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Development of natural gas vehicles in China: An assessment of enabling factors and barriers

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HIGHLIGHTS

- We assess the effectiveness of NGV policies in China.
- Relatively low natural gas price promotes NGV development.
- Coordinated development of refueling stations and NGVs is important.
- Policies that encourage private NGV development should be adopted.
- Middle-income and medium-sized cities are more suitable for developing NGVs.

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ABSTRACT

Replacing conventional gasoline or diesel vehicles with natural gas vehicles (NGVs) is necessary if China hopes to significantly reduce its greenhouse gas emissions in the short term. Based on city-level data, this paper analyzes the enabling factors and barriers to China's NGV development. We find that a shortage in natural gas supply and a relatively high price ratio of natural gas compared to gasoline are the main factors impeding China's NGV development. Imbalanced development between natural gas refueling stations and NGVs also hinder the popularity of these lower-carbon vehicles. While various policies have been implemented in recent years to promote NGVs in China, only those encouraging adoption of NGVs by the private sector appear effective. To promote further NGV development in China, the following strategies are proposed: (1) improve natural gas delivery infrastructure across the country; (2) reasonably reduce the relative price of natural gas compared to gasoline; (3) give priority to middle-income and medium-sized cities and towns, since siting natural gas refueling stations is easier in these areas; and (4) promote the use of NGVs in the private sector.

1. Introduction

As the world's fastest growing economy, China's fossil fuel consumption and greenhouse gas (GHG) emissions are growing rapidly. China surpassed the United States (US) and became the largest fossil fuel consumer in 2013 (BP, 2014a). The previous year (2012), China had already become responsible for the most carbon dioxide (CO_2) emissions of any country, accounting 26.4% of the world's total – almost equivalent to the US's and the European Union's emissions combined (Olivier et al., 2013). As one of the leading emerging economies that has an obligation to alleviate climate change, China has set the goals of reducing carbon dioxide emissions per unit of GDP by 40–45% by 2020 compared to 2005 levels and reaching peak carbon dioxide emissions by 2030,[1] and been focusing its efforts on controlling fossil fuel consumption and curbing carbon emissions.

Decomposition analysis identifies the transportation sector as the most important driving force for China's rising oil consumption between 2000 and 2009. Over this period, oil consumption increased by 71%, from 224 million tons to 384 million tons. Among the 160 million tons increase, nearly half – 76 million tons

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[1] The first mission mentioned here is promised by China at the Copenhagen in 2010, and the second is at Asia-Pacific Economic Cooperation (APEC) meetings in 2014 (UNFCCC, 2010; IFENG, 2014).

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– can be attributed to the transportation sector (Ma et al., 2012). Therefore, effective limits on the transportation sector's oil consumption are of crucial importance if China hopes to cut its overall oil consumption and emissions.

The rapid growth of oil consumption in the Chinese transportation sector may be attributed to several factors. First, China witnessed a sharp increase in the number of civil vehicles,[2] which increased nearly seven-fold, from 16 million to 109 million vehicles between 2000 and 2012 (NBS, 2013). During the same time period, the Chinese population became a more mobile one: In 2012, the total distance travelled by all passengers on a highway was 1.8 trillion kilometers (km) and the average distance of goods carriage reached 187 km, 1.7 times and 2.1 times higher, respectively, than the distances that people and goods traveled in 2000 (NBS, 2013). As the country becomes wealthier and more urbanized, more people will own their own vehicle – a trend difficult to reverse in the foreseeable future.

How can China curb its GHG emissions while maintaining the trend towards increased mobility in its transportation sector? Empirical and theoretical studies confirm that developing alternative fuel vehicles (AFVs), especially natural gas vehicles (NGVs), will be necessary to achieving these two seemingly opposing goals in the short term (Ou et al., 2010; Yao et al., 2011; Ma et al., 2013). There are two main types of AFVs that are commercially available: electric vehicles (EVs) and NGVs. Both have the potential to reduce and eventually eliminate the use of oil in the transportation sector. They are, therefore, known as “clean energy vehicles” or “low-carbon vehicles”. Compared to NGVs, EVs have more government support because China has set the goal of promoting electricity production from renewable energy, and EVs are considered the ideal technology for renewable energy utilization. However the emissions of AFVs heavily depend on their power source. In Europe and the US, EVs are recognized as “clean vehicles”, since electricity in these countries has diversified away from coal in many areas. For example, 55% of the US's electricity is generated from power plants running with natural gas, nuclear, hydropower, or renewable energy (World Bank, 2014). Life-cycle carbon emissions from a typical EV in the US are only 60% of that from a vehicle fueled by oil (Doucette and McCulloch, 2011). In contrast, 70% of China's electricity is still produced from coal-fired power plants (CEPYEC, 2013), a trend that energy companies estimate will continue for the next 20 years (BP, 2014b). Without carbon capture or carbon intensity control measures, life-cycle carbon emissions from EVs powered by coal-based electricity are almost the same as that from conventional gasoline vehicles (Zhou et al., 2013).

Although in the long run switching to EVs is a promising option in terms of energy savings and GHG mitigation, even widespread adoption of EVs would have a limited effect on China's GHG emission control in the short term. In contrast, NGVs provide a timely pathway to helping China achieve its carbon emission reduction goals. Substituting conventional gasoline vehicles with NGVs is technologically feasible, since the two categories of vehicles can be produced with almost the same technologies and a conventional vehicle can be easily converted to an NGV by simply refitting the car with a cylinder that works with both gasoline and natural gas (Yang et al., 1997). In addition, NGVs have been proven to reduce the emission of GHG, nitrogen oxides (NO_X), volatile organic compounds (VOC), and toxics,[3] emitting approximately 75%, 85%, 18%, and 40%, respectively, of the emissions of conventional gasoline vehicles (CEC, 2007). Moreover, if diesel vehicles, with the emission characters specified by the Europe IV standard, were substituted with NGVs, NO_X and particulate matter (PM) emissions could be reduced by 50% (Ryan and Caulfield, 2010). In addition to environmental benefits, such substitution would also bring economic advancement. The acquisition cost of a private NGV in China is only RMB 6000 to RMB 10,000 higher than that of an equivalent gasoline car – and the cost of converting a gasoline car into an NGV is only RMB 5000 to RMB 8000, around 10% of the car price. Assuming fuel cost savings of RMB 0.3 per km and an average driving mileage of 50 km per day (both conservative estimates), this additional cost would be fully compensated within one to two years. For commercial vehicles,[4] the cost of an NGV is RMB 20,000 to RMB 70,000 more than the cost of an equivalent conventional vehicle, but the extra upfront cost would be fully compensated within one year if the vehicle runs, on average, 200 km per day (fuel savings for commercial NGVs are approximately RMB 0.8/km) (Li, 2012).

Based on these advantages, NGVs have been widely promoted all over the world. From 2003 to 2012, global NGV ownership was growing at an annual rate of 21.6%, with more than 16 million NGVs on the road by the end of 2012 (IANGV, 2013). Furthermore, the adoption of NGVs has gradually extended from public transportation to private cars, taxis, heavy-duty trucks, garbage trucks, and other vehicles with special uses (Yeh, 2007). NGVs have come to pervade most sub-sectors in transportation, and have the potential to replace conventional gasoline and diesel vehicles altogether.

However, compared to the rapid development of NGVs worldwide, the adoption of these low-carbon vehicles in China has lagged behind. Although China ranks fifth worldwide for NGV ownership, with 1.57 million NGVs on the road by 2012 (up from just 6000 in 2000), overall market penetration remains low: just 1.13% of all civil vehicles are NGVs, ranking China 21st among the 79 countries with NGVs. In addition, our analysis indicates that the phenomenon of NGV underdevelopment in China is regional rather than national. Based on data for NGV adoption in China's major cities in 2012, we find that some provinces, such as Xinjiang, Shandong, and Sichuan, have advanced NGV development, with 56% of China's NGVs located in these three provinces. Xinjiang, in particular, is home to the largest number of NGV owners, boasting a market penetration of 21.2% and putting the province on par with the most highly developed NGV markets, such as Iran and Bangladesh (IANGV, 2013). However, in most other provinces, NGV market penetration is less than 1%. Lower penetration is on the one hand a symbol of underdevelopment, but it also indicates significant potential for growth.

