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Original Research

Analysis on Price Game and Supervision of Natural Gas Pipeline Tariff under the Background of Pipeline Network Separation in China

Wenjuan Zhao[1], Jianhua Huangfu[2]*, Lei Yu[3], Guoliang Li[4], Zeyu Chang[3], Muhammad Tayyab Sohail[5]

[1]School of Environment, Tsinghua University, Beijing 100084, P.R. China
[2]School of Economics, Capital University of Economics and Business, Beijing 100070, P.R. China
[3]China Petroleum Planning and Engineering Institute, CPPEI, Beijing 100089, P.R. China
[4]CNOOC Gas & Power Group, Beijing 100028, P.R. China
[5]School of Public Administration, Xiangtan University Hunan Xiangtan, 411105 P.R. China

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Abstract

In China, the separation of pipeline network effectively promotes the process of natural gas market-oriented reform and leads to the inclination of pipeline pricing autonomy to the middle party. In order to strengthen the safety of pipeline operation, PipeChina tends to increase the investment cost and increase the uncontrollability of pipeline price. Pipeline tariff is the bottleneck factor to adjust the revenue flow between shippers and carriers. Analyzing the behavior strategy choice of shippers and carriers in price game of pipeline transportation and exploring the supervision strategy of tariff are the key measures to ensure the virtuous cycle of natural gas industry chain. Combined with the results of strategic game among upstream companies, PipeChina and the Chinese government, it is found that PipeChina tends to overinvest in the construction of 'luxury pipelines', which delays the transportation of upstream companies. Therefore, it is urgent to introduce government supervision to regulate pipeline investment and operation cost. Therefore, China should actively improve the laws and regulations on tariff, promote the market mechanism of tariff, implement tariff based on the maximization of social welfare, and establish the 'joint management committee' of tariff inspection department, so as to reasonably regulate the pipeline tariff. This research was carried out with these main objectives to analysis on Price Game of Natural Gas Pipeline Tariff under the Background of Pipeline Network Separation and b) to Supervision Natural Gas Pipeline Tariff in China.

Keywords: pipeline network separation, tariff, investment, regulatory strategy, evolutionary game

*e-mail: huangfu950301@163.com

Introduction

The supply and consumption of natural gas is increasing rapidly worldwide, and this trend is expected to continue for decades [1]. A new cycle of liberalization reforms is also emerging at the global level, with more and more gas being priced through gas indices [2]. The current reform of the liberalization of the natural gas market in China has attracted global attention. Based on the direction of China's petroleum and natural gas market-oriented reform of 'regulating the middle and releasing the two ends', the construction of "national network of China's petroleum and natural gas pipeline" under the layout of "X+1+X" in China's oil and gas industry is one of the key measures to improve market flexibility. At the end of 2019, China's National Oil and Gas Pipeline Network Group Co., LTD. (PipeChina) forwarded the pipelines separation process and the independent development of pipelines' construction and operation business [3]. As being the middle party of the oil and gas production chain, PipeChina obtain revenue by providing transmission service; its revenue principle was set on the basis of 'allowable cost + reasonable benefit' principle issued in 'Notice on Printing and Distributing the Measures for the Administration of Price of Natural Gas Pipeline (Trial)' and the 'Methods of Auditing the Cost of Natural Gas Pipeline Transportation (for Trial Implementation)' with regulations of service cost method for pipeline of natural gas pricing. The essence of pipeline transport price is that pipeline companies are responsible for pipeline investment, financing and economic risks, whereas upstream companies stand the expenses of pipeline operation cost and fixed investment return [4]. As the position of carrier and shipper gradually differ, PipeChina becomes independent of operation and accounting with more control of pipeline construction, operation and pricing. PipeChina sets operation security and efficiency improvement as primary objective while weaken its cost control; additionally, under the lack of government supervision, there would be a tendency of constructing 'luxury pipelines' with high pressure resistance, high durability and low maintenance to enforce quality standard of equipment and materials resulting in excess investment and cost [5]. Due to the linkage between tariff and transportation cost, if cost cannot get effective control then tariff gets high, which drives high cost pressure for upstream companies, low shippers' enthusiasm and unstable cycle of natural gas supply chain, thus effective supervision of pipeline costs and regulations on tariff are urgently needed. Therefore, analyzing tariff structure and improve the pipeline transportation pricing mechanism, exploring shippers and carrier's behavior choice of the price game of natural gas pipeline tariff, improving supervision system of tariff is the inevitable requirements of regulating tariff and facilitating market-oriented reform of natural gas in China [6].

Tariff refers to the service fee charged to shippers when pipeline provides natural gas transportation business [7]. Mainly considering the heterogeneity of transport range [8], the 'transport range – price' relationship is effectively coordinated as the object of setting tariff gradually transits from downstream to the upstream with the evolution that tariff was unified by industry authorities then turn to a comprehensive gate station price [9]. Based on the characteristics of 'one part tariff' and 'two part tariff', combined with the practical experience of 'one company one rate', 'annual approval', 'loading rate lower limit' [10], the pricing of natural gas pipeline transportation fully coordinates pipeline cost recovery and social welfare maximization [11, 12] which forms the cost of service pricing mode. As market-oriented reformation of the oil and gas industry deepen, pipelines' separation in China's natural gas market has realized the transformation from vertically integrated management to horizontally multi-subject management, and improved the fair access mechanism of the natural gas pipeline's network, thus guaranteed the decisive position of market resource allocation [13]. However, with asset stripping of pipeline companies, the competition in the natural gas market has become increasingly complex and fierce. Although the exploration and exploitation of the upstream in the natural gas industry is gradually being more open, PipeChina may exclude competitive companies through raising tariff, implicit obstacles and cross-subsidies due to dependence on vertical integrated operation [14]. Discriminatory access to pipeline transportation leads to the complexity of multiple market subjects' combination of behavioral strategies, increases the complication and depth of government supervision, and reduces the effect of reform of China's natural gas market [15]. Therefore, a preliminary consensus on the supervision of natural gas pipeline transportation pricing has been formed world widely: the EU and the US have set up OFGAS and FERC respectively and other tariff regulatory agencies in the natural monopoly and competitive pipeline transportation field [16]. Although it is proposed that Chinese government should strengthen supervision of tariff and market after pipelines' separation on the basis of the tariff supervision practices in European countries and the US [17-21], there is no in-depth analysis yet [22-23].

