the government has not yet issued any documents related to the pricing of MP-PIP.

There are still relatively few studies on pipeline transportation in terms of specific pricing methods. Avalos et al. [9] analyzed the impact of natural gas pipeline capacity on regional pricing and market integration, where pipeline congestion raises pipeline delivery prices, as a way to propose pipeline construction

investment. Yuan et al. [10] analyzed China's oil downstream supply chain reform policies and created different scenarios to suggest multi-product pipeline interconnections that could improve energy environmental use efficiency. However, this study lacked pipeline transportation price analysis and their findings may be influenced by different pricing strategies.

In summary, there is less research on pipeline pricing strategies at the implementation level. The pricing strategy for MP-PIP should refer to the research results of other transportation modes. Moreover, the special attributes and structure of pipelines need to be considered, so as to avoid unreasonable pricing strategies causing lower pipeline capacity utilization. In addition, with the help of PPLOM to simulate the PC's pricing behavior and OS's logistics planning behavior, the feasibility of the results can be verified. Ultimately, the whole work is made to quantify the economic and environmental benefits.

3. PROBLEM DESCRIPTION

The primary logistics system for petroleum products mainly includes refineries, depots, and transportation modes such as pipeline, rail, ship (sea and river transport), or truck connecting refineries and depots. Refineries and depots are part of petroleum product producers, and we call them shippers. Likewise, we refer to the various modes of transportation as carriers. For this paper, truck is not used in calculations when competing for transportation modes because of its flexibility but is used as a reference for short-haul transportation when setting pipeline pricing. The shipper completes the transfer of petroleum products from the place of production to the place of consumption by entering into a transportation contract with a carrier, paying a reasonable transportation fee during this period.

Moreover, there are various cases of connecting refineries and depots. i) Single mode of transportation, where only one of pipeline, rail, or ship is available. ii) Two modes of transportation, where two of pipeline, rail, or ship exist (in this paper, we mainly consider those that have competitive conditions with pipeline, i.e., where both pipeline and rail or pipeline and ship exist). iii) Three modes of transportation, where pipeline, rail, and ship are reaching. Customarily, we use "route" as the name.

What cannot be ignored in the petroleum product logistics system is the range of transport capacity of each transport mode between two points. The pipeline cannot be overloaded because of its design capacity. The rail and ship can only perform as much transportation as they can handle within a certain time frame because of their load and travel speed limitations. Not only that, but for

refineries or oil depots, we need to consider the facility's ability to ship or receive in a real situation.

4. METHODOLOGY

4.1 Framework

The integrated framework of MP-PIP pricing strategy proposed in this paper is shown in Fig. 3. This framework consists of four modules, including the strategy objectives module, the PC pricing module, the parameters module (the shipper and carriers), and the logistics optimization module. The strategy objectives module integrates the economy and environment, and considers the following three conditions.

- 1) Condition 1: No damage to OS's interests.
- 2) Condition 2: Maximize PC's revenue.
- 3) Condition 3: Reduce carbon emissions.

The MP-PIP pricing module takes the strategy as the starting point and simulates the PC to update the pipeline route cost after proposing different pricing schemes by selecting different parameters. The updated pipeline route cost is used as the new parameter for PPLOM [11]. The parameters module is divided into two parts, the first part is the information provided by OS, including refinery supply plan, depot demand plan, refinery loading capacity, and depot unloading capacity. The second part is the transportation route capacity and cost information that can be provided by carriers including pipeline, rail, and ship. The logistics optimization module mainly refers to PPLOM, which is usually built by OS, to develop the least expensive logistics plan. After solving this model, the logistics plan can be obtained. Further, the current logistics plan can be evaluated for the OS's cost, each carrier's revenue, and transportation carbon emissions and fed back to the shipper and carriers. In the framework, it can be found that the key element on which MP-PIP pricing strategy relies is the PPLOM.

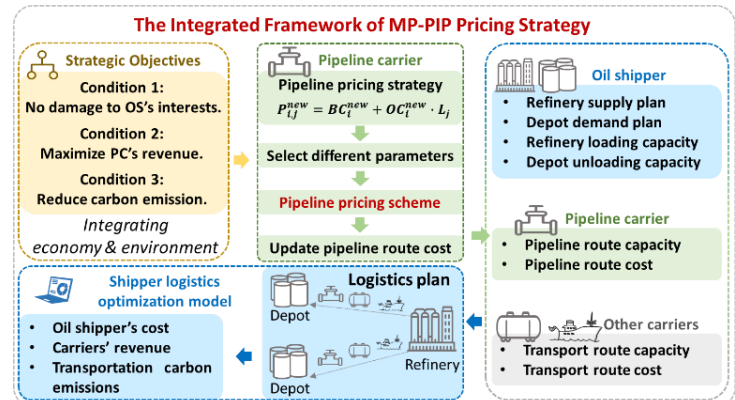


Fig. 1 MP-PIP pricing strategy integrated framework

4.2 Pipeline pricing strategy

Regarding the pricing strategy of other transportation modes, this paper proposes a new pricing strategy for MP-PIP as shown in Eq. (1). In the formula, $P_{i,j}^{new}$ denotes the new unit cost of region i route j . It includes the pipeline's starting price BC_i^{new} in addition to the pipeline transportation price per unit turnover OC_i^{new} and mileage L_j multiplier in the same region. It can be seen that we not only introduce the starting price but also make a distinction between different regions.