Why is the NGV market underdeveloped in the majority of China? This question is far from answered. Existing studies have confirmed that NGVs are a technologically feasible and environment-friendly option for greening China's transportation sector (Yang et al., 1997; Ou et al., 2010; Yao et al., 2011; Ma et al., 2013). For instance, with data collected from the field, Yang et al. (1997) found that developing the NGV market in Beijing is a cost-effective strategy in terms of pollution control and GHG mitigation. This conclusion was strengthened with a life-cycle analysis conducted by Ou et al. (2010). They showed that an NGV uses 14% less fossil energy and emits 28% less GHGs than a counterpart diesel vehicle. Existing studies also document extensive government support to promote NGV development, including the policy tools for setting up basic infrastructure, building public awareness, and compensating first-mover users who incur extra upfront costs. For example, supported by the State Planning Commission at that time,

[2] By civil vehicles, we mean vehicles operated by non-military and non-official agents, including both private vehicles and vehicles running for public transportation.

[3] Toxics consist of Benzene, 1-3 butadiene, and particulate matter by their weights.

[4] Commercial vehicles include light trucks, heavy trucks, and large- and medium-sized passenger cars. These vehicles are mainly fueled by diesel.

the Xinjiang local government waived highway tolls for all NGVs during 1995 (Yang et al., 1997). In 1999, the promotion efforts were expanded to twelve large- and medium-sized cities under the national initiative of "Clean Vehicle Action", which provided funding for R&D and market demonstrations of technology, as well as financial subsidies for NGV buyers (Ouyang, 2006; Wan, 2008; Yan and Crookes, 2009; Zhao and Melaina, 2006; Ma et al., 2013). The initiative was further extended to 26 cities in 2009. These practices could help overcome the market's initial reluctance. In short, developing NGV seems the most realistic, effective, and timely solution for China to meeting the urgent challenges of energy savings and GHG reduction.

However, existing studies fail to answer why the low-carbon vehicles generally supported by representatives from business, environmental groups, and government are still underutilized in most parts of China. We try to provide an empirical answer to this question. The potential barriers we consider in this study include: limited natural gas supply, insufficient supply infrastructure, relatively high upfront and operational costs, and socioeconomic constraints. Specially, we anatomize the impacts of promotion policies in NGV development. Following the practice of Yeh (2007), we categorize all promotion policies into four groups: promoting NGVs in public transportation, construction planning of natural gas refueling stations, fiscal incentives, and relaxing restrictions on retrofitting of private vehicle. We then evaluate the effectiveness of these policies in a unique framework. Our empirical assessment is based on NGV adoption data collected in 168 Chinese cities. The regression results identify the followings factors of importance for NGV development: (1) coordinated development of refueling stations and NGVs, (2) relatively low price of natural gas compared to oil, and (3) policies that encourage private NGV use.

Section 2 lays out our methodology for testing four hypotheses about NGV market development. We present the results of multiple regressions analyses in Section 3, and discuss them in depth in Section 4. In the final section of the paper, we explore the policy implications of the study.

2. Methods

Past research highlights several factors that potentially influence NGV development; these include regional natural gas supply, supply infrastructure, socioeconomic indicators, and NGV-relevant policies.

An adequate natural gas supply is a prerequisite for developing NGVs, and most advanced NGV markets are concentrated in countries with rich natural gas reserves, such as Iran, Pakistan, Argentina, Brazil, China and India. These countries all have abundant natural gas resources and most of their domestic demand for gas could be satisfied with domestic supply (BP, 2014a). But more than just having rich resources, countries with developed NGV markets also have advanced infrastructure – namely pipelines and refueling stations – to bring the gas to consumers. Even in countries abundant in natural gas, resources are usually concentrated in a few areas. In order to ensure effective supply of natural gas, it is necessary for governments to step in and construct or improve natural gas pipelines at the early phase of NGV development, or offer incentives encouraging private investors to do so (Yeh, 2007).

The distribution of natural gas resources in China is uneven. In order to deliver the gas reserved in the western regions to other parts, especially the relatively developed eastern coastal regions, the Chinese government initiated the construction of the west-east gas pipeline, the most important natural gas infrastructure in the country, in 2002. Where it is complete, this pipeline will provide eastern China with easy access to abundant natural gas resources and incentivize local NGV development. In the meantime, NGV development has been stalled in most regions where the pipeline is still under construction.

Beyond pipelines, the availability of natural gas refueling stations is also crucial to NGV development. Consumers often base their purchasing decisions partly on whether there is a sufficient number of refueling stations around their home or place of work. This was true in Canada, where NGV market development initially benefited from the rapid development of refueling stations (Flynn, 2002); later, a reduction in investment in refueling stations caused Canada's NGV market to falter (Janssen et al., 2006). Until very recently, a lack of refueling infrastructure stalled compressed natural gas (CNG) light commercial vehicle development in the U. K. (Kirk et al., 2014).

Nevertheless, from a macro perspective, building more refueling stations does not automatically lead to better NGV development: the higher the ratio of refueling stations to NGVs, the lower the profitability of each station – sometimes causing the stations to go out of business (Flynn, 2002). Therefore, achieving a balance between the rate of development of NGVs and refueling stations is essential. Janssen et al. (2006) suggest that the ratio of NGVs to refueling stations maybe a good indicator of this balance (or imbalance). Based on their suggestion, Yeh (2007) proposed a vehicle-to-refueling-station index (VRI), i.e. the number of NGVs (in thousand) to the number of refueling stations. International case studies show that the ideal VRI value is close to one.

However, it is important to note that the optimal number of refueling stations in a region is not only determined by the potential number of NGVs, but also depends on city layouts. Because of safety considerations, natural gas stations are usually kept outside of residential areas with high population densities, such as the downtowns of Beijing or Shanghai. Therefore, the degree of concentration of cities is supposed to be negatively related to NGV development.

Beyond resource and infrastructure availability, the relative price of natural gas to gasoline (the fuel price ratio) also matters when consumers are making their decision about an NGV purchase. The fuel price ratio to a great extent determines the opportunity cost of adopting NGVs instead of conventional fuel vehicles. The lower the fuel price ratio, the more NGV drivers will save on fuel – incentivizing more consumers to convert to NGVs. On the other hand, high natural gas prices weaken the economic advantage of using NGVs, especially if the advantage of fuel cost savings cannot counteract the inconvenience caused by relative low engine power and high maintenance costs. In Nigeria, an insufficient price advantage of natural gas compared to gasoline is one of the principal impediments to the market development of NGVs (Ogunlowo et al., 2015). In contrast, in Argentina, the low natural gas price drives NGV development (Collantes and Melaina, 2011). A similar situation occurs in Sichuan, China, where natural gas is abundant and the fuel cost of driving an NGV per km is only half that of driving conventional gasoline vehicle (Ma et al., 2013). With this cost advantage, 17% of China's NGVs are located in Sichuan, where the total civil vehicles only account for 4% of the nation's total. Overall, in countries with high NGV market penetration, the price ratio of natural gas to gasoline is usually between 40% and 60% (Yeh, 2007).

If the price advantage of natural gas is not enough to incentivize drivers, preferential policies such as subsidies may be used to support the development of NGVs (Janssen et al., 2006). In Canada, for example, the federal government implemented a "kick start" program in 1984, which offered subsidies $500[5] for each

[5] The cost for converting an oil-based vehicle to an NGV was $2400–$2900 in 1984 (Flynn, 2002), and the $500 subsidy ranged from 17% to 20% of that cost.

NGV conversion and $50,000[6] for each natural gas station construction. Meanwhile, the federal government and most provincial governments eliminated retail taxes on NGVs. Together, these measures raised consumers' acceptance of NGVs, and the number of NGVs in use nearly doubled one year after the "kick start" policy initiated (Flynn, 2002).

