

## Heterogeneous Pricing and Affordability of Residential Natural Gas Consumption: Lifestyle-Driven or Income-Determined?

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**Abstract:** With the huge increase in natural gas consumption, the distortion of natural gas prices, especially in the residential sector, is prominently shaped into a heavy burden for public finance. Although city gate price and a price linkage mechanism have been established, the price tolerance of residential natural gas should be considered when the price of residential gas fluctuates with the upstream gas price. Determinants of the price affordability of residential natural gas consumption at different economic development levels (Beijing, Nanjing, Zhengzhou) are investigated by field survey and online investigation and analyzed by a factor analysis and discriminant analysis. The results show that most residents are not sensitive to the price of natural gas, and their motivation for substituting gas with other energy is not strong. More than half of the residents have strong natural gas price affordability, while the weakest affordability occurred in Zhengzhou city among the research regions. The income level of the consumers, the convenience and reliability of natural gas, and the duration of natural gas consumption are the top three factors affecting the affordability of natural gas prices for residents. Policy implications are proposed to facilitate the implementation of natural gas price reform.

**Keywords:** Natural gas price; price affordability; questionnaire survey; impact factors; discriminant analysis

### 1 Introduction

China's natural gas market has developed rapidly in recent years. However, the natural gas pricing mechanism is not perfect, and has substantial impacts on the sustainable development of the natural gas market. With the advance of China's energy restructuring, the proportion of natural gas in China's primary energy consumption has increased from 2.2% in 2005 to 7.8% in 2018 with a projection of 10% in 2020 [1]. Meanwhile, the population with access to natural gas will increase from 330 million in 2015 to 470 million in 2020 [2]. Although China's natural gas price reform has been implemented in the manner of "easy before difficult," the government has laid more emphasis on the price reform of non-resident natural gas rather than residential gas, resulting in the lowest price of residential gas in a long

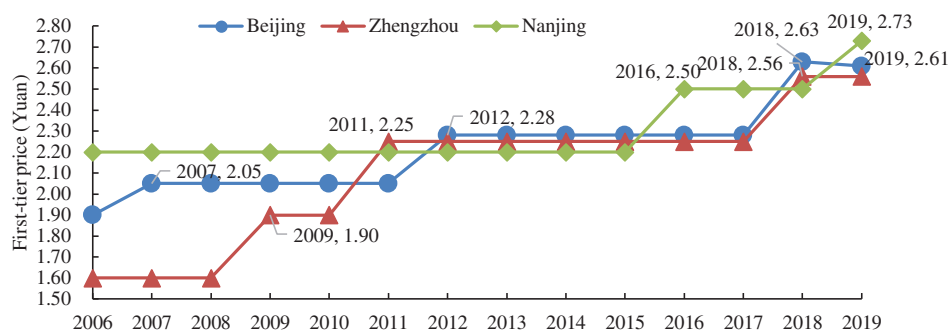


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time. Therefore, the reform of residential natural gas price is imperative and will be accelerated in the near future. However, there are still many constraints for the disorder of the upstream and downstream prices of residential natural gas and the cross-subsidies between the prices of residential and non-residential sectors.

The linkage between the upstream and the downstream price for residential natural gas consumption have been clearly built, resulting in frequent fluctuations in price. It is difficult to implement the target of China's natural gas price reform before 2000 due to its complex market environment. Natural gas price classification was changed into 3 to 6 categories, which sparked controversy between upstream gas suppliers and downstream gas companies on price settlement. The governments did not implement the dynamic adjustment mechanism for linking the benchmark price of natural gas to the price of alternative energy. It was not until June 2010 that the ex-factory price of natural gas was integrated into the first-tier and second-tier prices [3]. To build a natural gas price linkage mechanism, the National Development and Reform Commission of China issued a notice of accelerating the implementation of the natural gas price adjustment plan in 2010 [4]. However, the adjustment of residential gas prices is closely related to the stability of people's livelihoods which greatly restricts the promotion of a linkage mechanism for residential gas prices and would lead to the imbalance of natural gas supply [5]. Under the linkage mechanism of upstream and downstream price for residential gas, residential gas prices in Beijing rose by 0.35 yuan in July 2018 and fell by 0.02 yuan in November 2019. Therefore, residential gas prices may fluctuate more frequently when the price linkage mechanism is gradually improved.

The rising trend of residential natural gas price is obvious when the cross-subsidies are reduced. The cross-subsidy of natural gas is usually reflected by the fact that the price of residential gas has been lower than that of industrial and commercial gas for a long period. Also, this fact may trigger a dispute between upstream gas supply enterprises and urban gas enterprises over the issue of diverting the gas quota allocated to residents to non-residential users. The National Development and Reform Commission of China issued a notice in 2018 on adjusting city gate price of resident natural gas which reduced the cross-subsidy for urban gate stations. The adjusted city gate price means that the city gate station will no longer distinguish between the gas prices of residents and non-residents, which will increase the gas prices of residents to some extent [2]. Many cities have adjusted the terminal gas price. As seen in Fig. 1, Beijing and Zhengzhou raised prices for residential terminal gas by 0.35 yuan and 0.31 yuan per cubic meter respectively in 2018. It can be seen that a number of urban gas prices are generally adjusted, and the trend is upward along with the merging of city gate price. Therefore, the adjustment of natural gas prices should take into account the affordability of residential gas prices and the driving factors in the premise of promoting stable development of the market and ensuring people's livelihoods.



**Figure 1:** Natural gas price adjustment with year and price in Beijing, Nanjing and Zhengzhou

Other factors, such as the urban economic development level, residents' income level and the number of gas service providers, will hinder the timely linkage adjustment and further marketization of residential gas

pricing [6]. The present reform schedule of residential gas pricing has been implemented in the gate stations while there still are some problems in cross-subsidies between residents and non-residents, especially in the downstream gas retail price. Although policy documents for establishing a price linkage mechanism and sorting city gate price have been created, the effects of implementation varied greatly among different cities. Regions with better economic development levels, higher affordability and diversified gas sources can try to liberalize the prices before the residential natural gas prices are fully liberalized. Due to the importance of residential affordability in the restrictions for liberalizing gas prices, it is conducive to determine the factors that affect residential affordability and take measures to reduce the effects of these factors for further marketization of residential natural gas.

