

Cai, Zhengyu; Yu, Chin-Hsien; Zhu, Chunhui

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Government-Led Urbanization and Natural Gas Demand in China

Zhengyu Cai

Southwestern University of Finance and Economics

Institute of Development Studies

Chengdu, Sichuan 611130, China

and Global Labor Organization (GLO)

Email: czy@swufe.edu.cn

Chin-Hsien Yu

Southwestern University of Finance and Economics

Institute of Development Studies

Chengdu, Sichuan 611130, China

Email: evaniayu@gmail.com

Chunhui Zhu

South China Normal University

School of Marxism

Guangzhou, Guangdong 510631, China

Email: zhuchunhui85@163.com

Abstract

The Chinese government is actively promoting urbanization to stimulate its economic growth while facing increasingly prominent environmental concerns. The main objective of this research is to assess whether the Chinese government is making efforts to promote cleaner energy demand while pushing for urbanization. This study employs system GMM models to empirically investigate the causal relationship between urbanization and natural gas demand by using a sample of 30 provinces in China over the period 2005–2018. The estimates of the preferred specifications show that government-led urbanization has a positive impact on natural gas demand conditional on total energy use. By attaching natural gas facilities to new structures through the use of administrative power, the government induces natural gas demand while promoting urbanization. Robustness checks indicate that adding more potentially influential factors will not qualitatively change the results from the baseline. A constrained two-step static panel data estimation is used to estimate the depreciation rates of natural gas and of all fuel appliances, suggesting that the promotion of natural gas demand provides a relatively economical way to balance the trade-off between economic growth and the reduction of emissions. The empirical results also show that the dynamic model outperforms its static counterpart in predictions. Based on the results, policy recommendations are made towards the goals of the Fourteenth Five-Year Plan for the National Economic and Social Development of China.

Keywords: Natural gas; urbanization; dynamic panel model; China

JEL Classification: Q41, Q47, Q48, R11, R12

1. Introduction

Since the 1978 Chinese economic reform, China has been experiencing rapid urbanization. The population of urban residents has grown from 107 million in 1978 to 703 million in 2013, and the urbanization ratio has increased from 17.9% to 53.7% during the same period.¹ Unlike spontaneous rural–urban migrations in most Western countries, urbanization in China is mainly encouraged by central and local governments [1,2]. The governments use this method to stimulate aggregate demand and to maintain high-speed growth, as it will induce large-scale infrastructure constructions and industrial structure changes [1].² Such aggressive and non-marketized urbanization has stimulated highly intensive, traditional energy consumption (see Yan [3] for a literature survey). The mass usage of fossil fuels has produced excessive carbon dioxide (CO₂) emissions which has resulted in severe air pollution [4–8] and environmental degradation [7–9]. According to the commitment made by China in the Kyoto Protocol, China should have started to reduce its CO₂ emissions in 2005.

On the one hand, to meet the commitment, the government officials have claimed several actions to reduce emissions [10–12]. On the other hand, China has wanted to retain its rapid economic growth. To balance the trade-off between economic growth and emission reduction, one of the actions taken by the government has been to induce the demand for natural gas by binding gas supply facilities to

¹ Source: National Bureau of Statistics of the People’s Republic of China. Urbanization ratio is defined as the proportion of urban population to total population.

² Wang, Zhang, and Zhou [51] find that local government leaders have their own interests to expand city borders by their administrative power.

newly built urban residential infrastructures. As urbanization stimulates economic growth [13–15], and while natural gas is a cleaner and more efficient substitute to coal [16–18], there is the potential to achieve both the economic and environmental goals simultaneously if the government can induce the demand for natural gas by promoting urbanization. However, due to affordability, a shortage of gas supply, hazardous pipelines [19], and concerns about national energy security [20,21], the net effect of urbanization on natural gas demand remains unknown. Thus, the main objective of this study is to evaluate whether China is effective in its promotion of natural gas demand through the promotion of urbanization. To achieve this research goal, this study empirically tests the causal relationship between urbanization in China and demand for natural gas.

Many existing studies have focused on the relationship between urbanization and energy consumption [22–31]. Fan et al. [32] found that urbanization in China has contributed to the increase in residential energy consumption by 15.4% during the period 1996–2012. As a consequence, energy consumption has caused environmental degradation [7,8]. To deal with this issue, Khan et al. [7] and Muhammad et al. [9] advocated the promotion of renewable energy consumption. However, rarely has it been studied in the literature as to whether or not the promotion of urbanization increases cleaner energy consumption. To fill this gap, the current study uses dynamic panel models to investigate the causal relationship between urbanization and natural gas demand in China. The empirical results show a positive impact of government-led urbanization on natural gas demand in China, indicating that China has indeed been

making progress in cleaner energy promotion to meet the commitments made in the Kyoto Protocol and without losing its goal of economic growth.

Although some studies have found that urbanization does not improve energy efficiency [33], to the best of our knowledge, the existing literature does not examine whether it is economically efficient for the Chinese government to induce natural gas demand by promoting urbanization. This paper partially fills this research gap by applying a constrained two-step static panel model to estimate the depreciation rates of natural gas and of all fuel appliances. The estimated annual rates are 2.8% and 9.9%, respectively, suggesting that the promotion of natural gas consumption provides a relatively economical path to balance the trade-off between the reduction of emissions and economic growth from the perspective of capital accumulation.