$$P_{i,j}^{new} = BC_i^{new} + OC_i^{new} \cdot L_j \quad (1)$$

5. METHODOLOGY

5.1 Original scheme

This section solves the model directly according to the current pricing strategy, and the unit turnover price is 0.196, as seen in Section 4.2. The result of the solution is called the "original scheme". For Area A, the total logistics cost of OS amounts to 1.2×10^8 CNY, with 6.6×10^7 CNY for pipeline consignment, while for Area B, although the cost is about twice as high as for Area A, at 2.2×10^8 CNY, the pipeline consignment cost is only 4.4×10^7 CNY. In Area A, the share of pipeline consignment has reached 54.67%, higher than the 37.74% for ship and 7.59% for rail. Whereas in Area B, the share of pipeline consignment is the smallest among the three modes with only 20.17%. The share of rail and ship consignments is 52.01% and 27.51%, respectively. In other words, the current pricing strategy puts PS in an extremely disadvantageous position in the logistics market competition for petroleum products in Area B.

Table 1 Composition of OS's logistics transportation costs

Mode	Cost (10^4 CNY)	
	Area A	Area B
Pipeline	6573	4400
Rail	913	11347
Ship	4538	6002
Total	12024	21818

5.2 Multi-scheme analysis

5.2.1 Implementation process

In this section, we use the strategy proposed in Section 4.1 to conduct a multi-scheme pricing analysis. The specific process is shown in Fig. 2. i) The starting price is taken in steps of 5 in $[0, 45]$, such as 5, 10, 15, etc. In this way, 10 schemes are available for each region (including the original scheme). ii) Given the initial value of the unit turnover price, the new price of each pipeline route is obtained. iii) The logistics plan is solved with the help of PPLOM. iv) If the three conditions proposed in the

integrated framework (Fig. 1) can be satisfied, the turnover price is determined, otherwise recalculated, after adjusting the running price according to the data laws. v) Output the results after all schemes are solved.

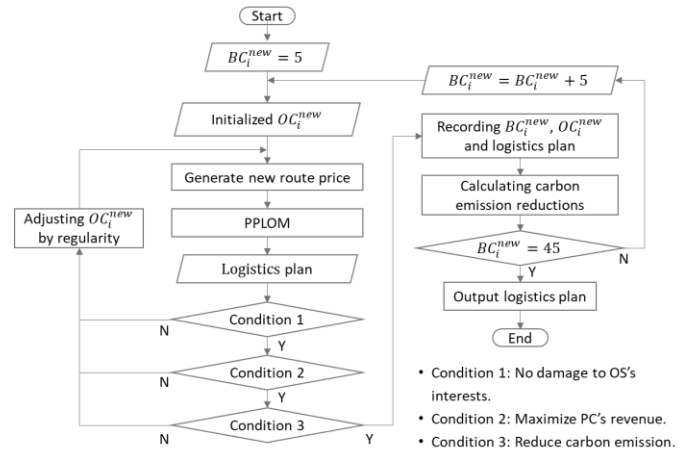


Fig. 2 Diagram of the method implementation process

5.2.2 Economic and environmental results

The results of the multi-scheme for Area A are shown in Fig. 3. The parameters corresponding to each scheme are shown in Table 2. In Fig. 3a, the introduction of the starting price helps improve PC's revenue, with a maximum increase of 3.33%. Similarly, the parties' co-benefits (the sum of the logistics cost saved by OS and the revenue increased by PC) increase with the starting price, up to a maximum of 2.43 million CNY. When the starting price is from 5 to 25 CNY/t, PC's revenue fluctuates slightly at 67 million CNY, and both parties' co-benefits are stable at 1.47 million CNY. When the starting price exceeds 25 CNY/t, PC's revenue rises significantly, exceeding 67.7 million CNY, and both parties' co-benefits also exceed 2.26 million CNY. Fig. 3b shows PC's transportation quantity and turnover, whose growth form remains consistent with Fig. 3a. The best solution results in an increase of 1.28% and 6.24% in PC's transportation quantity and turnover, respectively. The two jumps in PC's transportation quantity are at starting prices of 5 and 30 CNY/t, while the turnover includes 45 CNY/t in addition to these two points. Compared with the original scheme, PC's transportation quantity increases by 1370 kt (scheme 1~5, abbreviation S1~S5) and 1790 kt (S6~S9). PC's transportation turnover increases by 7.49×10^6 t·km (S1~S5), 1.51×10^7 t·km (S6~S8), and 2.09×10^7 t·km (S9). Of all pricing schemes in Area A, S6 is the most OS-friendly, and S9 is the most PC-friendly when other influences are not taken into account.

