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OPTIMIZE CHINA'S SEASONAL NATURAL GAS STORAGE: A WELFARE-ECONOMICS APPROACH

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ABSTRACT

China's strict coal-to-gas policy in the recent years has brought unexpected natural gas demand into the domestic market, leading to additional uncertainty and pressure, and further increased China's import dependency rate. The current situation urges China to establish valid storage system for natural gas, which have been proved to be a preferred method in circumstances with high uncertainties. In this paper, we implement a model based on welfare economics to show the optimal gas storage capacity and its monthly scheme. The result indicates the basic optimal natural gas storage size to be 11.91 billion cubic meters. Under normal conditions, the storage shall reach its peak near November, then begin to release through the next April, and switch back to injection progress to prepare for the upcoming winter.

Keywords: Natural gas storage, Working gas capacity, Coal to gas reform

NONMENCLATURE

Abbreviations	
SPR	Strategic petroleum reserve
UGS	Underground gas storage
GCD	Gas consumption day
HDD	Heating degree day
LNG	Liquified natural gas
Symbols	
z	Gas stockpile size
ε	Price elasticity in natural gas demand
λ	Target disruption dates
P_0	Average price
P^*	Equilibrium price
ω	Derived from inverse demand function
f	Fixed cost of storage
v	Variable cost of storage
r	Interest rate
μ	Season factor

1. INTRODUCTION

The natural gas consumption of China saw a rapid growth since 2017, as Chinese policymakers put extra attention on coal-to-gas energy reform. Combined heat and power plants together with rural inhabitants in the "Beijing-Tianjin-Hebei 2+26 cities", representing the two municipalities plus 26 major cities in the surrounding area, were ordered to stop burning coal, but switch to natural gas instead in the winter. Originally, the policy aimed to improve the long-quarreled poor air quality in the area, since coal combustion was believe to be a major source of particles in the air pollution. However, as the policy was introduced in urgent, domestic market was unprepared for the additional demand. Annual gas consumption reached 238.6 billion cubic meters as of 2017, 14.8% higher than 2016 [1], while domestic liquified natural gas (LNG) price rocketed above 7000 CNY per ton, more than 2 times higher than its average level, as in Figure 1. In order to maintain basic winter heating demand in the region, China restrained and rerouted gas supplies from western and southern provinces. Gas usage of large industrial gas consumers like ammonia and urea manufacturing were also restricted, bringing potential risks to downstream industries. On the other hand, domestic production grew by 8.2% to reach 148.0 bcms, but could only cover 34.4% of the total consumption growth. Therefore, imported natural gas saw a significant increase, with import dependency ratio reached 22% in 2017. As a result, China became the second largest LNG importer in Asia, behind Japan [2]. With import dependency rising sharply, establishing valid gas storage system would be an urgent task.

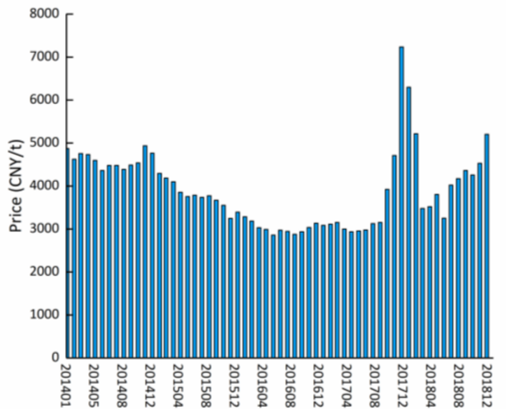

Fig 1 Average LNG price in China, 2014-2018

Stockpiling energy resources has been proved to be an effective way to face market fluctuation, and to decrease energy risk. China's strategic petroleum reserve system had been running since 2014, and the stockpile capacity had been extended steadily hence. With Phase 3 of the project under constructing, a capacity as much as 31.97 million tons was available as of 2017 [3]. Natural gas storage system featuring underground gas storage (UGS), however, are still under construction. Initially, several storage sites served for peak shifting purposes only. More depleted gas fields and underground caves were involved for larger storage. As of 2011, 2.24 billion cubic meters of gas were injected [4], and by 2017 it had reached 7.7 billion, with 25 underground sites in working state [2].