The research methods used in this paper, that is, static and dynamic panel models, are widely used in environmental and energy studies [8,9,28]. Yet, few such studies have compared the two types of models on their prediction performance. This study tries to examine this by comparing the mean squared prediction errors (MSPE), the mean absolute prediction errors (MAE), and the mean absolute percentage errors (MAPE) of the static and the dynamic panel models used in this paper. The results show that the dynamic panel model outperforms its static counterpart in predictions.

2. Methodology and Data

Natural gas demand is largely dependent on adequate gas supplies and gas appliance infrastructures. Demand for natural gas is likely to remain relatively stable after gas

facilities are installed. Thus, incremental demand for gas is associated with an increasing number of gas appliances, and the consumer's problem of choice is under a dynamic framework. Following Balestra and Nerlove [34], the demand for gas at time t can be defined as:

$$G_t^* = f(p_t, F_t^*) \quad (1)$$

where p_t is the relative price of gas adjusted for inflation, and F_t^* is the total demand for all types of fuel.

The natural gas and all fuel demand can be decomposed into two parts: intertemporal consumption change and additional consumption due to retirement and replacement of facilities. The intertemporal change of natural gas and total fuel consumptions are given by $\Delta G_t = G_t - G_{t-1}$ and $\Delta F_t = F_t - F_{t-1}$, respectively. To account for the additional energy use caused by appliance depreciation, define r_g and r_f as depreciation rates for natural gas appliances and all types of fuel appliances, respectively, where $0 < r_g < 1$ and $0 < r_f < 1$. Thus, $r_g G_{t-1}$ and $r_f F_{t-1}$ represent the portion of the total consumption of gas and fuel due to the improvement of appliances in time t . The new demand for gas and all types of fuel in time t are thus expressed as:

$$G_t^* = \Delta G_t + r_g G_{t-1} \quad (2)$$

and

$$F_t^* = \Delta F_t + r_f F_{t-1} \quad (3)$$

As discussed in the previous section, the existing literature has documented that

urbanization has positive effect on total energy use. Then, Equation (1) can be rewritten as:

$$G_t^* = f(p_t, F_t^*(X_t)) \quad (4)$$

where X_t represents the level of urbanization. Following Balestra and Nerlove [34], for the purpose of insuring appropriate identification of the parameters in the following empirical analysis, all the equations are under the assumption of linearity and Equation (4) can thus be rewritten as a linear equation:

$$G_t^* = \alpha_0 + \alpha_1 p_t + \alpha_2 F_t^* \quad (5)$$

By substituting Equation (2) and (3) into Equation (5), it becomes

$$G_t = \alpha_0 + \alpha_1 p_t + \alpha_2 \Delta F_t + \alpha_2 r_f F_{t-1} + (1 - r_g) G_{t-1} \quad (6)$$

In addition, the demand for all types of fuel in time t is defined as a linear function of urbanization:

$$F_t = \lambda_0 + \theta X_t \quad (7)$$

Substituting Equation (7) into (6) and rearranging it becomes

$$G_t = (\alpha_0 + \alpha_2 r_f \lambda_0) + \alpha_1 p_t + (1 - r_g) G_{t-1} + \alpha_2 \theta \Delta X_t + \alpha_2 \theta r_f X_{t-1} \quad (8)$$

which will be used to form the empirical model.

Based on Equation (8), a dynamic panel model is developed as the baseline empirical model:

$$\ln G_{it} = \beta_0 + \beta_1 \ln p_{it} + \beta_2 \ln G_{i,t-1} + \beta_3 \ln \Delta X_{it} + \beta_4 \ln X_{i,t-1} + \mu_i + v_{it} \quad (9)$$

where the subscript $i = 1, \dots, N$ denotes provinces; $t = 1, \dots, T$ denotes time periods. G_{it} is natural gas consumption in t , and $G_{i,t-1}$ is gas consumption in

period $t - 1$; p_{it} is the relative price of gas adjusted for inflation; ΔX_{it} can be interpreted as urbanization progress or speed of urbanization, which is the difference of urbanization levels between time t and $t - 1$, namely, $X_{i,t} - X_{i,t-1}$; μ_i represents unobserved provincial-level effects and v_{it} represents observation-specific errors. The coefficient of interest is β_3 , which can be interpreted as the effect of urbanization progress on natural gas consumption.

The unobserved provincial-level effects, μ_i , in Equation (9) are removed by first-differencing the equation, which results in the following differenced equation:

$$\begin{aligned} \Delta \ln G_{it} = & \beta_1 \Delta \ln p_{it} + \beta_2 \Delta \ln G_{i,t-1} + \beta_3 (\ln \Delta X_{it} - \ln \Delta X_{i,t-1}) \\ & + \beta_4 \Delta \ln X_{i,t-1} + \Delta v_{it} \end{aligned} \quad (10)$$

However, first-differencing is not a valid way to eliminate the province-specific fixed effects because it may induce serial correlation in the first-differenced errors, that is, $Cov(\Delta v_{it}, \Delta v_{i,t-1}) = -Var(v_{i,t-1}) \neq 0$. To mitigate this concern, the forward orthogonal deviations transformation is used to eliminate the fixed effects without introducing serial correlation in the transformed errors [35].