Numerous studies have employed the equivalent heating value method or income-expenditure method to evaluate the affordability of different natural gas consumers [7,8]. Also, the empirical studies about residential natural gas price affordability have considered the indicators of urban development level and the price level of alternative energy but neglected residents' willingness to pay and behavioral factors. To solve the problem of natural gas price marketization, it is necessary to comprehensively consider factors such as the regional economic level, residential income level and price affordability and to conduct a survey about residential affordability before and after price adjustment. In this study, the response of residents to the adjustment of natural gas prices can provide valuable policy recommendations for government decision-making. Using factor analysis and discriminant analysis to deal with the questionnaire data can clearly reflect the main influencing factors and the degree of influence on residents' bearing capacity. Therefore, there are three questions to be answered in this paper:

1. What is the energy-related lifestyle behind residential natural gas consumption, and what are the differences in gas price affordability in Beijing, Zhengzhou and Nanjing?
2. What are the main factors influencing residential natural gas price affordability? What are differences in main factors between the three cities?
3. Balancing resident well-being and the reduction of public investment burden, what are the measures for sustainable development of the residential natural gas sector?

This research investigates residents' affordability of natural gas prices and public perception about the heterogeneous natural gas pricing and measures their conditional support for the increase in natural gas price. Findings about lifestyle behavior change are conducive to the natural gas market reform. The next section presents a literature review on research methods and influencing factors of natural gas price affordability. Section 3 introduces the research methods and measurement indicators adopted in this study. The fourth section discusses and analyzes the investigation results and the determinants of natural gas price tolerance. The conclusions and policy recommendations are proposed at the end of this paper.

## **2 Literature Review**

### ***2.1 Research Methods of Price Affordability***

Different methods are used to study the price affordability of energy and fuels, as shown in Tab. 1. The contingent valuation method, as a typical method of stating preferences, is a common technique for measuring willingness to pay. Damigos et al. [9] used the conditional value method to investigate households' willingness to pay for the security of the natural gas supply in power generation, and the results showed that consumers were willing to pay additional electric bills to internalize the generated external cost of electricity. Jin et al. [10] adopted the conditional value evaluation method to investigate residents' willingness to pay for solar energy research and development in Beijing, and the results showed that more than 60% of the respondents were willing to pay with an average additional payment of 5.85 yuan per month. The income-expenditure method is another common method, which is mainly used to study the residential affordability of energy price by the ratio coefficient of residents' energy

**Table 1:** Research methods and influencing factors of affordability

Objects	Methods/Models	Influencing factors
Natural gas [7]	Income-expenditure elasticity model, equivalent heating value method, small-taking and interval-number methods	Income, price of alternative energy, residential environmental awareness
Reliable natural gas supply [15]	Contingent valuation method, a one-and-one-half-bound dichotomous choice model combined with a spike model, face-to-face interview	Education, income, family size, interests of energy issues
Energy transition [16–18]	Contingent valuation method, single-bounded dichotomous choice spike model	Education, income, prior knowledge
Security of natural gas supply [9]	Contingent valuation method	Environmental awareness, security awareness, education
Renewable energy [11–13]	A meta-regression analysis	Renewable energy type, consumers' socio-economic profile, consumers' energy consumption patterns
Solar energy [10]	Contingent valuation method	Educational attainment, household income, risk attitudes, attitudinal beliefs about energy problems, bid values
Renewable energy [14]	Case study	Sufficient subsidy, rigid regulation
Coal to gas [8,19]	Income-expenditure method	Income, sufficient subsidy, technology

expenditure to per capita disposable income. Liu [8] used the income expenditure ratio model to analyze the price affordability of Beijing residents for replacing coal with gas for heating and found that the gas heating expenditure of most households exceeded 3.0% of the household disposable income, which could be controlled at 0.3–3.4% through government subsidies. As a quantitative method, meta-regression analysis can furnish more insights into the factors which could explain the variation of results from different studies [11–13]. Ma et al. [11] used a multiple linear regression model to study consumers' willingness to pay for increasing the proportion of renewable energy generation in their power portfolio and found that consumers were favor of solar, wind or other renewable energy sources rather than hydro or biomass generation. Of course, other scholars adopted case study approach to analyze the affordability. Yuan et al. [14] studied the pricing and affordability of renewable energy in China by taking Shandong province as an example. Residents can afford renewable energy because the government provides sufficient subsidies and strict regulation. It is essential to build a more scientific pricing mechanism for the government, electric power groups and grid companies, and other stakeholders.

With the further research, it is not enough to study the affordability with only one method. A variety of methods are integrated to enhance the strengths and avoid weaknesses. He et al. [7] analyzed economic and psychological affordability of different income groups in Beijing for natural gas prices by establishing the income-expenditure elasticity model and adopting the equivalent calorimetric method to evaluate their comprehensive affordability. The results showed that residents with different incomes and environmental awareness have different comprehensive affordability of natural gas prices while the price of alternative

energy will reduce residents' price affordability. Jang et al. [15] used the contingent valuation method to survey the willingness to pay of 1,000 South Korean households for ensuring the safety of the LNG supply and processed the acquired data using the binary choice model and peak model method. Finally, they indicated that the respondent is willing to pay an average of \$8.68 per year in extra spending to ensure a continuous supply of natural gas. Lee et al. [16] employed the conditional value method and the spike model to evaluate Korean consumers' willingness to pay for replacing nuclear energy and coal-fired power generation with renewable energy. The results showed that consumers were willing to pay \$3.30 and \$3.00 per month to replace nuclear energy and thermal power respectively.

The studies above reveal that the words of alternative energy sources, government subsidies, and willingness to pay, etc. are closely connected to natural gas price affordability. However, the more specific studies are necessary to study natural gas price affordability for residential users. Therefore, this paper will investigate the price of natural gas, the acceptance of other alternative energy, the time of gas consumption, personal satisfaction of gas consumption, demographic information, and other energy related lifestyle by a questionnaire survey and determine the main factors for taking decisive measures to improve residential natural gas price affordability.

