China's Natural Gas Demand Projections and Supply Capacity Analysis in 2030

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ABSTRACT

This paper builds an econometric model to analyze the income elasticity and price elasticities of sectoral natural gas demand and forecasts China's natural gas demand up to 2030. The findings indicate that there is a long-term equilibrium relationship among sectoral natural gas demand, sectoral income and various fuel prices. The results also indicate that most price elasticities are smaller relative to developed countries; the effect of fuel prices on natural gas demand is partly offset by the government regulation. In the Business As Usual (BAU) scenario, China's natural gas demand will reach 340 bcm and 528 bcm and its foreign dependence will reach 27.9% and 43.2% in 2020 and 2030, respectively. The forecast and discussion in this paper provide important insights into China's energy policy design and pricing mechanism reform, and into the potential impact of China's growing natural gas demand on global energy market dynamics.

Keywords: Natural gas, Domestic production, Supply and demand, LNG and pipeline imports

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1. INTRODUCTION

Entering the 21st century, countries around the world are facing the dual challenges of energy security and climate change. Especially, the low-carbon economy as a new development mode has become an important driving force to achieve global emission reduction targets and promote economic recovery and sustainable development in the post-financial crisis era. The development of low-carbon economy needs a stable, economic, clean and safe energy supply system, and natural gas is a viable choice to support this system for this period. IEA (2012) claimed that natural gas is poised to enter a golden age. The rise of the North American shale gas revolution has caused large natural gas producing and consuming countries to be concerned about the potential for profound impacts to the future global energy market and energy trade patterns.

For China, its economy is entering a new normal development, and the Chinese government has made great efforts to adjust its energy structure to meet the growing demand for energy and reduce its dependence on coal and oil. As a result, the demand for natural gas is rapidly increasing. In addition, since 2012, many Chinese provinces and cities have experienced serious haze. In order

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to protect the environment and improve air quality, the Chinese government has accelerated the process of burning gas instead of coal, stimulating the rapid growth of natural gas demand in China. In 2014, China's natural gas consumption reached 180 bcm; a nearly threefold increase compared to 2005 with an average annual growth rate of 16.3%. In the Paris climate change conference at the end of 2015, China has promised that its carbon intensity will decrease 60%–65% by 2030 compared to 2005. Obviously, increasing the proportion of natural gas in primary energy consumption structure is an important measure for China to achieve this goal of greenhouse gas emission reduction and also to ensure its energy supply security.

In China, reducing and getting rid of the dependence on coal is the primary task of energy transformation. According to the "energy development strategy action plan (2014–2020)" issued by the State Council, by 2020, total coal consumption will be limited to 4.2 billion tons, while the proportion of natural gas consumption in primary energy consumption will reach more than 10%. In order to achieve this goal, China is actively boosting a variety of measures to protect the steady growth of natural gas, and it is striving to improve the level of domestic gas production. On the one hand, the domestic conventional gas field production capacity continues to increase, while the unconventional natural gas exploration has made new breakthroughs. According to China's Ministry of Land and Resources and China National Petroleum Corporation (CNPC) company statistics, in 2014, China's conventional natural gas production was 128 bcm, a net increase of 11.4 bcm with the growth rate of 9.8%. For unconventional natural gas production, coalbed methane production reached 3.6 bcm, representing a growth rate of 23.3% and shale gas production reached 1.3 bcm growing 5.5 times. In addition, China's natural gas import channels are also constantly improving. With the signing of a Sino-Russian gas deal, China has initially formed four natural gas import channels including northwest, southwest, northeast and sea-based/LNG channels. Among them, the pipeline imports are mainly from Turkmenistan, Uzbekistan, Burma, and Kazakhstan, with imports from Turkmenistan accounting for more than 80% of total pipeline imports. Liquefied natural gas (LNG) imports are mainly from Qatar, Australia, Indonesia, and Malaysia, with Australia being China's largest supplier accounting for 28% of total LNG imports in 2015, closely followed by Qatar at 25%.

However, China's natural gas consumption has experienced a new problem. Since 2014, with the domestic natural gas price reform, non-residential inventory and incremental gas prices are merged, which increased the inventory gas price by 0.04 yuan per cubic meter. This, coupled with the decreased domestic refined oil prices and coal prices induced by the decreasing international energy prices, has weakened the price advantage of domestic natural gas and the economic nature of industrial gas use has gradually been diminished. Subsequently, in 2014, China's natural gas demand growth slowed significantly far below expectation and its growth rate was only 8.9%, the lowest point in the past ten years.

A significant slowdown of natural gas supply and demand will present difficulties for China's future natural gas market. Especially, it may be limited by the price problem which is not conducive to the long-term stable development of China's natural gas market. According to the current global energy situation, lower oil prices will become the norm for a long time. Although the international natural gas prices are also at a relatively low level, China's domestic natural gas price is regulated by the government. This restricts the ability of natural gas prices to adjust in a timely fashion and keep pace with alternative energy price changes or to respond quickly to the changes in supply and demand relations.

Therefore, China's natural gas demand projection faces many uncertainties, such as changes in economic growth, natural gas and alternative energy price changes domestically and internationally and so on. Reasonable analysis and forecast for future natural gas demand is of great importance to formulation of China's energy policy and planning and can also provide useful inputs for the development of the natural gas industry. This paper aims to address these issues for China's natural gas demand up to 2030 from the perspective of all energy-use sectors. The main contributions are twofold. First, an econometric model is developed to investigate the influencing mechanisms of various factors on China's sectoral natural gas consumptions. Specifically, price elasticity of demand and cross-price elasticities of alternative energy sources for natural gas in different sectors are discussed. Second, based on our constructed long-term equilibrium model, China's sectoral natural gas demand up to 2030 is projected under four scenarios, which considered China's different economy development paths and the uncertain international energy market environment. Moreover, China's domestic natural gas supply capacity and pipeline natural gas plan are also discussed and the evolution of dependence on imported natural gas is estimated. Due to the significant increase in natural gas imports by China, the potential for more demand in the future, and impact on global prices observed, it seems clear that China's level and changes in demand for natural gas can affect global dynamics. Therefore, our results are of international importance, not just important to Chinese policy makers. We believe that international scholars, natural gas traders, and international policy makers will also be interested in our analysis and results.

