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Natural gas subsidies in the industrial sector in China: National and regional perspectives

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HIGHLIGHTS

- Natural gas subsidies of China's industrial sector are investigated.
- Regional heterogeneity is investigated from regional and provincial perspectives.
- Regional heterogeneity exists in the decomposition on natural gas subsidy.
- Regional policies for energy subsidy reform in developing countries are needed.

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ABSTRACT

This paper seeks to investigate the regional heterogeneity in natural gas subsidies of China's industrial sector. Price-gap approach and logarithmic mean Divisia index method (LMDI) are combined to accomplish this goal. The results show that there exists regional heterogeneity in the decomposition on the variation of industrial natural gas subsidy in China. In other words, the factors that contribute to the changes in subsidies differ from a regional basis. During 2007–2013, consumption exerted a positive impact on the increase of industrial natural gas subsidies, contributing more than 80% both in the eastern and northeastern regions, followed by 70.66% in the western region and 69.54% in the central region. During 2013–2016, the main factor affecting the changes in industrial natural gas subsidies is the pricing mechanism. The pricing mechanism played a significant positive role in the decline of industrial natural gas subsidies, with contribution rate of 367.73% in the northeastern region, 80.64% in the eastern region, 75.68% in the central region and 74.34% in the western region. Based on the results, we suggest that the policy measures enacted by government should differ in regions when promoting subsidy reform, especially for developing countries with unbalanced regional development.

1. Introduction

In the context of tackling climate change, fossil energy subsidies have been a global issue. The G20 summit in 2009 proposed to rationalize fossil fuel subsidies and eliminate fossil fuel subsidies in the medium term. As the world's largest energy consumer and carbon emitter, China's energy subsidy reform has attracted much attention. In 2007, China's natural gas subsidies were relatively small with a scale of 57.54 billion USD, accounting for only 10.68% of the total fossil fuel subsidies [1]. China's natural gas consumption has increased significantly in the past decade, and now it is the world's third-largest natural gas consumer. According to the BP World Energy Statistical Yearbook (2018)[1], global energy demand grew by 2.20% in 2017, while natural gas consumption grew by 3.02%. In that year, China's natural gas consumption grew rapidly by 31 billion cubic metres, taking up about 15% worldwide. With the rapid increase of natural gas consumption, the subsidies scales expanded rapidly in 2013, accounting for more than 50% of the entire fossil fuel subsidies. How the ratio will change in the future has attracted the attention of the Chinese government and the world.

In recent years, China has been constantly striving to formulate reform policies to develop a low-carbon economy, with the increasing contradiction between resource consumption and environmental pollution. The northern smog opened the prelude to China's comprehensive control of air pollution in 2013. In September 2013, the State Council of China promulgated ten measures of the Action Plan for the

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[1] https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

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Prevention and Control of Air Pollution[2], which serves as a guideline for action in the prevention and control of air pollution throughout the country. As one of the important measures to improve air quality, "coal to gas" has been widely promoted. The National Development and Reform Commission of China has issued opinions on how to do a good job of natural gas peak-to-winter work in October 2013, aiming at strengthening demand-side management of natural gas and striving to ensure the overall stability of natural gas peak-to-winter situation[3]. In December 2016, the National Development and Reform Commission of China enacted the 13th Five-Year Plan for Natural Gas Development[4], which proposed that the proportion of natural gas in the energy consumption structure should increase to more than 10% by 2020. However, the fact was that natural gas accounted for only 7% of primary energy consumption in China in 2017. Therefore, natural gas has great potential for consumption in China in the future.

China's natural gas prices have been regulated by the government following the basic principle of "cost-plus" for a long time. The cost-plus means that prices are determined by production costs and reasonable profits, entailing the phenomenon that the consumer price is clearly below market prices. The low end-consumer prices gave rise to heavy consumption, entailing inevitable natural gas imports. With the opening of the Central Asian A-line natural gas pipeline in 2009, natural gas imports and consumption have increased rapidly. The proportion of natural gas to total fossil fuel subsidies is nearly 50% in 2013 [2]. Therefore, China's natural gas consumption and subsidy growth deserve considerable attention.

The BP World Energy Outlook (2018)[5] proposes that natural gas demand growth is dominated by growth in the industrial and power sectors. According to China natural gas development report (2019)[6], Natural gas consumption in the industrial sector has become the main driver of China's natural gas demand in the past decade. Also, the National Bureau of Statistics[7] indicated that, the added value of China industries accounted for more than 40% of GDP in 2017. And the industrial sector consumed nearly 67% of total energy consumption and about 65% of natural gas in 2016. The average annual subsidy of natural gas in China's industrial sector in 2010–2015 was about 15.87 billion USD, accounting for 53% of the entire natural gas subsidy [3]. The natural gas subsidy is mainly determined by the industrial sector. Therefore, our study focused on natural gas subsidies in the industrial sector.

The changes in fossil energy subsidies are closely related to government policies. In recent years, the reforms on natural gas have mainly focused on the pricing mechanism. The objective of the reform of China's natural gas pricing mechanism is to establish a dynamic adjustment mechanism linked to the price of alternative energy, which can reflect the supply and demand of the market and the scarcity of resources. In other words, the price relationship between natural gas and alternative energy is gradually straightened out, and finally, the price pricing mechanism of natural gas determined by market competition is formed[8]. The Chinese government decided to carry out the pilot work of reforming the price formation mechanism of natural gas in Guangdong and Guangxi provinces in 2011[9] and it was implemented nationwide in 2013. According to the enactment of notice to adjust the price of natural gas by the National Development and Reform Commission[10], the link of natural gas price management has been adjusted from the factory to the gate station. Since then, the pricing method has changed from the cost-plus method to the market net return method. In September 2014, the Development and Reform Commission of China issued a notice on adjusting the price of non-resident natural gas[11], requiring that the price of the highest valve station for non-resident gas stocks be raised by 0.06 dollar per cubic meter. In April 2015, the Development and Reform Commission issued a notice on rationalizing the price of natural gas for non-residential use[12]. The document stated that the price of incremental gas maximum station would reduce by 0.07 dollar per cubic metre and the price of stock gas maximum station would increase by 0.01 dollar per cubic metre in order to achieve price integration and rationalize the price of natural gas for non-residential use. According to the policy document of National Development and Reform Commission on natural gas price reform[13], the maximum gate price for non-resident gas would be reduced by 0.11 dollar per cubic meter since November 2015, and the non-resident gas price has been changed from the maximum gate price management to the benchmark gate price management. In addition, the buyer and the seller can negotiate and determine the specific gate price within the upper 20% and lower unlimited range based on the benchmark gate price. In accordance with the document of National Development and Reform Commission on reducing the price of non-residential natural gas[14], the benchmark station price for non-resident gas was cut by 0.02 dollar per cubic meter since September 2017.

Although the Chinese government has made a lot of efforts to promote the market-oriented reform of natural gas, natural gas subsidies still have such problems as an intermittent rebound, regional differences, and failure to deepen the marketization. In order to better solve the above problems, we need to consider several questions: What are the factors influencing the change of subsidy scale? Are there differences in the effects of these factors on changes in subsidies in different industries or regions? Finding out these answers is of great significance to optimizing energy structure, environmental pollution control, and China's energy security.

To the best of our knowledge, abundant studies on China's energy subsidies have been reported. Lin et al. [4] described the inefficiency and unfairness of China's energy subsidies back in 2009 and Liu and Li [5] summarized the advantages and disadvantages of China's fossil energy subsidies and analyzed the necessity and obstacles of China's fossil energy reform. In order to further studies, numerous scholars have begun to analyze the economic and social impact of energy subsidies from different perspectives. On the one hand, increasing researches have been reported about the impact of policy measures on energy subsidies. The main simulation methods used widely in these studies included CGE model [6,7], Optimal control method [8,9] and I-O model [10,11]. It is worth mentioning that Liu and Li [5] concluded fossil energy subsidies reform would exert uncertain impacts on the economy, society and environment using CGE models. Besides, Lin and Chen [12] adopted Synthetic Control Method to evaluate the treatment effect of IBEP policy on reducing residents' electricity demand and electricity subsidies. On the other hand, numerous studies have investigated the rebound effect of energy subsidies in China. Shao et al. [13] found that mitigating the energy rebound effect can significantly reduce carbon emissions. Li et al. [14] focused on how the energy subsidies reform could mitigate the rebound effect in China, and how to achieve economic and environmental gains. Li [15] adopted a modified input-output model to estimate the economy-wide energy rebound

[2] http://www.gov.cn/jrzg/2013–09/12/content_2486918.htm.
[3] http://yxj.ndrc.gov.cn/gzdt/201310/t20131012_562124.html.
[4] http://www.ndrc.gov.cn/fzgggz/fzgh/ghwb/gjjgh/201706/W020170607564599576985.pdf.
[5] https://www.bp.com/en/global/corporate/energy-economics/energy-outlook.html.
[6] http://www.cngascn.com/homeNews/201909/36282.html.
[7] http://data.stats.gov.cn/easyquery.htm?cn = C01.
[8] http://www.ndrc.gov.cn/fzgggz/jggl/zcfg/201306/t20130628_748405.html.
[9] http://www.gov.cn/zwgk/2011–12/27/content_2030999.htm.
[10] http://www.ndrc.gov.cn/fzgggz/jggl/zcfg/201306/t20130628_748405.html.
[11] http://www.ndrc.gov.cn/zcfb/zcfbtz/201408/t20140812_621998.html.
[12] http://www.ndrc.gov.cn/zcfb/zcfbtz/201502/t20150228_665694.html.
[13] http://www.ndrc.gov.cn/zcfb/zcfbtz/201511/t20151118_758883.html.
[14] http://www.ndrc.gov.cn/zcfb/gfxwj/201708/t20170830_859307.html.

effects across China's economic sectors with the consideration of energy subsidies. To study the impact of fossil subsidies reform on the rebound effect in China, Li [16] conducted a comprehensive evaluation based on a multi-sector computable general equilibrium (CGE) model. The results indicated the rebound effect would be effectively mitigated by removing fossil energy subsides, but companied with significant negative impacts on the macro economy. However, Li and Sun [3] found that carbon dioxide emissions could not be effectively reduced by simply removing China's fossil fuel subsidies.

There is little literature on natural gas subsidies, especially the analysis on influencing factors of changes in subsidies. Liu and Lin [17] investigated the changes in the scale of natural gas subsidy in China and its decomposition factors, and the results indicated that pricing mechanism, price and consumption had an impact on the change in natural gas subsidies. Specifically, the influencing factors of the changes in natural gas subsidies were analyzed at the national level in their paper. However, the fact that the effect of these factors on subsidies might be characterized by time-phased, industry differences and regional heterogeneity was neglected. It is well known that natural gas is a regional energy source. In fact, China is so vast that economic development and consumption level differ greatly in regions, which entails price variance of natural gas and thus diverse subsidies at regional level. It is necessary to analyze and compare the regional heterogeneity of natural gas subsidies. This study will be a useful reference for the government to enact reasonable and targeted subsidy reform measures.

This paper tries to investigate the industry differences and regional heterogeneity in the decomposition analysis of the change in natural gas. We select China's industrial sector to do this research. Price-gap approach and LMDI methods are combined to complete the decomposition analysis from the perspective of the national level, regional level, and provincial level. The research route of this paper is to investigate the industry differences in the decomposition analysis at the national level and then to investigate the regional heterogeneity at both the regional and provincial level using provincial panel data.

The contribution of this paper to the existing literature lies in the following three aspects.

Firstly, to the best of our knowledge, this is the first study to estimate China's energy subsidies at the provincial level. There are great differences in economic development and energy structure in China's provinces. For developing countries with unbalanced regional economic development, energy subsidy reform also has regional problems. Therefore, regional differences should be considered in the study of energy subsidies and subsidy reform. The existing studies mainly focus on estimating the scale of energy subsidies and the impact of removing fossil fuel subsidies, ignoring regional differences. This paper discusses the regional differences of energy subsidies at the provincial level, which provides a new perspective for researchers in this field.

Secondly, considering the regional differences of China's economy and the differences of natural gas consumption levels in different places, this paper decomposes the variation of natural gas subsidy progressively in order from the national, regional and provincial levels. In addition, we have decomposed natural gas subsidies in different industries at the national level. When dealing with the energy problems of countries with unbalanced regional development, the analysis method adopted in this study can be used as a reference for other scholars.

Finally, we further discuss regional heterogeneity in the decomposition of energy subsidies from the perspective of the regional and provincial levels. Our study demonstrates that there exists regional heterogeneity in the decomposition analysis of natural gas subsidies. In the context of climate change, fossil energy subsidies are a global problem. As we all know, natural gas is a regional energy source. There exist a few regional problems in natural gas subsidy, such as how to guide the rational allocation of energy resources among regions. Hence, the regional heterogeneity of natural gas studied in this paper is not a unique problem in China, but maybe the issue in the world, even if the case studied in this paper is in China. In other words, the findings in our study can be extended to emerging and developing countries due to the similar issue of fossil fuel subsidies, especially for countries with unbalanced regional development.

The rest of the paper is organized as follows: In Section 2, we have the literature review related to energy subsidies. Section 3 introduces the empirical approach and describes the data sources, including how to estimate the scale of subsidies and decompose the influencing factors. Section 4 presents the empirical results and corresponding analysis. Conclusions and policy recommendations are presented in Section 5.

2. Literature review

The term 'subsidy' has been subject to many interpretations, especially as regards energy subsidies [18]. How to define subsidies is the first step in doing research on energy subsidies. In common parlance, subsidy refers to the payment or tax concession from the government. Corden [19] extended the concept to include in addition market transfers-that is, transfers from consumers to producers resulting from government interventions such as tariffs or price controls. The United Nations and International Energy Agency [20] define an energy subsidy as "any measure that keeps prices for consumers below market levels, or for producers above market levels, or that reduces costs for consumers and producers". According to Kojima and Koplow [21], a subsidy was defined as "a financial contribution by a government, or agent of a government, that confers a benefit on its recipients" by The World Trade Organization.

According to the above definition, Energy subsidies vary in different and complex ways. Governments can transfer debt, reduce government revenue, provide goods or services below market value, or provide viable price support for energy technology, all of which fall within the scope of subsidies [22]. Morgan [23] indicated that there exist about 17 different types of energy subsidies for many countries worldwide, with most of them oriented towards lowering the cost of energy production, some raising prices for producer and still others lowering prices for users. global energy subsidies can reach into trillions of dollars a year in accordance with the evidence in Sovacool [24].

With the increasing global concern over environmental and climate issues, energy subsidies have become the most controversial and political focus in international politics, energy enterprises and academic circles. Discussion on this issue in academic circles began as early as the 1990s. Rajagopalan and Demaine [25] studied the relative benefits of the use of electricity in the semi-arid region of Andhra Pradesh and the result shows that electric pumps have cost advantages over diesel engines, given the low operational costs arising from high subsidies. Anderson [26] several countries of Western Europe subsidized coal production, and most East European countries subsidized coal consumption, which entailed more environmental pollution. Radetzki [27] concluded that because production costs in Western Europe are much higher than import prices, local production requires high subsidies. Therefore, removing these subsidies will force the coal industry to shut down and increase coal imports. Reynolds [28] argued that there was an entropy subsidy loss phenomenon when industry replace a high-grade energy resource with a low-grade energy resource without technical progress. The entropy subsidy might cause energy prices to rise higher than expected.