Since a dynamic panel is employed, another threat to identification is endogeneity. GMM-type estimators are used to take care of this issue. Arellano and Bond [36] proposed to estimate Equation (9) by using all the available lags of the predetermined and endogenous variables in levels as instruments to develop a GMM estimator, which is called the Arellano-Bond estimator (or difference GMM).

However, too many such instruments would cause some technical issues. First, using lagged variables as instruments reduces sample size. Thus, uncollapsed instruments

are employed to retain the sample size following Holtz-Eakin, Newey, and Rosen [37]. Second, long lags would weaken instruments, which would bias estimates. Third, too many instruments will make Hansen J statistics uninformative, resulting in unconvincing p-values of 1. There are two basic options to mitigate the last two concerns: limit the order of lags and/or use standard instruments rather than the uncollapsed. Both options are executed in the empirical analysis.

Besides difference GMM, an alternative is to estimate the system of level and differencing equations (Equations (9) and (10) in this case) simultaneously [38], which is called system GMM. System GMM increases estimation efficiency and can identify the time-invariant factors. Like difference GMM, however, the caveat of system GMM is also to avoid too many instruments. Thus, the number of uncollapsed instruments is limited, and standard instruments are used.

The above-described models still leave some issues unresolved. First, the coefficient of interest, β_3 , can only be interpreted as the effect of urbanization progress on natural gas consumption rather than demand, as the dependent variable is G_{it} not G_t^* . Second, as the empirical models (9) and (10) are derived from Equation (8), it is possible that unreasonable estimates for r_f and r_g will be obtained if constraints are not added on corresponding coefficients.³

To resolve these issues, restrictions are imposed on the target coefficients. Intuitively and theoretically, $0 < r_g < 1$ and $0 < r_f < 1$ would be two natural

³ According to Equations (8) and (9), $r_g = 1 - \beta_2$ and $r_f = \beta_4/\beta_3$.

constraints. Empirically, to add these two constraints, Equation (8) needs to be rearranged as

$$G_t - (1 - r_g)G_{t-1} = (\alpha_0 + \alpha_2 r_f \lambda_0) + \alpha_1 p_t + \alpha_2 \theta (X_t - (1 - r_f)X_{t-1}) \quad (11)$$

Next, substitute Equation (2) into Equation (11) and let $X_t^* = X_t - (1 - r_f)X_{t-1}$,

$$G_t^* = (\alpha_0 + \alpha_2 r_f \lambda_0) + \alpha_1 p_t + \alpha_2 \theta X_t^* \quad (12)$$

Notice that Equation (12) is not dynamic anymore. Thus, a regular method is used to estimate it. This will be a two-step process. In the first step, the optimal values of (r_f, r_g) are estimated within their feasible ranges to maximize goodness of fit. Next, the natural gas consumption and urbanization variables are transformed by using the optima and re-estimating Equation (12) using the following empirical model:

$$\ln G_t^* = \beta_0 + \beta_1 \ln p_{it} + \beta_2 \ln X_{it}^* + \beta_3 \ln Z_{it} + \mu_i + v_{it} \quad (13)$$

where Z_{it} represents time-varying provincial-specific covariates. The coefficient of interest is β_2 . It is difficult to interpret X_{it}^* , as the transformation is just for parameter identification. Yet, according to Equation (11), the coefficient on X_t is also $\alpha_2 \theta$, which is β_2 in Equation (13). Thus, β_2 can be interpreted as the effect of urbanization on the dependent variable. As the dependent variable G_t^* is the net increment of natural gas demand now, β_2 could be interpreted as the elasticity between urbanization and natural gas demand.

This paper uses a short panel merged from multiple sources. Annual data for each variable from 30 Chinese provinces from 2005 to 2018 were collected and

resulted in 420 observations.⁴ The data used in this study were collected from the Wind Economic Database, except for total energy consumption. Average provincial demand for natural gas is adjusted using annual average temperatures, as temperature fluctuates among different provinces, contributing to a varying demand for natural gas. The National Development and Reform Commission sets natural gas pricing in China. The current natural gas price is marked up based on wellhead price and related costs. The central government and local distribution companies sequentially determine wellhead and city gate prices of natural gas. Finally, local governments set the gas price for end-users. As a result, the pricing process for natural gas in China leads to low price elasticity of demand. In this paper, the residential prices of natural gas are considered. All prices are adjusted for inflation using 2000 as the base year. Total energy consumption was collected from the China Stock Market and Accounting Research Database and several provincial statistical yearbooks.

Figure 1 shows the trends of the main variables, urbanization and natural gas consumption, by province from 2005 to 2018. According to the figure, the Chinese government is continuously promoting urbanization. In most of the provinces, the trends of urbanization and natural gas consumption are in the same directions, implying there may exist a positive correlation. Does natural gas demand increase through the promotion of urbanization in China? Formal tests on this question will be conducted in the next section. Table 1 reports the summary statistics.

⁴ The 30 provinces refer to 4 autonomous regions (no data for Tibet, which is excluded), 22 mainland provinces, and 4 municipalities governed directly by the central government. These 30 regions are at the same administrative hierarchy, reporting to the central government. Thus, they will all be described as “provinces” for simplicity.