The remainder of the paper is organized as follows. The next section provides a literature review. In section 3, sectoral natural gas consumption is modeled and natural gas production and import capacity are estimated. In section 4, four scenarios are put forward to simulate the uncertainties and China's natural gas demand is projected. The final section concludes with the main findings.

2. LITERATURE REVIEW

Natural gas is considered to be a better option than other fossil fuels to bring about a balance between stable economic growth and reduced carbon emission. Thus, it's important to assess the potential of natural gas consumption in the future in response to national energy planning and economic growth. Researchers and policymakers have paid more attention to forecasts of natural gas in the last decade.

Many countries' natural gas consumption has been predicted across different horizons from hourly to annual bases (Soldo, 2012), such as the U.S. (Baltagi et al., 2002; Huntington, 2007), Europe (Hoffler and Kubler, 2007; Smith, 2013), Asia Pacific (Aguilera et al., 2014), India (Parikh et al., 2007), Pakistan (Khan, 2015), Poland (Siemek et al., 2003), Spain (Fco et al., 2007), Turkey (Erdogdu, 2010; Melikoglu, 2013), Bangladesh (Wadud et al., 2011), Iran (Forouzanfar et al., 2010; Dalfard et al., 2013), Italy (Bianco et al., 2014) and Croatia (Potocnik et al., 2014), etc. The main methodologies applied to forecast natural gas demand can be divided into econometric models, bottom-up approaches, grey prediction models, input-output models, artificial intelligence approaches, and integrated models. Among these forecasting models, they can also be divided into univariate models and causal relationship models. The advantage of univariate models is that the assumption of these models is simple and only own behavior of energy demand should be considered. However, they also ignore the uncertainty and reality influence from energy policies, technology factors and others. The causal relationship model forecasts energy demand using one or more explanatory variables. These models are usually useful to exactly depict the causal relationship and driving force of energy demand. But, there is no doubt that these models have required more observations and increased the complexity of model estimations relative to univariate models. Among these forecasting

Table 1: Summary of China's Natural Gas Demand Forecast in the Previous Literatures

Forecasting (Billion Cubic Meters)					
2015	2020	2025	2030	Methodology	Source
—	360	—	—	—	China's Energy development strategy Action Plan (2014–2020)
231.1	297.3	350.7	392.4	Input-Output model	Duan (2011) (Reference Scenario)
133.1	198.2	—	340.7	System dynamics approach	Li et al. (2011) (Reference level)
170.2	345.7	—	—	Input-Output model	Fan and Xia (2012)
146.29	208.49	271.88	356.85	Co-integration model	Lin and Wang (2012) (Medium level)
158.9	219.4	290.6	369.1	Econometric model	EIA (2013) (Reference scenario)
185.5	376.12	—	—	Grey model	Wang and Lin (2014)
—	315.8	—	550.1	Econometric model	IEEJ (2014) (Reference scenario)
220.9	375.5	—	—	Bayesian Model Averaging	Zhang and Yang (2015) (Reference scenario)
—	265.5	338.9	411.1	Econometric model	IEA (2016) (The new policies scenario)
179.4	74.5	230.2	352.1	Integrated Global System model	MIT (2015)
210.5	399.5	—	—	Grey prediction model	Zend and Li (2016)
210.5	330.6	424.6	477.3	Logistic model	Shaikh and Ji (2016)

models, econometric models are generally considered more suitable for developing countries due to their data availability limitations (Wadud et al., 2011).

Although natural gas is considered to have the most potential and to be the most feasible energy source for optimizing the energy structure and responding to climate change in China's medium- and long-term energy development plans, there is still limited research on China's natural gas demand forecast. The current results of China's natural gas demand predicted by scholars and research organizations range from 74.5 bcm to 399.5 bcm in 2020 and from 340.7 bcm to 550.1 bcm in 2030 (Table 1). Such a wide range of results indicates that natural gas demand forecasting is faced with great challenges due to many uncertainties (Shaikh et al., 2017).

The future consumption of natural gas depends on many exogenous factors, including the macroeconomic environment, population growth, energy prices, technological progress, energy structure adjustment, policy changes and others. Different scenarios of these drivers can suggest quite different trends of natural gas demand in the future. The dynamic economic situation and policy orientation naturally leads to differences when comparing the forecasted results in Table 1 with actual natural gas consumption of 190 bcm in 2015.

A significant factor of uncertainty is the international natural gas price which has declined since 2014 due to ample supplies and low international oil prices. Moreover, China's economic growth began to fall below 7.0% since 2015, when it entered what may be a new normal pattern. Moreover, it is intended that there will be a shift to quality and efficiency from quantity and speed in terms of development.

In addition, China's natural gas pricing mechanism reform entered a new stage in 2015. The city-gate prices of stock of non-residential gas were merged with incremental gas prices. As a consequence, the prices of stock gas rose by 1.41%, while the incremental gas price dropped by 13.25%. The result is that non-residential gas prices are basically rationalized because the incremental gas prices previously had been adjusted to maintain a reasonable price level related to alternative energy prices under previous reform.

Combined with these new changes in both the internal and external situations and many uncertainties in the future, new scenarios should be reconsidered for China's natural gas demand forecast. Specifically, most previous literature takes national total natural gas demand as the dependent variable which ignores the sectoral characteristics of natural gas consumption and their different driving forces. Therefore, in this paper, sectoral natural gas demand is modeled and forecasted separately, so that China's natural gas consumption structure may be better understood.

3. NATURAL GAS DEMAND MODELLING AND SUPPLY CAPACITY ESTIMATION

In this section, China's natural gas demand is modelled by specific factors in different sectors using multicointegration and error correction models. China's natural gas production and import capacity during the period from 2016 to 2030 is estimated based on authoritative references and planned pipeline and regasification capacity according to China's government.