However, the managing system of gas storage is still complexed. State-owned underground sites of PetroChina were either bundled with long-distance pipelines or the responsible oil/gas field subsidiaries, until recently being reassessed to oil fields. The relationship between them and the pipeline is always surrounded with controversy, as the two sides would disagree on gas supplement, injection and withdraw rate, pricing issues, etc. A national pipeline company had been established, but yet to operate with full power.

Abundant studies on strategic petroleum reserves have been published since the 70's oil crisis. A two-period static model was first used by Nordhaus to determine SPR and tariff policy [5]. Samouilidis and Berahas [6] later employed decision tree model to determine optimal storage capacity. Teisberg [7] used dynamic programming model to illustrate SPR size and its acquisition/withdraw policy. Chao and Manne [8] further used dynamic programming to study the mutual interactions between OECD's oil demand, international oil price and the U.S. SPR policy. Murphy and Weiss [9] extended the model by taking into account a Nash dynamic game model among several oil-importing countries.

For studies within the range of China, Bai et al. [10] implemented dynamic programing to study China's optimal stockpile acquisition rate, and developed a two period model to analyze the relation between import tariff and stockpile policies [11]. ; Chen et al. [12] developed a multi-dimension stochastic dynamic programming model to describe the benefits from using stockpile delegation as an auxiliary of SPR policies for China. Bai et al further studied China's oil stockpile acquisition and reserve path by dynamic programing [13], and used Markov Decision Process to illustrate the impact of oil price and disruption risk on stockpiling policy [14].

Lise [15] used GASTALE model to simulate interactions among demand, supply, and investments in European natural gas market. J. de Joode et al [16] used extended GASTALE model to simulate seasonal gas storage in northwest Europe. Wang [17] considered price fluctuation and seasonal effect to build a UGS valuation model.

In brief, studies on the impact of gas market stagnation on China's natural gas storage are lesser. As a supplementary research, this paper applies a static model to determine the monthly optimal natural gas stockpiling pattern under different demand circumstances.

2. NATURAL GAS STORAGE CAPACITY MODELLING

2.1 Basic model

In this research, we implement the model from Lin and Du [18] to determine the natural gas storage capacity, but further magnify the decision-making period to 1 month. As a single-period static model, this model is capable to measure and adjust operational actions of gas storage. More description of this model could be found in [3] and [19].

We have to mention one important hypothesis as the original model did, that the acquisition of gas storage does not affect international gas price, as consistent with Teisberg, since China could not effectively impact international gas pricing for lack of a fully functional dynamic natural gas market. This model, in brief, started from the aspect that Chinese government is building the gas reserve for maximum social welfare, in consider of macroeconomic regulation and energy security. Once there is disruption in gas supply, it will be incapable to address the consumption demand, leading to a reduced consumer surplus. The purpose of the gas storage is to minimize this sort of surplus damage.

We define a dynamic unit "Gas Consumption Days" (GCDs) for the stockpile size. 1 GCD represents the size as much as the daily average consumption within the respective time period, which will be the basic unit in the model.

Upon the original model, we further introduce a seasonal factor μ, to emphasize the seasonal change of natural gas consumption within a year. As [20] and [21] indicates, Chinese gas market show a growing demand from spring through winter, leading to a decreasing elasticity. We set price elasticity of China's natural gas demand to be -0.233 in spring based on results from [20] and [22]. Season factor μ would change from 0 in spring to -.007, -0.014 and -0.021 through the seasons.

Eventually we have the model equation as follow.

$$\int_z^{365} \frac{1}{\lambda}\left[\omega(365-t+z)^{\frac{1}{\mu_i+\varepsilon}}+P_0-P^*\right]dt = f+v+rP^* \quad (1)$$

Where z stands for the unknown size of stockpile, in GCDs.