With the continuous deterioration of global environmental pollution, research on energy subsidy has gradually emerged in academic circles. Firstly, some researchers attempted to estimate the complex relationship between energy subsidies and carbon emissions in China. Larsen [22] investigated world fossil fuel subsidies and global carbon emissions by applying a simple model with interfuel substitution, using a more detailed sectoral data set that includes energy prices and consumption for an expanded sample of countries. The author concluded that substantial fossil fuel subsidies prevailed in a handful of large carbon-emitting countries and removing these subsidies would possibly reduce global carbon emissions by 7 percent. Choi et al. [29] studid if a share of the gasoline tax revenue is reinvested to subsidize biofuel production, economy-wide resource consumptions and emissions from the fossil fuel-related supply chains would decrease. Mojik [30] presented a brief overview of measures implemented in the Slovak Republic and the potential impact of various mitigation options in the energy sector. The results indicated that the country could achieve considerable emissions reduction depending on the measures applied. However, Li and Sun [3] completed an overall estimation for China's fossil fuel subsidies by each energy type and concluded that CO_2 mitigation cannot be achieved effectively only by removing fossil fuel subsidies. Burtt and Dargusch [31] analyzed the cost-effectiveness of household photovoltaic systems in reducing greenhouse gas emissions in Australia by linking subsidies with emission reductions.

In addition, the impact of energy subsidy reform on social welfare or households is also one of the debated issues in academia. Freund and Wallich [32] assessed the welfare effects of energy subsidy reform in Poland. Rentschler [33] estimated the regional variability of direct welfare effects of removing fuel subsidies in Nigeria, and highlighted the importance of understanding differences in vulnerability, and designing tailored social protection schemes which ensure public support for subsidy reforms. Feng and Hubacek [34] analyzed the impact of energy price hikes on different income groups using an energy-extended input-output approach, and the results showed that higher-income groups benefit more from low energy prices than low-income groups when tracing both direct and indirect effects of energy price variations.

Thirdly, in recent years, the research on the relationship between energy subsidies and rebound effect has been gradually deepened and refined. Li and Lin [35] incorporated endogenous energy efficiency into the model specification of rebound effect and highlighted the policy application via combining energy subsidies and technological progress with a rebound effect. Jin and Kim [36] presented a new approach for assessing energy rebound effect given the fossil-fuel subsidies and the results showed that there was a 1% rebound effect in most of the years. Li and lin [37] presented a detailed analysis of energy rebound effects in China's economy via the input-output model and further investigated the impacts of fossil-fuel subsidies on rebound effects.

Plenty of studies on China's energy subsidies have been reported over the past decade. The first scholar to pay attention to energy subsidies was Lin Boqiang [4], who described the inefficiency and unfairness of China's energy subsidies for the first time in 2009. Subsequently, Liu and Li [5] gradually contacted and studied the reform of fossil energy subsidies, and analyzed the necessity and obstacles of fossil energy reform. With the deepening of research, more and more literature focused on the impact of energy subsidies on the economy, society and residents from different perspectives. On the other hand, increasing researches have been reported about the impact of policy measures on energy subsidies and the main simulation methods used widely by them included CGE model [6,7], Optimal control method [8,9] and I-O model [10,11]. It is worth mentioning that Liu and Li [5] illustrated fossil energy subsidies reform would exert uncertain impacts on the economy, society, and environment with using CGE models. Besides, Synthetic Control Method (SCM) was used to evaluate the treatment effect of IBEP policy on reducing residents' electricity demand and subsidies in Lin and Chen [12]. On the other hand, many scholars focused on the rebound effect and its impact on energy subsidies in China. Shao et al. [13] found that mitigating the energy rebound effect can significantly reduce carbon emissions. Differing from the existing literature, Toroghi and Oliver [38] developed a novel method for estimating the rebound effect for rooftop PV based on economic and geographic information systems modeling. Su [39] indicated that household income, indoor floor area, and owning the house had positive influences on electricity consumption and the rebound effect was large for air conditioner and refrigerator in Taiwan. Li et al. [14] focused on how the energy subsidies reform could mitigate the rebound effect in China, and how to achieve economic and environmental gains. Li [15] adopted a modified input-output model to estimate the economy-wide energy rebound effects across China's economic sectors with the consideration of energy subsidies. Further, to explore how China's fossil subsidies reform would affect rebound effect, Li [16] conducted a comprehensive evaluation based on a multi-sector computable general equilibrium (CGE) model. The results indicated the rebound effect would be effectively mitigated by removing fossil energy subsidies, but companied with significant negative impacts on the macro economy. However, Li and Sun [3] found that carbon dioxide emissions could not be effectively reduced by simply removing China's fossil fuel subsidies due to the substitution from low-emitted fuels to high-emitted coal and from capital and labor to energy.

From the aforementioned review, although plenty of prior studies have considered the issues of energy subsidy, most of them mainly have focused on estimating the scale of energy subsidies, the macro/micro-economic impact of removing subsidies, as well as the rebound effects of energy subsidy reform and the inconclusive relationship between energy subsidies and carbon emission intensity. To the best of our knowledge, few existing studies have conducted the subsidy of the natural gas industry, especially from the perspective of the change in subsidy scale and its influencing factors. With the development of low-carbon economy, China's natural gas consumption has increased rapidly, which has attracted the attention of the government. According to the China Natural Gas Development Report 2019 [40], China's natural gas consumption reached 280.3 billion cubic meters in 2018, up 17.5 percent year on year, and its share in primary energy consumption was 7.8%, up 2 percentage points year-on-year. More surprisingly, the daily peak gas consumption exceeded 1 billion cubic meters for the first time. The market-oriented reform of natural gas pricing mechanism was enacted in China since 2013. It is doubtful whether the effects of the policies differ from regions. The answer to this question is of great significance to the studies on energy subsidy reform.

Currently, some literature on the issue of natural gas subsidy in China can be found. Wang and Lin [41] estimated the scale of natural gas subsidy in China during the 11th Five-Year Plan period from the perspective of the industry. However, there is limited literature on the mechanism and intensity of the impact of the fossil fuel market-oriented reform on the scale of subsidies, let alone the factors affecting subsidies. Most in line with our research topic, Liu and Lin [17] calculated the natural gas subsidies in China from 2007 to 2015 and conducted a decomposition. As we mentioned above, policy shocks tend to be characterized by time-phased, industry differences and regional heterogeneity. This paper focuses on natural gas subsidies in the industrial sector, which is the main natural gas consumption sector. In this paper, we will use provincial panel data to study the issue to reveal the industrial differences and regional heterogeneity of natural gas subsidies.

3. Methodology and data source

3.1. The research framework

This paper seeks to investigate the regional heterogeneity in natural gas subsidies of China's industrial sector. Price-gap approach and logarithmic mean Divisia index method (LMDI) are combined to accomplish this study from national and regional perspectives. The research route of this paper can be roughly divided into two steps. The first step is to analyze the differences in natural gas subsidy scale and decomposition analysis between the industrial sector and other two sectors at the national level. The second step is to study the regional heterogeneity of natural gas subsidy at both the regional and provincial levels. For ease of viewing, the research framework is presented in Fig. 1.

3.2. The Price-gap approach

The international methods for estimating the scale of energy

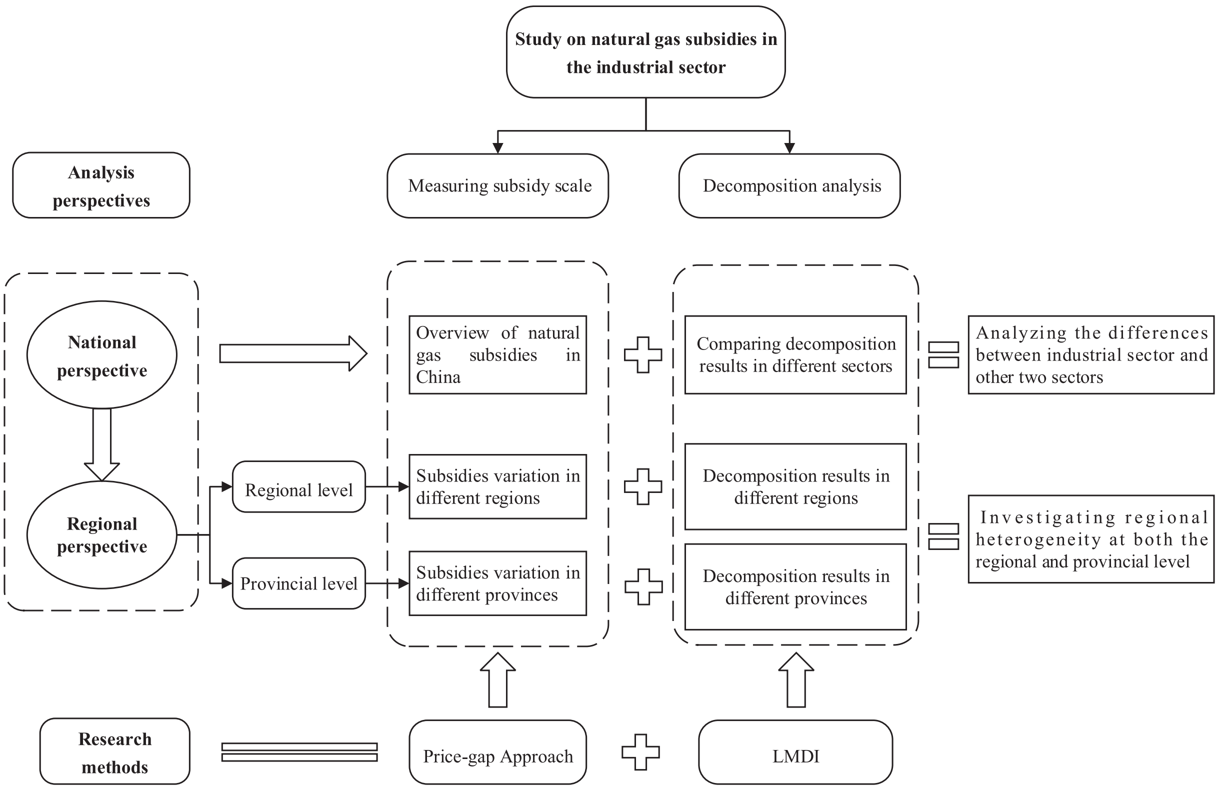

Fig. 1. The research framework.

subsidies mainly include[15]: (1) The price-gap approach (2) The snapshot approach (3) The producer subsidy equivalent (4) The consumer subsidy equivalent (5) The specific project Approach (6) The effective rate of assistance. These methods are commonly used in the world, but differ greatly from each other. For convenience sake, the results are presented in Table 1.

Comparing the six methods, the features of these methods are summarized as follows:

(1) The price-gap approach (PGA) directly aims at the price of energy products with low data requirements and simple calculation. Combining with price elasticity, PGA can analyze the impact of the cancellation of subsidies on energy consumption, and then measure the impact of the cancellation of subsidies on economic efficiency. Besides, this method has two good features: First, it directly aimed at the price of energy products, and the calculation process is simple, requiring relatively few and easily accessible data. Secondly, the price difference method focuses on the impact of government subsidies on the consumer side, so it is the preferred tool for calculating the consumer side subsidies. Hence, due to data availability issues, the price-gap approach is a pervasive method used by Chinese scholars.
(2) The object of snapshot approach (SA) is the government's support for the project, which can be used to calculate the scale of subsidies on both production side and consumption side. However, this method has some limitations. For example, the validity of cross-sectional data depends on the time series distribution of the data; in addition, the snapshot method amortizes capital expenditure or loss in a year, lacking consideration of capital fluctuations between different years, resulting in inaccurate estimates.
(3) PSE or CSE are both data-intensive methods, which can capture the impact that cannot be directly reflected in the price, but they require a high level of data.
(4) PSA can also analyze the transfer of subsidies, but it is difficult to solve the final price distortion problem.
(5) The effective rate of assistance (ERA) is the most comprehensive, theoretically covering all information of subsidies, but the analysis process is very cumbersome, and the data required for the actual operation process is extremely difficult to obtain.
(6) In summary, the most suitable method for calculating subsidy in our research is Price-gap approach considering the issue of data availability and the features of our research object.

An appropriate estimation method is of great significance for accurately estimating China's fossil energy subsidies. The price of natural gas in China has long been controlled by the government, which mostly subsidizes the consumption side. Considering the availability of data in China, like many studies on China's subsidy [3,42,41], we adopt the price-gap approach to estimate natural gas subsidies. The theoretical basis of the price-gap approach was put forward by [43], and was subsequently recognized and widely used internationally [22,44,45]. The basic thought of the price-gap approach is described as follows: the energy subsidy policy can depress the end-consumer price and thus promotes energy consumption. Therefore, the scale of energy subsidy can be estimated by calculating the difference between the market reference price without subsidies and the end-consumer price of energy products under the subsidy. The advantage of the price-gap approach lies in the direct connection with the price of energy products, which is relatively simple to calculate and has no strict requirement for data.

The following formula presents the detailed mechanism for using the price-gap approach to calculating natural gas subsidies [44]:

[15] Li H. Equity, Efficiency and Sustainable Development-China's Energy Subsidy Reform Theory and Policy Practice. Bei Jing: China Economic Publishing House; 2011.

Table 1
A comparison of the basic concepts of six approaches.

Approaches	Concepts or definitions	Literature
PGA	Estimated by calculating the difference between the market reference price without subsidies and the end-consumer price of energy products under the subsidy.	Corden (1957)
SA	Estimating the subsidy scale of an energy project by selecting cross-sectional data of a year	Steenblik (1955)
PSE/CSE	Defining a nominal amount of cash transferred to domestic producers (or consumers), which is equivalent to the value of all existing government subsidies, given the current level of output, consumption and trade. PSE measures the production-side subsidies, while CSE describes the effect of subsidies on lowering end-user prices.	IEA (2000)
PSA	Estimating the scale of energy subsidies for a specific project. Firstly, estimate the various subsidies covered by a specific project, and then sum up the various subsidies of the project to get the scale of subsidies.	Corden (1998)
ERA	It is estimated by measuring any direct or indirect action that affects the price of energy products, which focused on how nominal taxation affects resource allocation.	Corden (1966) Balassa (1965)

Note: Table shows the definitions of these methods for estimating the scale of subsidies. And the corresponding abbreviations is listed as below:
(1) The price-gap approach (PGA).
(2) The snapshot approach (SA).
(3) The producer subsidy equivalent (PSE).
(4) The consumer subsidy equivalent(CSE).
(5) The specific project Approach (SPA).
(6) The effective rate of assistance (ERA).

$$S_i = (MP_i - EP_i) \times C_i$$
$$S_i^t = (MP_i^t - EP_i^t) \times C_i^t$$
$$S^t = \sum_{i=1}^{n} S_i^t = \sum_{i=1}^{n} (MP_i^t - EP_i^t) \times C_i^t \tag{1}$$

where i and t represent sectors and periods respectively, which is consistent in the above formula. For example, S_i^t presents the subsidy in sector i in period t. MP is the market reference price of natural Gas; EP is the end-consumer price of natural gas; and C is the natural gas consumption. The core of applying price-gap approach is how to define market reference price (MP) and end-consumer price (EP). The meaning of MP and EP and the corresponding calculation method will be explained in detail in Section 3.3.