## **2.2 Influencing Factors of Price Affordability**

Price affordability is governed by many factors. As seen from Tab. 1, the main factors affecting price affordability can be analyzed from the perspective of individuals, families, society or governments. From the perspective of individuals, the factors include education level [15,17], environmental awareness [7,18], and interest towards energy issues [15]. From the perspective of families, the family income [7,15] and family size [15] are important factors. From the perspective of society or government, the main determinants include the price of alternative energy [7,12], degree of economic development [11], government subsidy policy [13,14] and technology [8,19]. Wang et al. [3] analyzed the influential factors about China's natural gas consumption from a sector perspective and found climate factor innovatively. The results show that income, energy prices and the winter temperature changes are the top three important factors affecting natural gas consumption. Based on these factors, price levels of alternative energies, targeted subsidies and peak shaving should be considered for increasing the affordability. In view of reality and experience, the subsidy policy is an important factor to promote the affordability and consumption of natural gas. Lin et al. [20] analyzed the sensitivities of the different industries to changes in natural gas price and the effect of gas price adjustment on different price levels, and proposed that targeted subsidies are needed by considering natural gas pricing reform as well as affordability concerns for different users in different regions. The rebound effect of gas subsidies in the residential sector was attributed more to the coal to gas program, which has significantly increased the consumption of natural gas and further elevated affordability in the residential sector [21].

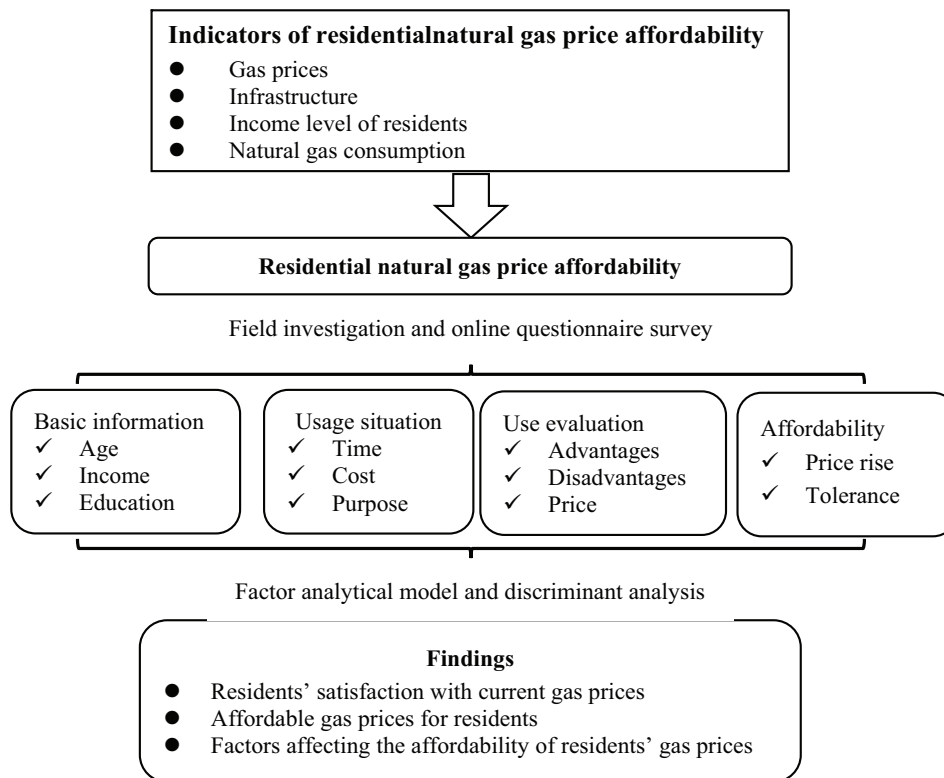
Otherwise, natural gas demand should be considered to study natural gas price affordability. Li et al. [22] analyzed natural gas price affordability of different residential users in Beijing based on the estimation of demand price elasticity and basic demand volume of natural gas. Furthermore, it is important to connect non-residential natural gas price with residential gas price affordability. Zeng et al. [23] adopted the non-residential natural gas price as the instrumental variable for residential natural gas price for address the endogeneity problems, and analyzed the substitution potential to use natural gas to replace electricity and LPG. Thus, it can be seen that there are differences on the significance of influential factors when studying the affordability of natural gas from different perspectives.

According to the above literature analysis, there are few studies on the price affordability of natural gas, and the differences in regional price affordability have seldom been considered. Therefore, this paper conducts a survey on three cities with different gas consumption patterns in China, namely, Beijing, Nanjing and Zhengzhou. Then, the regional differences in gas price affordability and its impact factors were analyzed.

### 3 Methodologies

#### 3.1 Research Framework

The analytical framework of this study is shown in Fig. 2. Based on the literature review in Section 2, residential natural gas price affordability is measured by four dimensions from the questionnaire design. The main factors affecting price affordability are identified by a factor analysis and discriminant analysis. The decision support for natural gas consumption with the increase in natural gas price is discussed, and policy suggestions are proposed to efficiently improve residents' affordability and implement natural gas pricing reform.



**Figure 2:** Framework of this research

#### 3.2 Methods and Data

##### 3.2.1 Questionnaire Survey for Natural Gas Price Affordability in the Residential Sector

Beijing, Zhengzhou and Nanjing are identified as the research areas because of the following four reasons. First, these cities have different levels of economic development, which is conducive to obtaining whether the residential natural gas price affordability is driven by the economic development level. For example, the per capita GDP of Beijing, Zhengzhou and Nanjing was respectively 140, 211, 101, 352 and 152, 886 yuan, respectively, in 2018 [24]. Second, there is a large amount of residential natural gas consumption in the three cities, which is helpful for the collection of survey data, and the choice of Beijing and Nanjing can reflect the impact of heating difference on natural gas consumption in northern and southern cities. Third, natural gas prices in the three cities have been increased to some extent in the past few years, which contributes to learning residents' response. Last, natural gas suppliers of the three cities have different types of ownership. The distribution suppliers in Beijing belong to the Beijing Gas Group company, a state-owned enterprise, whereas the suppliers for Nanjing and Zhengzhou

are private enterprises. This will help to find out the impacts of differences in infrastructure, service local policies and other aspects on the affordability of residents' natural gas prices.