2.2 Parameters

The variables in the model are listed in Table 1.

As energy commodity, crude oil, coal and natural gas would share similar irreplaceable market characteristics [19], with price-demand elasticity below zero. With a minus elasticity, this model would be available for natural gas.

The monthly average prices are from CEIC Database, and monthly consumptions are from [23].

Table 1 Model Parameters

Symbol	Description	Value	Unit
ε	Basic price elasticity in natural gas demand	-0.233	None
λ	Target disruption dates	31	GCD
P_0	Average price	2.040	¥/ m^3
P^*	Equilibrium price	2.510	¥/ m^3
ω	Derived from inverse demand function	0.470	None
f	Fixed cost of storage	0.300	¥/ m^3
v	Variable cost of storage	0.178	¥/ m^3
r	Interest rate	3.000	%
μ_1	Season factor spring	0	None
μ_2	Season factor summer	-0.007	None
μ_3	Season factor autumn	-0.014	None
μ_4	Season factor winter	-0.021	None

3. RESULTS AND DISCUSSION

3.1 Basic condition

Based on the original model without seasonal factor, the optimal stockpiling size of 2017 is 18 GCDs, or 11.91 bcms. In other words, to face a 31-day-long interruption, at least 18 GCDs or 11.91 bcms, shall be available in stockpile.

Furthermore, with the seasonal factor inserted, and assuming the storage system has been running with full function through the years, we are able to portray the monthly scheme from 2014 through 2018 using respective data, as it's shown in Fig. 2. Sizes in GCDs have been converted into bcms to show a more intuitive scheme.

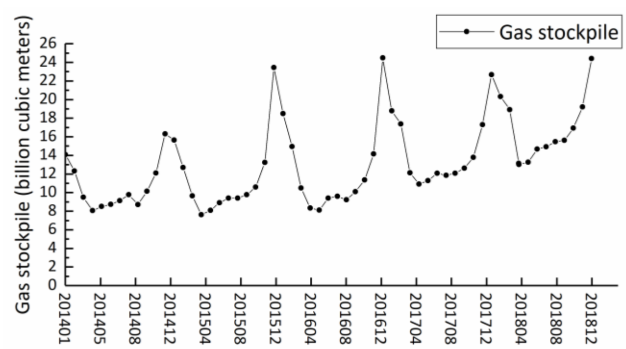

Fig 2 Gas storage scheme in basic condition, 2014-2018

Similar annual pattern could be seen in each year, as the stockpiling process would begin its injection process between April or May. Then, the storage will be reaching its highest in November, and begin to release until the next April. Injection speed tend to be slower during the summer due to considerable peak electricity demand with gas power plants.

Both maximum and minimum capacity saw a rising trend though the years except for winter 2017. Since 2015, the maximum storage reached beyond 24 bcms, while the lowest point remained around 8–15 bcms.

To find a possible explanation for the odd trend in 2017, we believe the urgent policy represented strong government interference, which altered the original market pattern, and brought unexpected data into the trend.

3.2 Results with altered gas demand

In the current research, we set additional scenarios to study the change of stockpile in different demands.

Scenario I will have a higher-than-average winter demand, caused by lower temperature or higher heating degree days (HDDs). Scenario II is set to have higher demands in the summer, as we assume natural gas powerplant policies are fully deployed, to provide additional electricity in the summer. Both I and II are mixed to generate a Scenario III. We select a complete storage cycle (2017-2018) to emphasize the difference between the basic condition and each scenario.