The Chinese government has also used policy tools to promote NGVs in public transportation, develop natural gas refueling stations, and stimulate NGV-related research and manufacturing activities through fiscal incentives. For example, the cities of Harbin, Qingdao, Chongqing, Xi'an, and Wuhan implemented annual plans to promote NGV development.[7] Since 2003 Harbin has required all public vehicles to be run on alternative fuels.[8] The cities of Chongqing, Shenyang, and those in Anhui and Gansu provinces planned balanced development of NGVs and refueling stations over five years,[9] setting targets for natural gas station construction between 2001 and 2015. Through the "clean vehicle action" program, the city council of Dandong provides a RMB 1000 subsidy for each taxi that is converted into an NGV – and RMB 1500 for each bus. Chengdu set up a special fund to subsidize NGV buses and natural gas suppliers when the natural gas price increased significantly. In the province of Sichuan, income taxes imposed on some qualified clean vehicle R&D enterprises were eliminated in 2007. These policies were conducive to the growing popularity of NGVs in public transportation in the short run, and they prepared select cities and provinces for long-term development of an NGV sector. In addition to the above policies that are commonly applied in Chinese cities, some pioneerings have relaxed the restrictions on private vehicle modification and allowed private users to retrofit their conventional gasoline vehicles into NGVs. Going beyond the focus on public transportation, these policies also incentivize private vehicle owners to convert to NGVs.[10]

Based on the review of past research, we developed four hypotheses regarding the factors affecting China's NGV development.

Hypothesis 1. NGV markets develop better in areas with abundant natural gas supply.

Hypothesis 2. NGV markets develop better in areas with more balanced development between the vehicles themselves and natural gas refueling stations.

Hypothesis 3. NGV markets develop better in areas with a lower price ratio of natural gas to gasoline.

Hypothesis 4. Incentive policies can effectively promote NGV market development.

The following econometric model is used to test these hypotheses:

$$development_i = \beta_0 + \beta_1 gassupply_i + \beta_2 vrid_i + \beta_3 pratio_i + \beta_4 policy_i + \beta_5 income_i + \beta_6 income_i^2 + \beta_7 popd\_diff_i + \beta_8 vehicle_i + \mu_i \quad (1)$$

In this model, i stands for each sample city and μ_i for the regression residues. β_j for $j \in [1, 8]$ are the parameters to be estimated in our model. They represent how NGV development is related to each key factor. Corresponding to the four hypotheses, we include in this model four factors that potentially affect the development of NGVs. The first one is natural gas supply (*gassupply*), which represents the amount of natural gas that a city could get access to. This variable is evaluated with data on natural gas supply from China's 2013 city statistical yearbook, which covers all statistics about gas supplied by city gas enterprises to production users, household users, and others.[11]

Second, we include the *vri* , as proposed by Yeh (2007), to evaluate if the development of refueling stations and NGVs is balanced. A *vri* value of one represents an ideal balance in the coordination between NGVs and refueling stations, and any large deviation is expected to hinder the long-term development of the NGV sector. Based on this hypothesis, we run the regression with a modified variable (*vrid*). It measures the degree to which *vri* of a sample city is close to one. The variable is measured with Eq. (2):

$$vrid = |vri - 1| = \left| \frac{ngv}{refuel} - 1 \right| \quad (2)$$

where *ngv* represents NGV ownership (in thousand) and *refuel* represents the number of refueling stations. Data for both variables were acquired from the statistics of the NGV branch of the Society of Automotive Engineers of the Sichuan province (NGV Branch of SAE Sichuan) in 2012. The smaller the *vrid* value is, the higher the matching degree will be.

The third factor that may affect the development of NGVs is the fuel price ratio (*pratio*), which is the ratio of the unit natural gas price to the unit #90 gasoline price, as shown in Eq. (3). Such a comparison makes sense since an average oil-based vehicle run 12.5 km with one liter of gasoline, the same distance as an NGV could run with one cubic meter of natural gas (Ma et al., 2013). Price data for natural gas and gasoline are also from the NGV Branch of SAE Sichuan. As specified above, among the three common types of gasoline in Chinese markets, the "#90" gasoline price is chosen for our evaluation, since it is usually used as the benchmark price of natural gas by the National Development and Reform Commission (NDRC) (CPG, 2010).

$$pratio = price_{natural\ gas} / price_{\#90\ gasoline} \quad (3)$$

Finally, promotion policies (*policy*) are crucial for NGV development. Based on the function of each policy, we group them into

[6] Construction of a refueling station capable of accommodating 200–300 vehicles cost $300,000 in 1984 (Flynn, 2002), and the subsidy from Canadian Federal Government accounted for 16% of the total investment cost.

[7] Harbin ordered that, from 2003 onwards, all newly adopted public vehicles are vehicles use alternative fuel (http://www.cafv.com.cn/DisplayView/Vip/Policy/PolicyDetail.aspx?id=472). The municipal government of Qingdao ordered that all newly adopted taxis are cars that use dual fuel or compressed natural gas (CNG) since 2002, and 85% of in-use taxis and 50% of in-use buses were to be converted into CNG vehicles by the end of 2004 (http://www.cafv.com.cn/DisplayView/Vip/Policy/PolicyDetail.aspx?id=347). Chongqing planned to adopt 90,000 new CNG vehicles during 2001–2010 (http://www.cqdpc.gov.cn/article-1-8663.aspx). The municipal government of Xi'an required that all in-use city buses, taxis, and sanitation vehicles be converted to CNG vehicles by the end of 2003, and newly purchased vehicles must be NGVs (http://www.china.com.cn/chinese/PI-c/46526.htm). Wuhan issued a regulation that required 2000–2500 buses, 6000–7000 taxis, and many other vehicles to be converted into NGVs by the end of 2010 (http://www.chinalawedu.com/falvfagui/fg22016/228086.shtml).

[8] Other alternative fuel vehicles refer to vehicles using liquefied petroleum gas, methanol, ethanol, and biodiesel as fuels.

[9] Chongqing planned to construct 450 CNG refueling stations during 2001–2010 (http://www.cqdpc.gov.cn/article-1-8663.aspx). Shenyang planned to build 10 natural gas refueling stations during 2002–2005 (http://www.cafv.com.cn/DisplayView/Vip/Policy/PolicyDetail.aspx?id=472). Anhui province planned to construct 172 new natural gas refueling stations during 2011–2015 (http://www.ahwang.cn/anhui/2011/0614/939251.shtml). Gansu province planned to construct 57 natural gas refueling stations during the period of 2006–2010 and 205 during 2011–2015 (http://www.gsei.com.cn/html/wjhb/wjhb/694_135359.html).

[10] After-market conversion is refitting a gasoline car with a cylinder that could let the car use both gasoline and natural gas. Switching between fuels is controlled by a change-over valve. By the end of 2012, provinces allowing private vehicles to be retrofitted to NGVs include Sichuan, Xinjiang, Shandong, Ningxia, Gansu, Qinghai, Hebei, and Henan.

[11] In order to ensure internal consistency, all variables are evaluated with 2012 data.

Table 1
Descriptive statistics of variables.

Variable	Unit	Obs	Mean	Std.Dev.	Min	Max
ngv	10,000 units	168	1.0185	2.0756	0.0100	15.0000
penetration	%	168	2.5590	4.0327	0.0400	31.8200
gassupply	100 million m^3	168	3.7865	9.9740	0.0200	92.4800
vrid	1	168	0.6023	0.3328	0.0001	3.2424
pratio	1	168	0.5394	0.0869	0.2910	0.8200
P1_pub	1	168	0.2917	0.4559	0	1
P2_infra	1	168	0.3690	0.4840	0	1
P3_subsidy	1	168	0.0833	0.2772	0	1
P4_private	1	168	0.4405	0.4979	0	1
p2p4	1	168	0.1726	0.3790	0	1
income	RMB10,000	168	4.2171	0.9471	2.6800	8.5300
popd_diff	persons/km^2	168	795.0844	1063.1500	0.7000	7587.0000
vehicle	10,000 units	168	49.6095	56.9884	3.1000	493.6000

four categories, namely, promotion of NGVs in public transportation (*P1_pub*), developing natural gas refueling stations and other infrastructures (*P2_infra*), financial supports, such as subsidies and tax exemptions (*P3_subsidy*), and relaxing restrictions on converting private oil-based vehicles into NGVs (*P4_private*). Categorical variables are used to evaluate each policy. If one or more policies in a certain group have been implemented by the end of 2012, the value of that policy variable is one; otherwise, it is zero. We conducted an intensive documentation survey to determine the value of each policy variable in all the 168 sample cities (for more details and the sources, see Appendix A).