Existing studies focus more on the pricing model of pipeline transportation and the fairness and accessibility of pipeline networks, while less on the behavior strategies of multiple subjects such as the government, upstream companies and PipeChina in the pipeline transportation pricing market, and even less on the regulatory model of pipeline transportation pricing [24-26]. After the separation of pipeline network, construction and operation businesses of pipelines develop independently, and it is significant to clarify the behavioral strategy game between the upstream and PipeChina, so as to ensure reasonable income of both parties [27-31]. Therefore, based on

the principle of 'cost and income', this paper first set the game model of pipeline tariff between upstream companies and PipeChina, and analyzes the upstream companies' strategy selection and the critical conditions of game equilibrium when pipeline companies make reasonable investment and excessive investment respectively. Meanwhile, an evolutionary game model among the government, upstream companies and PipeChina is constructed to analyze the saddle points of the behavior of multiple subjects in the price game; consequently, studies of regulatory strategies of natural gas pipeline tariff provides reference for regulating pipeline investment and promoting the rationalization of tariff and save environment [32-35]. This study is very important for a country like China, specific objectives of this research were a) to analysis on Price Game of Natural Gas Pipeline Tariff under the Background of Pipeline Network Separation and b) to Supervision Natural Gas Pipeline Tariff in China.

Method

Study Area

The China Oil and Gas Pipeline Network Corp., commonly referred to as PipeChina, was founded by the government in December 2019 in an effort to centralize control of the country's oil and gas pipelines. This study based on the behavior strategies of multiple subjects such as the government, upstream companies and PipeChina in the pipeline transportation pricing market, and even less on the regulatory model of pipeline transportation pricing.

Cost of Operation and Maintenance

Assuming that the PipeChina only consider the inlet at the beginning and the outlet at the end of the same pipeline in the same region (in full load operation), the volume of gas supply is an invariant *X*, average transportation range and the actual transportation range are both defined as *L*, permissible rate of return is *A%*, and the depreciation life of the pipeline is defined as n years. In the absence of government supervision, PipeChina decide the investment (regardless of project capital and loan) and choose {'reasonable investment', 'over investment'} to set tariff by applying principle of 'cost and income' combing with the cost of service method and two-part tariff mode; upstream companies choose {'accept', 'reject'} for gas transportation.

In the game model, taking the cost of service method as an example, tariff (after the date of delivery) is

S = (allowable cost + reasonable income) * actual transportation range/total turnover = (Depreciation and amortization expense + Operation and maintenance expense + effective assets * permissible rate of return) * actual transportation range/(actual transportation volume * average transportation range)

Model

Based on the hypothesis that the cost of operation and maintenance is D_1 with reasonable investment I_1, annual tariff $S_1 = (I_1/ n +D_1+A\%I_1)/X$, and the revenue is $W_1 = S_1X-D_1-I_1/n = A\%I_1$. In the case of over investment I_2, the operation and maintenance cost is D_2, the annual tariff is $S_2 = (I_2/n +D_2+A\%I_2)/X$, and the revenue is $W_2 = S_2X-D_2-I_2/n = A\%I_2$. If upstream companies reject the tariff, the income of PipeChina is $W_1' = -I_1$ and $W_2' = -I_2$ respectively. Additionally, with the cost of natural gas exploration and production Z, upstream company's income from natural gas sales is π, and the cost of gas transportation is W_1 and W_2, respectively, formulating income of natural gas sales $M_1 = \pi - a\%I_1-I_1/n-D_1-Z/n$ and $M_2 = \pi-A\%I_2-I_2/n-D_2-Z/n$ in the case of excessive investment. If the upstream company rejects the tariff offered by PipeChina, upstream company's income would be $M' = -Z$ as shown in Table 1.

Evolutionary Game between the Government and PipeChina

After introducing government regulation, this paper raised the following hypothesis. a. upstream company chooses 'accept' strategy based on the principle of maximizing economic benefits. b. pipeline company's strategy profile is {reasonable investment, over investment} as according to the assumption of subjects' bounded rationality, while the government choose {supervision, no supervision}. The probability of PipeChina choosing 'reasonable investment' is x ($0\leq x\leq 1$), and the probability of it choosing 'over investment' is $1-x$. The probability that government chooses 'supervision' is y ($0\leq y\leq 1$) and the probability that the government chooses 'no supervision' is $1-y$. c. since PipeChina over invested, its pipelines perform with higher safety so that the operation and maintenance cost D is relatively lower, that is, D_1 under 'reasonable investment' is higher than D_2 under 'over investment'.

Model

When the government chooses 'supervision', it is in charge of the supervision cost of human resources, financial resources and time, *C*. Meanwhile, government supervision improves its credibility and promotes market fairness and social welfare in further (quantified as M_1). However, PipeChina will be charged penalty cost *R* as a result of over investment, in which, the following scenarios should be considered: I) when the PipeChina makes reasonable investment, its income is $W_1=V\ A\%I_1$, and the government income is $P_1 = M_1-C$. II) When the pipeline is overinvested,

Table 1. Game Matrix between PipeChina and Upstream Companies.