3.3. Logarithmic Mean Divisia Index (LMDI)

The most common index decomposition model in academia is the Index Decomposition Analysis (IDA), which was first used by researchers to study electricity consumption trends in industry in the early 1980s [46]. Representative examples were the studies on analyzing the trends in industrial energy use in the UK [47] and US [48] respectively. IDA has been widely applied in energy studies since it was first used to analyze industrial electricity consumption. About 90 journal papers up to 1999 in conjunction with IDA were found in Ang & Zhang [49]. The popular decomposition methods among analysts can be divided into two groups: methods linked to the Laspeyres index and methods linked to the Divisia index [50]. Prior to 1990, decomposition analysis was conducted largely based on the concept of the Laspeyres index [50]. In the 1990s, a gradual shift towards the Divisia index was observed, or more specifically towards the method proposed by Boyd et al. [51]. Currently, the most popular IDA approach has been the logarithmic mean Divisia index (LMDI) methods since it was formally presented by Ang and Liu [52]. The LMDI method has almost possessed dominance in the IDA journal articles over the past decade [46], since it has the desirable properties of perfect decomposition and consistency in aggregation [52]. According to Ang and Liu [52], perfect decomposition can obtain the decomposition results without a residual term. In addition, consistency in aggregation allows estimates for sub-groups to be aggregated in a consistent manner.

The LMDI methods can be divided into two different methods (LMDI-I and LMDI-II) according to different weights used in aggregation [46,53], LMDI-I has been widely used, due to its simpler formula and perfect consistent in aggregation, in the studies on factors influencing CO_2 emission in China [54], driving forces of Iran's CO_2 emissions [55], impacts of energy consumption and treatment technology on SO_2 emissions [56], as well as changes in carbon intensity [10]. In order to mathematically analyze our study, Mathematical deduction and proof of LMDI approach to decomposition analysis are required. Considering the space limitation, the mathematical derivation is presented in Appendix A.

So, the LMDI method can help potential users to make reasonable judgement and decisions when implementing it in their studies. Hence, In this study, we adopt this LMDI method, which possesses the desirable properties as a decomposition method, to analyze the influencing factors of the change in natural gas subsidy scale and its decomposition. In our research, the main influencing factors studied are market reference price (MP), pricing mechanism (SR) and consumption (C). Specifically, we calculate the variation of natural gas subsidy explained by the influencing factors and the corresponding contribution rate. The derivation of the LMDI model used in our paper is shown below.

Initially, Eq. (1) can be transformed into the following form:

$$S_i^t = (MP_i^t - EP_i^t) \times C_i^t = \frac{(MP_i^t - EP_i^t)}{MP_i^t} \times MP_i^t \times C_i^t$$

$$\frac{(MP_i^t - EP_i^t)}{MP_i^t} = SR_i^t$$

Thus,

$$S_i^t = SR_i^t \times MP_i^t \times C_i^t \tag{2}$$

Eq. (3) can be obtained by taking logarithms on both sides of Eq. (2) as follows:

$$\ln S_i^t = \ln SR_i^t + \ln MP_i^t + \ln C_i^t \tag{3}$$

Making a mathematical transformation as follow:

$$\ln\left(S_i^t / S_i^{t-1}\right) = \ln\left(SR_i^t / SR_i^{t-1}\right) + \ln\left(MP_i^t / MP_i^{t-1}\right) + \ln\left(C_i^t / C_i^{t-1}\right)$$

$$\frac{\ln\left(SR_i^t / SR_i^{t-1}\right)}{\ln\left(S_i^t / S_i^{t-1}\right)} = SRcontri_i^t; \quad \frac{\ln\left(MP_i^t / MP_i^{t-1}\right)}{\ln\left(S_i^t / S_i^{t-1}\right)} = MPcontri_i^t$$
$$\frac{\ln\left(C_i^t / C_i^{t-1}\right)}{\ln\left(S_i^t / S_i^{t-1}\right)} = Ccontri_i^t \tag{4}$$

From Eqs. (2)–(4), the changes in subsidies can be decomposed as Eq. (5):

$$\Delta S_i = S_i^t - S_i^{t-1} = \Delta SR_i + \Delta MP_i + \Delta C_i$$
$$\Delta SR_i = SRcontri_i^t \times \Delta S_i$$
$$\Delta MP_i = MPcontri_i^t \times \Delta S_i$$
$$\Delta C_i = Ccontri_i^t \times \Delta S_i \quad (5)$$

where i and t represent sectors and periods respectively in the above formula. Hence, S_i^t is the subsidy in sector i in period t. MP is the market reference price of natural gas equivalent to the reference price of natural gas without subsidy in China; SR is the natural gas subsidy rate, which is used to measure the effect of the pricing mechanism; C is the natural gas consumption, implying the impact of consumption on the variation of subsidies scale. SRcontri, MPcontri, Ccontri represent the contribution rate of three decomposition factors (SR, MP and C) to the variation of natural gas subsidy, respectively. ΔSR, ΔMP, ΔC represent the decomposition amount of three influencing factors.

3.4. Indicator processing and data sources

As mentioned above, the key to applying the price-gap approach is how to define market reference prices (*MP*) and end-consumer prices (*EP*). The economic connotation of the market reference prices (*MP*) is the economic cost per unit of energy consumption. It is the final price that corresponds to the border price of internationally traded energy products and is adjusted according to transportation and distribution costs. It reflects the prices of commodities traded in competitive international markets. The economic connotation of the end-consumer price (*EP*) is the actual consumer price of an energy product, usually measured in terms of its average price in a major consumer market. The price gap, a measure of the degree to which energy subsidies distort the price of energy products, can be calculated after determining the *MP* and *EP*. Therefore, in this paper, the subsidy rate ($SR = MP\text{-}EP/MP$) is adopted as the operating index of the natural gas pricing mechanism.

In this paper, we use the national average benchmark price as the market reference price (*MP*). The national average benchmark price (*AP*) is a weighted average of the domestic benchmark price (*DP*) and the import benchmark price (*IP*), weighted by the respective consumption proportion of domestic and imported natural gas. How to calculate the domestic benchmark price is quite different in academia because natural gas prices in different regions have changed significantly, which is different from oil prices. We dealt with the domestic benchmark price in the same way as Lin and Liu [57]. Specifically, we use the provincial gate price for incremental gas (P_{ig}) plus the distribution cost (dc) as the domestic benchmark price. And the incremental price before 2013 was calculated based on the price growth rate of international fuel oil (60%) and liquefied petroleum gas (40%). According to Liu and Lin [17], this paper handled the corresponding indicators as follows. The distribution cost equaled to the terminal consumer price (cp_{ter}) minus the provincial gate price of stock gas ($P_{prov\cdot sg}$). In addition, the import benchmark price (*IP*) equaled the imported natural gas prices on CIF basis ($P_{ig/CIF}$) plus the transportation cost (*tc*).

In order to present the above index processing clearly, equations are added to explain the linkage, it is illustrated as:

$$AP = w_1 \times DP + w_2 \times IP$$
$$DP = P_{ig} + dc$$
$$dc = cp_{ter} - P_{prov\cdot sg}$$
$$IP = P_{ig/CIF} + tc$$

where, w_1 and w_2 denote the weight, weighted by the respective consumption proportion of domestic and imported natural gas. And other indicators are marked in the original paragraph.

The data for provincial gate price comes from National Development and Reform Commission (NDRC). The natural gas prices to end-consumer can be separated into the industrial, residential and commercial sector. The data on consumption of natural gas in three sectors are from China Entrepreneur Investment Club (CEIC). The average natural gas prices in 36 Chinese cities were used as the end-consumer prices (*EP*). The data of these cities were obtained from CEIC. The data on imported natural gas prices and consumption were derived from the development report of domestic and foreign oil and gas industry. In addition, the data of imported natural gas before 2010 was calculated using the average annual growth rate obtained from Chinese general administration of customs.

In terms of research on provincial natural gas subsidies, we took the industrial natural gas sector of 26 provinces[16] in China as the research subject and adjusted the period to 2007–2016[17]. China's average annual market reference price was used as the market reference price (*MP*) for estimating the subsidy of natural gas in the industrial sector of each province. The end-consumer price (*EP*) of natural gas in the industrial sector of 26 provinces was replaced by the used price of natural gas in the provincial capital cities. The data of the price for the provincial capital came from the end-user prices of natural gas in the industrial sector in 36 major cities in China. The data of the end-user prices of 36 major cities in China were obtained from CEIC. The natural gas consumption in the industrial sector in 26 provinces came from China's big data research platform for economic and social development. In addition, partial missing data are obtained by scatter point trend fitting method. To avoid the influence of inflation of currency, this paper used the consumer price index to deflate the nominal values to the 2017 constant price.

China's natural gas prices have been regulated by the government following the basic principle of "cost-plus" for a long time. The cost-plus means that prices are determined by production costs and reasonable profits, entailing the phenomenon that the consumer price is clearly below market prices. According to the enactment of notice to adjust the price of natural gas by the National Development and Reform Commission[18], the link of natural gas price management has been adjusted from the factory to urban gate station. Since then, the pricing mechanism has changed from the cost-plus method to the market net return method. The pricing mechanism of urban gate station price has two main steps.

The first step is to determine the pricing benchmark (central market). Considering the resource flow, consumption and pipeline distribution of China's natural gas market, Shanghai market is selected as the pricing benchmark. The second step is to establish a mechanism for linking gate station price in the central market to the price of alternative energy. Natural gas gate station price in the central market is determined by a principle. The principle is that natural gas gate station price in the central market is slightly lower than that of alternative energy with equal calorific value. Specifically, alternative energy sources are fuel oil and liquefied petroleum gas (LPG), with weights of 60% and 40%, respectively. The price of alternative energy with equal calorific value is calculated as weighted average of fuel oil and liquefied petroleum gas (LPG) unit calorific value prices. Meanwhile, in order to maintain the competitive advantage of natural gas, and encourage users to consume natural gas reasonably, natural gas gate station price is temporarily calculated at 90% of the price of alternative energy. The calculation formula is as follows:

$$P_{gas} = K \times (\alpha \times P_{fo} \times H_{gas}/H_{fo} + \beta \times P_{lpg} \times H_{gas}/H_{lpg}) \times (1 + R)$$

where P_{gas} is the natural gas gate station price in the central market. K represents the discount coefficient and tentatively set at 0.9. α and β denotes the weights of fuel oil and LPG at 60% and 40%, respectively. P_{fo} and P_{lpg} are the price of imported fuel oil and liquefied

[16] Due to the availability of data, Guangdong, Jiangxi, Guizhou, Yunnan, and Tibet were excluded.

[17] Limited by consumption data at the provincial level, the subsidies can only be estimated until 2016.

[18] http://www.ndrc.gov.cn/zcfb/zcfbtz/201112/t20111227_452929.html.

Table 2
Natural gas subsidy and respective subsidy rates of China during 2007–2017.

Year	Sectors	End-consumer price (USD/m^3)	Average subsidy rate (%)	Subsidies in sectors (billion USD)
2007	Industrial	0.33	18.16%	4.46
	Residential	0.28	29.70%	2.22
	Commercial	0.28	31.49%	1.34
Total subsidies scales(billion USD)				8.02
2017	Industrial	0.49	5.05%	4.20
	Residential	0.38	27.35%	7.56
	Commercial	0.48	7.64%	1.03
Total subsidies scales(billion USD)				12.79

Note: Table shows natural gas subsidy and respective subsidy rates in three sectors of China during 2007–2017.

petroleum gas (LPG) respectively calculated by the customs during the pricing period. H_{fo}, H_{lpg} and H_{gas} are the net calorific value (low calorific value) of fuel oil, liquefied petroleum gas and natural gas, taking 10,000 kcal/kg, 12,000 kcal/kg and 8000 kcal/m^3, respectively. R is the value-added tax rate for natural gas in China, currently 13%.

4. Empirical results and analysis

4.1. Analysis of natural gas subsidy based on national perspective

4.1.1. Overview of natural gas subsidies in China

The price of natural gas in the industrial sector is the highest, followed by the commercial sector, and the lowest is in the residential sector. As clearly shown in Table 2, the price of natural gas in industrial sector was 0.33 USD/m^3 in 2007, 0.05 USD/m^3 more than that in the residential sector. However, the gap had risen to 0.11 USD/m^3 in 2017, which indicated that the cross-subsidy of natural gas in residential sector was still relatively serious. Natural gas subsidy and respective subsidy rates in three sectors of China during 2007–2017 are shown in Table 2. As presented in Table 2, thanks to the reform of natural gas prices, the average subsidy rates of natural gas in China's industrial sector and commercial sector have decreased sharply, by 13.11% and 23.85% respectively. Although the value in the residential sector has also declined slightly, the average subsidy rate of natural gas in the residential sector has only dropped only by 2.35% to 27.35% in 2017. In terms of the change in the total subsidy of natural gas, the natural gas subsidies in China increased from 8.02 billion USD in 2007 to 12.79 billion USD. Natural gas subsidies in the residential sector tripled during 2007–2017, accounting for 59.11% of the total subsidies in 2017. There are two possible explanations for the result. On the one hand, Natural Gas Price Reform was not related to the residential sector. On the other hand, it benefited from the implement of "coal to gas" project.

We estimated the natural gas subsidy scale and subsidy rate during 2007–2017 showed in Fig. 2. It can be seen from Fig. 2 that the fluctuation trend of natural gas subsidy rate and subsidy scale is basically the same, with turning points in 2009, 2012 and 2016.

The first turning point in 2009: the international gas price fell sharply in 2009, influenced by the shale gas revolution in the United States and the fluctuation of international oil price. In the same year, a rare snow and ice disaster occurred in China, which caused the rapid expansion in domestic natural gas demand and the price rising of natural gas. These facts resulted in the dual decline of China's natural gas subsidy rate and subsidy scale. But natural gas subsidies rebounded by 2010–2012 for the possible reason that China's natural gas consumption was stimulated by the "four trillion CNY" plan. In the same period, international oil prices began to rebound. In fact, Chinese natural gas import and consumption have increased rapidly since the operation of the first imported gas pipeline A of Central Asia-China at the end of 2009.

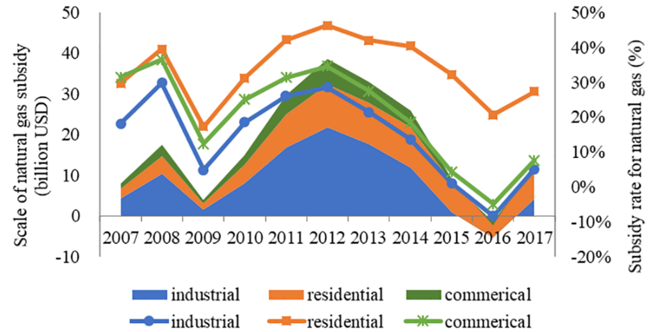

Fig. 2. Natural gas subsidy scale and subsidy rate during 2007–2017. Note: Figure shows the estimates of natural gas subsidy from 2013 to 2015 and its subsidy rate using price-gap approach.