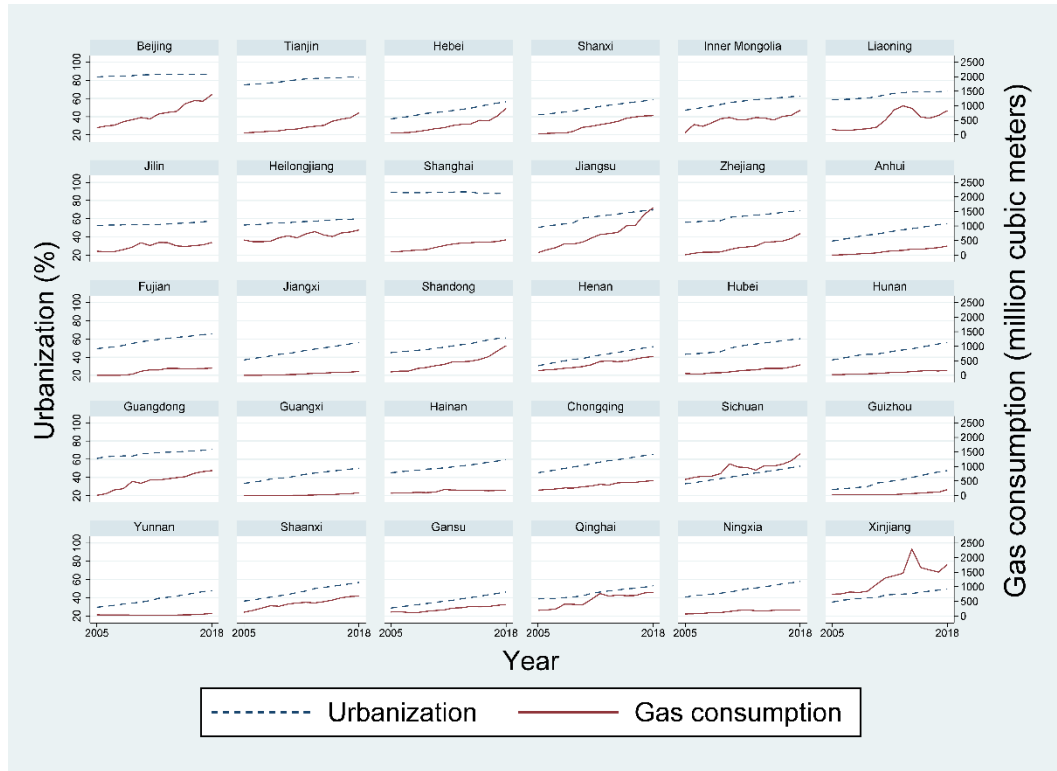


Fig. 1. Urbanization and natural gas consumption from 2005 to 2018.

Table 1

Summary statistics. Notes: Analytical sample includes 4 autonomous regions (no data for Tibet, which is excluded), 22 mainland provinces, and 4 municipalities governed directly by the central government. These 30 regions are at the same administrative hierarchy, reporting to the central government. Annual data for each variable from 2005-2018 were collected and resulted in 420 observations. There are 5 and 120 missing data for total energy consumption and coal price, respectively. We exclude these observations from the static model (Table 4).

	<i>N</i>	Mean	Std. Dev.	Min	Max
Urbanization (%)	420	53.322	14.027	26.870	89.600
Natural gas consumption (million $m^3/^\circ C$)	420	368.297	344.266	0.604	2295.541
Natural gas price (constant 2000 Yuan/ m^3)	420	1.897	0.703	0.861	4.367
Population density ($/km^2$)	420	2712.206	1274.495	188.520	6307.380
The ratio of secondary industry output to GDP (%)	420	45.892	8.337	16.540	61.500
The ratio of tertiary industry output to GDP (%)	420	43.288	9.315	28.600	83.090
Total energy consumption (10,000 tce)	415	13003.076	8246.983	819.100	40580.500
Coal price (constant 2000 Yuan/ton)	300	644.900	277.758	145.208	1945.811

3. Empirical Results

3.1 Model Selection

First, different specifications are trialed to examine the adequacy of the models. Table 2 reports the estimates of the baseline models. Specifications in Columns (1) to (3) are estimated by difference GMM, while Column (4) through Column (6) are estimated by system GMM. Each pair of Columns (1) and (4), Columns (2) and (5), and Columns (3) and (6) use the same uncollapsed instrument variables.⁵ For Columns (1) and (4), first-order lag of the real coal price is used as the uncollapsed instrument. For Columns (2) and (5), lagged real natural gas price is employed as the uncollapsed instrument. For Columns (3) and (6), real coal and natural gas prices are both included in the uncollapsed instrument set. Year and province dummies are used as standard instruments for difference and system GMM specifications, respectively, due to their exogeneity.