Game Agents		Pipeline Company	
		Reasonable Investment	Over Investment
Upstream Company	Accept	($A\%I_1$, π-$A\%I_1$-I_1/n-D_1-Z/n)	($A\%I_2$, π-$A\%I_2$-I_2/n-D_2-Z/n)
	Reject	(-I_1,-Z)	(-I_2,-Z)

Table 2. Game Matrix of the Government and PipeChina.

Game Agents		PipeChina	
		Reasonable Investment x	Over Investment 1-x
Goverment	Supervision y	($A\%I_1$, M_1-C)	($A\%I_2$-R, M_1+R-C)
	Non supervision 1-y	($A\%I_1$, 0)	($A\%I_2$, -M_2)

PipeChina 's income is $W_{2V}=VA\%I_2-R$ where PipeChina stands the punitive cost R in which R is used as the government's income to compensate its supervising cost, and government's income is $P_2 = M_1+R-C$.

When the government chooses the 'non supervision', there is no supervision cost but over investment reduces social welfare (quantified as M_2), thus two scenarios should be considered: III) in the case that pipeline is reasonably invested, the revenue of PipeChina is $W_3 = A\%I_1$, while the government's income is $P_3 = 0$. IV) When the pipeline is overinvested, PipeChina's income is $W_4 = A\%I_2$ and government's income is $P_4 = -M_2$. Consequently, in case of 'accept' strategy of upstream company, the game matrix between government and PipeChina can be constructed as in Table 2.

Results and Discussion

Analysis of Pipeline Tariff Composition

According to the principle of 'allowable cost + reasonable income', China's natural gas pipeline tariff mainly refers to the cost of service method and directed by the two-part tariff mode as shown in Fig. 1. The cost of service method determines the pipeline freight by the rate of the sum of total cost and revenue and the total turnover, and then determines different tariff according to transportation range. The reasonable income is determined by net assets and permissible return rate, and the reasonable income rate is not less than 75% and the after-tax investment return rate is 8% although it would drop as assets depreciate. The two-part tariff mode divides transportation cost into fixed cost and variable cost. Fixed cost is recovered through predetermined pipeline storage charge, which

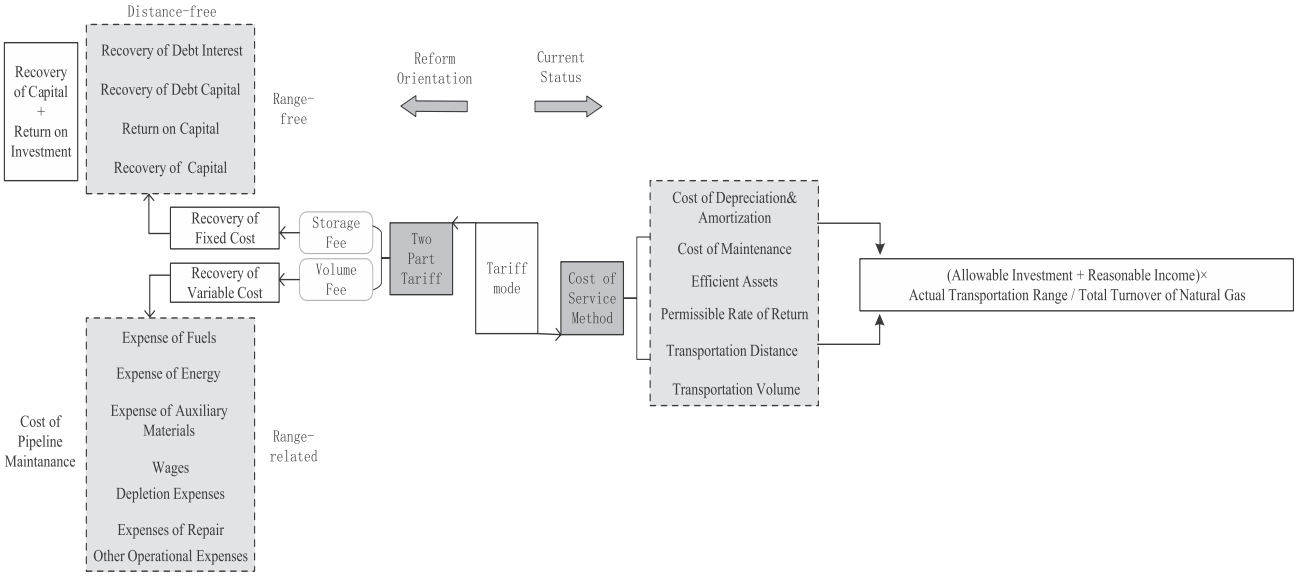

Fig. 1. China's Pipeline Transportation Pricing Model.

is uncorrelated with actual transportation volume, and unit fixed cost is inversely proportional to actual transportation. Variable cost refers to the expenses of pipelines' operation and maintenance, which are recovered through pipeline usage, and is proportionate to actual gas transportation while the unit variable cost has no correlation with actual gas transportation.

In the oligopoly market of natural gas, the upstream companies, PipeChina and the government all meet the 'rational-economic man' hypothesis indicating them adopt different strategies to maximize their own interests. PipeChina recoups investment and operation cost of pipeline through income of tariff and obtains investment return. Upstream companies pay tariff to PipeChina to transport gas and gain profit gap. Chinese government supervises tariff to effectively manage pipeline investment and ensures reasonable income of upstream and PipeChina.

Game between Upstream Companies and PipeChina

In Fig. 2, after the separation of pipeline network, upstream companies are responsible for exploration and exploitation, PipeChina is in charge of transportation business, and the downstream users receive natural gas for industrial and chemical use, heating, utility and transportation. After the separation, PipeChina has the monopoly position to the natural gas pipeline pricing, whereas upstream companies are the price takers. Therefore, Chinese government should tighten oversight over its supervision to fulfil the rationalization and standardization of the tariff.