3.1. Modelling China's Natural Gas Demand

The National Bureau of Statistics Yearbook for China reports seven natural gas sectors: Industry; Farming, Forestry, Animal Husbandry & Fishery; Construction; Transport, Storage, Postal & Telecommunication Service; Wholesale, Retail Trade, Accommodation & Catering Service; Residential; and Other Industry. According to the National Bureau of Statistics Yearbook for China, Industry, Residential, and Transport, Storage, Postal & Telecommunication Service are ranked the top three sector users, accounting for 63.9%, 18.6% and 12.3% of the total natural gas consumption in 2015, respectively. Therefore, to simplify the research and clarify the consumption structure, we form three sectors by integrating smaller natural gas sector users into these three dominant sectors. These three constructed sectors are Industry combined with Construction, Residential by itself, and Commercial combined with the remaining four sectors. The integrated sectors of Industry, Residential, and Commercial account for 64.0%, 18.6% and 17.4% of the total natural gas consumption in 2015, respectively.

3.1.1. Sectoral Natural Gas Demand Models

In general, economic theory suggests that economic activity, population growth, energy prices, energy intensity, energy investment and environmental policies natural influence natural gas demand (Zhang et al., 2018). There always exist differences in factors selection and model assumptions across different literature. In this paper, based on the data availability, model freedom and sectoral characteristics, we select the factors in each sector as follows. First, sectoral income, natural gas intensity and natural gas price are undoubtedly the three key determinants influencing each sector's natural gas demand. Second, different alternative energy prices are considered to differentiate the role of other inter-fuels as complementary or substituted fuels to natural gas. Commonly, electricity price is selected in each sectors' model due to the development of natural gas power generation in China. According to the data from National Bureau of Statistics of China, natural gas power generation has accounted for 17.8% of the total natural gas consumption in 2015. Specifically, the price of coal is included in the industrial model to identify its substitution role of natural gas for power generation, while gasoline price is included in the commercial model to analyze its influence on natural gas demand in transportation. Different sectors have their specific characteristics of natural gas consumption and are also influenced by different factors. Therefore, in this paper, multicointegration and error correction models of the natural gas consumption for our three constructed sectors are separately modelled selecting different driving factors reflecting differences in sector characteristics.

The specifications of the three sector models are as follow:
Industrial sector model:

$$Ln(E_t^I) = \alpha^I + \beta_1^I Ln(I_t^I) + \beta_2^I Ln(NGI_t^I) + \beta_3^I Ln(NGP_t) + \beta_4^I Ln(EP_t) + \beta_5^I Ln(CP_t) + u_t^I \quad (1)$$

$$\Delta Ln(E_t^I) = \gamma_0^I + \gamma_1^I ECT_{t-1}^I + \sum_{i=1}^{p} \gamma_{2,i}^I \Delta Ln(E_{t-i}^I) + \sum_{i=1}^{q} \gamma_{3,i}^I \Delta Ln(I_{t-i}^I) + \sum_{i=1}^{l} \gamma_{4,i}^I \Delta Ln(NGI_{t-i}^I) + \sum_{i=1}^{m} \gamma_{5,i}^I \Delta Ln(NGP_{t-i}) + \sum_{i=1}^{n} \gamma_{6,i}^I \Delta Ln(EP_{t-i}) + \sum_{i=1}^{w} \gamma_{7,i}^I \Delta Ln(CP_{t-i}) + \varepsilon_t^I \quad (2)$$

Residential sector model:

$$Ln(E_t^R) = \alpha^R + \beta_1^R Ln(I_t^R) + \beta_2^R Ln(NGI_t^R) + \beta_3^R Ln(NGP_t) + \beta_4^R Ln(EP_t) + u_t^R \quad (3)$$

$$\Delta Ln(E_t^R) = \gamma_0^R + \gamma_1^R ECT_{t-1}^R + \sum_{i=1}^{p} \gamma_{2,i}^R \Delta Ln(E_{t-i}^R) + \sum_{i=1}^{q} \gamma_{3,i}^R \Delta Ln(I_{t-i}^R) + \sum_{i=1}^{l} \gamma_{4,i}^R \Delta Ln(NGI_{t-i}^R) + \sum_{i=1}^{m} \gamma_{5,i}^R \Delta Ln(NGP_{t-i}) + \sum_{i=1}^{n} \gamma_{6,i}^R \Delta Ln(EP_{t-i}) + \varepsilon_t^R \quad (4)$$

Commercial sector model:

$$Ln(E_t^C) = \alpha^C + \beta_1^C Ln(I_t^C) + \beta_2^C Ln(NGI_t^C) + \beta_3^C Ln(NGP_t) + \beta_4^C Ln(EP_t) + \beta_5^C Ln(GP_t) + u_t^C \quad (5)$$

$$\Delta Ln(E_t^C) = \gamma_0^C + \gamma_1^C ECT_{t-1}^C + \sum_{i=1}^{p} \gamma_{2,i}^C \Delta Ln(E_{t-i}^C) + \sum_{i=1}^{q} \gamma_{3,i}^C \Delta Ln(I_{t-i}^C) + \sum_{i=1}^{l} \gamma_{4,i}^C \Delta Ln(NGI_{t-i}^C) + \sum_{i=1}^{m} \gamma_{5,i}^C \Delta Ln(NGP_{t-i}) + \sum_{i=1}^{n} \gamma_{6,i}^C \Delta Ln(EP_{t-i}) + \sum_{i=1}^{w} \gamma_{7,i}^C \Delta Ln(GP_{t-i}) + \varepsilon_t^C \quad (6)$$

In the industrial sector model, E_t^I, I_t^I, and NGI_t^I represent natural gas consumption in the industrial sector, value-added of secondary industry, and natural gas intensity of the industrial sector, respectively. In the residential sector model, E_t^R, I_t^R, and NGI_t^R represent natural gas consumption in residential sector, residential income, and natural gas intensity of the residential sector, respectively. In the commercial sector model, E_t^C, I_t^C, and NGI_t^C represent natural gas consumption of the commercial sector, value-added of tertiary industry, and natural gas intensity of the commercial sector, respectively. In addition, *NGP*, *EP*, *CP*, and *GP* in the three models represent domestic natural gas price, electricity price, coal price, and gasoline price, respectively.