In addition to these key variables, we also control for income (*income*), vehicle ownership (*vehicle*), and city layout as represented by the difference in population density between urban and suburban areas (*popd_diff*). It is generally believed that personal income level affects consumers' NGV purchase decisions Gao and Kitirattragarn (2008). On one hand, for those with lower incomes, the marginally higher prices of NGVs or the fees for converting an oil-based vehicle to an NGV may be significant barriers to NGV adoption. High income earners may have an entirely different concern about NGVs: the engine performance. Generally, NGVs may not be readily adopted by those with either very high or very low incomes. Instead, they should be most welcome among groups with middle-income. Based on this deduction, we would presume that the relationship between NGV development and income levels follows an inverted U-shaped curve. On the other hand, urban communities with higher income levels are more likely to be concerned about the environment, and thus more likely to adopt clean energy vehicles, such as NGVs (Franzen, 2003; Kahn, 2007; Helveston et al., 2015). In this way, income can be used as a proxy variable for environmental ideology. We assume that all factors affecting vehicle ownership would also affect the development of NGVs, so civil vehicle ownership (*vehicle*) is selected as a control variable encompassing all these other factors. It may be reasonable to assume that NGVs are more likely to be located in areas with developed transportation sectors and a larger number of vehicles. Finally, suburban–urban difference in population density (*popd_diff*) reflects the spatial layout of a city. The value of *popd_diff* would be greater in cities where most people are concentrated in the downtown areas. We extrapolate that such a concentrated city layout would impede NGV development. Data for income, civil vehicle ownership, and population density are collected from China's 2013 city statistical yearbook.

The dependent variable of the model is NGV development level (*development*), which is measured with two factors: (1) NGV ownership (*ngv*) and (2) NGV market penetration (*penetration*). The former represents the absolute level of NGV development in a region and the latter stands for the relative level. Although the two variables are correlated in theory, they still have independent economic meanings. While the absolute ownership of NGVs measures the degree of acceptance and adoption of NGVs, market penetration represents NGV development relative to that of conventional vehicles. In other words, market penetration measures how NGVs compete in an automobile sector that is dominated by oil-based vehicles. Taking both variables into account, we can analyze NGV development more comprehensively. NGV market penetration (*penetration*) is calculated with Eq. (4) using data about civil vehicle ownership (*vehicle*) from China's 2013 city statistical yearbook (DUSEINBS, 2013) and national economic and social development statistical bulletins. Distribution of all variables is summarized in Table 1.

$$penetration = ngv/vehicle \tag{4}$$

3. Results

Multiple regressions are run to analyze the potential impact of the above factors on regional NGV development. Specifically, six regression models were introduced on the basis of the original model, as shown in Eq. (1). Models I and IV are pure market analysis. They respectively investigate how NGV ownership and its market penetration are influenced by market forces and established infrastructure, without considering the impact of policies. Such impacts are considered in Models II and V, with all four policy variables included as individual variables. Empirical evidence also shows that policies pertaining to natural gas refueling station construction (*P2_infra*) and NGV promotion in the private sector (*P4_private*) are complementary to each other, since a private NGV promotion policy tends to be more effective in regions with established natural gas station infrastructure. We further consider this interaction impact by including in Models III and VI a policy interaction variable of *P2P4*, which is the product of *P2_infra* and *P4_private*. The regression results are shown in Table 2.

4. Discussion

4.1. Natural gas supply

Across all six models, natural gas supply proves to be a significant factor that affects NGV development. As natural gas supply

Table 2
Regression results.

Variables	*ngv*			*penetration*		
	I	II	III	IV	V	VI
gassupply	0.4824***	0.4372***	0.3910***	0.4822***	0.4366***	0.3930***
	(6.10)	(6.45)	(6.12)	(6.14)	(6.51)	(6.19)
vrid	−0.1310*	−0.0487*	-0.0254	−0.1301*	−0.0483*	−0.0253
	(−1.86)	(−1.70)	(−1.03)	(−1.86)	(−1.72)	(−1.03)
pratio	−2.4538***	−1.8442***	−1.6192***	−2.4456***	−1.8261***	−1.6149***
	(−5.52)	(−4.63)	(−4.52)	(−5.54)	(−4.64)	(−4.54)
P1_pub		0.2554	0.1403		0.2524	0.1348
		(1.43)	(0.76)		(1.43)	(0.74)
P2_infra		0.4466***	0.1858		0.4467***	0.1849
		(2.80)	(1.06)		(2.82)	(1.05)
P3_subsidy		−0.0149	0.1074		-0.0006	0.1251
		(-0.07)	(0.37)		(−0.00)	(0.45)
P4_private		0.6666***	0.4826***		0.6677***	0.4817***
		(4.53)	(2.93)		(4.57)	(2.93)
p2p4			0.6504**			0.6522**
			(2.10)			(2.12)
income	10.0630***	8.4062***	7.4164***	10.0635***	8.3959***	7.3965***
	(3.42)	(3.15)	(3.08)	(3.44)	(3.17)	(3.07)
income^2	−3.8027***	−3.1446***	−2.7504***	−3.8025***	−3.1402***	−2.7455***
	(-3.97)	(-3.63)	(-3.53)	(-4.00)	(-3.65)	(-3.52)
popd_diff	−0.1388**	−0.0905*	−0.0570	−0.1382**	−0.0897*	−0.0576
	(−2.34)	(−1.66)	(−1.13)	(−2.34)	(−1.66)	(−1.15)
vehicle	0.4508***	0.3444***	0.3675***	−0.5480***	−0.6560***	−0.6346***
	(3.55)	(3.06)	(3.47)	(−4.34)	(−5.88)	(−6.02)
N	168	168	168	168	168	168
R^2	0.4743	0.6243	0.6179	0.4379	0.6064	0.6035
Adj. R^2	0.4513	0.5978	0.5883	0.4133	0.5787	0.5728
F	20.6215	23.5660	20.8871	17.8078	21.8503	19.6628
Prob > *F*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Notes: In order to eliminate heteroskedasticity, logarithmic transformation is performed for all variables except the categorical ones. Feasible generalized least squares estimate method (FGLS) is used for estimation. Residuals of each model follow normal distribution with a mean of zero. Figures in parentheses in the table are *t*-test values.

* Denotes significance at the 0.1 significance level.
** Denotes significance at the 0.05 significance level.
*** Denotes significance at the 0.01 significance level.