The questionnaire is designed according to the following steps. First, the questionnaire was designed to collect information, including basic information, energy related lifestyle of the residents in the three cities and their current use and evaluation of natural gas. Second, based on the existing literature, the questionnaire is employed to ensure that the designed questions comprehensively include the factors affecting residents' natural gas price affordability. Meanwhile, the deficiencies of the questionnaire were corrected. Third, the questionnaire is reviewed by a two-step test. The first step is to conduct questionnaire tests in a small range in order to test whether the respondents' understanding of the questionnaire is consistent with the original intention of the question design as well as the reliability, validity and discrimination of the collected data. The second step is to ask researchers in social statistics and surveys for professional advices. According to the feedback from the review, the inadequacies of the questionnaire are modified and finalized for the formal investigation (Appendix A).

The questionnaire comprises three parts. The first part is the basic information of the respondents, including gender, age, education, monthly family income and family structure. The second part is the natural gas consumption behavior of the interviewees, including the expenditure, usage style, payment method and payment frequency, etc. The third part investigates users' evaluation of natural gas consumption and price, including the advantages and disadvantages of natural gas use and the satisfaction of gas companies' services, their feelings on the current natural gas price level and the acceptable price increase under the circumstance of no behavioral change in natural gas consumption. The design of questions is elaborated to test the reliability of the questionnaire through feedback.

With the design of the questionnaire, the members of the investigation team are responsible for distributing and recycling the questionnaire. The team members are selected through strict interview and training. They all have an interview on their primary understanding of the natural gas field. Then, the selected members are trained to have a deeper research background of the price tolerance of residential natural gas, so that the investigation team has a better ability of collaborative research. Finally, the members of the natural gas price affordability research group are trained to improve their communication skills during the investigation process. Meanwhile, to improve the quality and efficiency of questionnaire recovery, the members should be familiar with the contents of the questionnaires and the information of research background to answer questions for the interviewees.

The questionnaires are distributed and collected through field research and fixed-point online distribution by the network questionnaire platform. In the field survey, questionnaires are distributed in community squares, shopping malls, parks and bus stations in the three cities. The Questionnaire Star platform is used to implement online questionnaire survey by the residents of Beijing, Zhengzhou and Nanjing. The field distribution of questionnaires can help to explain the questionnaires to the respondents on the spot. Field investigation has both the disadvantages of low efficiency and similarity of respondents and the advantages of high accuracy and strong pertinence. Therefore, the number of questionnaires can be increased to compensate for the shortage of field research by online questionnaire collection. After all questionnaires are collected, the investigation team will screen the returned questionnaires for invalid questionnaires by the designed logic of questionnaire answers and the filling completeness of the questionnaire. All samples are subject to validation.

### *3.2.2 Determinants of Natural Gas Price Affordability Based on a Hybrid Factor Analysis and Discriminant Analysis*

Factor analysis is a method of information concentration, condensing multiple information items into several general indicators. Factor analysis suggests an additional rotation function to study the

correspondence between indicators and the items based on a principal component analysis to name and explain the meaning of factors [25]. The factors affecting natural gas consumption patterns are not limited to the family characteristics of the population. These household characteristics which are used to study the natural gas consumption of individual households are variables of the natural gas consumption of households. Of course, the impact of external environmental factors should also be considered. The factor analysis method can account for various factors and analyze the price affordability of natural gas consumers. This paper employs factor analysis to synthesize many original variables  $x_i$  ( $i = 1, 2, \dots, p$ ) into  $X_j$  ( $j = 1, 2, \dots, k$ ) ( $p > k$ ) factor variables through formula  $x = AX + \varepsilon$  [26]. In the formula,  $X$  is the factor variables,  $A$  is the factor load matrix, and  $\varepsilon$  is the special factor. A few explanatory variables which are extracted from the variables in the questionnaire are named common factors, and the obtained common factors should be further analyzed [27].

The next step of this research is to use a discriminant analysis to distinguish the importance and regional differences of these factors. The discriminant analysis method can establish a classification discriminant function based on the factors from the factor analysis of the three categories of strong, ordinary and weak residents [28]. The main factors of the capacity are analyzed from the coefficient of the discriminant function. According to the literature review, the natural gas price affordability of the respondents is affected by many factors. Factor analysis is used to extract multiple factors into seven types of common factors according to the principal component analysis method, and then discriminant analysis is built to distinguish the interviewed participants into strong, ordinary, and weak. To obtain discriminant equation  $Y(X) = \sum_{n=1}^k c_n X_n$ , the discriminant coefficient ( $c$ ) is the eigenvector when the sum of squares of the deviations within a group is minimized and the sum of squares of deviations between groups is maximized.

According to the above equations, this study analyzes the main factors affecting residential natural gas price affordability in different cities. SPSS 25.0 software is used to implement a factor analysis and a discriminant analysis for statistical analysis of the questionnaire survey data.

### 3.3 Sample Data

A total of 2,000 questionnaires are distributed by online investigation and field survey from August 25 to September 10, 2019. Finally, 1,000 online questionnaires and 462 field questionnaires are collected with a recovery rate of approximately 73%. There are 205, 82 and 175 field survey responses in Beijing, Nanjing and Zhengzhou, respectively. After the questionnaire survey is completed, six field questionnaires from Beijing, one from Nanjing, and five from Zhengzhou are removed due to the invalid answers. Finally, 1,450 valid questionnaires are obtained, of which 559 are from Beijing, 455 from Nanjing, and 436 from Zhengzhou.