Table 2

Urbanization progress and natural gas consumption. Notes: The dependent variable is log natural gas consumption. All explanatory variables are in log form. All specifications include year dummies. The values in parentheses are robust standard errors. The values in brackets are p-values. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

	Difference GMM			System GMM		
	(Arellano-Bond Estimator)			(Bundell-Bond Estimator)		
	(1)	(2)	(3)	(4)	(5)	(6)
Lagged Natural Gas Consumption	0.619*** (0.125)	0.824*** (0.267)	0.743*** (0.197)	0.970*** (0.018)	0.978*** (0.018)	0.964*** (0.019)
Natural Gas Price	-0.588 (0.921)	-0.519 (0.971)	-0.687 (0.650)	0.086 (0.058)	0.104* (0.061)	0.062 (0.060)
Urbanization Progress	-0.096 (0.161)	0.010 (0.105)	-0.055 (0.088)	0.053** (0.021)	0.084*** (0.023)	0.051** (0.019)
Lagged Urbanization	1.059 (1.532)	4.066 (3.172)	1.834 (1.835)	0.212** (0.079)	0.239*** (0.082)	0.222** (0.082)
Number of IVs	24	24	36	55	55	80
Sargan Test	3.655	3.334	10.864	50.216	35.606	65.037

⁵ One may notice that the number of instrumental variables is different between difference GMM and system GMM, as system GMM has more parameters to estimate.

	[0.723]	[0.766]	[0.900]	[0.058]	[0.487]	[0.338]
Hansen J Test	6.055	9.164	17.667	12.283	18.008	12.362
	[0.417]	[0.165]	[0.478]	[1.000]	[0.995]	[1.000]
Arellano-Bond	-1.467	-1.395	-1.929	-2.344	-2.487	-2.392
Test AR(1)	[0.142]	[0.163]	[0.054]	[0.019]	[0.013]	[0.017]
Arellano-Bond	-1.669	-1.211	-1.533	-0.707	-0.601	-0.734
Test AR(2)	[0.095]	[0.226]	[0.125]	[0.479]	[0.548]	[0.463]
<i>N</i>	345	345	345	375	375	375

All specifications in Table 2 indicate that natural gas consumption is highly autocorrelated.⁶ The elasticity of natural gas consumption between the past and present varies from 0.743 to 0.978. The price elasticity of natural gas consumption is not significant in all specifications, except that only one is significant at the 10% level in the system GMM specification, but with the unexpected sign. This may be due to the aforementioned inelastic gas price setting. For urbanization variables, the coefficients estimated by the difference GMM models are not accurate. Reliable results are from the system GMM models.

Although the specification in Column (4) is one of the models that include the least number of instrumental variables among the reported system GMM specifications, the Hansen J test statistics is uninformative as the p-value equals to 1. This means the instruments are still too many for this specification. The Hansen J test should be considered with a Sargan test at the same time because of their complementary features. The Hansen test is robust to heteroskedasticity, but it is easily weakened by instrument proliferation. Although the Sargan test is not robust to heteroskedasticity or autocorrelation, it is not weakened by having more instruments. The Sargan test rejects the null hypothesis that the instruments are valid in Column

⁶ Longer lags of natural gas consumption were also tested, but higher-order autocorrelations appear insignificant.

(4) at the 10% level, which suggests modification of the specification is needed. The AR (1) test fails to reject the null hypothesis that there is no autocorrelation in error terms at the 1% level.

To improve the model, the specification in Column (5) uses real natural gas price instead as the GMM-style instrument. The number of instrumental variables is still 55. All the coefficients of interest are significant at the 0.01 level and substantial in magnitudes. The elasticity between urbanization progress and natural gas consumption is 0.084, which means that for each 1% increase in urbanization progress in Beijing in 2012, its natural gas consumption will increase by 7.75 million cubic meters; or, correspondingly, a 5.41 million cubic-meter increase for Shanghai; or a 12.87 million cubic-meter increase for Sichuan. The Hansen and Sargan over-identification tests indicate that this specification is reliable, with p-values of 0.995 and 0.487, respectively. The Arellano-Bond tests fail to reject the null hypothesis that the transformed errors do not contain first- and second-order autocorrelation at the 1% level, also revealing a good signal of specification validity.

In order to investigate more potential specifications and understand how excessive instruments influence estimation results, real coal and natural gas prices both are included as uncollapsed instrumental variables. Column (6) shows that the addition of one more GMM-style instrument does not qualitatively change the estimates in magnitudes, but the coefficient of urbanization progress becomes less significant. Including an additional uncollapsed instrument raises the number of instruments to 80, which severely deteriorates the validity of the Hansen J test by

rapidly increasing the corresponding p-value. If the p-value reaches 1, the Hansen test is not informative. In Column (6), the p-value of Hansen test is 1, which is less convincing than that in Column (5). Furthermore, the p-value of the Sargan test is 0.338, which is smaller than that in Column (5). Therefore, the specification in Column (5) is better than that in Columns (4) and (6) and will be used as the preferred specification.

It is worth noting that the coefficients on the lagged urbanization ratio are highly significant in all system GMM specifications, indicating that there may exist a lag effect of urbanization ratio on natural gas consumption.⁷ Taking Column (5) as an example, the elasticity between the urbanization ratio in the previous year and natural gas consumption in the current year is 0.24, which means a 1% increase in urbanization ratio in the past year will increase natural gas consumption by 0.24% in the following year. Considering the time-consuming nature of gas appliance installation, this lag effect is expected.