Game Equilibrium Analysis

Since I_2 is greater than reasonable investment I_1, then $W_2>W_1$. Considered with the game matrix, when the tariff does not exceed the downstream price and the upstream company rejects the tariff, upstream company's income would be *-Z*. If upstream company accepts the tariff, its income must be higher than *-Z*, thus 'accept' is the dominant strategy of upstream company. When PipeChina ensures the income of upstream company is higher than *-Z* while maximizes the safety of pipeline operation, excessive investment increases the tariff. Therefore, the {overpriced, accept} strategy is the Nash equilibrium of the game between PipeChina and upstream company.

According to

$$\pi - A\%I - \frac{I}{n} - D_2 - \frac{Z}{n} > -Z \quad , \quad I < \frac{n\pi - nD_2 - (n-1)Z}{1+nA\%}$$

can be formulated.

In the light of the game results, this paper considered the following three cases. a. In the case of *I>[nπ-nD2-(n-1)Z]/(1+nA%)*, the upstream company will withdraw from the natural gas trade by rejecting the tariff because its transportation income is lower than -Z, while PipeChina bears the sunk cost of the pipeline investment. b. in the case of *[nπ-nD1-(n-1)Z]/(1+nA%)<I<[nπ-nD2-(n-1)Z]/(1+nA%),* upstream company accept the tariff to ensure its income more than -Z, while PipeChina seizes surplus profit from its over investment. c. In the case of $I = [n\pi - nD_1 - (n-1)Z]/(1+nA\%)$, investment is reasonable.

Therefore, PipeChina tends to overinvest to construct 'luxury pipeline' due to the autonomy of pipeline company on construction, operation and pricing, causing pipeline investment approaches $[n\pi - nD_2 - (n-1)Z]/(1+nA\%)$, which tightens the profit of upstream companies and squeezes the social welfare. Although the income of upstream company is greater than -Z, upstream company will choose to exit the market if its income is negative in the long term. Thus, it is important to introduce government supervision to China's natural gas transportation market in order

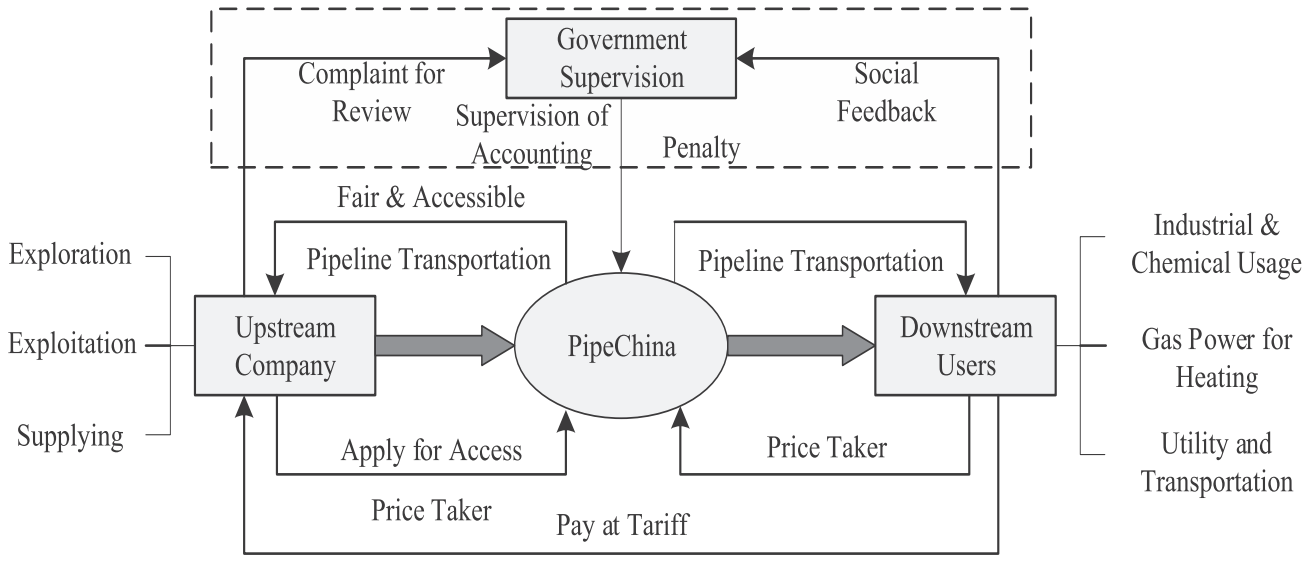

Fig. 2. Relationship of Subjects in China's Natural Gas Market.

to guarantee reasonable revenues of upstream and pipelines.

Evolutionary Stability Analysis

Setting PipeChina's expected income as U_x when it applies 'reasonable investment' strategy, expected income as U_{1-x} when it applies 'over investment' strategy, and expected average income as $\bar{U}_P$, then

$$U_x = yA\%I_1 + (1-y)A\%I_1 = A\%I_1$$
$$U_{1-x} = y(A\%I_2 - R) + (1-y)A\%I_2 = A\%I_2 - yR$$
$$\bar{U}_P = xA\%I_1 + (1-x)(A\%I_2 - yR)$$

Therefore, replication dynamic of PipeChina's evolutionary game is

$$E(x) = \frac{dx}{dt} = x(U_x - \bar{U}_P) = x(1-x)(A\%I_1 - A\%I_2 + yR).$$

Similarly, setting the government's expected income as U_y when it applies 'supervision' strategy, U_{1-y} when the government applies 'non supervision' strategy, and expected average income as $\bar{U}_G$, then

$$U_y = x(M_1 - C) + (1-x)(M_1 + R - C) = M_1 + (1-x)R - C$$
$$U_{1-y} = -M_2(1-x)$$

$$U_G = y(M_1 + (1-x)R - C) - M_2(1-y)(1-x)$$

Therefore, replication dynamic of the government's evolutionary game is

$$F(y) = \frac{dy}{dt}y\left(U_y - \bar{U}_G\right) = y(1-y)\left((M_1 - C + (1-x)(R + M_2)\right)$$