The second turning point in 2012: Chinese government began to implement the reform of natural gas pricing mechanism since 2013. As a result, natural gas subsidies in the industrial and commercial sectors have been significantly reduced. The subsidy rate of the residential sector was still relatively high after the subsidy fell slightly. The reason was that Natural Gas Price Reform was not related to the residential sector in the period.

The third turning point in 2016: In 2015, the Chinese government finally realized the integration of the stock gas and the incremental gas, and lowered the price by 0.11 USD/m^3. However, the adjustment was not transmitted to the terminal consumer price in time, which resulted in the negative natural gas subsidy in the industrial sector and commercial sector in a short term. However, the end-user prices fell slightly in three sectors at the end of 2016. the price of imported natural gas has risen sharply at the same period, with its average import price reaching 0.61USD/m^3. These facts led to the rebound in subsidies. In addition, it was noted that the natural gas subsidy scale of the residential sector began to exceed that of the industrial sector since 2015.

4.1.2. Decomposition results in different sectors

In this section, we applied the price-gap approach and LMDI method to estimate the variation and decomposition of natural gas subsidies from the perspective of different sectors. The decomposition results are shown in Figs. 3–5. Some interesting findings are from the comparison of these decomposition results. Firstly, the trend of the change in subsidy scale and decomposition of influencing factors in Figs. 3 and 4 are quite similar, which indicates that the decomposition of natural gas subsidies in the industrial and commercial sectors is similar during the study period. Specifically, the pricing mechanism made the most significant contribution to the changes in subsidies in these two sectors, especially after the reform of pricing mechanism in 2013. The natural gas subsidy in the industrial sector dropped sharply during 2014–2015. The pricing mechanism contributed nearly 10.45 billion USD in the decomposition, accounting for 96.01% of the total decline. In the same

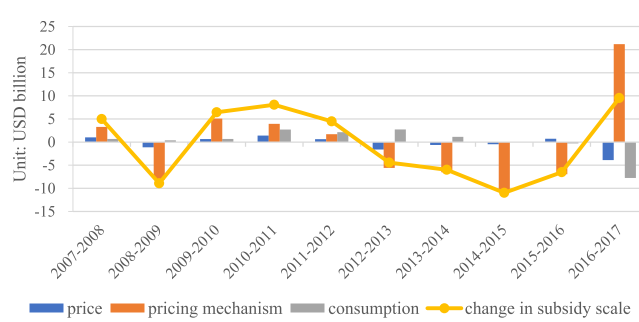

Fig. 3. Variation and decomposition of natural gas subsidies in China's industrial Sector during 2007–2017.

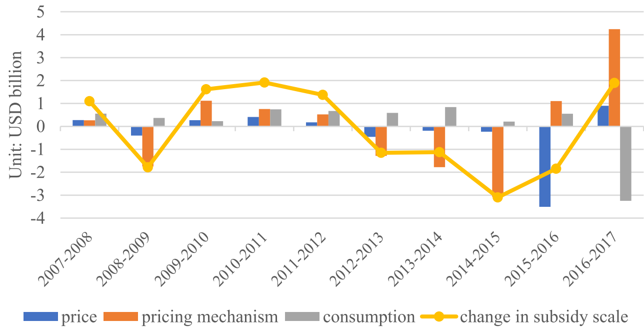

Fig. 4. Variation and decomposition of natural gas subsidies in China's commercial sector during 2007–2017.

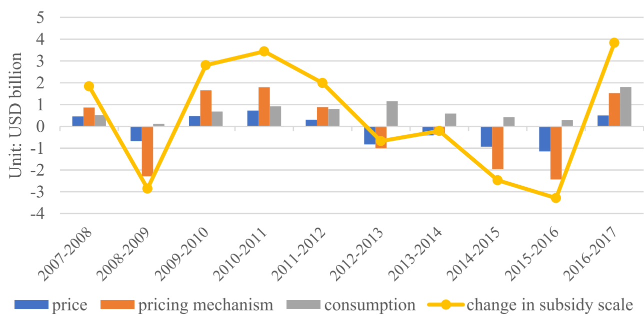

Fig. 5. Variation and decomposition of natural gas subsidies in China's residential sector during 2007–2017.

period, the contribution rate of the pricing mechanism in the residential and commercial sectors are 79.02% and 98.12% respectively.

Secondly, the influence of price mechanism in the residential sector in 2013 is not significant, far less than that in the other two sectors. One possible reason is that the 2013 pricing mechanism reform did not involve the use of natural gas in the residential sector. However, the natural gas subsidies in the residential sector continued to decline in 2014–2016, which may contribute to the positive externalities of pricing mechanism reform. Overall, the influences of price reform in the residential sector was still weak compared with other sectors.

We decomposed the influencing factors of natural gas subsidy changes in different industries in 2007–2013, 2013–2015 and 2015–2017, for the sake of the time-phased and industry differences in energy subsidy reform. Fig. 6 illustrated the decomposition results of the three sectors at different stages.

As shown in Fig. 6(a), the contribution rate of consumption in the three sectors was the highest during 2007–2013. The contribution rate of consumption in the commercial sector emerge highest, 98.01%, followed by 82.12% in the industrial sector and 62.21% in the residential sector. One possible reason for this result is that with the rapid development of urbanization in China, the domestic natural gas consumption has increased significantly. China's natural gas consumption rose from 70.5 billion cubic meters in 2007 to 170.5 billion cubic meters in 2013.

Fig. 6(b) shows that the pricing mechanism played a major role in promoting the decline of subsidies. Its contribution rates in the industrial, residential and commercial sectors are 101.21%, 87.31% and 115.22%, respectively. From 2013 to 2015, natural gas subsidies in industrial, residential and commercial sectors decreased by 8.38 billion USD, 1.29 billion USD and 2.09 billion USD annually. The reason for this result is that the government implemented a series of measures to reform the natural gas market in this period. In 2013, the government adjusted the management of natural gas prices from the factory to the gate station and implemented the highest ceiling price management at the gate station price. In September 2014, the gate station price of non-resident stock gas was raised by 0.06 USD per cubic meter. In April 2015, the maximum gate price of incremental gas decreased by 0.07 USD per cubic meter, and the highest gate price of stored gas increased by 0.006 USD per cubic meter in order to achieve the integration of incremental gas and stock gas prices. The maximum gate price for non-resident gas has been reduced by 0.11 USD per cubic meter since November 2015, and the non-resident gas price has been changed from the maximum gate price management to the benchmark gate price management. As these reform policies and measures didn't involve the gas consumption in the residential sector, the contribution rate of pricing mechanism of the residential sector was the lowest compared with other two sectors.

Fig. 6(c) showed the decomposition of the three sectors during 2015–2017. Unlike the previous two stages, the pricing mechanism in this stage was still the most contributing factor in the industrial sector and commercial sector, with a contribution of 104.34% and 145.26% respectively. But the biggest decomposition factor of the residential sector was consumption, which contributed 84.31%.

The reasons for this result may lie in two aspects: first, the government continued to deepen the market-oriented reform of natural gas pricing mechanism (shown in 5th paragraph of section1), guiding the rational allocation and consumption of resources, which resulted in a rebound in natural subsidies in the industrial and commercial sectors. Secondly, during this period, the government implemented the coal to gas project, especially the clean heating in northern rural areas, which greatly increased the consumption of residents. These reasons explained the rebound of the subsidy reform during 2015–2017. The subsidy scale of the three sectors increased by 15.97 billion USD, 8.06 billion USD and 3.71 billion USD respectively. It also provided an explanation for the inflection point in 2016 mentioned in Section 1.

4.2. Analysis of natural gas subsidy in the industrial sector from a regional perspective

The previous two sections discussed the time-phased and industry differences of subsidy decomposition. This section uses provincial panel data to analyze the regional heterogeneity of subsidy decomposition. Price-gap approach and LMDI methods are combined to complete the decomposition analysis to investigate the regional heterogeneity at both the regional and provincial level using provincial panel data. In this section, we study the industrial gas subsidies in 26 provinces during 2007–2016 and these provinces are grouped into four regions including Northeast, Eastern, Central and Western regions (seen in Table 3).

4.2.1. Results at regional level

(1). Discussion on the subsidies variation in different regions.

It is necessary to compare the subsidy situation of different regions at different time points for the sake of analyzing the regional heterogeneity. Fig. 7 presents the subsidies situation of industrial natural gas in four regions in China in 2007, 2010, 2013 and 2016, including the scale of subsidies and the corresponding average subsidies rate in each region. The subsidies in the four regions were all positive, and the order of subsidies was basically the same each year. The order from big to small was the western region, eastern region, central region and northeast region. However, only the western region had significant positive subsidies, while the other three regions had negative valuations by 2016. Overall, the scale of industrial natural gas subsidies presents a high trend in the west and low in the east. One possible explanation was that changes in subsidies scale are related to end-consumer prices in different regions. As shown in Fig. 8, comparatively speaking, the end-consumer price of industrial natural gas in western region has always been the lowest, which could entail the high subsidy rate. In 2007, the end-consumer price in the western region was only about 0.28 USD, while the prices in the other three regions were higher than 0.38 USD. It is worth noting that there are negative subsidies in the three regions

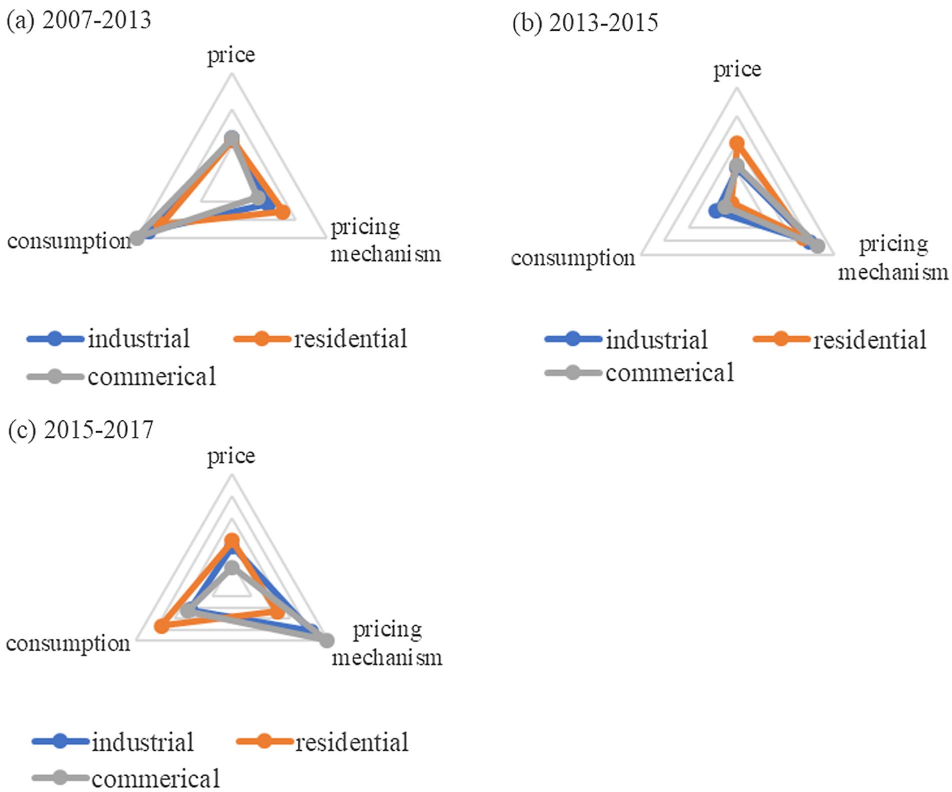

Fig. 6. Decomposition results in three sectors at different periods. Note: We decompose the influencing factors of natural gas subsidy changes in different industries in 2007–2013, 2013–2015 and 2015–2017, for the sake of the time-phased and industry differences in energy subsidy reform. Figure illustrates the decomposition results of three sectors at different three stages.

except for the western region in 2016, which may be attributed to the rationalization of the price structure of natural gas in these areas, resulting in a significant increase in the utilization efficiency of natural gas. The results indicate to some extent that China's natural gas market-oriented reform has achieved remarkable results in non-residential sectors since the government implemented the reform of pricing mechanism in 2013.

(2). Analysis on decomposition results in different regions

During 2007–2013, the subsidies of the industrial sectors in the four regions (northeastern, eastern, central, and western regions) all experienced significant growth. The highest subsidy growth rate was 274.04% in the central region, followed by 265.23% in the eastern region and 149.34% in the western region, and 98.36% in the northeast region was the lowest. Fig. 9 demonstrated the decomposition analysis in the industrial sector in the two periods before and after the reform in 2013.

As shown in Fig. 9(a), during 2007–2013, consumption was the most significant factor contributing to the decomposition of natural gas subsidies in the industrial sector. During the period, consumption contributed more than 80% to the eastern and northeastern regions, followed by 70.66% in the western region and 69.54% in the central region. A large amount of natural gas consumption was needed in China at this period due to the rapid industrialization. Consumption is the main driving factor for the growth of subsidies for natural gas in the industrial sector.

In Fig. 9(b), during 2013–2016, the pricing mechanism played a significant positive role in the decline of industrial natural gas subsidies. The effect of the pricing mechanism on the changes in subsidies differed in regions. Its contribution rates were 367.73% in the northeastern region, 80.64% in the eastern region, 75.68% in the central region and 74.34% in the western region. During the study period, natural gas subsidies in the industrial sector declined sharply with the largest decrease in the northeast and the east, followed by the central region and the lowest in the west. One explanation was that the government began to implement the reform of natural gas pricing mechanism in non-residential sectors since 2013 and its provincial gate price began to be linked to the market price of alternative energy sources in perfect competition. As a result, the end-consumer price of natural gas in the industrial sector rose several times in 2013–2017. It is worth noting that the pricing mechanism gave full play to its influential effect in the decline of natural gas subsidies in the industrial sectors in all regions, while consumption exerted the restraining effect in all regions. Reference prices only played a restraining role in the northeastern region.

Table 3
Relations between four regions and 26 provinces.

Northeast region (3)								
Liaoning	Jilin	Heilongjiang						
Eastern region (9)								
Beijing	Tianjin	Hebei	Shanghai	Jiangsu	Zhejiang	Fujian	Shandong	Hainan
Central region (5)								
Shanxi	Anhui	Henan	Hubei	Hunan				
Western region (9)								
Inner Mongolia	Guangxi	Sichuan	Chongqing	Shanxi	Gansu	Qinghai	Ningxia	Xinjiang

Source: The Seventh Five-Year Plan adopted by the Fourth Session of the Sixth National People's Congress of China in 1986.

