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The growth and development of natural gas supply chains: The case of China and the US

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ABSTRACT

This paper compares growth and development of natural gas markets in the United States and in China between 2000 and 2015. The results demonstrate that, for both countries, the level of development of the natural gas supply chain improved over time, although in recent years, growth in these markets has slowed down. The analysis also shows that while the focus in terms of development and growth for China is the downstream natural gas market, it is the upstream markets for the United States. The paper's analysis suggests that for China to improve growth and development of its natural gas industry, the country's policy should incentivize the development of production and transportation; the US, on the other hand, should allocate resources to the development of its pipeline distribution system.

1. Introduction

Over the last several decades, the continuous development of urbanization and industrialization processes has resulted in a substantial increase in demand for primary energy. For example, global energy consumption increased almost four-fold from 3730 million tonnes oil equivalent (Mtoe) in 1965–13,147 Mtoe in 2015 (BP, 2016). This rapid rise in demand for energy has yielded higher carbon dioxide (CO_2) emissions. Indeed, fossil fuel use in relation to human activities led to the creation of 33.5 billion tonnes of CO_2 emissions worldwide in 2015 (BP, 2016).

As the world's two largest economies and CO_2 emitters (see Table 1), the United States and China have implemented a series of measures to cope with rising global CO_2 emissions. Natural gas (NG), as a cleaner transition energy than other fossil fuels (Holz et al., 2016), has been widely used. In 2015, consumption of NG accounted for approximately 31.3% and 5.9% of the total energy needs in the United States and China, respectively (Dong et al., 2016a; 2016b). With the rapidly increasing demand for NG in the United States and China (Dong et al., 2018a; Ruester and Neumann, 2008), investigating the growth and development of the NG supply chain is of theoretical and practical significance and has attracted attention among researchers and practitioners.

We classify the assessment methods for growth and development of markets into three types (Zeng and Gu, 2000):

(i) *Distance-based coordinating degree model* (e.g., deviation coefficient minimizes coordinating degree model, membership function coordinating degree model, Geordie coefficient coordinating degree model, data envelopment analysis (DEA) coordinating degree model, and Euclidean distance coordination degree (EDCD) model).
(ii) *Change type coordinating degree model* (e.g., gray system theory coordinating degree model).
(iii) *Integrated type coordinating degree model.*

Among these assessment methods, the EDCD model is effective in computing multi-dimensional data and can identify the distance between the *actual state* and *ideal state*; the actual state measures the current state of development throughout the supply chain, while the ideal state depicts the state where balanced growth and efficiency among stakeholders along the supply chain is reached (Zhou and Zhou, 2009); see also Section 3.2.2. We use these measures to evaluate coordination among stakeholders located across the supply chain.

To the best of our knowledge, we are the first to evaluate the growth and development of the NG supply chain using the EDCD model, a method that explicitly models the various stakeholders along the NG supply chain. We use the EDCD model to assess the degree of growth and development of the NG supply chain in the United States and in China from 2000 to 2015. The analysis develops a multifactorial comprehensive evaluation index system and employs an integrated

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Table 1
Comparison of the NG supply chain between the US and China in 2015.

Category	United States	China
Gross domestic product (GDP)	16,672.7	8908.3
Energy consumption	2280.6	3014.0
CO_2 emissions	5485.7	9153.9
NG proved reserves	10.4	6.8
NG production	767.3 (2.2%)	138.0 (10.4%)
NG import	74.4	59.8
NG export	50.5	–
NG pipelines	484,826 (0.1%)	150,000 (12.5%)
NG consumption	778.0 (1.0%)	197.3 (13.7%)
Share of NG in total energy needs	31.3 (1.2%)	5.9 (6.1%)
Level of NG market	Mature	Developing

Notes: Gross domestic product (GDP) is measured in constant 2010 US dollars (billions), total energy consumption is measured in Mtoe, CO_2 emissions are measured in millions of tonnes, NG proved reserves are measured in trillions of cubic meters, NG production, import, export, and consumption are measured in billions of cubic meters, NG pipelines are measured in kilometers, and share of NG in total energy needs is measured in percentage. The values in brackets denote the average annual growth rates for 2000–2015. **Date sources:** BP (2016); EIA (2016); NBS (2016); World Bank (2016).

approach (i.e., factor analysis method, EDCD model). Dong et al. (2015) evaluated the NG sector in China and concluded that this sector expanded from 2008 to 2013 and that this expansion is the outcome of increased domestic supply and demand, technological innovation, policy, and reforms in these markets. The approach taken in this paper shows that although the increase in demand for NG resulted in the downstream markets developing rapidly during the investigated period, lack of investment in the midstream markets mitigated the effects of this expansion and resulted in development of the downstream markets having only limited impacts on the upstream market for NG in China. This paper also complements Tian et al. (2014), who used the US shale gas experience to shed light on how China might overcome the innovation problem inherent in exploring and developing shale gas with complex geological formations by identifying key barriers throughout the NG supply chain that may hinder the development of these markets. The results of this paper support the conclusions of Brown and Yücel (2008), who investigated regional transmission and pricing in the NG markets of the US and concluded that development of the US NG pipeline system is key. Our analysis extends the conclusions of those authors, suggesting that a key driver leading to the expansion of the US NG markets is the upstream NG markets. We then use our analysis and forecast growth and development trends in China and the US using the Ridge regression.