There are five Nash equilibrium if replication dynamics $dx/dt = 0$, $dy/dt = 0$: $U_1(0,0)$, $U_2(0,1)$, $U_3(1,0)$, $U_4(1,1)$, $U_5((R+M_1+M_2-C)/(R+M_2), (I_2-I_1)A\%/R)$, and Jacobian matrix as shown below:

$$G = \begin{pmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{pmatrix}$$

$$G_{11} = \frac{\partial E(x)}{\partial x} = (1-2x)(A\%I_1 - A\%I_2 + yR)$$
$$G_{12} = \frac{\partial E(x)}{\partial y} = x(1-x)R$$
$$G_{21} = \frac{\partial F(x)}{\partial x} = -y(1-y)(R + M_2)$$
$$G_{22} = \frac{\partial F(x)}{\partial y} = (1-2y)(M_1 - C + (1-x)(R + M_2))$$

Any initial point and evolution point lays in the two-dimensional plot $V = \{(x, y) | 0 \le x \le 1, 0 \le y \le 1\}$; Compare social welfare M_1 and the government supervision costs C to get the following analysis.

Hypothesis I: If $M_1 > C$, $(R+M_1+ M_2-C)/(R+M_2) > 1$, then U_5 is meaningless. Stability analysis of other equilibrium points is displayed in Table 3.

From the stability analysis results, the replication dynamics plot of the strategies between PipeChina and the government can be drawn as Fig. 5a) shown. When $M_1 > C$, the game between two parties tends to reach $U_4(1,1)$, the stable point {reasonable investment, supervision}. Starting with different initial conditions, the government may choose 'supervision' or 'non supervision', and PipeChina may choose 'reasonable investment' or 'over investment', however, the final game results tend to be the equilibrium of 'supervision' and 'reasonable investment'.

Hypothesis 2: If $M_1 < C$, $(R+M_1+ M_2-C)/(R+M_2) < 1$, then $0 < U_5 < 1$ is equilibrium point. Stability analysis of other equilibrium points is displayed in Table 4.

From the stability analysis results, the replication dynamics plot of the strategies between PipeChina and the government can be drawn as Fig. 5b) shown. When $M_1 < C$, there is no equilibrium between two parties. The strategies of market participants are influenced by factors including investment I, punitive cost R, social welfare M and government's cost on supervision C. Making $y = (I2-I1)A\%/R$, where y stands for the probability of government's supervision strategy change that is correlated to the probability of PipeChina applying reasonable pricing strategy, x. The correlation can be concluded as following: if $y_1 = y$, all xs stay stable; If $y_1 > y$, Evolutionary Stable Strategy (ESS) is $x = 1$; If $y_1 < y$, ESS is $x = 0$. This indicates that the higher the probability of government's supervision, the more inclined the PipeChina is to invest reasonably. Making $x = (R + M_1 + M_2 - C)/(R + M_2)$, where x stands for the probability of PipeChina applying reasonable pricing strategy that is correlated to the probability of government's supervision strategy change, y. The correlation can be concluded as following: if $X_1 = x$, all ys stay stable; If $x_1 > x$, ESS strategy is $y = 0$; If $x_1 < x$, ESS strategy is $y = 1$. This indicates that the higher the probability of reasonable investment of PipeChina, the more inclined the government applies 'non supervision' strategy.

After the separation oil and gas pipeline network in China, PipeChina tends to improve the quality of equipment and materials to consolidate the pipeline operation safety, attracted cost of investment increase which boost the tariff, thereby inhibiting the upstream to participate in transportation market which then induces the decrease of social welfare. Thus, the government should strengthen supervision on the income of each party of transportation so as to improve the social welfare, M_1. When the PipeChina overinvests, the government chooses 'supervision' and normalizes pipeline investment through economic penalty R, then gradually reaches the equilibrium point, {government supervision, reasonable investment}. However, since there is no economic penalty R and $M1$ is less than regulatory cost C when PipeChina makes reasonable

Table 3. Equilibrium point stability analysis if $M_1>C$.

Equilibrium Point	(G_{11},G_{22})	*det* (*G*)	*tr* (*G*)	Results
(0,0)	(-,+)	-	+	Unstable Point
(0,1)	(+,-)	-	-	Saddle Point
(1,0)	(+,+)	+	+	Unstable Point
(1,1)	(-,-)	+	-	Stable Point

Table 4. Equilibrium Point Stability Analysis under $M_1<C$.

Equilibrium Point	(G_{11},G_{22})	*det* (*G*)	*tr* (*G*)	Results
(0,0)	(-,+)	-	+	Unstable Point
(0,1)	(+,-)	-	-	Saddle Point
(1,0)	(+,+)	+	+	Unstable Point
(1,1)	(-,+)	-	0	Saddle Point
$((R+M_1+M_2-C)/(R+M_2),$ $(I_2-I_1)A\%/R)$	(0,0)	-	0	Saddle Point

investment, the government chooses 'non-supervision' strategy to minimize its 'opportunity cost'. When the government loosens supervision, the pipeline investment turns to increase leading to decline in social welfare. When M_1 is higher than C, government intensifies supervision to motivate pipeline company invest reasonably; therefore, based on the principle of "M_1 equals C", strategy profile between pipeline company and the government will fall into game on a loop: PipeChina reasonably increase investment by upgrading equipment and materials, while the government makes up for the social welfare losses that beyond reasonable investment.