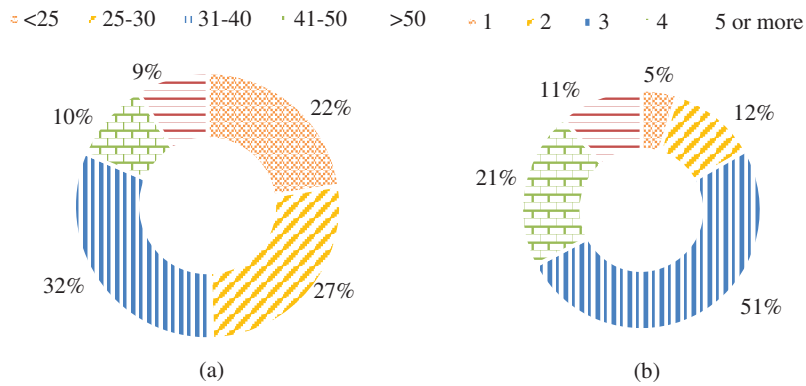
Because the overall sample size of this survey is large, the minimum sample size was mainly affected by the level of error and confidence level [29]. In general, samples are taken with an allowable error of 3% and a confidence level of 95%. At this time, the minimum total sample size is 1,068. The effective sample size obtained in this survey meets the theoretical requirements.

## 4 Results and Discussions

### 4.1 Sample Description

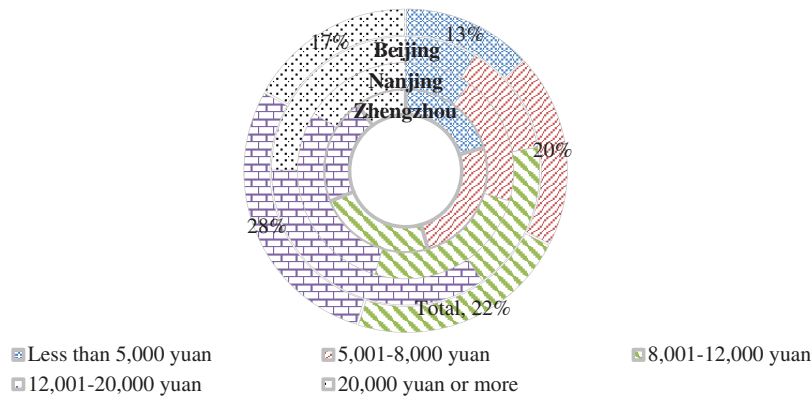
The statistical results for basic information of the respondents are shown in Fig. 3. The majority of respondents are between ages 25 and 40. This portion of the population is the main source of household income and familiar with natural gas expenditure and price. Fig. 3 also depicts the family size of natural gas users, and most of the households have 3 to 5 persons. It is assumed that the number of family members will influence the natural gas consumption and gas bills.





**Figure 3:** Basic statistics of natural gas users

As shown in Fig. 4, 13%, 20%, 22%, 28%, and 17% of the respondents were in the low, middle-low, middle, middle-upper, and high monthly household income levels, respectively. The income level of respondents in these three cities is conform to the economic level of these cities and meets the representativeness of the sample data. Beijing (25%) had the highest share of high monthly income among three cities while Zhengzhou (16%) had the lowest, which reflects the reliability of the questionnaire.



**Figure 4:** Monthly household income

Public awareness about natural gas price is divergent and exhibits a regional difference. As shown in Fig. 5a, most of respondents (42%) know little about the current price of natural gas, and they are just aware of the approximate price of natural gas; only 41.8% of people know the price. Possible reasons are that ordinary people care about the total gas fee instead of the price and that the natural gas expenditure is lower than the electricity bill, which accounts for a negligible percentage of total household expenditure. This fact indicates that most residents are not sensitive to natural gas prices, and the residents of Nanjing are less sensitive to natural gas prices than these of Beijing and Zhengzhou.

Natural gas is widely accepted as one of the primary residential energy resources. Fig. 5b shows the time and purpose of using natural gas. Fifty-seven percent of respondents have adopted natural gas for more than five years, and users have invested in the sunk cost of natural gas equipment. With the increase in utilization time, the use of natural gas tends to become the consumption inertia. Therefore, behavioral change in natural gas consumption requires higher motivation to overcome the sunk cost. Compared with the slight influence of rising natural gas prices and strong dependence of natural gas, the change in the residents' natural gas usage would not be noticeable. Moreover, consumption behavior is an important part of energy related

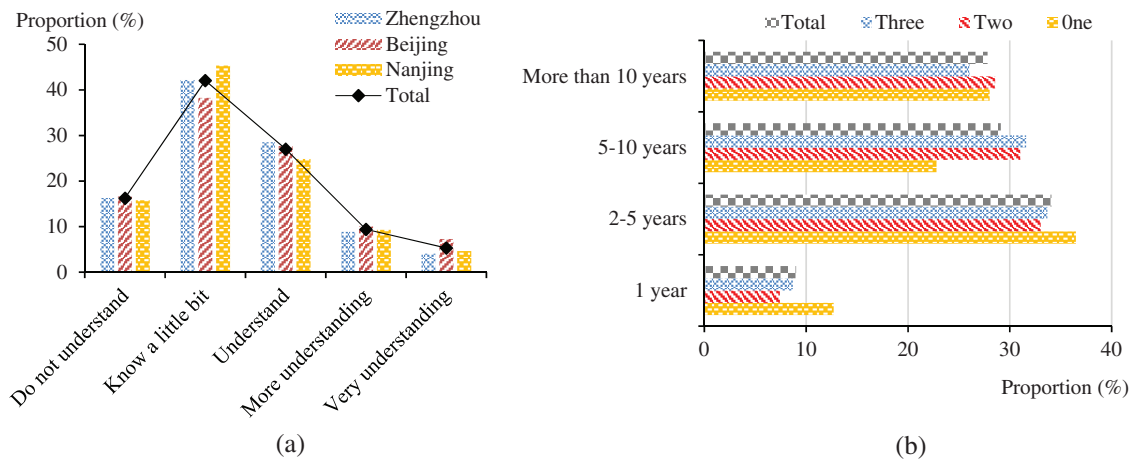


Figure 5: Price understanding and use of natural gas

lifestyle, and consumption inertia could enhance the driving force of lifestyle on residents' natural gas price affordability.

The monthly household gas consumption is shown in Fig. 6; more than 80% of households spend less than 100 yuan per month, and most of the natural gas expenditure (48%) is 41–80 yuan per month. Beijing (15.9%) has the lowest percentage of natural gas consumption below 40 yuan per month while Nanjing has the lowest percentage (34.1%) of natural gas consumption greater than 80 yuan per month. Beijing and Zhengzhou require winter heating, and the coal-to-gas heating policy will lead to an increase in average monthly gas costs in the future.