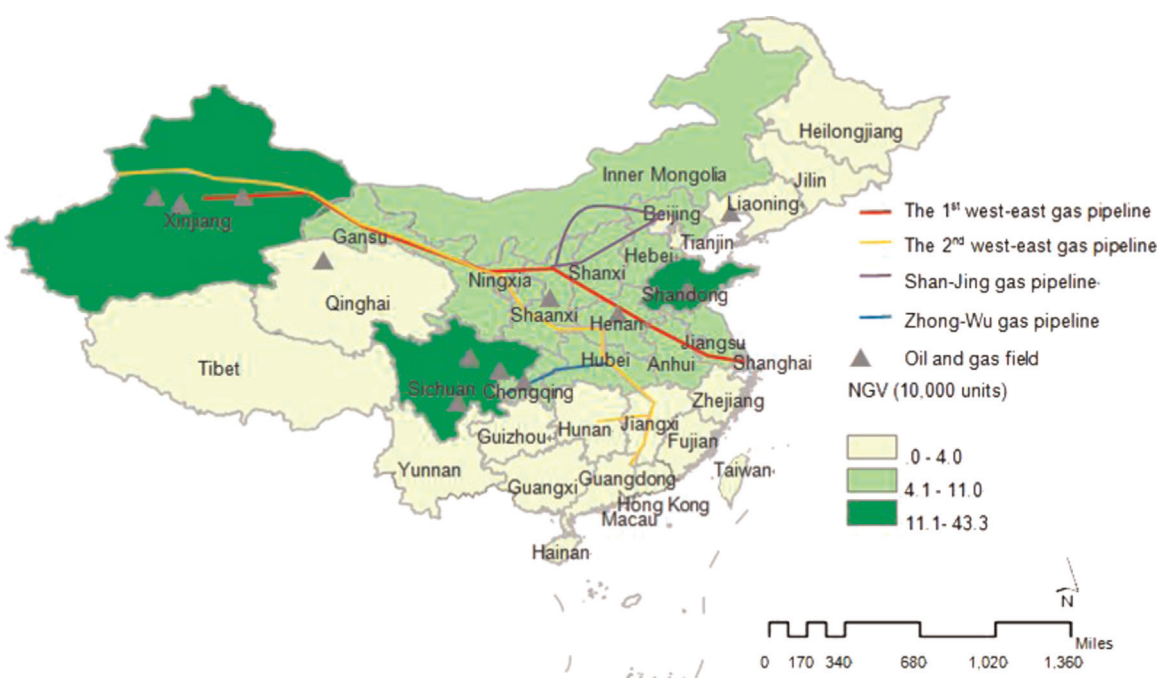

Fig. 1. NGV distribution in China (data source: Society of Automotive Engineers of Sichuan, Natural Gas Vehicle Branch). *Note*: All sample provinces are divided into three groups with hierarchical cluster analysis on NGV ownership. Location of gas pipelines are depicted approximately rather than based on exactly GIS coordinates. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

increases by 1%, NGV ownership and NGV market penetration increase by 0.4%, on average.[12] China's regionally unbalanced NGV development supports this finding. Almost 70% of NGVs are distributed in the six provinces of Xinjiang, Shandong, Sichuan, Hebei, Shaanxi, and Henan, which have abundant natural gas resources. If NGV ownership in Chongqing, Gansu, Ningxia, and Anhui are also included, the proportion reaches 80%. On the contrary, in provinces that lack natural gas supply, such as Zhejiang, Guizhou, Yunnan, Fujian, Jiangxi, Guangxi, and Tibet, less than 10,000 people own NGVs, and their combined contribution to national NGV ownership is under 2%. Geographically, the difference in NGV distribution in China is clearly related to the location of natural gas resources (see Fig. 1).

Through a hierarchical cluster analysis, all sample provinces are divided into three groups, according to NGV ownership. As shown in Fig. 1, the three provinces highlighted in dark green are categorized in group 1 as NGV developed regions. They are located either in major natural gas production regions or closely adjacent to them. Xinjiang is the province where the Tarim Basin is located. It has quite a few oil fields, and is the origin of the west-east gas pipeline. Similarly, Sichuan has four oil and gas fields, respectively located in its southern, central, northwest, and northeast regions of the province. Natural gas production in these two provinces in 2012 accounted for 23.6% and 22.6% of the national total, respectively (DESNBS, 2013). The other province with developed NGV markets, Shandong, is adjacent to the large oil and gas fields of Liaohe, Dagang, Zhongyuan, and Shengli.

Provinces in group 2 usually have relatively developed NGV sectors (highlighted by light green in Fig. 1) and could satisfy regional demands for natural gas in various ways. Among this group, the provinces of Gansu, Ningxia, Shaanxi, Shanxi, Henan, Anhui, and Jiangsu, are along the main channel of China's first west-east gas pipeline,[13] which transports about 11 billion m^3 of natural gas to these provinces each year. The Shan-Jing line covers Hebei and Inner Mongolia. Hubei is covered by the Zhong-Wu line, which starts in Zhong County in Chongqing. As the economic center of China's northwest region, Shaanxi is home to the Changqing gas field. The municipality of Chongqing, another major owner of NGVs, has large local gas fields in its own jurisdictions, as well as easy access to inexpensive gas resources from Sichuan.

The rest of the provinces are categorized as group 3, where NGV sectors are less developed (highlighted with yellow in Fig. 1). These provinces are located either along minor pipelines, such as the Shan-Jing gas pipelines and the branches of the west-east gas pipelines, or in regions without access to natural gas supply, thus have very limited access to natural gas supply. For instance, the Shan-Jing line covers Tianjin. Hunan and Guangdong are located along the second west-east pipeline. Natural gas supply in Qinghai largely depends on sterile gas fields in Qaidam Basin. In general, NGV ownership in these provinces is correspondingly low, with a total less than 190,000, accounting for only 9% of the national total.

Usually, it is the shortages in natural gas supply that restrict local NGV development. However, Beijing and Shanghai are two exceptions. NGV development in these two giant municipalities of China is rather limited, although Beijing and Shanghai have been supplied with plentiful natural gas from the first west-east pipeline as early as 2004. Yet in these two metropolises, both NGV ownership and market penetration are low. Why did sufficient natural gas supply fail to induce the rapid development of NGVs in these metropolises? High population density may explain it. Out of safety considerations, natural gas refueling stations are usually kept away from districts where residential and business communities are concentrated. This convention excludes refueling stations from most parts of Beijing and Shanghai, and makes it inconvenient for NGV drivers in the two cities to refuel their vehicles. Also due to safety considerations, the two municipal governments imposed very strict laws that limit after-market conversion of in-use vehicles to NGVs and intentionally maintain a high price for natural gas (BJGOV, 2013; Chinanews, 2013). Both practices are unfavorable to NGV development.

In addition to imbalanced distribution of NGV ownership across China, our data also reveals tremendous geographic variation in NGV market penetration. Generally speaking, market penetration follows the same pattern as NGV ownership in terms of geographic distribution: higher market penetration is usually observed in regions with higher NGV ownership, and lower market penetration occurs in regions with lower ownership. As shown in Table 3, 12 out of 19 cities with NGV market penetration higher than 5% are located in provinces with advanced NGV development and abundant natural gas resources. In contrast, in all regions with less developed NGV markets and limited access to gas resources, such as Tianjin, Beijing, Guangdong, and Shanghai, NGV market penetrations are below the average (less than 1.57%). There are exceptions, though: In the provinces of Shandong, Hebei, Anhui, Henan, and Jiangsu where NGV markets are developed or relatively developed, local NGV market penetration is still below average. This exception indicates the potential influence of other factors, such as infrastructure construction and incentive policies, on NGV development.

4.2. Balance between refueling stations and NGVs

As can be seen in the regression results, the balance between refueling stations and NGVs (measured by *vrid*) significantly influences NGV market penetration. The greater the deviation of the current NGV-refueling station matching level (*vri*) from the ideal level (defined as $vri=1$ by Yeh (2007)), the lower the penetration of NGVs among all civil vehicles. This result is confirmed by the scatter plot in Fig. 2. The *vri* value reflects the ratio of NGVs to refueling stations. A higher *vri* value suggests that individual refueling stations are supporting too many NGVs, which leads to longer waiting time for refueling, perhaps inconveniencing consumers to the point that they may be more reluctant to switch from a conventional vehicle to an NGV. A lower *vri* value, in contrast, means lower profitability or even bankruptcy of refueling stations, resulting in a short supply of refueling stations. This could also turn consumers away from NGVs. Thus, a reasonable strategy for a government to develop the local NGV sector is to maintain the ratio of NGVs (in thousand) to natural gas refueling stations at 1:1. For regions with excessive NGVs, this means speeding up construction of natural gas refueling stations, and for regions with idle refueling capacity, this means promoting the use of NGVs.

While most cities in our sample follow the rule of higher *vrid*, lower NGV *penetration*, there are some exceptions that deserve our special attention. For example, even with relatively few natural gas refueling stations, the cities of Dongying and Dezhou in Shandong province and Urumqi in Xinjiang province still maintain a high market penetration of NGVs (higher than 25%) among their civil vehicles. The popularity of NGVs in Dongying, Dezhou, and Urumqi

[12] Based on analysis in Section 4, the incentive policies are believed to contribute significantly to NGV development, so the effect of gas supply is estimated on the basis of Models II, III, V and VI, which include variables of incentive policies.