The data have been transformed as follows: the value-added of each industry is deflated to real value based on 2015 constant prices using the GDP index for the corresponding industry, the various nominal energy prices are also deflated to real prices based on 2015 constant prices by the CPI index, all the data are in natural logarithms, and all are annual over the period from 1985 to 2015.

We obtained the data on sectoral natural gas consumption and energy consumption from the China Statistical Yearbook 2016. Chinese government reports are the sources of the natural gas price data, and the Wind database is the source of the electricity price data. We also collected gaso-

Table 2: Unit Root Tests

	ADF			PP		
Variable	Level	First Different	Second Different	Level	First Different	Second Different
^{E}I	–1.367	–4.767***		–1.369	–4.767***	
I^{I}	–2.664	–2.671	–4.195**	–0.759	–1.969	–6.610***
$N^{G}I$I	–1.206	–4.504***		–1.213	–4.423***	
E^{R}	0.122	–5.1^{27}***		–0.991	–5.128***	
I^{R}	–2.664	–2.671	–4.195**	–0.759	–1.969	–6.610***
NGI^{R}	–2.357	–5.884***		–2.450	–5.875***	
^{E}C	0.226	–8.245***		–0.214	–12.156***	
I^{C}	–3.559	–2.841	–4.337***	–2.080	–2.318	–6.195***
NGI^{C}	–0.038	–8.437***		–0.544	–8.919***	
NGP	–2.577	–7.9^{16}***		–2.430	–11.1^{88}***	
EP	–1.645	–3.208	–5.730***	–1.182	–3.290	–8.060***
CP	–1.400	–4.407***		–1.420	–4.407***	
GP	–2.491	–4.471***		–2.401	–4.559***	

Note: ** and *** denote significance at the 5% and 1% levels, respectively.

line price data from the Wind database and the fitted values are based on a linear regression between the Chinese gasoline price and the Brent price. In a similar fashion, we gathered coal price data from the Wind database and the fitted values are based on a linear regression between the Chinese coal price and Japan's steam coal import cif price.

3.1.2. Natural Gas Demand Models Estimation

First, ADF and PP tests are used to test the unit root of variables shown in Table 2. The results indicate that all of the variables are nonstationary, and are I(1) or I(2). Referring to Granger and Lee (1989), multicointegration model is used in this paper. Multicointegration is a deeper kind of cointegration, in which the variables are linked by not only one but two coexisting equilibrium forces (Escario et al., 2012). Considering two variables, where one is I(1) and the other is I(2), they cannot be cointegrated directly. But if there is a linear combination of two I(2) variables which is I(1), the linear combination can be cointegrated with another I(1) variable. In this paper, each sectoral model has two I(2) variables which can have a linear combination of I(1) process and then be cointegrated with other I(1) variables. Granger and Lee (1990) introduce a two-step estimated procedure for multicointegration. However, Engsted et al. (1997) consider that Granger and Lee's (1990) procedure is less attractive in practice. They propose a one-step procedure for estimation and inference which has favorable statistical properties compared to the two-step procedure by Granger and Lee (Engsted et al., 1997). According to Engsted et al. (1997), a single equation residual based regression procedure for 1(2) cointegration can be conducted as a straightforward generalization of the Engle-Granger procedure developed for I(1) variables. Hence, least squares regression residuals are first constructed from the regression and subsequently the integration order can be tested by an ADF t-ratio test.

Moreover, to investigate the long run relationship between variables, we employ cointegration with structural breaks as proposed by Gregory and Hansen (1996). In their study, they propose three tests of cointegration with structural change that are extensions of the standard ADF test of Dickey and Fuller and Phillips' two test statistics Z_α and Z_t of cointegration as follows.

$$ADF^{*} = \inf_{\tau \in T} ADF(\tau) \tag{7}$$

Table 3: Cointegration Test with Structural Break and Multicointegration Test

Cointegration Test with Structural Break (Gregory and Hansen, 1996)

	Industrial	Residential	Commercial	1% Critical Value	5% Critical Value
ADF^*	–6.322	–6.179	–4.811	–6.92	–6.41
Z_t^*	–5.718	–6.284	–4.893	–6.92	–6.41
Z_a^*	–33.361	–35.348	–27.496	–90.35	–78.52

Multicointegration test based on single equation procedure from Engsted et al. (1997)

Industrial Residual ADF=–5.264**
Residential Residual ADF=–5.456**
Commercial Residual ADF=–6.890**

Note: Critical value are taken from Gregory and Hansen (1996). ** denote significance at the 5% level.

$$Z_t^* = \inf_{\tau \in T} Z_t(\tau) \tag{8}$$

$$Z_\alpha^* = \inf_{\tau \in T} Z_\alpha(\tau) \tag{9}$$

Table 3 presents the results of the ADF, Z_α and Z_t for each sectoral model[1]. The results show the null hypothesis that cointegration with no structural change cannot be rejected at the 5% significant level. It indicates there is no structural change in the cointegration. Therefore, the one-step estimation procedure proposed by Engsted et al. (1997) is applied. Using the ADF test, we test the residuals under the null hypothesis of a unit root. The results in Table 3 show that we can reject the null hypothesis of a unit root at the 5% significance level. Therefore, we conclude that the residuals are stationary and multicointegration does exist among our variables.

OLS cannot take advantage of the long-run covariance information, as it is not asymptotic efficient, so we employ Fully Modified OLS (FMOLS). The advantage of the FMOLS model is that it introduces appropriate correction to overcome the inference problem in OLS estimation, and, hence, the t-test for long-run estimates are valid. Then, we apply FMOLS to estimate cointegration equations for the three sectors. The estimated coefficients of cointegration and ECM equations of three sectoral models are reported in Table 4. The residual diagnosis tests show that the model is well fitted and the cointegration estimation is efficient.

The cointegration equation for each sector can be written as follows.