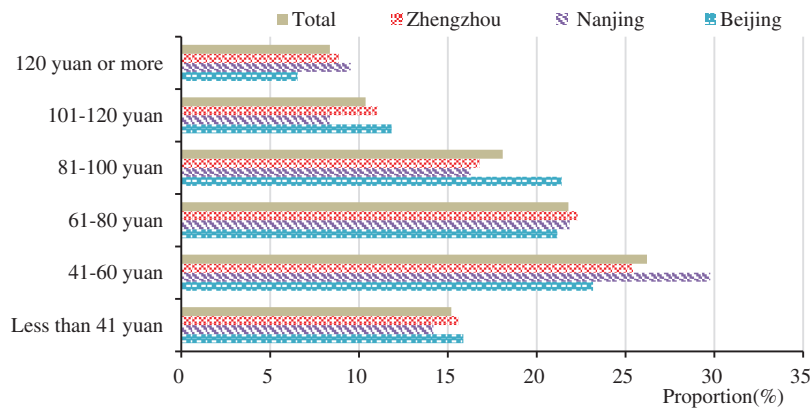
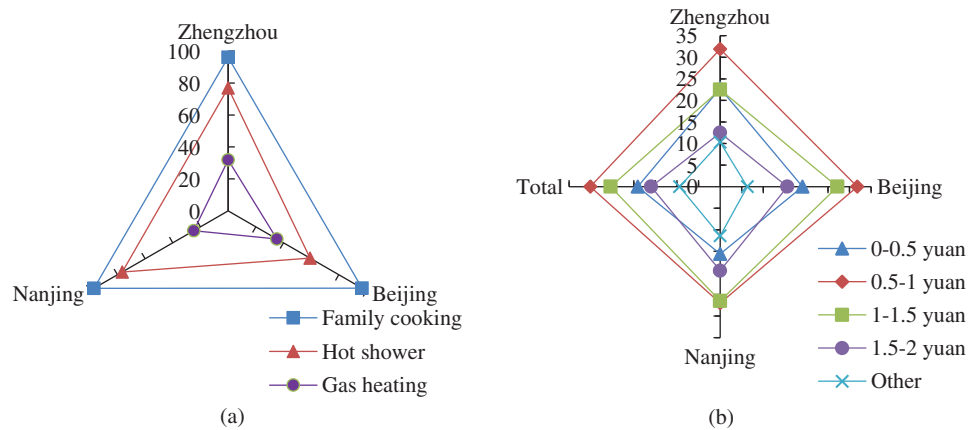


Figure 6: Proportion of monthly gas fee in different cities

As depicted in Fig. 7a, among the three cities, 96.6% of residents use natural gas for home cooking, while 71.1% for hot water showers, and 30.5% for self-heating. The results reveal that home cooking relies heavily on natural gas, and it can be the future choice for winter heating and boiling water. In addition, residents in different regions exhibit different behaviors in the use of natural gas. Beijing and Zhengzhou have more gas-fired requirements than Nanjing. This phenomenon indicates that with the difference in natural gas heating in the northern and southern regions, seasonal variation should be considered in the natural gas supply. Furthermore, respondents in Nanjing and Zhengzhou consume more natural gas for showering (hot water) than Beijing, and some residents in Beijing use alternative energy sources such as electricity or solar energy for water heating.



**Figure 7:** Natural gas applications and acceptable price increases (a) Purpose, (b) Affordable price

Residents are pursuing a more comfortable lifestyle for cooking and winter heating, which increases their dependence on natural gas consumption. According to the survey, residents who believe that natural gas is more economical and environmental friendly will give their conditional support for the increase of natural gas price. This implies that natural gas is widely accepted by the public as a source of clean household energy. Some respondents consider natural gas as the more convenient, more environmental and cheaper energy.

#### 4.2 Residential Natural Gas Price Affordability

Residential natural gas price affordability is the highest price that residents are willing to pay for 1 m<sup>3</sup> natural gas supply. For the satisfaction evaluation of the current price level of natural gas, 73.9% of respondents thought it was at a “suitable” level, 18.5% reckoned that the price was high, and 7.6% felt that the price was low. It can be seen that 81.5% of the residents can accept the current gas prices, which means that the current gas prices in these cities are within the affordability range of most residents, and there is a possibility for natural gas pricing reform.

Beijing, Zhengzhou, and Nanjing have adjusted their gas pricing mechanism to properly link the upstream and downstream natural gas price for the residential sector. Although the small change in the price of natural gas has a slight effect on the overall economy, it is quite distinct for the residents with different income levels and energy requirements. To measure natural gas price affordability, the respondent is required to answer a maximum tolerable price adjustment range for which they will not change their consumption behaviors. As shown in Fig. 7b, respondents who accept the increases of 0.5 yuan, 1 yuan, 1.5 yuan, and 2 yuan and above accounted for 19.1%, 30.1%, 25.4%, and 15.9%, respectively, whereas 9.4% of the respondents chose other options and answered that they would keep using natural gas regardless of the price adjustment. From the perspective of energy consumption, it shows that the more the use, the higher the residents’ dependence and preference for natural gas, and the energy-related lifestyle can positively motivate the price affordability.

A previous study predicted that the natural gas city gate price would be at 2.0–2.5 yuan/m<sup>3</sup> and the profit of a gas company would be approximately 10–20%. This indicates that the gas terminal sale price should range from 2.5 to 3.5 yuan/m<sup>3</sup> [30]. Currently, both Guangzhou and Shanghai have the highest gate price of 2.04 yuan/m<sup>3</sup>, and their terminal sale prices are at 3.45 and 3 yuan/m<sup>3</sup>, respectively. According to the prediction method of terminal gas prices and the current highest gas prices in [30], residents from these cities have strong affordability of natural gas, and the threshold of 1 yuan demonstrates the distinct

affordability of residents from these three cities. Moreover, the natural gas affordability of residents from Zhengzhou is lower than for residents from the other two cities.