[13] The west-east gas pipeline project is built to transfer natural gas from the Tarim Basin in Xinjiang to China's eastern parts. Construction of the first pipeline commenced in 2002 and completed in 2004, covering Xinjiang, Gansu, Ningxia, Shaanxi, Shanxi, Henan, Anhui, Jiangsu, and Shanghai. The second pipeline was built 2008–2009, covering Xinjiang, Gansu, Ningxia, Shaanxi, Henan, Hubei, Hunan, Jiangxi, and Guangdong.

Table 3
NGV penetration in sample cities (unit: number of cities).

Province	Group	NGV penetration > 10%	5–10%	1.57–5%	< 1.57%	Total	Average penetration (%)
Shandong	1	2	2	2	11	17	4.2
Sichuan	1	1	4	11	1	17	4.8
Xinjiang	1	1	1			2	16.5
Hebei	2		1	3	7	11	1.9
Anhui	2			8	7	15	2.0
Chongqing	2			1		1	4.4
Gansu	2	1	2	2	1	6	5.6
Henan	2			5	12	17	1.4
Jiangsu	2				13	13	0.8
Ningxia	2	2	1			3	10.7
Shaanxi	2			8	2	10	2.4
Hubei	2			1	4	5	1.4
Inner Mongolia	2			5		5	2.0
Shanxi	2		1	3	7	11	1.7
Heilongjiang	3			1	1	2	1.4
Hunan	3				9	9	0.5
Jilin	3			2	3	5	1.4
Liaoning	3			1	6	7	0.9
Qinghai	3			1		1	4.5
Tianjin	3				1	1	0.9
Guangdong	3				8	8	0.2
Beijing	3				1	1	0.2
Shanghai	3				1	1	0.1
Total		7	12	54	95	168	2.6

Notes: Through hierarchical cluster analysis, all sample provinces are divided into three groups, Groups 1–3, which respectively refers to regions with developed, relatively developed, and less developed NGV sector. Average market penetration for each province is the average market penetration of the sample cities in that province.

may be attributed to sufficient natural gas supply and a long tradition of using natural gas as a major alternative power source. However, it is reasonable to forecast that the NGV sector would further develop if more refueling stations were built in these cities.

4.3. Price ratio of natural gas to gasoline

Price ratio of natural gas to gasoline (*pratio*) is another factor that significantly affects NGV development. The lower the ratio (i.e. relatively cheap natural gas compared to gasoline), the greater the local NGV ownership and the higher the NGV market penetration. This has been proven by all models. As suggested by Yeh (2007), we divide all sample cities into three groups: the high price group ($Pratio < 0.6$), the medium price group ($0.4 \leq Pratio \leq 0.6$), and the low price group ($Pratio < 0.4$). Yeh (2007) found that the price ratio of natural gas to gasoline in most countries with high NGV market penetration lies in the range of [0.4,0.6], which is partially confirmed with evidence from our sample. The ratio in most cities in China (over 70% in our sample) is kept in this range. While development of the NGV sector varies greatly among these cities, the average NGV penetration rate among this group still reaches 2.7%, above the national average. Another one fifth of sample cities could be defined as the high price group, which includes the cities of Beijing, Shanghai, and many others in the provinces of Guangdong, Liaoning, Hubei, and Hunan. The average NGV market penetration rate in the high price group is only 0.2%, and the total NGV ownership is less than 111,000, only 5.3% of the national total. For these cities, lowering the natural gas price using fuel subsidies could encourage car owners to retrofit their vehicles to use natural gas as fuel and incentivize potential customers to purchase NGVs. Comparing the medium and high price group, a relatively low fuel price ratio may be favorable for NGV development. Cities with extremely low fuel price ratios are few in China, only accounting for 8% of the total. Most of them are in areas with a large number of NGVs, such as Xinjiang, Gansu, and Inner Mongolia, with an average NGV market penetration topping 5%. People in Urumqi (in Xinjiang), in particular, own more than 150,000 NGVs, which accounts for more than 27% of the city's local civil vehicles. For these cities to further promote NGV development, a pricing strategy may not be a good choice.

It should be noted here that, thanks to the Chinese government's administrative control on fuel prices, we could separate the influence of fuel price on NGV development from that of natural gas supply. Although natural gas prices are theoretically determined by the interaction of demand and supply, this is not the case in China. Instead, fuel prices in China, including that of natural gas and gasoline, are strictly controlled by the NDRC. In our sample, the Pearson coefficient between fuel price ratio and natural gas supply is only 0.2123, indicating low correlation. Besides, the Variance Inflation Factor is less than 10, indicating non-collinearity between these two variables. Thus, we may conclude that relative natural gas price independently and negatively influence the development of NGVs in China.

4.4. Incentive policies

As mentioned in Section 3, four kinds of incentive policies have been implemented in China, including *P1_pub*, *P2_infra*, *P3_subsidy*, and *P4_private*. Two of them, i.e. popularization of NGVs in the public transportation sector (*P1_pub*) and economic incentives (*P3_subsidy*) played a very limited role in promoting NGV development in China. Compared to the large private sector, the number of public transportation vehicles is quite small. Thus, even a substantial increase in the share of NGVs in the public sector would not significantly raise NGV ownership or its penetration in the civil transportation sector as a whole. Similarly, one-off financial supports, such as subsidies, tax deductions, and exemptions for NGV purchases, do not sway consumers' vehicle purchasing decisions, and thus does not significantly promote NGV development. Only policies providing lasting incentives for the private use of NGVs

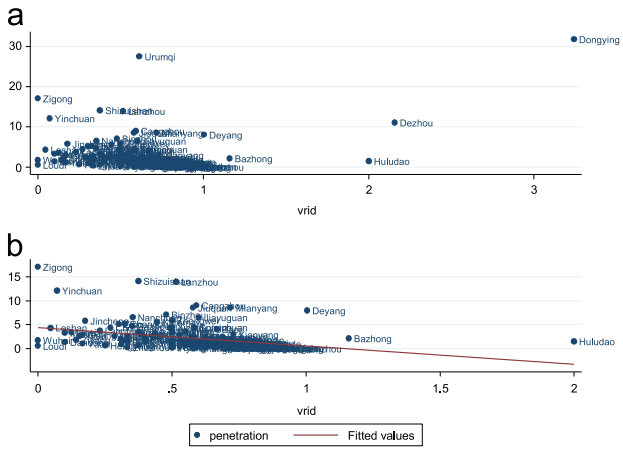

Fig. 2. NGV *penetration* and *vrid* of sample cities in China. *Note*: (a) covers all sample cities, whereas (b) excludes some far-lying ones, like Dongying, Dezhou and Urumqi, in order to exhibit the decreasing trend with a relatively high resolution.

could lead to the rise of a clean-energy vehicle sector in China.

It has already been shown in our analysis above that reducing NGV drivers' daily operation costs by lowering the relative price of natural gas is an effective policy tool available to a government if it plans to raise local NGV ownership and market penetration. Also, relaxing the restrictions on retrofitting private cars to NGVs, as well as other policies focusing on improving NGV development in the private sector (*P4_private*), could significantly contribute to NGV development. The policy effect of developing private NGV sectors would be further enhanced if sufficient natural gas refueling stations and other infrastructure were provided under the directions of NGV infrastructure construction policies (*P2_infra*). Policies encouraging after-market conversion and NGV development in the private sector are essential to the development of NGVs.

5. Conclusions and policy implications

With the missions of reducing carbon dioxide emissions per unit of GDP by 40–45% by 2020 compared to 2005 levels and reaching peak carbon dioxide emissions around 2030,[14] China is urgently seeking effective means to reduce oil consumption in the short term. Replacing conventional gasoline or diesel vehicles with NGVs in the transportation sector may be an effective strategy, since emissions in this sector contributed the most to China's carbon emissions growth in recent years. Overall, China's NGV sector is still underdeveloped. Despite the fact that its NGV ownership has been growing rapidly from 6000 in 2000 to 1.57 million in 2012, ranking the fifth in the world, China falls far behind other NGV developed countries in terms of market penetration, ranking 21st among 79 countries with NGVs. In-depth analysis of NGV development in China's prefecture-level cities reveals quite an imbalanced distribution across provinces. For instance, 63% of China's NGVs are located in the five provinces of Xinjiang, Sichuan, Shandong, Shaanxi, and Chongqing, where natural gas is abundant. In contrast, 37% of NGVs are scattered among all the other 26 provinces.