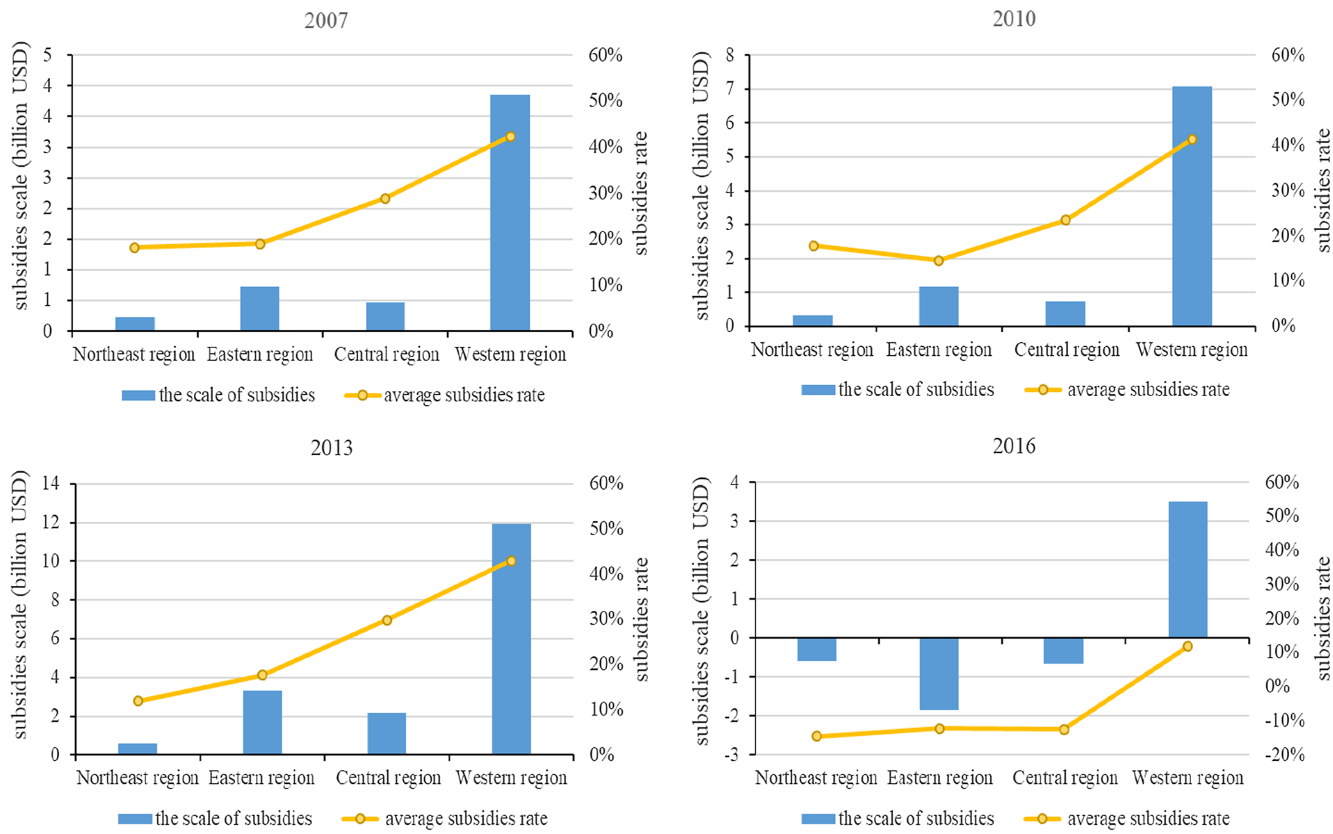

Fig. 7. Subsidies in different regions at different points in time. Note: Figure presents the subsidies situation of industrial natural gas in four regions in China in 2007, 2010, 2013 and 2016, including the scale of subsidies and the corresponding average subsidies rate in each region.

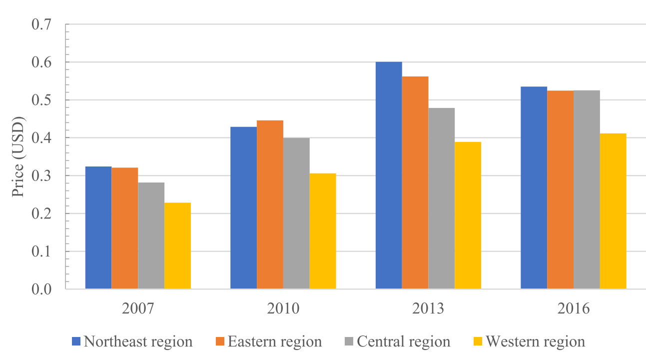

Fig. 8. Natural gas prices in industrial sectors in four regions at different points in time. Note: Figure shows the end-consumer price of industrial natural gas in four regions of China.

4.2.2. Analysis results at provincial level

(1). Discussion on changes in the scale of subsidies

Table 4 shows the scale of natural gas subsidies in the industrial sectors of 26 provinces during 2007–2016. The results present that natural gas subsidies in different provinces have significant spatial heterogeneity. The top five provinces are Sichuan, Chongqing, Xinjiang, Shanxi, and Inner Mongolia in the scale of subsidies in 2007, all of which belong to the western region. The top three subsidy scale exceeded 0.81 billion USD, and the subsidy scale in Sichuan's industrial sector was as high as 1.53 billion USD. Next is the eastern region, where the subsidies scale is relatively small at the level of 0.16–0.32 billion USD, such as Hebei (10), Jiangsu (10), Hainan (12). In addition, the subsidies scale in Shandong, Zhejiang and Fujian are all under 80.65 million USD. Subsidies in central provinces are the smallest. Except for Henan (22), other places are extremely small. In particular, the total subsidies in Shanxi, Hubei, Hunan and Anhui are less than 0.24 billion USD.

What's more, in the four municipalities directly under the Central Government, except for Chongqing as mentioned above, the subsidy scale of the other three municipalities is very small, with an average scale of 64.52 million USD. The subsidies scale in the Beijing-Tianjin-Hebei region are mostly at the average level of 0.16 billion USD.

Overall, the subsidy levels of 26 provinces in 2007–2010 shows a low trend in the East and high in the West. In the eastern region, only Hebei and Jiangsu provinces have an average annual subsidy level of more than 0.16 billion USD, while there is six in the western region. Differences in the region began to narrow down after 2010. In terms of time series, the fluctuation trend of subsidy changes in most provinces is the same, with inflection points in 2009 and 2013. This trend is similar to previous analysis of the changes in national natural gas subsidies, which imply that industrial subsidies accounted for a large proportion of the national natural gas consumption subsidies. In 2007, the proportion of natural gas consumption in the industrial sector was 68.65%, which remained around 65.09% during 2007–2016.

One thing is worth to be discussed here. It seems that the above results presented in Table 4 are conducted without considering economic size of each province, when the subsidy absolute amount analyzed. Therefore, we provide another perspective of the analysis based on economic size since economic bases differ in provinces. It is to make a comparative analysis with the above result shown in Table 4.

Specially, we establish an index to measure the relative subsidy of natural gas in each province. The index is designed to control the possible impact of economic volume on the size of subsidies. The index is defined as follows:

$$RSI = \frac{S}{GDP} \times 100$$

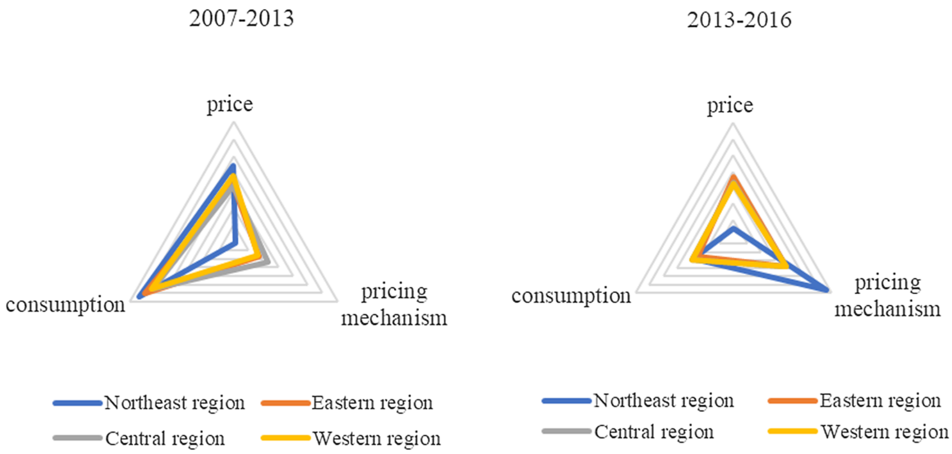

Fig. 9. Decomposition of natural gas subsidies in industrial sectors in different regions before and after the price reform in 2013. Note: Figure shows the decomposition analysis in the industrial sector in the two periods before and after the reform in 2013. (a) presents the decomposition result during 2007–2013 and (b) presents the decomposition result during 2013–2016.

Where, *RSI* denotes the relative subsidy index, *S* denotes the original subsidy presented in Table 4, *GDP* denotes the economic volume of each province. GDP data are from the National Bureau of Statistics of China. The recalculated results (RSI) are shown in Table 5. It shows the relative scale of natural gas subsidies in the industrial sectors of 26 provinces with the consideration of economic size.

In terms of specific values, there are obvious differences between Table 5 and Table 4. As seen from Table 5, The top five provinces are Xinjiang, Ningxia, Chongqing, Hunan and Qinghai in 2007. In other words, except Xinjiang and Chongqing, compared to Table 4, the others fall out of the top five, but still remain in the top ten. Besides, the top ten provinces remain largely unchanged in 2007 except that Henan was replaced by Qinghai. The top 10 provinces still belong to the western region which is consistent with that of Table 4. In general, the results with the consideration of economic size are different from that in Table 4. But it seems that the subsidies scale remains differ in provinces, even after with the consideration of economic size. Also, it means that the spatial heterogeneity of gas subsidies in different provinces still exists. This comparative analysis shows that the economic size has an impact on the ranking of natural gas subsidies at provincial levels, but it would not change the basic conclusion of this study, that is, the existence of regional heterogeneity.

(2). Analysis on decomposition results

Table 4 showed the cumulative effects of various factors on natural gas subsidy variation of 26 provinces during the entire study period[19]. During this period, the cumulative variation of natural gas subsidies in most provinces was negative. All provinces have declined to vary degrees except Shanxi, Qinghai and Xinjiang. This indicated that there was regional heterogeneity in the variation and decomposition of natural gas subsidies in the industrial sector. We therefore conclude that the contribution of these factors to the decomposition of natural gas subsidies differ in provinces.

Next, we discuss the effects of various driving factors.

Price effect (MP): The scale of subsidies for natural gas in industrial

Table 4
Scale of natural gas subsidies in the industrial sectors of 26 provinces in 2007–2016.

Regions	Provinces	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Northeast region	Liaoning	−0.50	9.33	−10.50	−1.92	11.33	31.21	13.33	9.85	−6.06	−24.86
	Jilin	6.51	11.15	6.64	11.20	9.44	15.00	16.02	7.53	−2.21	−1.35
	Heilongjiang	11.68	29.22	1.60	12.20	32.24	18.99	5.72	−4.80	−15.34	−13.44
Eastern region	Beijing	5.08	9.99	3.54	9.44	11.71	16.97	12.37	7.73	1.32	−0.66
	Tianjin	4.25	11.58	1.92	9.41	20.57	27.16	23.36	15.55	6.10	−4.47
	Hebei	10.54	25.60	14.58	24.08	31.61	37.82	28.05	15.25	3.25	3.05
	Shanghai	3.72	9.15	−1.38	5.57	18.89	28.35	21.68	12.48	−1.03	–22.05
	Jiangsu	10.49	28.27	3.28	23.62	48.79	76.35	65.11	45.44	1.36	−0.43
	Zhejiang	2.77	5.37	−1.85	1.65	7.74	13.52	0.94	−17.34	−31.10	−25.04
	Fujian	0.04	0.52	−0.39	1.20	2.05	4.77	1.87	−1.52	−8.60	−14.33
	Shandong	5.29	12.08	−15.14	0.30	18.28	33.44	20.83	−4.85	−28.76	−43.79
	Hainan	12.90	13.27	−7.50	4.14	36.51	35.67	27.07	22.85	8.48	−15.45
Central region	Shanxi	5.24	8.71	7.10	11.17	20.07	30.18	27.63	21.56	9.68	−2.27
	Anhui	1.88	3.69	1.82	6.28	11.49	16.29	14.90	5.78	−2.25	−4.12
	Henan	22.01	40.98	10.89	21.04	36.52	79.67	67.30	35.97	5.38	−21.13
	Hubei	3.81	7.26	1.76	6.81	14.30	20.42	13.60	8.34	−4.06	−15.32
	Hunan	2.50	5.99	1.90	4.23	7.58	10.93	9.17	5.81	−0.85	−0.94
Western region	Inner Mongolia	28.66	47.01	42.34	44.72	59.48	66.41	72.26	61.08	26.44	1.95
	Guangxi	−0.64	−0.04	−0.19	−0.36	−0.14	−0.23	−0.22	−1.29	−3.59	−6.46
	Sichuan	95.73	151.10	78.52	166.65	171.47	146.94	216.42	148.84	86.67	75.58
	Chongqing	51.80	78.94	43.40	65.32	86.49	84.84	49.81	36.33	−4.25	−6.47
	Shanxi	26.45	61.61	22.84	47.03	66.33	76.98	84.43	85.69	70.96	41.47
	Gansu	17.42	23.16	15.37	21.26	26.69	38.47	34.70	29.25	14.75	11.85
	Qinghai	7.50	27.14	16.37	23.33	42.29	69.48	63.48	61.84	47.55	35.69
	Ningxia	11.27	19.30	10.68	18.38	30.51	34.89	27.99	17.58	11.11	4.53
	Xinjiang	54.58	97.18	48.70	92.94	159.58	180.09	180.64	257.42	163.39	74.20

Note: Table shows the scale of natural gas subsidies in the industrial sectors of 26 provinces in 2007–2016. Natural gas subsidies in different provinces have significant spatial heterogeneity.

Table 5
Relative scale index of natural gas subsidies in the industrial sectors of 26 provinces with the consideration of economic size.