To test the robustness of the models, some potential influencing factors are included as covariates in the preferred specification. Table 3 reports the results of the specifications with different combinations of the covariates. Column (1) includes provincial population density in the model. The estimated coefficients of interest do not qualitatively and quantitatively change. The estimate of population density is positive, which is expected, but not significant.

Next, industrial structure is included in the model as industrial usage of natural

⁷ Higher-order lags were also tested; however, the estimates are insignificant.

gas accounts for the second largest share of the total consumption. First, the secondary industry is considered for its energy-consuming nature. Column (2) reports the results of the specification including the ratio of secondary industrial output to GDP as an additional covariate. The coefficients of interest are still robust, though smaller in magnitudes, while the coefficient on secondary industry share is positive and significant. This reflects the fact that the secondary industry in China has turned to rely on cleaner energy sources, so that natural gas consumption is sensitive to the scale of the secondary industry.

Table 3

Robustness Checks. Notes: The dependent variable is log natural gas consumption. All explanatory variables are in log form. All specifications include year dummies. The values in parentheses are robust standard errors. The values in brackets are p-values. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Lagged Natural Gas Consumption	0.976*** (0.021)	0.978*** (0.017)	0.978*** (0.017)	0.976*** (0.019)	0.978*** (0.017)	0.977*** (0.018)	0.976*** (0.019)	0.968*** (0.024)
Natural Gas Price	0.097 (0.061)	0.119** (0.051)	0.117** (0.053)	0.115** (0.052)	0.119** (0.051)	0.113** (0.054)	0.115** (0.052)	0.092 (0.068)
Urbanization Progress	0.084*** (0.023)	0.052** (0.021)	0.068*** (0.022)	0.053** (0.020)	0.052** (0.021)	0.068*** (0.022)	0.053** (0.020)	0.051** (0.021)
Lagged Urbanization	0.256** (0.095)	0.218** (0.081)	0.312*** (0.086)	0.226** (0.094)	0.216** (0.097)	0.319*** (0.096)	0.224** (0.108)	0.243** (0.110)
Population Density	0.016 (0.033)			0.009 (0.031)		0.008 (0.030)	0.009 (0.030)	0.013 (0.031)
Secondary Industry (GDP%)		0.213*** (0.061)		0.212*** (0.060)	0.215*** (0.069)		0.216*** (0.069)	0.176 (0.118)
Tertiary Industry (GDP%)			-0.263** (0.113)		0.004 (0.149)	-0.260** (0.109)	0.007 (0.145)	-0.020 (0.153)

Total Energy Consumption								0.010 (0.025)
Sargan Test	35.501 [0.445]	28.027 [0.792]	30.775 [0.672]	28.016 [0.755]	28.026 [0.755]	30.770 [0.627]	28.014 [0.714]	27.732 [0.683]
Hansen J Test	16.478 [0.997]	18.286 [0.991]	18.658 [0.989]	18.480 [0.986]	15.722 [0.997]	18.521 [0.986]	17.407 [0.988]	17.873 [0.979]
Arellano-Bond Test AR(1)	-2.510 [0.012]	-2.378 [0.017]	-2.416 [0.016]	-2.397 [0.017]	-2.358 [0.018]	-2.436 [0.015]	-2.378 [0.017]	-2.362 [0.018]
Arellano-Bond Test AR(2)	-0.596 [0.551]	-0.655 [0.513]	-0.646 [0.518]	-0.650 [0.516]	-0.658 [0.511]	-0.641 [0.521]	-0.652 [0.514]	-0.683 [0.494]
<i>N</i>	375	375	375	375	375	375	375	370

The specification in Column (3) uses the ratio of tertiary industry output to GDP as a covariate. The estimate is negative and highly significant, as expected, and the coefficients of interest remain robust. The estimated elasticity is -0.263, which means that a 1% increase in the service industry share is projected to reduce natural gas consumption by approximately 0.26%. This result reflects the low energy-consuming nature of tertiary industry.

Columns (4) to (6) report the results of including pairwise covariates from Columns (1) to (3). For all these specifications, the coefficients of the interest are robust. Column (4) includes population density and secondary industry share. The estimates of the covariates are similar as they are separately included in the models. Column (5) considers secondary and tertiary industry shares simultaneously. However, the negative effect of tertiary industry share is inaccurate in this specification and the sign even turns to the unexpected side. Given the persistent scale of agriculture, collinearity between these two industries is suspicious.

To partially confirm the conjecture, Column (6) runs the specification with population density and tertiary industry share in the model. As expected, the

significant and negative coefficient on tertiary industry share reappears, while the effect of population density remains insubstantial. In Column (7), all the above covariates are controlled for in the model. As expected, the results show that the estimate of tertiary industry is not statistically accurate again, which is possibly due to the potential collinearity between secondary and tertiary industry share.

Lastly, to partially examine whether the positive effect comes from an increase in total energy use, the specification in Column (8) also controls for total energy consumption. The results remain robust. The estimated coefficient on total energy consumption is positive but not significant, which means urbanization progress increases natural gas consumption conditional on total energy consumption. Note that all the specifications in Table 3 pass the Hansen and Sargan tests.