Industrial sector:

$$\begin{aligned} Ln(E_t^I) &= 0.706Ln(I_t^I) + 0.944Ln(NGI_t^I) - 0.069Ln(NGP_t) - 0.142Ln(EP_t) \\ &\quad + 0.273Ln(CP_t) - 5.920 \end{aligned} \tag{10}$$

Residential sector:

$$\begin{aligned} Ln(E_t^R) &= -1.378Ln(I_t^R) + 1.547Ln(NGI_t^R) + 0.384Ln(NGP_t) - 0.085Ln(EP_t) \\ &\quad + 0.132t + 10.803 \end{aligned} \tag{11}$$

Commercial sector:

$$\begin{aligned} Ln(E_t^C) &= 0.404Ln(I_t^C) + 1.310Ln(NGI_t^C) - 0.087Ln(NGP_t) - 0.331Ln(EP_t) \\ &\quad - 0.049Ln(CP_t) - 0.689 \end{aligned} \tag{12}$$

1. In Gregory and Hansen (1996), they estimated the cointegration with structural breaks based on I(1) variables. However, in our paper, I(2) variables are also included in the system. It's difficult to statistically answer whether the Gregory and Hansen procedure can be applied to I(2) system. In our conjecture, it should be feasible because a linear combination of I(2) is a special case of I(1) process. But, it's still a problem pending a definitive answer.

Table 4: Estimated Results of the Cointegration and ECM Equations

Industrial

I^I	NGI^I	NGP	EP	CP	*Constant*
0.706***	0.944***	–0.069*	–0.142*	0.273***	–5.920***
(12.253)	(9.254)	(–1.828)	(–1.983)	(4.756)	(–9.239)

Residual Diagnosis Test

Adjusted R^2	0.995
Q(10)	9.450
$Q^2(10)$	5.380
ADF	–2.994***

ECM Estimation

ECT^I_{t-1}	$\Delta Ln(E^I_{t-1})$	$\Delta Ln(I^I_{t-1})$	$\Delta Ln(NGI^I_{t-1})$	$\Delta Ln(NGP_{t-1})$	$\Delta Ln(EP_{t-1})$	$\Delta Ln(CP_{t-1})$
–0.413	0.682	0.235	–0.226	–0.079	0.145	0.243**
(–1.316)	(1.655)	(0.600)	(–0.506)	(–0.981)	(0.689)	(2.182)
Constant						
0.010						
(0.220)						

Residential

I^R	NGI^R	NGP	EP	t	*Constant*
–1.378***	1.547***	0.384*	–0.085	0.132**	10.803*
(–3.706)	(11.186)	(2.136)	(–0.308)	(2.253)	(2.122)

Residual Diagnosis Test

Adjusted R^2	0.991
Q(10)	2.936
$Q^2(10)$	7.393
ADF	–4.801***

ECM Estimation

ECT^R_{t-1}	$\Delta Ln(E^R_{t-1})$	$\Delta Ln(I^R_{t-1})$	$\Delta Ln(NGI^R_{t-1})$	$\Delta Ln(NGP_{t-1})$	$\Delta Ln(EP_{t-1})$	*Constant*
–0.324	1.666**	0.208	–1.793**	–0.001	0.685	0.032
(–0.362)	(2.648)	(0.256)	(–2.588)	(–0.006)	(1.715)	(0.321)

Commercial

I^C	NGI^C	NGP	EP	GP	*Constant*
0.404***	1.310***	–0.087*	–0.331***	–0.049**	–0.689
(9.669)	(65.442)	(–1.896)	(–5.780)	(–2.348)	(–1.530)

Residual Diagnosis Test

Adjusted R^2	0.998
Q(10)	6.652
$Q^2(10)$	7.823
ADF	–4.615***

ECM Estimation

ECT^C_{t-1}	$\Delta Ln(E^C_{t-1})$	$\Delta Ln(I^C_{t-1})$	$\Delta Ln(NGI^C_{t-1})$	$\Delta Ln(NGP_{t-1})$	$\Delta Ln(EP_{t-1})$	$\Delta Ln(GP_{t-1})$
8.299**	–4.023	7.106	4.441	–4.559***	2.402	1.245
(–2.862)	(–1.589)	(1.179)	(1.449)	(-3.036)	(1.282)	(1.721)
Constant						
–0.286						
(–0.493)						

Note: *, **, *** denote significance at the 10%, 5% and 1% level, respectively. The values in () denote t-statistics.

Generally, the results show that China's economic development and natural gas intensity have positive influences on natural gas consumption in industrial and commercial sector. When we look at the elasticities, some findings may be summarized.

First, the income elasticity of natural gas demand is significantly positive in industrial and commercial sectors, while the value of the elasticities are less than 0.8. This implies sectoral natural gas demand will increase no more than 8% if sectoral income increases by 10%.

Second, the own-price elasticity of natural gas demand is significantly negative in the industrial and commercial sectors, implying that a natural gas price rise will lead to the decline in the quantity demanded if other inter-fuel substitution prices remain unchanged. This is consistent with the results in most countries in the previous literature, while the elasticity value in China is smaller (Griffin, 1977; Pindyck, 1979; Renou-Maissant, 1999; Asche et al., 2008). This indicates that China's natural demand is relatively inelastic in response to price changes. The most likely reason is that the pricing mechanism for natural gas in China is still under reform and its degree of marketization is still low.

Third, the most unusual result appears in the residential sector where its own-price elasticity of natural gas demand is positive, while the income elasticity of natural gas demand is negative at the 10% significance level. While somewhat unusual, the findings in previous literature on the own-price elasticity and income elasticity of demand in residential sector are also mixed. Asche et al. (2008) investigated the elasticities of residential natural gas demand in 12 European countries. They found that in Austria, Belgium, Italy and Spain, both the short-run and long-run own-price elasticities are positive, while the income elasticities in Denmark, Finland, and Netherlands are negative. Asche et al. (2008) didn't provide any economic explanation, but stated that the presence of positive own-price elasticities and negative income elasticities is also found in other energy demand studies, for example, Maddala et al. (1997), Baltagi and Griffin (1997), and Haas and Schipper (1998). The reasons are complicated, involving China's government policies and subsidies. A possible reason is that increasing income may diversify people's lifestyles and correspondingly reduce its use of cooking equipment at home and, therefore, also the gas used for cooking. In the meantime, the substitutes for household-use gas is weak due to fixed civilian infrastructure.