Regions	Provinces	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Northeast region	Liaoning	0.00	0.07	−0.07	−0.01	0.05	0.13	0.05	0.03	−0.02	−0.11
	Jilin	0.12	0.17	0.09	0.13	0.09	0.13	0.12	0.05	−0.02	−0.01
	Heilongjiang	0.16	0.35	0.02	0.12	0.26	0.14	0.04	−0.03	−0.10	−0.09
Eastern region	Beijing	0.05	0.09	0.03	0.07	0.07	0.09	0.06	0.04	0.01	0.00
	Tianjin	0.08	0.17	0.03	0.10	0.18	0.21	0.16	0.10	0.04	−0.03
	Hebei	0.08	0.16	0.08	0.12	0.13	0.14	0.10	0.05	0.01	0.01
	Shanghai	0.03	0.07	−0.01	0.03	0.10	0.14	0.10	0.05	0.00	−0.08
	Jiangsu	0.04	0.09	0.01	0.06	0.10	0.14	0.11	0.07	0.00	0.00
	Zhejiang	0.01	0.03	−0.01	0.01	0.02	0.04	0.00	−0.04	−0.07	−0.05
	Fujian	0.00	0.00	0.00	0.01	0.01	0.02	0.01	−0.01	−0.03	−0.05
	Shandong	0.02	0.04	−0.04	0.00	0.04	0.07	0.04	−0.01	−0.05	−0.06
	Hainan	1.03	0.88	−0.45	0.20	1.45	1.25	0.85	0.65	0.23	−0.38
Central region	Shanxi	0.09	0.12	0.10	0.12	0.18	0.25	0.22	0.17	0.08	−0.02
	Anhui	0.03	0.04	0.02	0.05	0.08	0.09	0.08	0.03	−0.01	−0.02
	Henan	0.15	0.23	0.06	0.09	0.14	0.27	0.21	0.10	0.01	−0.05
	Hubei	0.04	0.06	0.01	0.04	0.07	0.09	0.05	0.03	−0.01	−0.05
	Hunan	0.03	0.05	0.01	0.03	0.04	0.05	0.04	0.02	0.00	0.00
Western region	Inner Mongolia	0.45	0.55	0.43	0.38	0.41	0.42	0.43	0.34	0.15	0.01
	Guangxi	−0.01	0.00	0.00	0.00	0.00	0.00	0.00	−0.01	−0.02	−0.04
	Sichuan	0.91	1.20	0.55	0.97	0.82	0.62	0.82	0.52	0.29	0.23
	Chongqing	1.11	1.36	0.66	0.82	0.86	0.74	0.39	0.25	−0.03	−0.04
	Shanxi	0.46	0.84	0.28	0.46	0.53	0.53	0.52	0.48	0.39	0.21
	Gansu	0.64	0.73	0.45	0.52	0.53	0.68	0.55	0.43	0.22	0.16
	Qinghai	0.94	2.66	1.51	1.73	2.53	3.67	2.99	2.68	1.97	1.39
	Ningxia	1.23	1.60	0.79	1.09	1.45	1.49	1.09	0.64	0.38	0.14
	Xinjiang	1.55	2.32	1.14	1.71	2.41	2.40	2.14	2.78	1.75	0.77

Note: Table shows the relative scale of natural gas subsidies in the industrial sectors of 26 provinces with the consideration of economic size during 2007–2016. The results show that the scale of natural gas subsidies remains differ in provinces, even though with the consideration of economic size.

sectors of most provinces have declined, and the price effect exerted a little positive impact on the decline. Compared with other decomposition factors, price effect exerted restraining effect, especially in Liaoning, Shandong, Sichuan provinces.

Pricing mechanism effect (SR): as seen in Table 6, pricing mechanism exerted an overall positive effect in the decline of the scale of natural gas subsidies in the industrial sectors in all provinces but with some fluctuations and regional heterogeneity. It could be seen that the effect of pricing mechanism made a significant contribution to the reduction of subsidies in 22 provinces during the entire period. The expressive contribution rates among them are 346.64% in Liaoning, 463.89% in Hebei, 562.38% in Jiangsu, 368.21% in Hunan and 564.45% in Sichuan. As a result, it can be concluded that whether the pricing mechanism is effectively implemented or not, pricing mechanism has a critical impact on the natural gas subsidies during the entire period. This conclusion is consistent with the results of Liu and Lin [17].

Consumption effect (C): during the entire period, just like price effect, consumption had a restraining impact on the subsidy decline in the industrial sectors of 22 provinces. But the inhibitory effect and decomposition of consumption are larger than the price factor on average by about 0.23 billion USD.

5. Conclusions and policy implications

As the world's largest energy consumer and carbon emitter, China's energy subsidy reform has attracted much attention widely. China's natural gas consumption has increased sharply, accounting for about 15% of the growth in global natural gas consumption in 2017. Hence, natural gas consumption in China has become the main source of international natural gas demand growth. In view of the significant gap between the economic development and energy consumption structure of different provinces in China, we need to consider the regional heterogeneity in the study of natural gas subsidy,

This paper sought to investigate the industry differences and regional heterogeneity of natural gas subsidies in China. The industrial sector was selected for this study since it is the largest gas sector accounting for more than 65% of natural gas consumption. Price-gap approach and LMDI methods are combined to complete the study from the perspective of national level, regional level, and provincial level.

The findings of this paper are summarized as follows:

There exist industry differences and phased features in the decomposition at the national level. The contribution rate of consumption in the three sectors (industrial, residential and commercial sector) during 2007–2013 was the highest. But during 2013–2015, natural gas subsidies in the three sectors decreased sharply with an average annual decrease of 8.38 billion USD, 1.29 billion USD and 2.09 billion USD respectively. The pricing mechanism played a key positive role in the decline of natural gas subsidies in the three sectors, with contributions up to 101.21%, 87.31% and 115.22% respectively. This finding also indicated that a series of price reform measures implemented by the government since 2013 had achieved remarkable effects. However, since the reform measures did not involve the residential sector, the effect of the pricing mechanism on the residential sector was not obvious. During 2015–2017, pricing mechanism was still exerting positive effects both in the industrial sector and commercial sector, while consumption was the largest contributor in the residential sector during the period. One possible explanation for this is that the government cut the gate prices of non-residential sectors, leading to an increase in the consumption of natural gas by industrial and commercial sectors, which in turn leads to a decline in the final consumer price and ultimately a rebound in natural gas subsidies. By contrast, the rebound in gas subsidies in the residential sector was attributed more to the “coal to gas” program, which has significantly increased the consumption of natural gas in the residential sector.

There was regional heterogeneity in the decomposition analysis in

[19] Annual decomposition of each provinces has been accomplished in detail. But it is showed in the appendix limited by the length of the article (see Table A in Appendix).

Table 6
Factor Decomposition Analysis of natural gas subsidy variation of 26 Provinces during entire study period.

Region	Provinces		Decomposition			Contribution rate		
		△scale	△MP	△SR	△C	MPcontri	SRcontri	Ccontri
Northeast region	Liaoning	−24.36	43.43	−84.19	16.41	−178.29%	345.64%	−67.35%
	Jilin	−7.86	2.35	−23.17	12.97	−29.85%	294.88%	−165.03%
	Heilongjiang	−25.12	9.40	−30.90	−3.62	−37.43%	123.00%	14.43%
Eastern region	Beijing	−5.74	1.93	−13.48	5.82	−33.57%	234.91%	−101.34%
	Tianjin	−8.72	−4.28	−20.59	16.15	49.12%	236.06%	−185.18%
	Hebei	−7.48	5.70	−34.65	21.46	−76.14%	462.89%	−286.74%
	Shanghai	−25.78	3.18	−40.57	11.61	−12.35%	157.41%	−45.05%
	Jiangsu	−10.93	5.96	−61.46	44.57	−54.54%	562.38%	−407.84%
	Zhejiang	−27.81	1.61	−16.92	−12.49	−5.77%	60.85%	44.92%
	Fujian	−14.37	1.96	−27.26	10.94	−13.61%	189.74%	−76.13%
	Shandong	−49.08	40.41	−96.02	6.54	−82.33%	195.66%	−13.32%
	Hainan	−28.35	−1.95	−27.40	1.00	6.89%	96.64%	−3.53%
Central region	Shanxi	−7.52	0.71	−1.26	1.87	−3.16%	408.60%	−305.44%
	Anhui	−6.00	1.64	−18.88	11.24	−27.39%	314.57%	−187.18%
	Henan	−43.14	8.89	−86.17	34.13	−20.61%	199.73%	−79.12%
	Hubei	−19.13	2.48	−26.22	4.61	−12.97%	137.06%	−24.09%
	Hunan	−3.44	1.19	−12.65	8.02	−34.51%	367.79%	−233.28%
Western region	Inner Mongolia	−26.71	6.99	−41.68	7.98	−26.17%	156.07%	−29.89%
	Guangxi	−5.82	1.05	−6.08	−0.79	−17.98%	104.39%	13.59%
	Sichuan	−20.14	19.68	−113.69	73.87	−97.68%	564.39%	−366.71%
	Chongqing	−58.27	22.20	−101.68	21.21	−38.10%	174.49%	−36.39%
	Shanxi	15.02	−4.67	−33.00	52.69	−31.09%	−219.71%	350.79%
	Gansu	−5.57	1.88	−11.89	4.43	−33.78%	213.38%	−79.61%
	Qinghai	28.18	−7.59	−18.65	54.42	−26.92%	−66.15%	193.07%
	Ningxia	−6.74	3.45	−17.50	7.31	−51.18%	259.64%	−108.46%
	Xinjiang	19.62	−12.98	−81.74	114.34	−66.17%	−416.63%	582.80%

Note: Table shows the cumulative effects of various factors on natural gas subsidy variation of 26 provinces during entire study period (2007–2016).ΔSR, ΔMP, ΔC represent the decomposition amount of three influencing factors (SR, MP and C), respectively. SRcontri, MPcontri, Ccontri represent the contribution rate of three decomposition factors (Pricing mechanism, Price and Consumption) to the variation of subsidy, respectively.

the industrial sectors at the regional level. Firstly, the subsidies of the industrial sectors in the four regions (Northeast, Eastern, Central, and Western regions) all experienced significant growth during 2007–2013. The highest subsidy growth rate was 274.04% in the central region, followed by 265.23% in the eastern region and 149.34% in the western region, and 98.36% in the northeast region was the lowest. But the scale of natural gas subsidies in the industrial sector in each region dropped sharply since 2013, with the largest drop in the northeast and the east, followed by the central region and the lowest in the west. Secondly, during 2007–2013, consumption was the most significant factor contributing to the decomposition of natural gas subsidies in the industrial sector in all regions and exerted a positive influence on the growth of natural gas subsidies. During the period, consumption contributed more than 80% to the eastern and northeastern regions, followed by 70.66% in the western region and 69.54% in the central region. On the contrary, during 2013–2016, the pricing mechanism played a significant positive role in the decline of industrial natural gas subsidies. The effect of the pricing mechanism on the changes in subsidies differed in regions. Its contribution rates were 367.73% in the northeastern region, 80.64% in the eastern region, 75.68% in the central region and 74.34% in the western region. This result presents that the pricing mechanism reform implemented by the government in 2013 achieved remarkable results. At the same period, consumption exerted the restraining effect in all regions, while reference prices played a restraining role only in Northeast region.

There exists regional heterogeneity in the industrial natural gas subsidies and its decomposition analysis at provincial level in 2007. The top five provinces with the highest subsidies are Sichuan, Chongqing, Xinjiang, Shanxi and Inner Mongolia, all of which belong to the western region. The second echelon was the eastern provinces, and the subsidies scale of each province was as low as the level at 0.16–0.32 billion USD. Natural subsidies in central provinces were the smallest. Overall, the subsidy level of 26 provinces during 2007–2010 presented a distribution trend of low in the East and high in the West. In the eastern region, only the average annual subsidy scale of Hebei and Jiangsu provinces were more than 0.16 billion USD, while there was six in the western region. Differences in the region began to narrow after 2010. The cumulative scale changes of natural gas subsidies in most provinces are negative except for the three western provinces of Shanxi, Qinghai and Xinjiang, other provinces had declined in varying degrees. This indicated that there was regional heterogeneity in the factor decomposition of change in natural gas subsidies in the industrial sector. The pricing mechanism exerted overall positive effects in the decline of the scale of natural gas subsidies in the industrial sectors in all provinces but with some fluctuations. Price and consumption had a restraining influence in the subsidy decline in the industrial sectors of 23 provinces during 2007–2016. But the inhibitory effect and decomposition of consumption are larger than the price factor.

Based on the aforementioned conclusions, three policy implications are presented as follows:

Firstly, considering the industry differences, the market-oriented reform of natural gas pricing mechanism needs to distinguish non-residential natural gas from residential natural gas. In the non-residential gas sector, the government can let both suppliers and consumers trade competitively in national oil and gas trading centers such as Shanghai and Chongqing. The advantage of this approach lies in the spontaneous formation of efficient market prices based on the supply and demand market transactions, avoiding the market distortions caused by the government's participation in natural gas pricing. Additionally, this method is conducive for effective supervision and management of market transactions. In the field of residential gas, it is difficult for the terminal consumer price of residents to be fully marketed in a short time due to the difference in the economic affordability of residents. A suggestion is that the upstream gas price could be equal to the final consumer price acceptable to the residents plus the transmission and distribution cost and reasonable profit.

Secondly, Natural gas subsidies have regional heterogeneity and different regions have different gas pipeline transportation fees, resulting in regional differences in terminal consumer prices. We propose that the cost of pipeline transportation in a place can be divided into two parts. The first is the cost determined by the distance between the local pipeline network and the gas source, and the second is the cost generated by the management fee of the local pipeline operation company. According to the applicable scope of different pipeline pricing in different regions, the "point-to-point" method can be used for pilot regional reform. In addition, in the early stages, more developed pipeline networks and mature market areas should be selected as provincial pilot areas. Pilot areas should design regional pipeline transportation fees according to the overall layout of China's natural gas market reform to mitigate the impact of price distortions caused by regional heterogeneity. Overall, this study can be a useful reference for China to rationally allocate regional energy subsidy reform tasks and formulate corresponding regional subsidy policies.

Finally, based on the results, we suggest that policy measures enacted by the government should differ in regions when promoting subsidy reform, especially for developing countries with unbalanced regional development, such as China.

Of course, there are some constraints for employing this method. From the Eqs. (3) and (4) in the paper, the LMDI formulae contain logarithmic terms and the variables cannot have negative values. In theory, however, the subsidy and subsidy rate indicators are likely to be negative. A more likely situation is the occurrence of zero values. So, this is a limitation of the LMDI method, as well as an inevitable constraint for the decomposition analysis employing this method.

In the context of climate change, fossil energy subsidies are a global problem. As we all know, natural gas is a regional energy source. There exist a few regional problems in natural gas subsidy, such as how to guide the rational allocation of energy resources among regions. Hence, the regional heterogeneity of natural gas studied in this paper is not a unique problem in China, but may be the issue in the world, even if the case studied in this paper is in China. In other words, the findings in our study can be extended to emerging and developing countries due to the similar issue of fossil fuel subsidies, especially for countries with unbalanced regional development.

CRediT authorship contribution statement

Boqiang Lin: Conceptualization, Data curation, Methodology, Software, Writing - original draft. **Yunming Kuang:** Data curation, Methodology, Software, Writing - original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. . Mathematical proof: The LMDI approach to decomposition analysis[20]

A.1 Divisia integral index

The proposed method is derived from the Divisia index. For ease of understanding, we refer to the case of energy-related CO_2 emissions for industry. Assuming n industrial sectors and m fuel types, we may express the aggregate CO_2 emissions (C) in terms of industrial production, energy emission factor, fuel mix, and energy intensity:

$$C = \sum_{i=1}^{n}\sum_{j=1}^{m} C_{ij} = \sum_{i=1}^{n}\sum_{j=1}^{m} Y_i \cdot U_{ij} \cdot S_{ij} \cdot I_i \tag{A.1}$$

where C_{ij} is the CO_2 emissions for fuel j in sector i, Y_i is the industrial output of sector i, $U_{ij} = C_{ij}/E_{ij}$

is the emission factor of fuel j in sector i, $S_{ij} = E_{ij}/E_i$ is the energy consumption share of fuel j in sector i (E_{ij} is fuel j consumption and E_i the total energy consumption, both in sector i), and $I_i = E_i/Y_i$ is the energy intensity of sector i.