Analysis of Regulatory Strategies for Tariff

Improve Laws and Regulations on China's Natural Gas Tariff

Placing sound laws and regulations of natural gas transportation pricing is the legal basis of supervision on tariff. As international energy hubs, the UK and

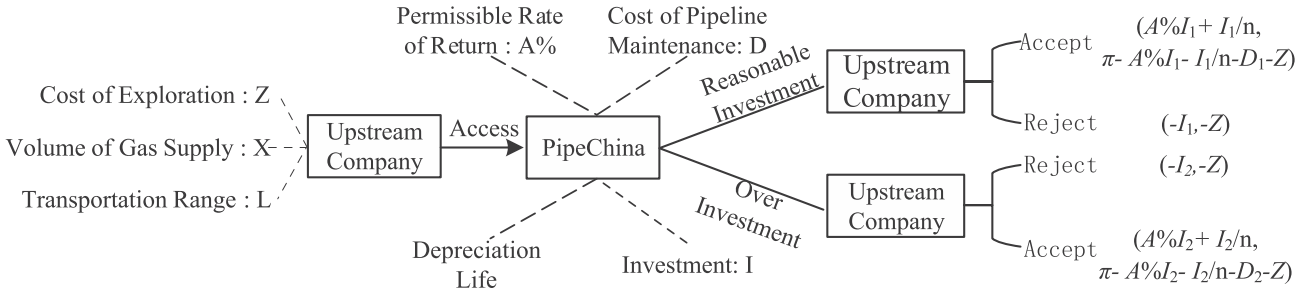

Fig. 3. Behavior Choices of Upstream Companies and PipeChina in China.

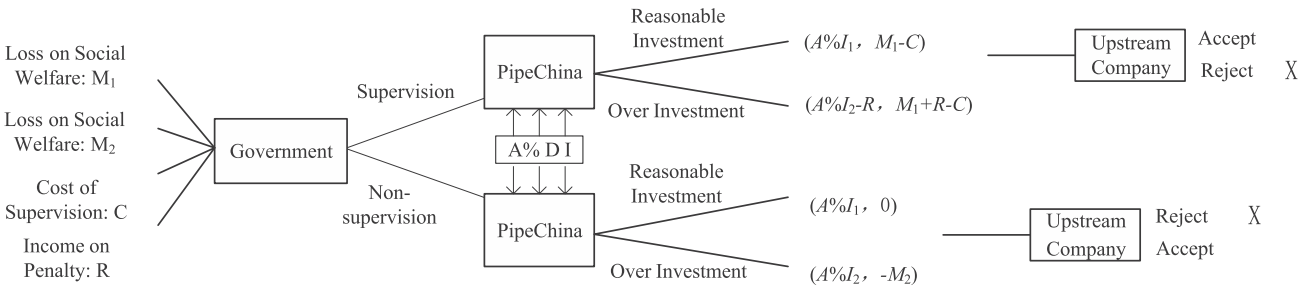

Fig. 4. Evolutionary Games between Government and PipeChina when Upstream Companies Accept.

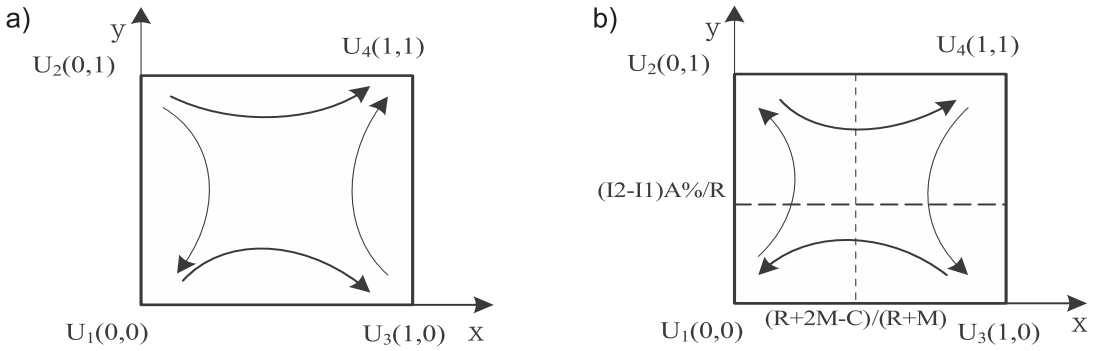

Fig. 5. Replication Dynamic Plots of Strategies between PipeChina and the Government.

the US have set mandatory laws and regulations to separate the natural gas pipeline transportation from the upstream supply and downstream sales so as to realize the independent operation of natural gas transportation from the aspect of legislation, as Table 5 listed. Meanwhile, clarifying details of non-discriminatory access and information disclosure supervision of natural gas pipeline network provides an effective top-level policy for access and operation of natural gas pipeline network.

With the deepening of the natural gas marketization process, diversified subjects actively flood into the natural gas transportation market effectively avoid information asymmetry, increase ease of cost supervision, and ensure the tariff accurately reflects the service cost and market demand of pipeline transportation. However, there are only 'Notice on Printing and Distributing the Measures for the Administration of Price of Natural Gas Pipeline (Trial)', 'Methods of Auditing the Cost of Natural Gas Pipeline Transportation (for Trial Implementation)', and 'Measures for the Non-discriminatory Third-party Access Regulation of Oil and Gas Pipeline Network Facilities' in China's current natural gas tariff regulation system. Current regulations and laws are lower-tiered and low efficiency at adjusting the behavior of subjects in natural gas market, and clauses are too macroscopic to offer reference to specific code of conduction. For instance, PipeChina should open up when there is surplus for pipeline transportation, access discriminatory exists with absence of mandatory, and lack of the unified standards of calculation and disclosure of surplus for pipeline transportation. Although the pricing method of natural gas pipeline transportation is changed from 'one pipeline one rate' to 'one area one rate', the heterogeneity of end users is still not taken into consideration and the pricing autonomy of PipeChina lacks effective supervision. Therefore, Chinese government should speed up to build legal system of tariff, formulate a comprehensive and flexible pipeline pricing mechanism, foster the compulsory access of pipeline network without discrimination, ensure the openness and transparency of natural gas market information, and to provide effective legal support for the process of natural gas market-oriented reform.