This paper contributes to the existing literature by applying both factor analysis methods and the EDCD model, thus explicitly investigating the barriers to development and growth of the NG sector throughout the supply chain. That is, the paper establishes a multifactor comprehensive evaluation index system that accounts for the various parts of the NG supply chain. The paper compares the growth and development of NG supply chains in two regions experiencing rapid development and growth in the supply of NG (including liquefied natural gas (LNG) and shale gas) in the context of highly different market structures. This comparison helps us better understand obstacles to development of the NG supply chains – what may facilitate development and what may hinder expansion and growth. This work identifies a key bottleneck of the NG supply chain that affects both China and the US – the midstream markets. It suggests that the value from development of the midstream NG markets is greater than the private value created for the firms operating in this area and that it may warrant the use of public policy to promote more rapid development of the pipeline system.

The United States and China are the world's two largest economies, energy consumers, and CO_2 emitters (Table 1). Both China and the United States meet their increasing energy needs while modifying their energy consumption structure by substituting NG for coal. It is noteworthy that, although the NG market of the United States is more mature than that of China, China's NG market is currently undergoing substantial changes in its production, transportation, and consumption (Dong et al., 2017a, 2017b).

During the past several decades, a number of studies has evaluated and analyzed certain aspects of the NG supply chain in the United States and China. For example, Lu et al. (2016) used ecological network analysis to evaluate China's NG supply security. Other studies evaluating China's NG supply chain include Tian et al., (2014, 2015) and Zhang et al. (2016). For the United States, Ruester and Neumann (2008) analyzed the prospects for LNG development and Brown and Yücel (2008) investigated regional transmission and pricing in the NG markets (see also, e.g., Brown, 2017; Ji et al., 2018; Paltsev et al., 2011). However, based on a review of the literature to date, few studies have systematically evaluated the growth and development of the NG supply chain in the United States and in China.

The remainder of this paper is organized as follows. Characteristics of the NG supply chain in both the United States and China are discussed in Section 2. An index system based on the analysis of factors influencing the development of various parts of the NG supply chain is introduced in Section 3, where we also present the main procedure for measuring the development of NG supply chains. The results and degrees of development and coordination in the two countries are presented in Section 4. Finally, Section 5 concludes and provides policy implications.

2. NG supply chain

2.1. China

China's NG industry is currently undergoing substantial changes in its production, transportation, and consumption (Dong et al., 2018b), although it is at the early stages of development compared to developed countries (Table 1). Domestic NG output in China was only 28.1 billion cubic meters (bcm) in 2000. However, output has increased at an average annual growth rate of 11.2%, reaching 138.0 bcm in 2015 (Fig. 1), and China is expected to become the third largest NG producer by 2035 (BP, 2015). Even so, domestic NG production cannot meet the demand and China imported 32% of its total NG demand in 2015, which reached 59.8 bcm. In the same year, China's NG consumption reached 197.3 bcm, making China the third largest global NG consumer after the United States and Russia. China is expected to surpass Russia and become the second largest global NG consumer around the year

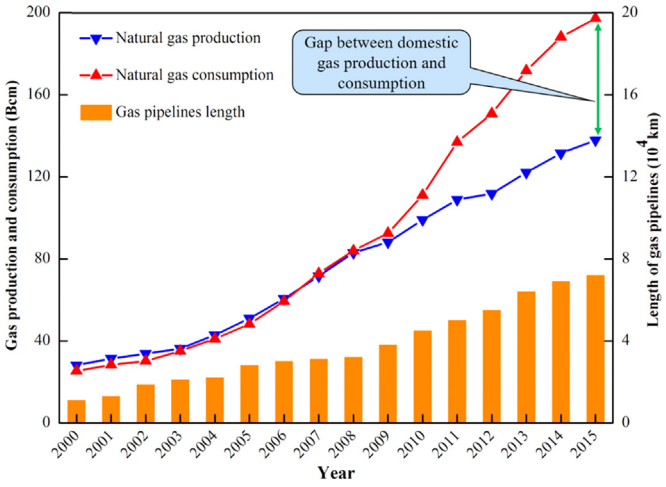

Fig. 1. NG production, consumption, and pipeline length in China. **Data source:** BP (2016).