Finally, the cross-price elasticities for inter-fuel substitution presented in Table 4 vary greatly from positive to negative, indicating the differences in the roles of different fuels in influencing the demand for natural gas, which also reflects the differences in the demand characteristics of the sectors. Specifically, electricity cross-price elasticities are significantly negative in each sector, which is consistent with the conclusions of most OECD countries as verified by Pindyck (1979) and Asche et al. (2008) but is contrary to the conclusions for the U.S. found by Urga and Walters (2003) and Serletis et al. (2010). Among the three sectors, the electricity cross-price elasticity is smallest in the residential sector and largest in the commercial sector. In addition, the inter-fuel cross-price elasticity for coal is significantly positive in the industrial sector, while the cross-price elasticity for gasoline is significantly negative in the commercial sector. Compared with the own-price elasticity in each sector, inter-fuel substitution is more elastic. It means that natural gas demand is more sensitive to inter-fuel prices than the natural gas price itself, which implies the natural gas price transmission in the industrial chain is not efficient. This further demonstrates two points: one is that China's natural gas market-oriented pricing has not yet formed and the other is that China is in the process of energy structural transformation, in which correcting the price mechanism is the key.

3.2. Estimation of China's Natural Gas Production

According to the statistics from Ministry of Land and Resources of the People's Republic of China, China's production of conventional gas, coal-bed methane, and shale gas were 117.73 bcm, 2.926 bcm and 0.2 bcm in 2013, respectively. In the future, China's domestic natural gas production still faces many uncertainties and difficulties, which include both geological and technological challenges.

In this paper, China's future natural gas production is estimated based on China's energy development plan and the international reports from the US Energy Information Administration (EIA) and International Energy Agency (IEA) (Table 5). EIA (2013) provided a relatively low pro-

Table 5: China's Natural Gas Production Prediction

Production	2013	2020			2030		
		Base 1	Base 2	Base 3	Base 1	Base 2	Base 3
Conventional gas	117.73	79.3	—	185	64.3	—	150
Coalbed methane	2.93	32.3	—	30	60.1	—	90
Shale gas	0.2	7.2	—	30	63.3	—	60
Sum	120.85	118.8	172	245	187.7	260	300

Note: Data source: EIA (2013), IEA (2015) and China's Energy Development Strategy Action Plan (2014–2020) and China's Ministry of Land and Resources.

duction scenario and predicted that China's natural gas production will only reach 118.8 bcm in 2020 and 187.7 bcm in 2030. IEA (2015), on the other hand, provides a moderate forecast result and predicted that China's natural gas production will reach 172 and 260 bcm in 2020 and 2030, respectively. IEA (2015) also indicates that China's natural gas production prospects will depend heavily on its unconventional gas development, which faces various barriers from environmental and social hazards and geological challenges. According to China's Energy Development Strategy Action Plan (2014–2020), China's natural gas production will reach 245 bcm in 2020 and China's Ministry of Land and Resources estimated that domestic production will increase to 300 bcm in 2030.

3.3. Estimating Import Capacity

China began to import LNG-based natural gas in 2006 and pipeline gas since 2010, and the trading volume of imported gas has increased quickly. According to China's National Bureau of Statistics, China imported 33.6 bcm and 26.8 bcm of natural gas by pipeline and LNG in 2015, respectively. China's dependence on foreign natural gas has also increased quickly to 31.3% in 2015, while imports were only 1.8% in 2006. In addition, China imports LNG from 15 countries in 2015. Australia, Qatar, Malaysia, Indonesia, and New Guinea are the top five sources of LNG-based gas imports for China, accounting for 92.3% of the total LNG import in 2015. Turkmenistan is the largest exporter of pipeline gas to China, accounting for 82.7% of China's total pipeline imports in 2015.

Currently, China's pipeline construction for the transport of natural gas has entered a period of rapid development, and a pipeline network is forming to improve China's energy supply security and distribution efficiency.

Table 6 presents the situation of China's natural gas pipeline construction and its import capacity. The start-up of the China-Myanmar gas pipeline in 2013 adds 12 bcm of natural gas supply capacity, providing greater diversification of natural gas supplies. At present, Central Asia is the main import source of pipeline gas to China, where Central Asia pipelines A/B/C have been put into use. According to plan, Central Asia pipelines A/B/C can provide a maximum of 55 bcm gas capacity imported from Turkmenistan, Kazakhstan and Uzbekistan. Central Asia pipeline D has progressed with the signing of a construction agreement by China and Uzbekistan, Kyrghyzstan, and Tajikistan; it is one of the most difficult projects in the history of world pipeline construction. It will provide an extra 30 bcm of gas import capacity once completed. In addition, two China-Russia lines are planned for the future as shown in Table 6, which would ship up to 68 bcm of pipeline gas. The China-Russia east line has been under construction since 2014 and plans to transport natural gas from Russian Siberia to the northeast region of China in 2018 at a volume of 38 bcm of pipeline gas. The China-Russia west line is still in the process of negotiation by the two governments due to disagreement of pipeline gas pricing. In general, the existing and planned natural gas pipeline projects can augment China's capacity to a maximum of 165 bcm.

Table 6: Summary of China's Natural Gas Pipeline Construction and Import Capacity

Pipeline	Capacity (Bcm)	Main Import Sources	Operation (year)	Overseas Length (km)
China-Myanmar pipeline	12	Myanmar	2013	793
Central Asia pipeline A/B line	30	Turkmenistan, Kazakhstan	2010	1830 (A/B/C line)
Central Asia pipeline C line	25	Turkmenistan (10 Bcm), Kazakhstan (5 Bcm), Uzbekistan (10 Bcm)	2014	
Central Asia pipeline D line	30	Turkmenistan	Plan	840
Power of Siberia pipeline (China-Russia east line)	38	Russia	Under construction	4000
Altai pipeline (China-Russia west line)	30	Russia	Plan	2600

Note: Data source is from China National Petroleum Corporation

In addition, China has developed substantial LNG regasification capacity to facilitate waterborne LNG-based natural gas imports. At the end of 2016, China had 67 bcm/y of LNG import capacity operating, with an additional 9 bcm/y of capacity under construction. This 76 bcm/y of import capacity is spread over 17 separate regasification facilities, which are owned and operated by both State-Owned Enterprises and independents. It is worth noting that 2016 imports of LNG-based natural gas employed just 51% of the installed capacity. Thus, there currently exists capacity to expand this source of natural gas imports, which currently provides access to an additional 16 natural gas suppliers.