Improving the Market Mechanism for Natural Gas Pipeline Tariff

In the UK and the US, natural gas pipeline transportation is separated from upstream supply and downstream sales, and a secondary market trading mechanism is constructed to ensure the differentiation and diversification of natural gas pipeline transportation market. With the improvement of laws and regulations on natural gas pipeline tariff, China should be equipped with a market mechanism for pipeline tariff, and refine key market factors including pipeline transportation pricing, metering reception, scheduling balance, cost settlement and supervision mechanism. Taking advantages of the market media in natural gas trading center, Chinese government should push ahead with flexible delivery of natural gas spot and futures. First, the following approaches should be taken precedence: establishing standard tariff mode of natural gas pipeline transportation, determining system of secondary distribution of pipeline capacity, and adding pricing mechanism of third-party gas source is supplemented. Secondly, combined with the location information of the download points of the natural gas pipeline, the transportation requirements and technical standards of different natural gas are determined, and the mechanisms such as gas metering reception mode, implementation standard, and information disclosure and dispute resolution are clarified. In addition, build a balanced coordination mechanism of natural gas pipeline network to accelerate the construction of intelligent systems such as balanced prediction, automatic control and early warning, and strengthen the flexibility of pipeline dispatching combined with the commercial operation of pipeline storage transaction. Finally, the standardization of income and expense settlement of pipeline tariff should be supported, and an efficient dispute resolution mechanism should be equipped to guarantee the clear division of rights, responsibilities and interests of multiple subjects in the natural gas pipeline tariff market.

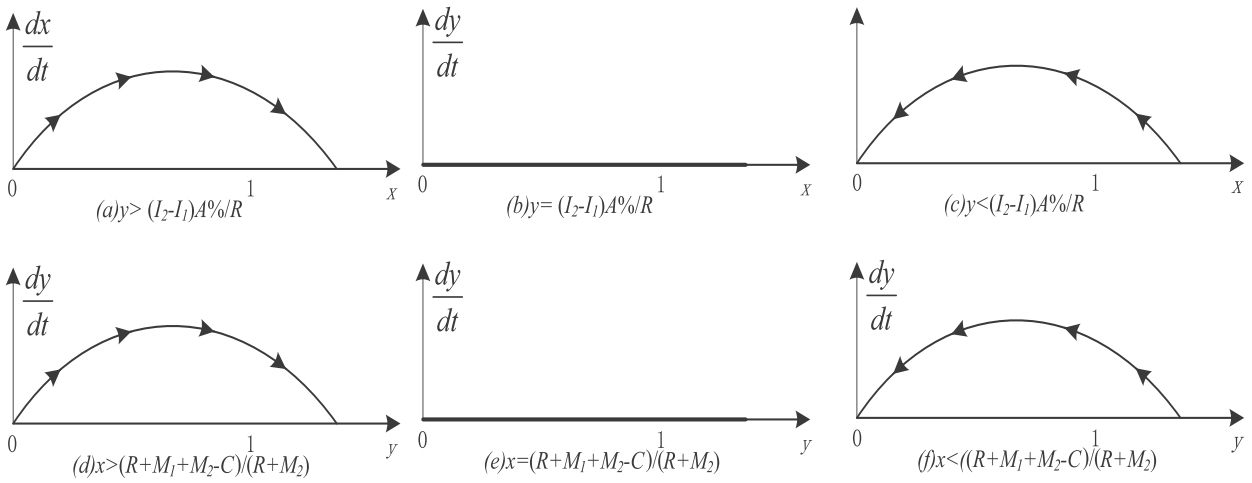

Fig. 6. Replication Dynamic Phase Plots of game between the government and PipeChina.

Implement Transportation Pricing Based on the Maximization of Social Welfare

Pipeline' s investment directly affects the distribution of cost and income of various subjects in natural gas pipeline transportation market. When the pipeline investment is too high, the pipeline transportation cost of upstream company will expand, and the profit for upstream will be squeezed, and even the company will withdraw from the natural gas market because its income is not enough to cover its expenditure. Nevertheless, if the pipeline's investment is too low, it not only affects the quality of pipeline construction but also limits the profitability of pipeline construction and impedes the entering of PipeChina. Therefore, the government should implement pipeline transportation pricing based on the maximization of social welfare, refine the investment standard of 'allowable cost + reasonable income' principle, and force PipeChina to strictly control the pipeline's investment.

First of all, the cost of service method determines the tariff according to the actual gas transportation, which is not conducive to the balanced gas consumption of downstream users. Therefore, the two-part tariff is introduced, and pipeline users need to purchase the transportation storage in advance and pay for it without any discussion, so as to ensure the investment recovery and promote the balanced gas consumption of pipelines. On the basis of the two-part tariff, employing the return on investment and maximum tariff model of Europe and America for reference, pipeline transportation pricing is implemented to maximize social welfare:

$$W = \frac{A\%I}{(\beta - \alpha)},$$

in which W: income of pipeline, $A\%$: permitted rate of return, I: investment, N : depreciation life.