Varied market and policy factors potentially influence the development of NGVs. In addition to the supply of natural gas, our study confirms the roles of fuel price and private NGV promotion policies in China's NGV development. The findings align with common sense: (1) relatively high natural gas prices undermine the advantage of NGVs in terms of cost savings, thus potentially dampening consumers' willingness to embrace NGVs; (2) policies restricting the use of NGVs in the private sector, such as restrictions on after-market conversion of private vehicles, are the main barriers for NGV development in most regions. Relaxing these restrictions would greatly stimulate the market.

Some important policy implications could be derived from our study. First, the network of natural gas pipeline should be further extended so as to provide more access to natural gas across the country, especially the remote areas. As an initiative of public infrastructure construction, the task should be led by the government and possibly accomplished under two modules: (1) publish financed programs or (2) projects led by state-owned enterprises. The second module was undertaken in China and the PetroChina Company Limited was responsible for the first and second stages of the west-east gas pipeline construction. However, the business model caused some concern about monopoly in the natural gas supply market. Thus, more diversified capital, including National Council for Social Security Fund, the League of Nations Energy Industrial Investment Fund, and Baosteel Group Corporation, was involved in the third stage construction. We assume that diversified market structure is more suitable for the sustainable development of China's natural gas market, as well as its NGV market. Second, the government should subsidize natural gas and maintain a certain gradient between the gasoline price and the natural gas price, if it has a plan to develop NGVs. Such a subsidy could be justified by the large negative externalities of oil compared to natural gas. Third, adoption of NGVs should be encouraged through lifting restrictions on after-market conversion of private vehicles. Finally, small towns and cities with low population densities should be given priority in developing NGVs, since the construction of natural gas refueling stations is relatively easy and there is room for them in small cities. In addition, taking both economic advantages and low risks into consideration, NGVs are most likely to be adopted in small towns and cities where residents are more likely to earn middle incomes.[15] In contrast, plans to develop NGVs in metropolises should be postponed, since siting refueling stations in these areas is difficult.

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Appendix A

See Appendix Table A1.

[14] The first mission mentioned here is promised by China at the Copenhagen in 2010, and the second is at Asia-Pacific Economic Cooperation (APEC) meetings in 2014 (UNFCCC, 2010; IFENG, 2014).

[15] Empirical study of this paper shows that the relationship between NGV development and average income is inverted U-shaped, i.e. residents from middle-income cities are more willing to use NGVs (see Table 2).

Table A1
Incentive policies and sources.[a]

No.	City	Policy type[b] P1	P2	P3	P4	Names of the policies	Sources[c]
1	Anqing		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
2	Anyang				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
3	Baiyin		Y		Y	Twelfth five-year gas stations development planning in Gansu province	http://www.gsei.com.cn/html/wjhb/wjhb/694_135359.html
4	Baoding	Y		Y	Y	Implementation plan for promoting liquefied natural gas (LNG) bus and long-distance passenger vehicles in Baoding	http://info.bd.gov.cn/content.jsp?code=000445835/2012-02030
5	Bazhong	Y	Y		Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
6	Beijing	Y	Y			Development plan for clean vehicle promotion and refueling stations construction in Beijing	http://www.cngascn.com/up_files/news/18959000.pdf
7	Bengbu		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
8	Binzhou				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
9	Bozhou		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
10	Cangzhou				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
11	Changchun	Y				Development plan for clean vehicle in Changchun	http://economy.enorth.com.cn/system/2001/08/02/000106295.shtml
12	Changsha	Y				Notice about speed up the development of compressed natural gas vehicles in Changsha	http://gov.rednet.cn/c/2006/09/26/991980.htm
13	Changzhou	Y		Y		Implementation plan for promoting NGVs in Changzhou	http://wenku.baidu.com/link?url=grfqYWVsfsz3xRN07Spfgro3IqHInfUHrXSD7YwkbSLDBBaR6hZDfm0g-DbVwLak44eRbF7Ch_rbV8KC5m5Y-i1c0f__f3PyyNGo6SOPgvi
14	Chengde				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
15	Chengdu	Y	Y	Y	Y	CNG refueling stations construction plan in Chengdu; Detailed rules for special gas prices adjust funds management in Chengdu	http://www.chengdu.gov.cn/GovInfoOpens2/detail_ruleOfLaw.jsp?id=BIeNQC8TlrjbHijoY7Z2 http://www.chengdu.gov.cn/law/detail.jsp?id=998
16	Chizhou		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
17	Chongqing	Y	Y	Y		Promotion plan for NGVs in Chongqing; Incentives related to promoting NGVs in Chongqing	http://www.cqdpc.gov.cn/article-1-8663.aspx http://govinfo.nlc.gov.cn/search/htmlflash4Radar?docid=586196
18	Chuzhou		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
19	Dandong	Y		Y		Development plan for clean vehicle in Dandong	http://www.chinalawedu.com/falvfagui/fg22016/146412.shtml
20	Daqing	Y	Y			Development and implementation plan for compressed natural gas vehicles in Daqing	http://www.daqing.gov.cn/zfgw/szfbwj/4636.shtml
21	Dazhou	Y	Y		Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
22	Deyang	Y	Y		Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
23	Dezhou		Y		Y	Natural gas refueling stations construction plan in Dezhou	http://www.dezhou.gov.cn/n1070/n52119/n52120/n52144/n52145/344690_4.html
24	Dongguan	Y	Y	Y		Natural gas refueling stations construction plan in Dongguan; Incentives for promoting NGVs in Dongguan	http://www.gd.xinhuanet.com/newscenter/2008-09/16/content_14410195.htm. http://www.dgeia.com/news/2009/200908/2009-08-26/20090826104053_2224.shtml
25	Dongying		Y		Y	Natural gas refueling stations construction plan in Dongying	http://www.jyz.com.cn/glzq/ShowArticle.asp?ArticleID=22393
26	Erdos	Y				NGVs running test in Erdos and the surrounding areas	http://www.most.gov.cn/dfkj/nmg/zxdt/201203/t20120305_92994.htm
27	Fuyang		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
28	Guang'an	Y	Y		Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
29	Guangyuan	Y	Y		Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
30	Handan				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
31	Hanzhong		Y			Natural gas refueling stations construction plan in	http://www.hanzhong.gov.cn/xxgk/gkml/zfjzfbwj/hzfwj/201410/t20141018_20735.html

Table A1 (*continued*)