To study how the aggregate emissions are affected by the factors on the right hand side of Eq. (A.1) over time, we take the logarithmic differentiation of Eq. (A.1) with respect to time:

$$\frac{d\ln C}{dt} = \sum_{i=1}^{n}\sum_{i=1}^{m} \frac{Y_i \cdot U_{ij} \cdot S_{ij} \cdot I_i}{C}\left(\frac{d\ln Y_i}{dt} + \frac{d\ln U_{ij}}{dt} + \frac{d\ln S_{ij}}{dt} + \frac{d\ln I_i}{dt}\right) \tag{A.2}$$

Integrating Eq. (A.2) over the time interval [0, T] yields:

$$\ln\left(\frac{C_T}{C_0}\right) = \sum_{i=1;j=1}^{n} \int_0^T w_{ij}(t)\left(\frac{d\ln Y_i(t)}{dt} + \frac{d\ln U_{ij}(t)}{dt} + \frac{d\ln S_{ij}(t)}{dt} + \frac{d\ln I_{i(t)})}{dt}\right)dt \tag{A.3}$$

where

$$w_{ij}(t) = \frac{Y_i(t) \cdot U_{ij}(t) \cdot S_{ij}(t) \cdot I_i(t)}{C(t)} = \frac{Y_i(t) \cdot U_{ij}(t) \cdot S_{ij}(t) \cdot I_i(t)}{\sum_{i=1}^{n} X_i(t) \cdot U_{ij}(t) \cdot S_{ij}(t) \cdot I_i(t)} \tag{A.4}$$

Exponentiating Eq. (A.3) yields:

[20] This proof is provided from Ang and Liu (2001), please refer to the original text for more details.

$$\frac{C_T}{C_0} = \exp\left(\sum_{i=1 j=1}^{n} \int_0^T w_{ij}(t)\frac{d\ln Y_i(t)}{dt}dt\right) \times \exp\left(\sum_{i=1 j=1}^{n} \sum_{j=1}^{T} \int_0^T w_{ij}(t)\frac{d\ln U_{ij}(t)}{dt}dt\right)$$
$$\times \exp\left(\sum_{i=1 j=1}^{n} \sum_{j=1}^{n} \int_0^T w_{ij}(t)\frac{d\ln S_{ij}(t)}{dt}dt\right) \times \exp\left(\sum_{i=1 j=1}^{n} \sum_{j=1}^{n} \int_0^T w_{ij}(t)\frac{d\ln I_i(t)}{dt}dt\right) \tag{A.5}$$

A.2 Discretization

A discrete approximation of Eq. (A.5) is needed in empirical studies. The following log-change formula may be used:

$$\frac{C_T}{C_0} \cong \exp\left(\sum_{i=1 j=1}^{n} \sum_{ij=1}^{m} w_{ij}(t*)\ln\frac{Y_{i,T}}{Y_{i,0}}\right) \times \exp\left(\sum_{i=1 j=1}^{n} \sum_{ij=1}^{m} w_{ij}(t*)\ln\frac{U_{ij.T}}{U_{ij,O}}\right)$$
$$\times \exp\left(\sum_{i=1 j-1}^{n} \sum_{i=1}^{m} w_{ij}(t*)\ln\frac{S_{ij,T}}{S_{ij,0}}\right) \times \exp\left(\sum_{i=1}^{n} \sum_{i=1}^{m} w_{ij}(t*)\ln\frac{I_{i,T}}{I_{i,0}}\right) \tag{A.6}$$

where $w_i(t^*)$ is a weight function given by Eq. (A.4) at point $t*$ $[0, T]$. In Eq. (A.4), the precise point is not known. Boyd et al. [15] proposed the use of an arithmetic mean weight function given by the arithmetic average of two end-point weights, i.e.

$$w_{ij}(t*) = 0.5\cdot\left(\frac{C_{ij,0}}{C_0} + \frac{C_{ij.T}}{C_T}\right)$$

This formulation has been called the Arithmetic Mean Divisia Index Method (AMDI).

This method has been adopted in many energy decomposition studies but it has the drawbacks of leaving a residual term and an inability to handle zero values in the data set. The logarithmic mean of two positive numbers is defined as:

$$L(x, y) = (y - x)/\log(y/x) \text{ for } x \neq y \tag{A.7}$$

and L(x,x) = x. Their proposed weight function is given by

$$W_{ij(t*)}=\frac{L(w_{ij,0}, w_{ij,T})}{\sum_i L(w_{ij,0}, w_{ij,T})}$$

where

$$w_{ij,0} = \frac{C_{ij,0}}{C_{i,0}}$$

And

$$w_{ij,T} = \frac{C_{ij,T}}{C_{i,T}}$$

This formulation is what we have referred to as the LMDI II. Although superior to the AMDI Method, this method is not consistent in aggregation. With reference to Eq. (A.7), proposing the use of the aggregate total value as the item of weight. In the weight function, we may therefore take L (C_{ij},0, C_{ij}, T) as the logarithmic mean of the factorial value and

$$L\left(\sum_{i=1 j=1}^{n} \sum_{i=1}^{m} C_{ij,0} \sum_{i=1 j=1}^{n} \sum_{i=1}^{m} C_{ij,T}\right) = L(C_0, C_T)$$

as the logarithmic mean of the aggregate value. Thus, we define

$$\tilde{w}_{ij}(t*) = \frac{L(C_{ij,0}, C_{ij,T})}{L(C_0, C_T)} \tag{A.8}$$

It is shown in Section 2.3 that inserting Eq. (A.8) into Eq. (A.6) yields the following identity:

$$\frac{C_T}{C_0} \equiv \exp\left(\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{w}_{ij}(t*)\ln\frac{Y_{i,T}}{Y_{i,0}}\right) \times \exp\left(\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{w}_{ij}(t*)\ln\frac{U_{ji,T}}{U_{ij,0}}\right)$$
$$\times \exp\left(\sum_{i=1 j=1}^{n} \sum_{i=1}^{m} \tilde{w}_{ij}(t*)\ln\frac{S_{ij,T}}{S_{ij,0}}\right) \exp\left(\sum_{i=1 j=1}^{n} \sum_{j=1}^{m} \tilde{w}_{ij}(t*)\ln\frac{I_{i,T}}{I_{i,0}}\right) \tag{A.9}$$

Eq. (A.9) may be written as:

$$D_{tot} = D_{pdn}\cdot D_{cmf} D_{mix}\cdot D_{int} \tag{A.10}$$

where $D_{tot} = C_T/C_0$ and the indices D_{pdn}, D_{emf}, D_{mix}, and D_{int} are respectively the factorial effects associated with industrial production, fuel emission factor, fuel mix, and energy intensity. The formulation based on Eq. (A.8)–(A.10) is our proposed method and will be referred to as the Log Mean Divisia Index Method I (LMDI I). Its weight function is simpler than that of the LMDI II.

A.3 Proof of perfect decomposition

To prove that Eq. (A.9) is an identity, the right-hand side of the equation may be written as:

$$\exp\left(\sum_{i=1j=1}^{n}\sum_{ij=1}^{m}\tilde{w}_{ij}(t*)\left(\ln\frac{Y_{i,T}}{Y_{i,0}}+\ln\frac{U_{ij,T}}{U_{ij,0}}+\ln\frac{S_{ij,T}}{S_{i,i,0}}+\ln\frac{I_{i,T}}{I_{i,0}}\right)\right)$$

$$=\exp\left(\sum_{i=1;j=1}^{n}\sum_{L=1}^{m}\frac{L(C_{ij,0},C_{ij,T})}{L(C_0,C_T)}\left(\ln\frac{Y_{i,T}}{Y_{i,0}}\frac{U_{ij,T}}{U_{ij,0}}\frac{S_{ij,T}}{S_{ij,0}},\frac{I_{i,T}}{I_{i,0}}\right)\right)$$

$$=\exp\left(\sum_{i=1,j=1}^{n}\frac{(C_{ij,1}-C_{ij,0})/\ln(C_{i,j,T}/C_{ij,0})}{(C_T-C_0)/\ln(C_T,C_0)}\ln\left(\frac{C_{ij,T})}{C_{i,j,0}}\right)\right)$$

$$=\exp\left(\sum_{i=1;j=1}^{n}\sum_{j=1}^{m}\ln\left(\frac{C_T}{C_0}\right)\frac{C_{ij,T}-C_{ij,o}}{C_T-C_0}\right)=\exp\left(\ln\left(\frac{C_T}{C_0}\right)^{\frac{n}{2}\sum_{i=1}^{m}(C_{j,T}-C_{j,o})}\right)$$

$$=\frac{C_T}{C_0}$$

Due to space constraints, derivation process of the consistence in aggregation, another desirable property of the LMDI I method, is not provided here, but can be found in Section 3 in Ang and Liu (2001). Besides, a practical guide to LMDI and quantity indicator for both additive and multiplicative decomposition analysis is provided in Ang (2005).

Appendix B. . Factor decomposition on subsidy variation of provinces

See. Table B1.

Table B1
Annual factor decomposition of subsidy variation of 26 provinces from 2007 to 2016.

Provinces	year	△scale	Decomposition			Contribution rate		
			△MP	△SR	△C	MPcontri	SRcontri	Ccontri
Beijing	2008	4.92	1.53	1.70	1.69	0.31	0.35	0.34
	2009	−6.45	−1.60	−4.82	−0.03	0.25	0.75	0.00
	2010	5.90	1.24	2.93	1.73	0.21	0.50	0.29
	2011	2.28	1.85	0.96	−0.53	0.81	0.42	−0.23
	2012	5.25	0.85	1.60	2.81	0.16	0.31	0.53
	2013	−4.60	−0.82	−3.36	−0.41	0.18	0.73	0.09
	2014	−4.65	−0.22	−4.45	0.02	0.05	0.96	0.00
	2015	−6.40	−0.35	−6.57	0.52	0.05	1.03	−0.08
	2016	−1.98	−0.55	−1.46	0.03	0.28	0.74	−0.01
Tianjin	2008	7.33	1.54	4.05	1.74	0.21	0.55	0.24
	2009	−9.66	−1.38	−8.51	0.23	0.14	0.88	−0.02
	2010	7.49	0.97	4.94	1.57	0.13	0.66	0.21
	2011	11.16	2.50	6.81	1.85	0.22	0.61	0.17
	2012	6.59	1.41	2.58	2.60	0.21	0.39	0.40
	2013	−3.80	−1.42	−6.13	3.76	0.37	1.61	−0.99
	2014	−7.81	−0.43	−9.48	2.09	0.06	1.21	−0.27
	2015	−9.45	−0.96	−10.30	1.82	0.10	1.09	−0.19
	2016	−10.57	−6.51	−4.56	0.50	0.62	0.43	−0.05
Hebei	2008	15.06	3.57	5.96	5.54	0.24	0.40	0.37
	2009	−11.02	−5.03	−8.16	2.18	0.46	0.74	−0.20
	2010	9.49	3.91	1.07	4.51	0.41	0.11	0.48
	2011	7.53	4.85	−2.02	4.70	0.64	−0.27	0.62
	2012	6.22	2.06	4.39	−0.24	0.33	0.71	−0.04
	2013	−9.77	−1.85	−9.73	1.80	0.19	1.00	−0.19
	2014	−12.81	−0.47	−12.86	0.53	0.04	1.01	−0.04
	2015	−11.99	−0.74	−13.77	2.51	0.06	1.15	−0.21
	2016	−0.20	−0.60	0.48	−0.07	3.03	−2.39	0.36
Shanxi	2008	1.30	0.54	0.59	0.17	0.41	0.45	0.13
	2009	0.51	0.64	0.84	−0.97	1.26	1.64	−1.90
	2010	0.55	0.25	−0.40	0.70	0.46	−0.73	1.27
	2011	−2.14	−0.64	−1.04	−0.46	0.30	0.49	0.22
	2012	2.63	0.38	0.67	1.58	0.15	0.25	0.60
	2013	−0.57	−0.37	−0.93	0.72	0.64	1.63	−1.26
	2014	−0.37	−0.03	−0.41	0.07	0.09	1.10	−0.19
	2015	−0.35	−0.04	−0.36	0.05	0.12	1.02	−0.14
	2016	−0.25	−0.03	−0.22	0.01	0.13	0.89	−0.02

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Table B1 (*continued*)