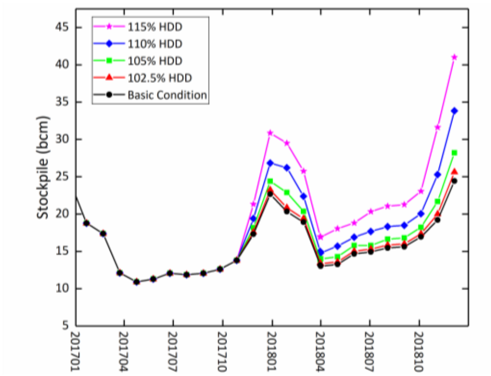

Fig 3 Scenario I

According to [24–26], natural gas consumption clearly have a linear relation with HDD, thus we add extra 2.5%, 5%, 10% and 15% winter HDD for scenario I, 2.5%, 5%, 10% and 15% extra summer demand for scenario II, to see the respond of stockpile size.

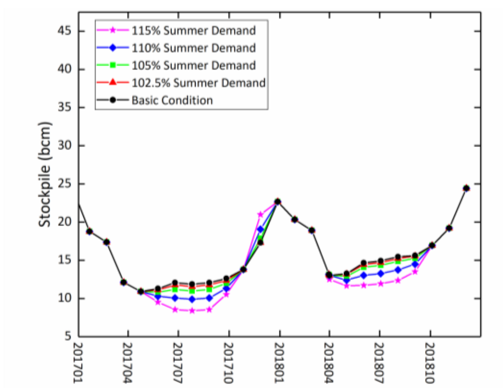

Fig 4 Scenario II

First of all, increased seasonal demand do have certain impact on the storage scheme. As the seasonal demand grow, the peak of injection or valley of withdraw tend to move towards respective directions. When the parameter is set to 2.5%, its impact on stockpile scheme is insignificant.

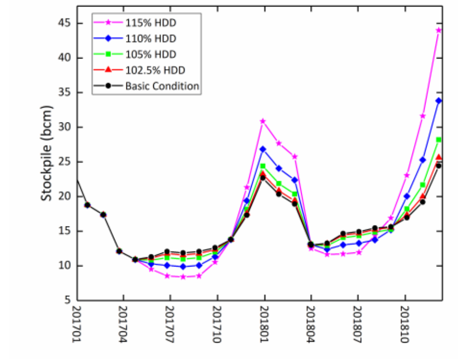

Fig 5 Scenario III

As it's shown in Fig 5, the mixed scenario saw a more drastic fluctuation. To meet the strict demand in winter and summer, the stockpile has to prepare for the next decision period earlier than average.

3.3 Sensitivity analysis

In this section, we try to vary major parameters, namely elasticity, target disruption dates and interest rate, to observe the reaction of optimal stockpiling, respectively, as in Fig. 6-8.

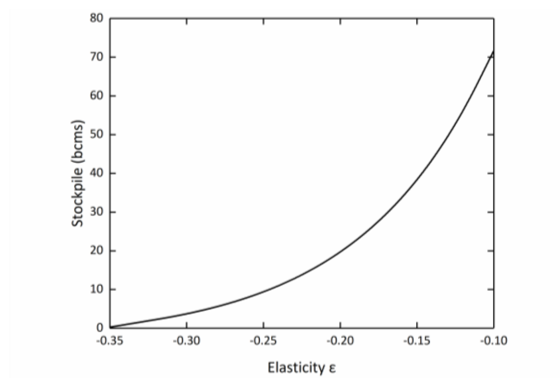

Fig 6 Sensitivity of stockpile to elasticity

Overall, this model has sharp sensitivity towards the elasticity. Fig. 6 shows the respond of stockpile to elasticity, that more storage is needed when demand turns towards inelasticity.

Stockpile also grows as target date increases, but tend to be less sensitive as it reaches beyond 80 days, and for minor disruptions below 15 days, stockpile is merely necessary.