No.	City	Policy type[b]				Names of the policies	Sources[c]
		P1	*P2*	*P3*	*P4*		
						Hanzhong	
32	Harbin	Y	Y			Tenth five-year NGVs development planning in Harbin	http://www.chinaev.org/DisplayView/Vip/Policy/PolicyDetail.aspx?id=472
33	Hebi				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
34	Hefei		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
35	Hengshui				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
36	Heze				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
37	Huaibei		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
38	Huainan		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
39	Jiaozuo				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
40	Jiayuguan		Y		Y	Twelfth five-year gas stations development planning in Gansu province	http://www.gsei.com.cn/html/wjhb/wjhb/694_135359.html
41	Jinan	Y	Y		Y	Promoting natural gas bus in Jinan; Tenth five-year NGVs development planning in Jinan	http://www.sd.xinhuanet.com/news/2011-04/27/content_22632924.htm http://www.most.gov.cn/dfkjgznew/200506/t20050624_22710.htm
42	Jining				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
43	Jiuquan		Y		Y	Twelfth five-year gas stations development planning in Gansu province	http://www.gsei.com.cn/html/wjhb/wjhb/694_135359.html
44	Kaifeng				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
45	Karamay	Y			Y	Promoting natural gas bus in Karamay	http://www.mofcom.gov.cn/aarticle/difang/xinjiang/201006/20100606980297.html
46	Laiwu				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
47	Langfang	Y	Y		Y	Clean vehicle promotion in Langfang	http://www1.lf.gov.cn/WebSite/Item/4656.aspx
48	Lanzhou	Y	Y	Y	Y	Government subsidies for natural gas bus and taxi in Lanzhou; Twelfth five-year gas stations development planning in Gansu province	http://lzcb.gansudaily.com.cn/system/2010/09/24/011705237.shtml
49	Leshan	Y	Y		Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
50	Liaocheng				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
51	Linyi				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
52	Lu'an		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
53	Luohe				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
54	Luoyang				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
55	Luzhou	Y	Y		Y	Development plan for clean vehicle industry in Luzhou	http://www.sc.gov.cn/zwgk/jjjs/jjdt/200804/t20080414_268205.shtml
56	Lvliang		Y			Natural gas refueling stations construction in Lvliang	http://www.llfgw.gov.cn/5/qhllllls2012nsqgzzjj2013.htm
57	Maanshan		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
58	Meishan	Y	Y		Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
59	Mianyang	Y	Y		Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
60	Nanchong	Y	Y		Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
61	Nanjing	Y				Implementation plan for promoting NGVs in transportation sector in Jiangsu	http://www.jiangsu.gov.cn/jsgov/tj/jtyst/201212/t20121207_300167.html
62	Nantong	Y				Implementation plan for promoting NGVs in transportation sector in Jiangsu	http://www.jiangsu.gov.cn/jsgov/tj/jtyst/201212/t20121207_300167.html
63	Nanyang				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
64	Neijiang	Y	Y		Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
65	Pingdingshan				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
66	Puyang				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
67	Qingdao	Y	Y	Y	Y	Clean vehicle promotion in Qingdao	http://auto.enorth.com.cn/system/2005/06/06/001039009.shtml
68	Qingyang		Y		Y	Twelfth five-year gas stations development planning in	http://www.gsei.com.cn/html/wjhb/wjhb/694_135359.html

						Gansu province	
69	Qinhuangdao	Y			Y	Suggestions on NGVs promotion in Qinhuangdao	http://www.qhd.gov.cn/front/zfthird.action?id=65409&tid=127
70	Rizhao				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
71	Sanmenxia				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
72	Shangluo		Y			Twelfth five-year natural gas refueling stations development planning in Shangluo	http://www.shangluo.gov.cn/info/1054/4623.htm
73	Shangqiu				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
74	Shenyang	Y				Promoting natural gas bus in Shenyang	http://www.chinanews.com/df/2011/07-27/3214749.shtml
75	Shenzhen	Y	Y	Y		Natural gas refueling stations construction planning in Shenzhen	http://www.sznews.com/news/content/2006-06/03/content_140001.htm
76	Shijiazhuang				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
77	Shizuishan				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
78	Suining	Y	Y		Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
79	Suzhou-Jiangsu	Y				Implementation plan for promoting NGVs in transportation sector in Jiangsu	http://www.jiangsu.gov.cn/jsgov/tj/jtyst/201212/t20121207_300167.html
80	Suzhou-Anhui		Y	Y		Development plan for NGVs in Suzhou	http://www.110.com/fagui/law_117994.html
81	Tai'an				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
82	Taiyuan		Y			Natural gas refueling stations construction planning in Taiyuan	http://www.sx.xinhuanet.com/newscenter/2010-09/14/content_20893215_4.htm
83	Taizhou	Y				Implementation plan for promoting NGVs in Taizhou	http://law.baidu.com/pages/chinalawinfo/1726/19/10de949b0ce264562275eaa7eee3a3be_0.html
84	Tangshan				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
85	Tianjin	Y	Y	Y		Development plan for NGVs in Tianjin	http://www.ccin.com.cn/ccin/news/2007/10/29/25298.shtml
86	Tongling		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
87	Urumqi			Y	Y	Subsidies for natural gas price in Urumqi	http://xjny.ts.cn/content/2012-02/09/content_6558525.htm
88	Weifang				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
89	Weihai				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
90	Wuhan	Y	Y			Development plan for NGVs in Wuhan	http://www.chinalawedu.com/falvfagui/fg22016/228086.shtml
91	Wuhu		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
92	Wuwei		Y		Y	Twelfth five-year gas stations development planning in Gansu province	http://www.gsei.com.cn/html/wjhb/wjhb/694_135359.html
93	Wuxi	Y				Implementation plan for promoting NGVs in transportation sector in Jiangsu	http://www.jiangsu.gov.cn/jsgov/tj/jtyst/201212/t20121207_300167.html
94	Xi'an	Y	Y	Y		Eleventh five-year NGV industry development planning in Xi'an	http://wenku.baidu.com/link?url=qIjM7atJmBsChfJp-Dzlh_Zi4Hnyzf0_tkTH1bjCQOF4LVkM96_pCo8mB79RsbSnkh670XZs2-_Ijej28Rc9DgMxapc6A7VbjipiGMDeDXu http://www.chinalawedu.com/news/1200/22598/22604/22705/22723/2006/4/xi538016464416460021 1224-0.htm http://www.china.com.cn/chinese/PI-c/46526.htm
95	Xingtai				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
96	Xining				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
97	Xinxiang				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
98	Xinyang				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
99	Xinzhou		Y			Natural gas refueling stations construction in Xinzhou	http://xinzhou.china.cn/txt/2008-09/11/content_2468269.htm
100	Xuancheng		Y			Twelfth five-year natural gas refueling stations development planning in Anhui province	http://www.ahwang.cn/anhui/2011/0614/939251.shtml
101	Xuchang				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
102	Yaan	Y	Y		Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
103	Yangquan	Y	Y			Natural gas refueling stations construction in Yangquan	http://laws.66law.cn/law-119187.aspx
104	Yantai				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
105	Yibin	Y	Y		Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
106	Yinchuan	Y	Y	Y	Y	Clean vehicle promotion in Yinchuan	http://www.zhb.gov.cn/zhxx/gzdt/200709/t20070928_109642.htm. http://www.chinacar.com.cn/news/news_12_69504.html
107	Yingkou		Y			Natural gas refueling stations construction plan in Yingkou	http://www.yingkou.gov.cn/gkml/shizhengfu/syj/201203/t20120317_187475.htm
108	Zaozhuang				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
109	Zhangjiakou				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
110	Zhanjiang	Y				Natural gas bus promotion in Zhanjiang	http://www.zhanjiang.gov.cn/_Layouts/ApplicationPages/Modules/TFightTBuild/TFightTBuildDetail.aspx?id=0E9FF1CA-

Table A1 (*continued*)

No.	City	Policy type[b] P1	P2	P3	P4	Names of the policies	Sources[c]
111	Zhaoqing		Y			Natural gas refueling stations construction plan in Zhaoqing	BA69-435A-9594-3D1025ACD03F http://www.zqgx.gov.cn/dw-bsdt/infoopen/News_View.aspx?id=148
112	Zhengzhou				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
113	Zhenjiang		Y			Implementation plan for promoting NGVs in transportation sector in Jiangsu	http://www.jiangsu.gov.cn/jsgov/tj/jtyst/201212/t20121207_300167.html
114	Zhongshan		Y	Y		Natural gas refueling stations construction plan in Zhongshan	http://www.zs.gov.cn/main/zwgk/open/view/index.action?id=23000
115	Zhongwei				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
116	Zhoukou				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
117	Zhumadian				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
118	Zibo				Y	Lift ban on private vehicles' retrofitting	NGV Branch of SAE-Sichuan
119	Zigong		Y	Y	Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml
120	Ziyang		Y	Y	Y	Development plan for clean vehicle industry in Sichuan province	http://www.sc.gov.cn/sczb/lmfl/szfbgt/200708/t20070821_198409.shtml

[a] Cities which have not implemented any of the four policies before the end of year 2012 are not included in this table.
[b] *P1*, *P2*, *P3*, and *P4* refer to the policy variables of *P1_pub*, *P2_infra*, *P3_subsidy*, and *P4_private*, respectively. If any policy in each category is implemented in the city, its value of corresponding variables is "Y", otherwise, it is null.
[c] Information regarding promotion of NGV in private sectors (*P4_private*) is from the NGV Branch of SAE-Sichuan.

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