The combined import capacity, both installed and planned, would reach 241 bcm/y. This assumes the completion of the D line and the two Russian pipelines. Should the Russian lines not be completed, the total import capacity will be 173 bcm/y.

4. CHINA'S NATURAL GAS DEMAND FORECAST AND UNCERTAINTY ANALYSIS

In this section, China's natural gas demand up to 2030 is forecasted using the estimated cointegration model in section 3.1.2. To investigate the different impacts of the economic situation and the energy market environment on China's natural gas demand, we include our BAU scenario with three of IEA's scenarios for comparison. Then, we project the gap between supply and demand of natural gas over time and we discuss the potential opportunities and difficulties for natural gas development in China.

4.1. Scenario Analysis

Economic growth and energy prices seem to be the most important and uncertain factors influencing China's natural gas demand in the future. Therefore, in the following scenarios, we describe different assumptions for GDP growth and various energy prices. We establish some basic assumptions and common factors for all scenarios at the outset.

Economic growth: The level of economic activity is the key factor influencing the demand of natural gas. According to our calculation, the ratio of GDP growth to growth of each sectoral income indicator I is basically stable (see Table 7). Therefore, sectoral income growth is set by their ratio to GDP growth on a recent three-year average value. In the IEA's current policies scenario and IEA's new policies scenario, China's GDP growth follows IEA (2016)'s assumptions and its real

Table 7: The Ratio of GDP Growth to Growth of Each Sectoral Income Indicator in the Recent Three Years

National GDP/sectoral GDP	Industrial	Residential	Commercial
2012	0.995	1.050	0.999
2013	0.998	1.050	0.995
2014	0.999	1.052	0.995

GDP growth is assumed to grow at an average annual rate of 6.2%, 5.7% and 5.2% during the period of 2015~2020, 2021~2025 and 2026~2030, respectively.

Total primary energy consumption: We calculate sectoral energy consumption based on its average share of the total energy consumption during 2010–2014.

International energy prices: Price is an important factor which can influence the behavior of energy consumer and decide the competitive advantages among alternative fuels. Considering the indirect linkage between China's energy prices and international energy prices, the domestic price variables in this paper are forecasted using the fitted value of OLS regression with specific international energy prices. For the natural gas price, there is no unified global pricing benchmark and the Asia-Pacific natural gas prices are usually priced based on an oil index. In this paper, we choose the Japanese natural gas import price. We select the Brent price to model China's gasoline price as well as Japan's steam coal import CIF price to model China's coal price. Furthermore, as thermal power accounts for more than 70% of China's power generation, we model the electricity price using domestic coal price. The historical data for the Brent price, Japan's natural gas import price and Japan's steam coal import price are obtained from BP. The prediction of these prices in different scenarios is based on our prediction or refers to the different scenarios in World Energy Outlook 2016 from the IEA.

4.1.1. BAU: Low Energy Price Scenario

In our BAU scenario, energy prices are the most uncertain factor affecting natural gas demand. In the current context of loose supply and weak demand, low energy prices seem to be the most viable scenario and will continue for a long time. In our low energy price scenario, Brent prices are assumed at 70 $/barrel and 90 $/barrel, Japan's natural gas import prices are assumed at 8 $/MBtu and 11 $/MBtu and Japan's steam coal import prices are assumed at 60 $/tonne and 70 $/tonne at the 2014 constant price in 2020 and 2030, respectively.

Economic growth: China's economic growth has entered a new normal, from extensive growth to quality growth, sustainable development has become China's basic policy orientation of regulating economic growth. Therefore, the continued decline in China's economic growth rate has become an accepted fact. Based on our review of many reports, government and private, we expect China's real GDP average annual growth rate to be 6.5%, 5.5% and 5.0% for the period of 2015~2020, 2021~2025 and 2026~2030, respectively.

Total primary energy consumption: According to Chinese government announcements, China has committed to reduce its carbon dioxide emissions per unit of GDP by 40%~45% by 2020 and 60%~65% by 2030 from the 2005 level. In our BAU scenario, we assume that China's carbon dioxide emissions per unit of GDP can be reduced by 40% and 60% by 2020 and 2030, respectively. By our calculation, based on the BAU GDP growth scenario, China's energy consumption will reach about 4.98 billion tce and 5.54 billion tce in 2020 and 2030, respectively. It indicates that if China can achieve its cap on annual primary energy consumption of 4.8 billion tce by 2020 by its 13th Five-year plan, it will be able to achieve the carbon emission intensity target of 40%.

4.1.2. IEA's Current Policies Scenario

In the IEA's current policies scenario, Brent prices are assumed at 82 $/barrel and 127 $/barrel, Japan's natural gas import prices are assumed at 9.9 $/MBtu and 13 $/MBtu and Japan's steam coal import prices are assumed at 68 $/tonne and 84 $/tonne at the 2014 constant price in 2020 and 2030, respectively. In this scenario, we also assume that China's carbon dioxide emissions per unit of GDP can be reduced by 40% and 60% by 2020 and 2030, respectively. By our calculation, China's energy consumption will reach about 4.96 billion tce and 5.67 billion tce in 2020 and 2030, respectively, based on the estimated GDP in this scenario.

4.1.3. IEA's New Policies Scenario

In IEA's new policies scenario, Brent prices are assumed at 79 $/barrel and 111 $/barrel, Japan's natural gas import prices are assumed at 9.6 $/MBtu and 11.9 $/MBtu and Japan's steam coal import prices are assumed at 66 $/tonne and 77 $/tonne at the 2014 constant price in 2020 and 2030, respectively. In this scenario, we assume that China's carbon dioxide emissions reduction per unit of GDP can reach its upper goal at 45% and 65% by 2020 and 2030, respectively. Thus, China's energy consumption will reach about 4.49 billion tce and 4.86 billion tce in 2020 and 2030, respectively, based on the estimated GDP in this scenario. According to the statistics of China's National Energy Administration, China's total energy consumption has reached 4.36 billion tce in 2016. It indicates that if China wants to achieve this carbon emission reduction goal, its annual average growth of total energy consumption should be controlled to no more than 0.74%. This seems to be a great challenge for China.