Table 2 Corresponding parameters of each scheme

Scheme	Area A		Area B	
	BC_a^{new} (CNY/t)	OC_a^{new} (CNY/t·km)	BC_b^{new} (CNY/t)	OC_b^{new} (CNY/t·km)
Original	0	0.196	0	0.196
1	5	0.175	5	0.178
2	10	0.154	10	0.161
3	15	0.134	15	0.144
4	20	0.113	20	0.128
5	25	0.093	25	0.112
6	30	0.072	30	0.098
7	35	0.052	35	0.084
8	40	0.032	40	0.071
9	45	0.012	45	0.057

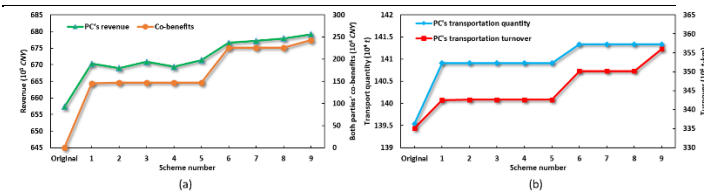


Fig. 3 PC's revenue, co-benefits, PC's transportation quantity, and turnover corresponding to different schemes (A)

The results of the multi-scheme for Area B are shown in Fig. 4. The parameters corresponding to each scheme are shown in Table 2. In Fig. 4a, PC's revenue steadily increases with the starting price until it stabilizes after exceeding 30 CNY/t. Overall, PC's revenue increased by the highest 22.02%, reaching co-benefits of 9.98 million CNY. After S6, PC's revenue reaches 53.5 million CNY. Compared to the original solution, S7 boosted PC's revenue by 9.75 million CNY. At this point, OS and PC co-benefits can reach 9.98 million CNY. Among them, the regions with faster rise are S3 to S6, which means that Area A is more sensitive to the starting price in the range of 15 to 30 CNY/t. Fig. 4b shows the results are more complicated than Area A, especially PC's transportation quantity shows a jump between S4 to S6. However, on the whole, PC's transportation quantity in Area B does not increase with the increase of starting price. The fundamental reason is that the pipeline layout is not reasonable and there are overlapping paths due to multiple circles. Certainly, this is also related to the small demand for depots in Area B. Nevertheless, it is noteworthy that the turnover has been steadily increasing, which indicates that the new pricing strategy favors PC to improve the utilization of long-distance pipeline capacity. Taking S9 as an example, the turnover increases by 8.01×10^7 t·km to 3.05×10^8 t·km compared to the original scheme. If the choice is based on PC's revenue, S6 is the most favorable. However, from the perspective of turnover, S9 is the largest.

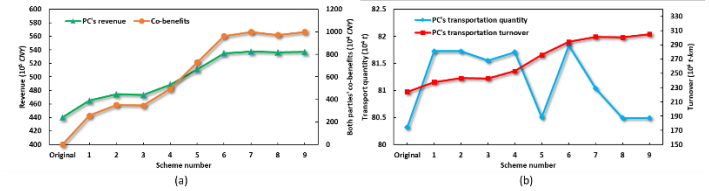


Fig. 4 PC's revenue, co-benefits, PC's transportation quantity, and turnover corresponding to different schemes (B)

It is worth mentioning that in today's deteriorating environment, we cannot only focus on the economic benefits. With the implementation of energy conservation and emission reduction policies, the development of petroleum products logistics is bound to take into account the environmental benefits. In this paper, the changes in turnover of pipeline, rail, and ship in the solution results of all schemes are counted and converted into carbon emissions, as shown in Fig. 5. In Area A (Fig. 5a), the emission reductions of S1~S5 are all contributed by rail, with a reduction of 30 t. For S6~S8, in addition to rail contribution of 46 t, ship contributes 7.5 t. The largest carbon emission reduction is for S9, which reaches 74 t, of which 76% is contributed by rail. In Area B (Fig. 5b), the carbon emission reductions for S1~S3 range from 54~75 t from rail. The emission reductions of S4~S9 are jointly determined by rail and ship, with a maximum reduction of 150 t from rail (S6) and 125 t from ship (S9). The largest reduction in carbon emissions is from S7 with 221 t, followed by S6 with 218 t. In summary, although Area A competes mainly with ship on transport routes, rail is still a contributor to the change in turnover, even though there are only 2 depots (D6 and D9). Similarly, Area B has only depot D10 with ship, but the contribution of energy saving and emission reduction by ship is not small, up to 73%. According to our reflections, the change in price parameters has a global impact on the logistics plan and the analysis is not sufficient only in terms of the routes related to the content of the study.