### 4.3 Analysis of Influencing Factors of Affordability

#### 4.3.1 Factor Analysis for Key Components of Natural Gas Price Affordability

A factor analysis is employed to classify the factors into different dimensions. The initial 17 factors are merged into 7 common factors by the factor analysis on the 1104 sample data and the extraction from the rotated component matrix. The first column contains the advantages of natural gas consumption and the current status of gas infrastructure construction, which are shaped into objective practicality of natural gas ( $X_1$ ). The second column classifies the user's age and the usage time of natural gas as the time factor ( $X_2$ ). The third column considers the user's education and income level as the economic factor ( $X_3$ ); the fourth column is the utilization pattern other than cooking ( $X_4$ ), while the fifth column is cooking ( $X_5$ ). The sixth ( $X_6$ ) and the seventh columns ( $X_7$ ) are the parameters of total natural gas consumption and good price, respectively.

#### 4.3.2 Overall Discriminant Analysis

To obtain the highest upward floating price that residents can afford, this study employs the questionnaire survey results with the assumption of no change in the present natural gas usage behavior. Thus, the sample data could be divided into three categories: "0–0.5 yuan" for weaker affordability, "0.5–1 yuan" for general affordability, and "more than 1 yuan" for strong affordability.

The connotation of residential natural gas price affordability is the range in which the dependent variable can withstand the upward adjustment of natural gas prices. The dependent variable is a three-category variable. A discriminant analysis is used to examine the four main factors that distinguish the residents' gas price affordability. According to the results of the factor analysis and discriminant analysis, the main factors affecting residents' natural gas price affordability ( $Y$ ) are objective practicality ( $X_1$ ), time factor ( $X_2$ ), economic factor ( $X_3$ ), and use factor ( $X_4$ ). [Tab. 2](#) shows the results from the overall discriminant analysis.

**Table 2:** Summary of discriminant analysis

Independent variable X	Normalized typical discriminant coefficient	
	First function	Second function
Objective practicality ( $X_1$ )	0.495	0.553
Time factor ( $X_2$ )	-0.628	0.586
Economic factor ( $X_3$ )	0.628	0.310
Use factor ( $X_4$ )	0.204	-0.485
Eigenvalue variance percentage/%	93.4%	6.6%

First function:  $\lambda = 0.114$  Wilke Lambda = 0.890 Chi-square value = 127.623\*\*\*.

Second function:  $\lambda = 0.008$  Wilke Lambda = 0.992 Chi-square value = 8.788\*\*.

\*\* $p < 0.01$  \*\*\* $p < 0.001$ .

According to the standardized typical discriminant coefficient values in [Tab. 2](#), the factors closely related to the first discriminant function are the time factor ( $X_2$ ) and economic factors ( $X_3$ ) while those closely related to the second discriminant function are the time factor ( $X_2$ ) and objective practicality ( $X_1$ ). Therefore, from the above results, the main factors affecting the residential natural gas price affordability are time and economics. The old who have used natural gas for a longer period has a weaker natural gas price affordability. Furthermore, residents with higher education and income levels have stronger natural

gas price affordability, and this is also true for the users who regard natural gas as more practical and convenient than other fuels.

#### 4.3.3 Regional Discriminant Analysis

A discriminant analysis is performed based on samples from three regions: Beijing, Zhengzhou, and Nanjing. According to the equal test on the mean value within each group, the  $p$ -values of the stability tests on the difference among the four groups of Beijing indicators are greater than 0.05, indicating no significant difference in each index among different groups, and the discriminant analysis is not suitable for the data for Beijing. The reason for this fact may be that Beijing's natural gas infrastructure construction and the subsidies for natural gas users with weak natural gas price affordability are better than those of Nanjing and Zhengzhou, resulting in insignificant data differences.

Because the index for the factor ( $X_4$ ) is not significant in the factor analysis, a discriminant analysis is employed for the three other factors for Zhengzhou and Nanjing. The discriminant analysis results are summarized in Tab. 3. In Zhengzhou, the factors closely related to the first discriminant function are time factor ( $X_2$ ) and objective practicability ( $X_1$ ) while those closely related to the second discriminant function are the time factor ( $X_2$ ) and economic factor ( $X_3$ ). In Nanjing, the factors for the first discriminant function are economic factors ( $X_3$ ) and time factors ( $X_2$ ); those closely related to the second discriminant function are objective practicability ( $X_1$ ) and time factors ( $X_2$ ). This shows that the main factors governing residential natural gas price affordability in Zhengzhou are time and objective practicality, which indicates the lifestyle-driven characteristic of Zhengzhou. The main factors of residential natural gas price affordability in Nanjing are economical ability and objective practicality, indicating the integration of convenience and good pricing for natural gas consumption in Nanjing.

**Table 3:** Summary of discriminant analysis

Independent variable X	Normalized typical discriminant coefficient			
	Zhengzhou First function	Zhengzhou Second function	Nanjing First function	Nanjing Second function
Objective practicality ( $X_1$ )	0.563	0.258	0.384	0.668
Time factor ( $X_2$ )	-0.621	0.741	-0.676	0.636
Economic factor ( $X_3$ )	0.469	0.633	0.707	0.353
Eigenvalue variance percentage/%	98.8%	1.2%	84.9%	15.1%

Zhengzhou, First function:  $\lambda = 0.226$  Wilke Lambda = 0.814 Chi-square value = 73.991\*\*\*.

Second function:  $\lambda = 0.003$  Wilke Lambda = 0.997 Chi-square value = 0.947.

Nanjing, First function:  $\lambda = 0.147$  Wilke Lambda = 0.850 Chi-square value = 60.131\*\*\*.

Second function:  $\lambda = 0.026$  Wilke Lambda = 0.974 Chi-square value = 9.546\*\*.

\*\* $p < 0.01$  \*\*\* $p < 0.001$ .