To sum up, the system GMM specification in Column (5) of Table 2 is preferred. Various combinations of additional covariates are also tested. The results are robust to the preferred specification. Population density is less likely to affect natural gas consumption, while industry structure plays a role.⁸

3.2 Depreciation Rates

The system GMM specification works well under the dynamic panel setting in this case. However, when the depreciation rates of appliances are calculated based on the estimates, it turns out to be difficult to obtain plausible depreciation rates of total fuel appliances. All the estimated depreciation rates of total fuel appliances are larger than

⁸ To examine whether the results are driven by income, the specification with real GDP per capita as a covariate is also estimated. The coefficients of the interest are not qualitatively changed in such a specification. Yet, the coefficient on income is insignificant. The results are suppressed for space conservation.

1 for the specifications in Table 2, which is incompatible with the theoretical expectations. In order to confirm that the depreciation rates are reasonable, the alternative estimation strategy discussed in Section 2 is employed.

Table 4 reports the results of the two-step estimation of Equation (13) by using a fixed-effect estimator with constraints on the depreciation rates.⁹ Columns (1) to (6) show the results of the specifications with different covariates. Column (1) is the benchmark without any covariates, indicating the depreciation rate of all fuel appliances is 0.5% per year, and the depreciation rate of gas appliances is 4.3% per year, which is not comparable with those in Ref. [34].¹⁰ Besides, the estimated coefficient of urbanization has the expected positive sign but is not significant. Furthermore, the price elasticity of natural gas demand is significant and large in magnitude.

Table 4

The Effect of Urbanization on Natural Gas Demand. Notes: The dependent variable is log net increment of natural gas accounting for the depreciation of gas appliances. All explanatory variables are in log form. All specifications include year dummies. The values in parentheses are robust standard errors. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

	(1)	(2)	(3)	(4)	(5)	(6)
Natural Gas Price	-2.877*** (0.466)	-2.817** (1.037)	-2.828** (1.031)	-3.035*** (0.941)	-3.113*** (0.988)	-3.356*** (1.116)
Urbanization	0.037 (0.107)	1.260** (0.590)	1.285** (0.570)	1.399** (0.640)	1.472** (0.627)	1.322** (0.607)
Coal Price		-0.339 (0.514)	-0.333 (0.521)	-0.317 (0.518)	-0.313 (0.521)	-0.197 (0.519)
Population Density			0.062 (0.687)	0.035 (0.681)	0.035 (0.665)	-0.221 (0.720)

⁹ Different estimators, such as random effect and maximum likelihood with bootstrap/OIM, are also tested. However, the results are not reasonable due to the corner solutions of τ_f and τ_g that are not plausible. Different constraints of depreciation rates are also tried. It shows that the depreciation rates are implausible compared with Balestra and Nerlove [34] if the upper bound is high.

¹⁰ The authors found a rate of 11% for all fuel appliances, and 2%–3% for natural gas appliances.

Secondary Industry (GDP%)	-0.594 (1.102)	-1.439 (1.243)	-1.254 (1.248)			
Tertiary Industry (GDP%)				-1.252 (2.183)	-1.060 (2.102)	
Total Energy Consumption						-0.710 (0.929)
r_f	0.5%	9.9%	9.9%	9.9%	9.9%	9.9%
r_g	4.3%	2.8%	2.8%	2.8%	2.8%	2.8%
R^2	0.303	0.251	0.251	0.252	0.254	0.247
N	342	254	254	254	254	249

Column (2) of Table 4 includes real coal price as a covariate, considering the substitutability between coal and natural gas. In this specification, the depreciation rate of all fuel appliances is 9.9%, but the rate decreases to 2.8% for gas appliances. The coefficient of interest becomes significant. The price elasticity of natural gas demand is still reasonable in this specification, but the coal price elasticity of natural gas demand has an unexpected sign and is insignificant.

Column (3) also includes population density with coal price as covariates. r_f and r_g are still 9.9% and 2.8%, respectively, which are close to the results in Ref. [34]. In this specification, the coefficient of the interest is still significant and large in magnitude. Column (4) adds secondary industry share as a covariate. r_f and r_g still remain 9.9% and 2.8%, respectively. The estimated elasticity between urbanization and natural gas demand is 1.399. Notice that this number is much larger than the coefficients on urbanization progress in Tables 2 and 3, as the definitions of dependent and independent variables are different. Despite this, both cases indicate a positive relationship between urbanization (progress) and natural gas demand

(consumption). The estimate of secondary industry share is negative and insignificant which is different from that in Table 3. This is possibly due to the inclusion of coal price in the specification because there is still a long way to go for secondary industry to eliminate coal consumption.

Column (5) includes coal price, population density, and secondary and tertiary industry shares as covariates. It shows that the estimates of r_f and r_g are still robust. A more exhaustive set of covariates is also tested. The unreported results show that the estimates for depreciation rates for all fuel appliances and gas appliances are the same as in Columns (2) to (5). The estimated elasticity between urbanization and natural gas demand becomes even larger with more covariates, which reinforces the positive relationship. Column (6) also controls for total energy consumption. The results are robust with an insignificantly negative estimate on total energy consumption, which indicates there is a positive effect of government-led urbanization on natural gas demand conditional on total energy consumption.