4.1.4. IEA's 450 Scenario

In the IEA's 450 scenario, Brent prices are assumed at 73 $/barrel and 85 $/barrel, Japan's natural gas import prices are assumed at 9 $/MBtu and 10.8 $/MBtu and Japan's steam coal import prices are assumed at 61 $/tonne and 59 $/tonne at the 2014 constant price in 2020 and 2030, respectively. Under this scenario, China's medium- and long-term economic growth is assumed to be better than expectation, and it is assumed to grow at an average annual rate of 6.5%, 6.0% and 5.5% during the period of 2013~2020, 2021~2025 and 2026~2030, respectively. In this scenario, we also assume that China's carbon dioxide emissions reduction per unit of GDP can reach its upper goal at 45% and 65% by 2020 and 2030, respectively. Thus, China's energy consumption will reach about 4.59 billion tce and 5.11 billion tce in 2020 and 2030, respectively.

4.2. The Gap between Supply and Demand

According to the scenario assumptions, our forecasts for China's natural gas demand are as follows. In the BAU scenario, China's natural gas demand will reach 340 bcm and 528 bcm in 2020 and 2030, respectively. In the IEA's current policies scenario, China's natural gas demand will reach 331 bcm and 515 bcm in 2020 and 2030, respectively. In the IEA's new policies scenario, China's natural gas demand will reach 308 bcm and 507 bcm in 2020 and 2030, respectively. And, in the

IEA's 450 scenario, China's natural gas demand will reach 324 bcm and 487 bcm in 2020 and 2030, respectively.

Combined with the domestic natural gas supply and import capacity, we found that China's natural gas supply situation is more optimistic in the future. In the BAU demand scenario and base 3 production scenario, the gap between supply and demand in 2020 is 95 bcm, which can be fully satisfied by pipeline natural gas. Even in 2030, this gap is only 228 bcm, which can be mainly supplemented by pipeline gas and a small amount of LNG, assuming all planned pipeline development is completed. Under this situation, China's dependence on foreign natural gas will decrease to 27.9% in 2020 and increase to 43.2% in 2030 in the BAU scenario.

4.3. Opportunities and Difficulties

At the end of 2016, China's National Energy Administration had published China's natural gas development report, which is the first white paper on the development of natural gas. The report provides a number of outlook for the future of natural gas development. For example, in 2020, the proportion of natural gas in the primary energy consumption reaches 10%, the gas accessibility ratio of urban residents reaches 50%~55% and gasification vehicle reaches 10 million and so on.

Obviously, related government policies are promoting the orderly development of natural gas. China's natural gas development is facing great opportunities. First, the domestic natural gas market system is becoming more open. On the one hand, government will gradually loosen market access conditions of natural gas upstream exploration and mining, enhancing the competitiveness of market participants. On the other hand, natural gas pipeline transportation and sales have been gradually separated, and the local monopolies by national petroleum companies will be broken. These developments will improve operational flexibility and reduce management costs. Second, a market-oriented natural gas pricing mechanism is forming. The Chongqing oil and natural gas trading center was built in January of 2017, which is the second national energy commodity trading center following the one in Shanghai. It indicates that the role of the market in the formation of natural gas prices will be further enhanced. Finally, the Belt and Road Initiative of China has strengthened the oil and gas pipeline networks which can provide sufficient oil and gas imports for energy supply security.

However, China's natural gas industry and the future demand is still facing uncertainties and difficulties. First, renewable energy continues to highlight its cost advantage even if natural gas prices continue to slump. According to the estimation in China's wind power development roadmap 2050, China's land-based wind power generation price will reach 0.51 RMB/kwh and 0.48 RMB/kwh in 2020 and 2030, respectively, which will be lower than natural gas power generation prices. Second, the lack of sufficient natural gas storage equipment and weak peak load capacity, resulting in gas shortage during winter in China's northeast area, is difficult to solve. Third, the long-term contract involving natural gas has locked China into higher prices. Based on the rapid growth of natural gas consumption from 2000 to 2013, China established a large number of LNG receiving terminals and signed a considerable amount of the take-or-pay LNG long-term contracts with higher natural gas prices. Therefore, China has to purchase gas based on these long-term contracts even if the natural gas spot price is much lower. Fourth, the industry is currently dominated by the Chinese national oil companies, Sinopec and PetroChina, with limited participation from international oil companies. This will constrain the pace of development and the quality of the reservoir management even if international service companies are involved in all projects. And the quality of environmental management and community engagement also face uncertainty influencing the development of shale gas (Andrews-Speed and Len, 2015). These dilemmas need new policies and continued cost improvements to make natural gas more economical and more efficiently integrated into the economy.

5. CONCLUSIONS

This paper investigates the influencing factors of China's sectoral natural gas demand and provides a projection of natural gas demand up to 2030. Some findings can be drawn from the study presented below.

First, China's natural gas demand presents sectoral characteristics which are affected by different factors in different sectors. Although domestic energy pricing is not fully market-oriented, there is still a long-term equilibrium relationship between natural gas demand and natural gas price and other inter-fuel substitution prices. It also supports the necessity for China's market-oriented pricing mechanism reform.

Second, income elasticities and price elasticities for natural gas demand in industrial and commercial sectors is consistent with expectations, which follow classic economic theory. In general, natural gas demand will decrease in response to own price increase, while there is an alternative relationship between natural gas and other fuels, such as coal.

Finally, China's natural gas demand is forecast to reach 340 bcm and 528 bcm in 2020 and 2030, respectively in the BAU scenario. The supply capacity of natural gas is large enough to meet China's natural gas demand. Although the proposed long-term pipeline developments may bring difficulties to the current natural gas development in China, it can also improve the supply stability for China's natural gas demand. In the long run, the development of natural gas market penetration is still dependent on the government's policy guidance and market-oriented reform process.

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