## 5 Conclusions and Policy Recommendations

### 5.1 Conclusions

(1) Most residents are not sensitive to the price of natural gas, and their motivation for substituting gas with other energy sources is not strong. Residents' natural gas price affordability is driven by lifestyle, which shows that the respondent will have natural gas consumption inertia, and changes in consumption behavior require strong motivation. According to the survey, only 42% of the respondents know the current price of natural gas; nearly half of the residents' monthly natural gas costs are between 41 and 80 yuan, and less than 20% of people paid a monthly cost of 100 yuan or more. Nanjing has the lowest percentage of residents who

are aware of the gas price among the three cities. Furthermore, the percentage of high monthly natural gas expenditure is lowest in Nanjing. These facts show that the respondents in Nanjing have the lowest gas price sensitivity.

(2) More than half of the residents have strong natural gas price affordability, and the weakest price affordability occurred in the poor regions among the research regions. Residents who accept a gas price increase of more than 1 yuan per  $m^3$  accounted for 50.7% under the circumstances of maintaining the present natural gas consumption behavior. Zhengzhou, the least developed region in our research, has the weakest affordability, and this fact suggests that income level is a considerable but complex factor. A laddered natural gas pricing system should be designed by a behavioral analysis.

(3) Economy, practicality, and time are the main decision factors for residents' natural gas price affordability. Time includes the age of the respondent and the time of natural gas consumption, which have a negative effect on the price affordability of natural gas. The user's higher economic level and positive evaluation of natural gas infrastructure construction could be helpful for increasing the price affordability of natural gas.

(4) The effects of economy, practicality, and time factors on the price affordability of natural gas varied among different regions. The residential natural gas price affordability in Zhengzhou was mainly affected by time and practicality while these of Nanjing are mainly influenced by economic factors and objective practicality. Compared with these two cities, Beijing has a more advanced economic level and gas infrastructure. However, the differences in residents' feedback on these two factors were subtle and not significant in the model test.

## ***5.2 Policy Recommendations***

(1) Based on the natural gas price linkage mechanism, the principle of small amplitude and low frequency should be followed when adjusting the price of residential natural gas. Residential gas price reform should be implemented gradually with a small change. Because the impacts of small-scale price adjustments to residents are much lower than their sensitivity to gas prices, low-frequency price adjustments will never change the residential dependence on natural gas consumption. Furthermore, the low-frequency adjustment principle could smooth the reform process of natural gas price through consultation with local communities.

(2) Local governments should strengthen the efficiency of subsidy policies, and increase the affordability of residents with lower economic level. It is important to adopt more subsidy policies by subsidizing certain gas and expand the range of the first-stage gas volume in order to improve the affordability of low-income households. In this way, local governments can have the consideration to the interests of both residents and city gas companies when setting the price of natural gas ladders to be closer to marketization.

(3) Urban gas enterprises should strive for the infrastructure construction of pipeline, business services, safety protection, maintenance, convenient payment methods, etc. These efforts will help to increase the positive evaluation of natural gas by residents, improve the affordability of natural gas price of residents, and reduce the resistance of natural gas price reform. To get the support, good service is a kind of corporate social responsibility.

(4) As for regional satisfaction of natural gas consumption, policy implementation and service quality should be integrated into the governmental agenda. Zhengzhou can improve natural gas infrastructure construction and their service quality. Nanjing should pay attention to subsidies and infrastructure construction. This will improve the satisfaction of users, attract more natural gas users and expand the market. Zhengzhou and Nanjing may learn Beijing's subsidy policies and set a ceiling gas volume, both ensuring the economic value of natural gas and improving living standards further.

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## Appendix A

Survey of residents' natural gas usage

Dear Participant,

We are a research group for a survey on residents' use of natural gas and satisfaction. You are invited to participate to this investigation. This survey is anonymous and confidential, and the results are for research purposes only, without any risk to you. Thanks for your support!

1. Your gender:

Male  Female

2. Your age:

Under 25 years old  25–30 years old  31–40 years old  41–50 years old  More than 50 years old

3. The highest degree you are studying or have earned:

High school and below  University undergraduate and college  Master's degree  Doctoral degree and above

4. Your monthly household income (household):



5000 yuan and below  5001–8000 yuan  8001–12000 yuan

12001 yuan–20000 yuan  20,000 yuan or more

5. Your family structure (household):

Living alone  2  3  4  5 or more

6. Your family resides in:

City  Rural

Second, the use of natural gas

7. How long has your family been using natural gas?

1 year  2–5 years  5–10 years  11 and above

8. What is the use of natural gas in your home? [Multiple choices]

Home cooking  Hot shower  Gas heating  Other

9. Do you know the price of gas used by the residents of the city where you live?

I don't know  I know a little  I know  I know much  I know very much

10. What method do you generally choose to pay:

Gas service center  Bank  Community self-service machine  Mobile app

11. How often does your family buy gas:

One month  Two months  Three to five months  Half a year  Over half a year

12. How much does your family spend on natural gas at a time:

200 yuan or less  201–300 yuan  301–400 yuan  401–500 yuan  500 yuan or more

13. What is your monthly electricity bill?

Under 100 yuan  100–150 yuan  151–200 yuan  201–250 yuan  250 yuan or more

14. How much gas does your house generate each month?

Below 40 yuan  41–60 yuan  61–80 yuan  80–100 yuan  100 yuan or more

3. Evaluation of natural gas use

15. What do you think is the most affordable energy source below?

Natural gas  Electricity  LPG

16. What do you think is the most environmentally friendly energy source?

Natural gas  Electricity  LPG  Coal  Firewood

17. What do you think are the advantages of using natural gas? [Multiple choice questions] \*

Easy to use  Cheap

Compared with other fuels  Easier to obtain and less price

Strong compression, small footprint, more convenient  High safety

18. How do you feel about the gas prices of local residents?

Very high  Higher  Suitable  Lower  Very low

19. If the price of natural gas rises, how much will it increase will have a significant impact on the way your home uses gas (such as reducing its use and discarding other energy sources)?

0 ~ 0.5 yuan  0.5 ~ 1 yuan  1 ~ 1.5 yuan  1.5 ~ 2 yuan  Others

20. If you are supplying natural gas, what problems do you think exist or may exist in natural gas management? [Multiple choice questions] \*

- Different prices in the same city
- Project installation fee is not in place
- Unreasonable gas price distribution
- Failure to repair in a timely manner
- Other