To sum up, the empirical results show that the government promotes urbanization in China, which causes a significant increase in natural gas demand. Thus, China is indeed making progress in its promotion of cleaner energy use while fostering urbanization to achieve its economic ambitions. Notice that this study does not directly examine the effect on emission reduction. Instead, it attempts to study the way in which China balances the trade-off between economic growth and environmental protection. With its administrative power, the government levels urbanization to stimulate the economy and to promote cleaner energy use

simultaneously. Natural gas facilities as the alternative energy supply to coal are compulsively bound to new housing in China, which induces demand for natural gas during the expansion of urban areas.

Such progress is only likely to happen in China. Urbanization in China is mostly a process of the expansion of urban boundaries led by the governments, rather than agglomeration by market forces, as in Western countries. Only by equipping the strong administrative power can a government promote urban expansion on such a large scale, thereby stimulating investments (including investment of natural gas infrastructures) and inducing cleaner energy demand.

3.3 Prediction Performance

One of the advantages of the dynamic panel data model is that it can provide more accurate predictions, although the fixed-effect model promises reasonable depreciation rates and provides estimates of the effect of urbanization on natural gas demand rather than consumption. To examine the forecasting ability of the different estimation models used in this study, in-sample forecasts on natural gas consumption and demand from 2006 to 2018 are obtained from the models. Next, the MSPE, MAE, and MAPE are calculated for selected specifications. Table 5 reports the results.

Table 5

Prediction Performance. Notes: The prediction errors are computed using the in-sample forecasts on natural gas consumption from 2006 to 2018 for the indicated specifications.

	Dynamic Model (System GMM)			Static Model (Fixed Effect)	
	(1) Table 2 Column (5)	(2) Table 3 Column (7)	(3) Table 3 Column (8)	(4) Table 4 Column (5)	(5) Table 4 Column (6)
MSPE	0.060377	0.058666	0.058292	0.653530	0.652663
MAE	0.164127	0.161380	0.160325	0.627197	0.629161

MAPE	0.039849	0.039118	0.039052	0.351504	0.353805
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Columns (1) to (3) report the prediction errors for the specifications of Table 2 Column (5), Table 3 Column (7), and Table 3 Column (8), respectively, which are estimated by system GMM. As discussed above, the first column is the preferred specification without covariates. The second and third columns are the specifications with covariates. The third column is better than the second for its more thorough controls and smaller prediction errors. Columns (4) and (5) of Table 5 report the prediction errors for the specifications of Table 4 Column (5) and Column (6), respectively, which are estimated by the fixed-effect estimator. According to all three prediction evaluation statistics in Table 5, system GMM specifications have obvious advantages in prediction compared with the fixed-effect ones because of the dynamic setting, although the latter are able to integrate plausible depreciation rates of energy appliances. Among the three selected system GMM specifications, Columns (2) and (3) have better performance for their smaller prediction errors. The model in Column (8) in Table 3 marginally outperforms Column (7) in Table 3, according to the errors. Overall, the last column in Table 3 has the best predictive performance in this study.

4. Conclusions and policy remarks

This paper investigates the causal relationship between urbanization and demand for natural gas using a sample of 30 provinces in China over the period 2005–2018. The preferred dynamic system GMM estimates show that urbanization progress has a positive impact on natural gas consumption. Robustness checks indicate that the

addition of more potentially influential factors will not qualitatively change the results from the baseline. A constrained two-step static panel data estimation confirms the positive effect of urbanization on natural gas demand, and this model is also used to estimate the depreciation rates of natural gas and of all fuel appliances. The estimated annual rates are 2.8% and 9.9%, respectively, suggesting that promoting natural gas demand provides a relatively economical way to balance the trade-off between economic growth and the reduction of emissions. The empirical results also show that the dynamic model outperforms its static counterpart in predictions.

This study has some limitations and implications for policymakers. The empirical results provide evidence that the government-led urbanization in China causes more natural gas demand and consumption conditional on total energy use, indicating that the Chinese government is making efforts to achieve the goal of increasing cleaner energy use while promoting urbanization. While the results endorse the efforts made by the Chinese government, this study does not examine the effects on net social welfare. First, the shift from traditional energy to cleaner energy causes structural unemployment. Second, urbanization brings negative externalities [39–41], such as congestion [42], crime, and pollution, which may offset the benefits of using cleaner energy. Third, while gas development positively affects labor market outcomes [43,44], it also raises environmental concerns [45–50]. Finally, it remains unclear how government-led urbanization will affect the welfare of rural and urban residents. Besides, this study does not directly examine the effect on emission reduction, which will be potentially complicated by the environmental Kuznets effect,

and of potential interest for future studies.

With these limitations in mind, this study suggests that under a unique institutional background, the Chinese government can induce cleaner energy demand by attaching natural gas facilities to new structures to achieve both economic and environmental goals. Thus, before other feasible paths open up, the Chinese government should maintain its promotion of urbanization with forced natural gas appliance attachment because it is an available and economical way to release the stress on environmental issues. This could be a promising path for the Chinese government to achieve one of its main goals of the Fourteenth Five-Year Plan for the National Economic and Social Development by increasing the urbanization rate to 65%, while meeting the environmental commitments made in the Kyoto Protocol.

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