The baseline coefficient $\beta(\beta \geq 2)$ and real-time coefficient $\alpha(0 \leq \alpha \geq 1)$ of social welfare are introduced to represent the social welfare at the actual investment, which increases and then decreases with the change of investment level as shown in Fig. 7. Assuming $\beta = 2$, under reasonable investment $\alpha = 1$, the profit of pipeline company maximizes, which is $A\%I$. The change of investment leads to the decline of social welfare and the income of PipeChina accordingly. But in practice, the regulatory authorities need to quantify the real-time change coefficient of social welfare, determine whether the trend of change is linear or non-linear and the social welfare base is a range or determined value, so as to clarify the income model of pipeline companies and control them to invest reasonably.

Establish a Joint Inspection Department of the Tariff

In order to effectively supervise the natural gas pipeline transportation and maintain the market order, there is a common international practice to set up a special agency for supervision. China can draw lessons from the energy market control office (OEMR) of FERC in the US and gas and electricity market office of OGEM in the UK: setting up independent regulatory agencies of natural gas industry that is responsible for access and exit PipeChina, pipeline's investment verification

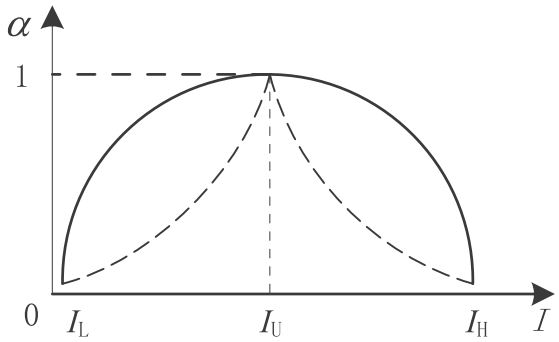

Fig. 7. Trends of Social Welfare Real-time Coefficient Changes.

and approval, the accessibility of pipeline network operation without discrimination, so as to effectively regulate natural gas pipeline tariff.

With the current status of the development of gas industry in China, the tariff inspection department can be jointly formed by 'three barrels of oil', PipeChina, and National Energy Administration with accounted for one third of rights on each. The department is responsible for the formulation and implementation of natural gas pipeline market access and exit policy, audit and regulate PipeChina's investment, operation cost and revise rate of return on investment, and verify the tariff of natural gas pipeline then realize the independent control of natural gas market. In order to further the rationalization of pipeline investment, the inspection department firstly levies a penalty income proportional to the excess investment and inhibits the incentive of excess investment as confiscate the excess income. Secondly, the management platform of by government and PipeChina should be established to extend the communication between subjects, timely disclose the investment, operation and pricing information of pipeline transportation to lessen information asymmetry. In addition, to execute high-frequency and small sampling supervision and cut the regulatory cost, streamlining departments and staffs, hiring industry experts for efficient supervision; meanwhile, urge PipeChina to elevate the self-audit mechanism, pre-audit the pipeline investment, lower the risk of punishment inspection. Finally, other approaches should be included: adjust the proportion of pipeline investment, limit the amount of financing, and avoid seizing illegal interests through leverage effect.

Conclusion and Recommendations

Based on the principle of 'allowable cost + reasonable income', PipeChina should cooperate to ensure the safe operation of pipelines and the steady recovery of investment while providing pipeline transportation services. After pipeline network separation in China, PipeChina tends to improve the quality standards of equipment and materials to strengthen the safety of operation, while it raises the investment of pipeline and increases the cost pressure of upstream for transportation, it is critical to regulate the investment and standardize the tariff. Therefore, this paper explored the strategic behavior choice of shippers, carriers and government in the game of natural gas pipeline tariff based on the composition of pipeline tariff, and analyzed the supervision strategy of tariff. The main research conclusions are as follows:

(1) As China's natural gas pipeline transportation market lacks of supervision, PipeChina tends to overinvest in the construction of 'luxury pipeline' to pursuit political achievement, resulting in raking in excess profits from the increase of tariff. Being a rational economic man, the upstream company can only passively accept the price of pipeline transportation, which leads to the market chaos that the investment level of pipeline is constantly improving and the profit space of the upstream companies is constantly compressed. However, government supervision can effectively restrain the excess investment of pipeline and improve the social welfare M_1. When the investment is reasonable, M_1 is less than the regulatory cost C, the government supervision gradually decreases and the PipeChina increases the excess investment. When M_1 grows higher than C, the government improves the regulatory intensity to lead to reasonable investment, and finally realizes the circular game. However, due to the huge capital volume of oil and gas industry, the social welfare improvement degree M_1 is much greater than the government regulation cost C, thus 'regulation' is always the government's dominant strategic choice.

(2) Aiming at effective supervision of the investment of natural gas pipeline, this paper analyzed the supervision strategy of the tariff from the perspectives of perfecting the laws and regulations and the market mechanism of the tariff, enacting pipeline transportation pricing based on the maximization of social welfare, establishing the inspection department of the tariff. First of all, according to the development status of China's natural gas industry, government decision-making departments should provide a compulsory top-level legal basis for the tariff of natural gas pipeline transportation services, and fully guarantee the legal accessibility and operation of natural gas pipeline network. Secondly, market sectors such as tariff, metering reception, balanced schedule, accounts settlement and supervision mechanism should be improved to ensure the efficient operation of the secondary natural gas trading market. In addition, it refines the investment standard of 'allowable cost + reasonable income' principle to control PipeChina to reasonably control the investment and maximize social welfare. Finally, an independent regulatory agency for the natural gas industry should be set up to perfect the policy of entering and exiting the market of natural gas pipeline transportation, supervise the investment and operating cost of pipeline network and correct the rate of return on investment, and verify the tariff and realize the independent control of the natural gas market. This research was carried out in China and suggestions maybe more suitable and beneficial for Chinese government and policy makers.

Conflict of Interest

The authors declare no conflict of interest.

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