Provinces	year	△scale	Decomposition			Contribution rate		
			△MP	△SR	△C	MPcontri	SRcontri	Ccontri
Inner Mongolia	2008	18.35	7.79	1.18	9.37	0.43	0.07	0.51
	2009	−4.66	−11.47	−14.49	21.30	2.46	3.11	−4.57
	2010	2.38	8.98	4.73	−11.34	3.78	1.99	−4.77
	2011	14.76	9.07	6.02	−0.33	0.61	0.41	−0.02
	2012	6.93	3.75	3.21	−0.02	0.54	0.46	0.00
	2013	5.85	−3.91	−3.33	13.10	−0.67	−0.57	2.24
	2014	−11.18	−1.49	−1.37	−8.33	0.13	0.12	0.75
	2015	−34.64	−3.94	−17.59	−13.11	0.11	0.51	0.38
	2016	−24.49	−1.79	−20.04	−2.66	0.07	0.82	0.11
Liaoning	2008	9.83	0.71	8.81	0.32	0.07	0.90	0.03
	2009	−19.83	43.30	−72.07	8.93	−2.18	3.63	−0.45
	2010	8.58	−1.04	10.36	−0.74	−0.12	1.21	−0.09
	2011	13.25	1.31	6.21	5.73	0.10	0.47	0.43
	2012	19.88	1.17	10.66	8.05	0.06	0.54	0.41
	2013	−17.88	−1.19	−10.60	−6.10	0.07	0.59	0.34
	2014	−3.48	−0.26	−3.63	0.41	0.07	1.04	−0.12
	2015	−15.91	−3.12	−12.91	0.12	0.20	0.81	−0.01
	2016	−18.80	2.54	−21.02	−0.32	−0.14	1.12	0.02
Jilin	2008	4.64	1.81	2.14	0.70	0.39	0.46	0.15
	2009	−4.51	−2.24	−2.80	0.52	0.50	0.62	−0.12
	2010	4.56	1.80	0.40	2.35	0.40	0.09	0.52
	2011	−1.76	1.80	−5.03	1.47	−1.03	2.86	−0.84
	2012	5.57	0.72	2.02	2.83	0.13	0.36	0.51
	2013	1.02	−0.88	−3.91	5.81	−0.86	−3.84	5.70
	2014	−8.49	−0.25	−8.06	−0.18	0.03	0.95	0.02
	2015	−9.74	−0.76	−8.44	−0.55	0.08	0.87	0.06
	2016	0.86	0.33	0.52	0.01	0.39	0.60	0.01
Heilongjiang	2008	17.54	4.02	14.12	−0.60	0.23	0.81	−0.03
	2009	−27.62	−2.44	−23.90	−1.29	0.09	0.87	0.05
	2010	10.60	1.08	9.91	−0.39	0.10	0.94	−0.04
	2011	20.04	3.61	11.61	4.81	0.18	0.58	0.24
	2012	−13.25	1.49	−11.04	−3.71	−0.11	0.83	0.28
	2013	−13.27	−0.62	−13.09	0.45	0.05	0.99	−0.03
	2014	−10.52	−1.34	−5.28	−3.90	0.13	0.50	0.37
	2015	−10.54	0.86	−11.36	−0.04	−0.08	1.08	0.00
	2016	1.90	2.75	−1.88	1.03	1.45	−0.99	0.54
Shanghai	2008	5.43	1.27	4.05	0.11	0.23	0.75	0.02
	2009	−10.53	−1.43	−9.28	0.18	0.14	0.88	−0.02
	2010	6.95	1.03	3.51	2.41	0.15	0.51	0.35
	2011	13.33	1.91	8.71	2.71	0.14	0.65	0.20
	2012	9.45	1.39	5.22	2.84	0.15	0.55	0.30
	2013	−6.66	−1.40	−8.44	3.18	0.21	1.27	−0.48
	2014	−9.20	−0.37	−8.88	0.05	0.04	0.97	−0.01
	2015	−13.51	−0.52	−13.27	0.28	0.04	0.98	−0.02
	2016	−21.03	1.31	−22.19	−0.15	−0.06	1.06	0.01
Jiangsu	2008	17.77	3.77	7.55	6.45	0.21	0.43	0.36
	2009	−24.99	−2.98	−22.04	0.04	0.12	0.88	0.00
	2010	20.33	2.13	15.79	2.42	0.11	0.78	0.12
	2011	25.18	6.08	13.46	5.64	0.24	0.53	0.22
	2012	27.56	3.67	7.81	16.08	0.13	0.28	0.58
	2013	−11.24	−3.98	−16.22	8.96	0.35	1.44	−0.80
	2014	−19.66	−1.22	−21.86	3.42	0.06	1.11	−0.17
	2015	−44.09	−1.20	−44.38	1.49	0.03	1.01	−0.03
	2016	−1.79	−0.30	−1.56	0.07	0.17	0.87	−0.04
Zhejiang	2008	2.60	0.83	1.81	−0.04	0.32	0.70	−0.01
	2009	−7.22	−1.74	−7.63	2.14	0.24	1.06	−0.30
	2010	3.49	−6.25	19.23	−9.48	−1.79	5.50	−2.71
	2011	6.10	0.69	4.11	1.30	0.11	0.67	0.21
	2012	5.78	0.62	2.59	2.57	0.11	0.45	0.44
	2013	−12.58	−0.27	−13.20	0.88	0.02	1.05	−0.07
	2014	−18.29	0.14	−16.05	−2.38	−0.01	0.88	0.13
	2015	−13.76	2.24	−11.08	−4.92	−0.16	0.81	0.36
	2016	6.07	5.34	3.28	−2.56	0.88	0.54	−0.42
Anhui	2008	1.81	0.56	0.57	0.67	0.31	0.32	0.37
	2009	−1.87	−0.68	−2.57	1.38	0.36	1.37	−0.74
	2010	4.46	0.74	2.42	1.30	0.17	0.54	0.29
	2011	5.21	1.51	3.62	0.08	0.29	0.70	0.02
	2012	4.80	0.82	1.09	2.89	0.17	0.23	0.60
	2013	−1.39	−0.88	−3.89	3.38	0.63	2.79	−2.42
	2014	−9.12	−0.22	−10.16	1.25	0.02	1.11	−0.14
	2015	−8.03	−0.81	−7.67	0.45	0.10	0.96	−0.06
	2016	−1.87	0.59	−2.31	−0.16	−0.32	1.23	0.08

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Table B1 (*continued*)

Provinces	year	△scale	Decomposition			Contribution rate		
			△MP	△SR	△C	MPcontri	SRcontri	Ccontri
Fujian	2008	0.48	0.04	0.37	0.08	0.08	0.77	0.16
	2009	−0.91	−0.84	−2.46	2.40	0.93	2.72	−2.65
	2010	1.59	0.29	−0.18	1.48	0.18	−0.12	0.93
	2011	0.85	0.28	0.01	0.57	0.33	0.01	0.67
	2012	2.72	0.19	0.02	2.50	0.07	0.01	0.92
	2013	−2.90	−0.18	−3.98	1.25	0.06	1.37	−0.43
	2014	−3.39	−0.36	−6.97	3.95	0.11	2.06	−1.17
	2015	−7.08	0.39	−7.15	−0.32	−0.06	1.01	0.05
	2016	−5.73	2.14	−6.91	−0.97	−0.37	1.21	0.17
Shandong	2008	6.79	1.73	0.87	4.20	0.25	0.13	0.62
	2009	−27.22	31.02	−50.65	−7.58	−1.14	1.86	0.28
	2010	15.44	−0.81	16.42	−0.17	−0.05	1.06	−0.01
	2011	17.98	0.77	16.87	0.34	0.04	0.94	0.02
	2012	15.16	1.50	7.41	6.25	0.10	0.49	0.41
	2013	−12.61	−1.50	−14.77	3.66	0.12	1.17	−0.29
	2014	−25.68	−0.39	−25.90	0.62	0.02	1.01	−0.02
	2015	−23.92	1.28	−24.90	−0.30	−0.05	1.04	0.01
	2016	−15.03	6.83	−21.36	−0.49	−0.46	1.42	0.03
Henan	2008	18.97	6.41	8.21	4.34	0.34	0.43	0.23
	2009	−30.09	−5.83	−22.79	−1.46	0.19	0.76	0.05
	2010	10.15	3.18	9.02	−2.05	0.31	0.89	−0.20
	2011	15.49	4.92	8.77	1.80	0.32	0.57	0.12
	2012	43.15	3.30	6.39	33.47	0.08	0.15	0.78
	2013	−12.37	−4.14	−13.11	4.88	0.33	1.06	−0.39
	2014	−31.33	−1.12	−20.64	−9.57	0.04	0.66	0.31
	2015	−30.59	−1.53	−30.08	1.03	0.05	0.98	−0.03
	2016	−26.52	3.70	−31.92	1.70	−0.14	1.20	−0.06
Hubei	2008	3.46	1.13	2.26	0.07	0.33	0.65	0.02
	2009	−5.50	−1.00	−5.65	1.15	0.18	1.03	−0.21
	2010	5.05	0.77	2.93	1.34	0.15	0.58	0.27
	2011	7.48	1.77	4.31	1.40	0.24	0.58	0.19
	2012	6.13	1.02	2.30	2.80	0.17	0.38	0.46
	2013	−6.83	−0.95	−4.10	−1.78	0.14	0.60	0.26
	2014	−5.26	−0.24	−7.87	2.85	0.05	1.50	−0.54
	2015	−12.40	−1.64	−8.63	−2.13	0.13	0.70	0.17
	2016	−11.26	1.62	−11.78	−1.10	−0.14	1.05	0.10
Hunan	2008	3.49	0.84	1.97	0.68	0.24	0.57	0.19
	2009	−4.09	−0.91	−3.77	0.59	0.22	0.92	−0.14
	2010	2.33	0.60	1.46	0.27	0.26	0.63	0.11
	2011	3.35	1.01	1.49	0.86	0.30	0.44	0.26
	2012	3.35	0.55	1.22	1.58	0.16	0.37	0.47
	2013	−1.76	−0.57	−2.66	1.47	0.32	1.52	−0.84
	2014	−3.36	−0.17	−5.13	1.94	0.05	1.53	−0.58
	2015	−6.66	−0.33	−6.91	0.58	0.05	1.04	−0.09
	2016	−0.09	0.17	−0.32	0.06	−1.89	3.55	−0.66
Guangxi	2008	0.60	−0.04	0.21	0.44	−0.07	0.35	0.73
	2009	−0.15	0.02	−0.14	−0.04	−0.16	0.91	0.25
	2010	−0.18	−0.06	0.18	−0.30	0.31	−1.00	1.69
	2011	0.22	−0.04	0.38	−0.12	−0.19	1.75	−0.56
	2012	−0.09	−0.01	0.03	−0.11	0.12	−0.34	1.21
	2013	0.01	0.01	0.10	−0.10	1.16	8.80	−8.96
	2014	−1.07	0.01	−0.47	−0.61	−0.01	0.44	0.57
	2015	−2.31	0.21	−3.16	0.64	−0.09	1.37	−0.28
	2016	−2.87	0.93	−3.21	−0.59	−0.33	1.12	0.21
Hainan	2008	0.37	2.75	−1.18	−1.19	7.35	−3.16	−3.19
	2009	−20.77	−9.35	−7.77	−3.65	0.45	0.37	0.18
	2010	11.64	−4.04	18.73	−3.06	−0.35	1.61	−0.26
	2011	32.37	2.60	19.97	9.80	0.08	0.62	0.30
	2012	−0.84	2.15	−1.03	−1.96	−2.58	1.23	2.34
	2013	−8.61	−1.76	−7.65	0.80	0.20	0.89	−0.09
	2014	−4.22	−0.56	−3.04	−0.63	0.13	0.72	0.15
	2015	−14.36	−1.38	−12.75	−0.24	0.10	0.89	0.02
	2016	−23.94	7.62	−32.67	1.12	−0.32	1.37	−0.05
Sichuan	2008	55.38	25.50	10.79	19.09	0.46	0.20	0.35
	2009	−72.58	−28.49	−42.27	−1.82	0.39	0.58	0.03
	2010	88.13	24.17	10.65	53.31	0.27	0.12	0.61
	2011	4.82	29.61	3.26	−28.05	6.15	0.68	−5.82
	2012	−24.52	9.47	10.11	−44.11	−0.39	−0.41	1.80
	2013	69.48	−10.13	−20.04	99.65	−0.15	−0.29	1.43
	2014	−67.58	−4.04	−38.21	−25.33	0.06	0.57	0.38
	2015	−62.17	−10.94	−45.02	−6.21	0.18	0.72	0.10
	2016	−11.09	−15.48	−2.97	7.35	1.40	0.27	−0.66

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Table B1 (*continued*)

Provinces	year	△scale	Decomposition			Contribution rate		
			△MP	△SR	△C	MPcontri	SRcontri	Ccontri
Chongqing	2008	27.14	13.54	3.46	10.14	0.50	0.13	0.37
	2009	−35.54	−15.27	−19.30	−0.97	0.43	0.54	0.03
	2010	21.92	11.07	2.87	7.99	0.51	0.13	0.36
	2011	21.16	13.21	5.17	2.79	0.62	0.24	0.13
	2012	−1.65	5.11	5.25	−12.01	−3.10	−3.19	7.30
	2013	−35.03	−3.71	−39.86	8.54	0.11	1.14	−0.24
	2014	−13.48	−0.96	−17.93	5.41	0.07	1.33	−0.40
	2015	−40.58	−1.80	−38.51	−0.27	0.04	0.95	0.01
	2016	−2.22	1.01	−2.83	−0.40	−0.45	1.28	0.18
Shanxi	2008	35.17	8.74	9.69	16.74	0.25	0.28	0.48
	2009	−38.77	−10.04	−11.79	−16.95	0.26	0.30	0.44
	2010	24.18	6.91	5.84	11.43	0.29	0.24	0.47
	2011	19.31	9.83	−1.48	10.96	0.51	−0.08	0.57
	2012	10.65	4.26	4.81	1.57	0.40	0.45	0.15
	2013	7.45	−4.55	−5.12	17.11	−0.61	−0.69	2.30
	2014	1.27	−1.90	−2.33	5.50	−1.50	−1.84	4.34
	2015	−14.73	−7.43	−10.46	3.16	0.51	0.71	−0.21
	2016	−29.49	−10.49	−22.17	3.17	0.36	0.75	−0.11
Gansu	2008	5.74	4.24	3.15	−1.65	0.74	0.55	−0.29
	2009	−7.79	−4.88	−3.05	0.14	0.63	0.39	−0.02
	2010	5.90	3.75	0.43	1.72	0.64	0.07	0.29
	2011	5.42	4.18	−1.26	2.51	0.77	−0.23	0.46
	2012	11.78	1.92	1.50	8.36	0.16	0.13	0.71
	2013	−3.77	−2.06	−2.20	0.49	0.55	0.58	−0.13
	2014	−5.45	−0.71	−3.49	−1.24	0.13	0.64	0.23
	2015	−14.50	−2.02	−7.89	−4.59	0.14	0.54	0.32
	2016	−2.90	−2.53	0.94	−1.30	0.87	−0.32	0.45
Qinghai	2008	19.64	3.21	0.74	15.69	0.16	0.04	0.80
	2009	−10.77	−5.47	−5.54	0.24	0.51	0.51	−0.02
	2010	6.96	4.06	2.26	0.65	0.58	0.32	0.09
	2011	18.96	5.58	2.68	10.70	0.29	0.14	0.56
	2012	27.19	3.27	2.10	21.82	0.12	0.08	0.80
	2013	−6.00	−3.75	−2.41	0.16	0.63	0.40	−0.03
	2014	−1.65	−1.40	−0.96	0.72	0.85	0.58	−0.44
	2015	−14.29	−5.18	−13.55	4.44	0.36	0.95	−0.31
	2016	−11.86	−7.90	−3.97	0.00	0.67	0.33	0.00
Ningxia	2008	8.02	3.14	2.67	2.22	0.39	0.33	0.28
	2009	−8.61	−3.74	−2.77	−2.11	0.44	0.32	0.24
	2010	7.70	2.93	1.92	2.85	0.38	0.25	0.37
	2011	12.13	4.19	2.91	5.03	0.35	0.24	0.42
	2012	4.39	1.95	−3.22	5.66	0.44	−0.74	1.29
	2013	−6.90	−1.77	−2.78	−2.36	0.26	0.40	0.34
	2014	−10.41	−0.50	−4.88	−5.03	0.05	0.47	0.48
	2015	−6.47	−1.34	−5.83	0.70	0.21	0.90	−0.11
	2016	−6.58	−1.40	−5.52	0.35	0.21	0.84	−0.05
Xinjiang	2008	42.60	15.52	20.18	6.89	0.36	0.47	0.16
	2009	−48.48	−18.03	−24.98	−5.47	0.37	0.52	0.11
	2010	44.24	14.13	20.64	9.47	0.32	0.47	0.21
	2011	66.64	21.59	20.66	24.39	0.32	0.31	0.37
	2012	20.51	10.11	−8.03	18.43	0.49	−0.39	0.90
	2013	0.55	−10.18	−9.61	20.33	−18.51	−17.48	36.99
	2014	76.78	−4.85	−4.95	86.58	−0.06	−0.06	1.13
	2015	−94.03	−19.69	−22.76	−51.58	0.21	0.24	0.55
	2016	−89.18	−21.59	−72.89	5.29	0.24	0.82	−0.06

Note: Table shows annual factor decomposition of natural gas subsidy variation of 26 provinces from 2007 to 2016.

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