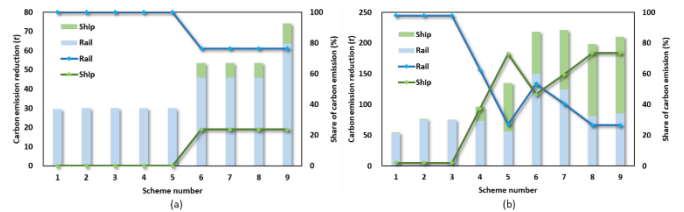


Fig. 5 Carbon emission reductions from other carriers

5.3 Discussion and recommendations

In PPLM solving process, we only consider pipeline, rail, and ship, but in fact, trucks are all the transportation modes that can be chosen between refineries and depots. The truck unit cost considers the minimum price, namely, when the transport distance is less than 30 km, the price is uniformly 30 CNY/t. When the distance

exceeds 30 km, the transportation price per unit turnover is 0.6 CNY/t·km. Therefore, when determining the base price of pipeline routes, the starting price in Area A and B should not exceed 30 CNY/t so that the competitiveness of short-distance pipelines is not diminished.

Through the above comparative analysis, the most suitable solution for both Area A and B is S6, which means that the starting price is 30 CNY/t for both and the transportation price per unit turnover is 0.072 and 0.098 CNY/t·km, respectively. In Area A, the adoption of S6 increases PC's revenue by 1.93 million CNY and reduces the revenue of other carriers by 2.26 million CNY. The transport market reduces carbon emissions by 53.5 t. The shipper's share of pipeline transportation costs increases by 1.76%. In Area B, after adopting S6, PC's revenue increases by 9.48 million CNY, and other carriers' revenue decreases by 9.62 million CNY. Overall, the new strategy reduces carbon emissions by 218.56 t. The shipper's share of pipeline transportation costs increases by 4.36%.

6. CONCLUSION

The unreasonable pricing strategy has reduced the competitiveness of MP-PIP in the logistics market for petroleum products, especially as some pipelines with long distances. This issue directly leads to lower pipeline capacity utilization and lower PCs' revenue. Moreover, the pipeline is among the transportation modes with the lowest carbon emissions. With the guide of PPLOM which only aims at economic optimum, OS cannot avoid making the logistics system for petroleum products generate more carbon emissions. Facing this unfavorable situation, we propose an integrated framework that couples logistics optimization model and pricing strategy for MP-PIP. This framework is used to ensure the competitive advantage of pipeline over rail and ship in the context of marketization, which in turn maximizes PC's revenue and promotes the low carbon development of logistics market. In order to make OS cooperate with PC's pricing strategy, this study also establishes the condition that the pricing scheme does not harm OS's interests. Therefore, this study introduces a starting price in the pricing formula and proposes the practice of allowing non-uniform parameters in different regions. We take two regions in China as the research objects. After multi-scheme analysis, better and more reasonable parameters are sought for subjects.

During the solution process, this paper analyzes the variation of PC's revenue, PC's transportation quantity, and PC's transportation turnover for each scheme under the premise of satisfying three purposes. Besides, we quantitatively evaluate the environmental benefits of

the downstream logistics market for petroleum products in both regions with the proposed new pricing strategy. After an in-depth analysis of indicators, the pricing scheme is finalized. The results show that the selected scheme can increase PC's revenue by 1.93 million CNY and 9.48 million CNY per month in two regions. Meanwhile, the new strategy is also able to reduce 53.5 t and 218.56 t of carbon emissions from primary logistics for petroleum products, which has obvious environmental benefits and contributes to the low-carbon transition of this industry. In conclusion, with the aim of sustainable development of petroleum product logistics, the policy implications proposed in this paper are as follows.

1) 4) Establishing OS carbon tax collection standards at the national level. This could motivate OS to use low-carbon transportation modes, such as pipelines.

2) Building a logistics cooperation framework between OS and PC at a strategic level. The cooperation framework can establish a long-term dialogue mechanism and facilitate both parties to make demands.

3) Establishing a logistics information sharing platform between OS and PC at a tactical level. A sharing platform can greatly improve the efficiency of information interchange.

4) Requiring a transparent and open pricing scheme of PC at an implementation level. In the logistics system, mutual trust between the two parties is the driving force to promote cooperation.

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