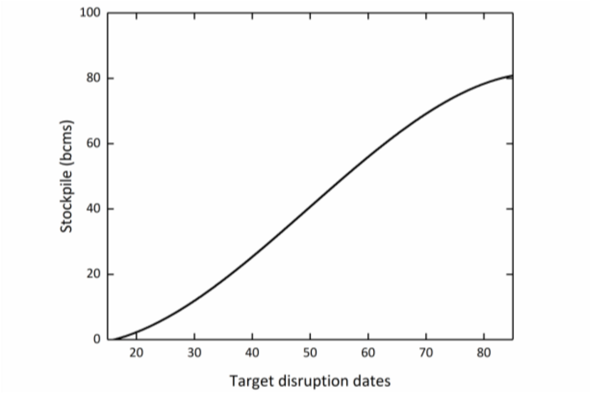

Fig 7 Sensitivity of stockpile to disruption dates

As for the interest rate, high capital cost brought by high interest rate will consequently limit the size of stockpile. But the model tends to be less sensitive towards interest rate.

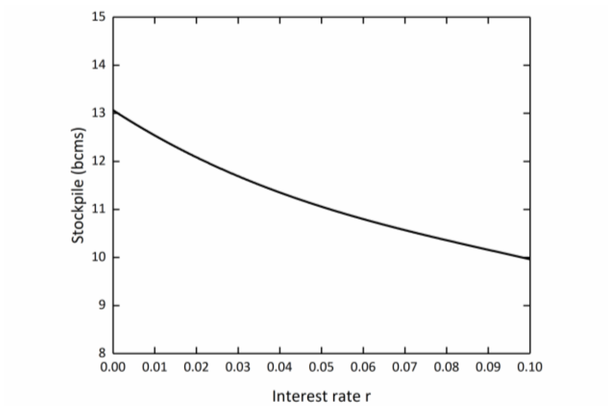

Fig 8 Sensitivity of stockpile to interest rates

4. COUCLUSION AND RECOMMENDATION

According to the calculation of the basic condition, the optimal gas stockpiling size would be 11.91 bcms as of 2017, 54.6% larger than the current size (7.7 bcms). The current research then focused on optimal storage pattern, that the injection would begin in April, and start to release from November until the next April, to form an annual cycle, as the result illustrates.

This paper also set 3 scenarios, consisting of 2 different demand situation and their combination, to see the response of the stockpile scheme. Higher winter demand will bring higher extremum storage size, and push the injection starting point earlier, while higher summer demand would have opposite effects. Additional fluctuation also appears in the altered condition.

Based on our results, we offer following advices, looking forward to improve China's natural gas storage system with steadiness and soundness.

Obviously, current natural gas storage could be suitable for ordinary peak-shifting purposes, but seems to be insufficient to cover a normal-sized supply disruption. The maximum storage ability shall reach at least 26 bcms in the future, to deal with seasonal gas demand. With more underground storage sites to be built, location and size of the facility shall be carefully planned, to meet highly diversified seasonal needs in different provinces.

We also advise China to officially add natural gas storage capacity into the statistic system to provide data and reference for in-depth studies.

We strongly recommend such a strict coal-to-gas policy to be carefully revised before deployment. Switching and replacing major energy could take decades to finish, consider Britain's disposal of coal plants. The government is boosting the progress in an imprudent way, by paying subsidies to gas users to meet the dire need, and have already encountered considerable pressure on annual budgets. With the uncertainties it had brought to both domestic and east Asian gas market, we believe related policies are doing more harm than good at the time.

On the other hand, as China is rich in coal resources, the primary task in energy reforming shall be to fully empower it, rather than cutting it off. Industries like coal-to-gas conversion, which is suffering heavy deficit, and advanced coal cleaning, shall receive sufficient government support, both politically and peculiarly.

Current study still has limitations. The reliability of the model was restricted by its typical assumptions, that China's acquisition of natural gas would have certain impact on international market. We used diluted elasticity for the model, as it's highly elasticity-sensitive, but the real price-demand elasticity of natural gas has obvious change during seasons with different demand pattern. Additionally, using dynamic model rather than a static one would obtain more realistic results, consider stochastic dynamic programming. The flaws mentioned above are to be readdressed in future studies.

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