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A Modelling Approach to Supply and Demand of Gasoline in the Passenger Car Sector in China up to 2030

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Gasoline and diesel consumption in China have been increasing, but at rather different rates. It is expected that their increase rates will differ further due to slow down of the economy, mainly affecting diesel demand, and fast development of the private car sector thus fast increase in gasoline. On the supply side, a certain degree of uncertainty and flexibility also exist, mainly resulting from potential changes in oil import amount and quality, development of alternative liquid fuels, retrofitting refineries and building new ones, and others. In this paper, this paper presents a modelling based approach to analyse supply potential and flexibility of gasoline up to 2030, and the demand for gasoline from the private car sector under various development scenarios. Results indicate that production ratio between diesel and gasoline in China can change in the range between 1.27 and 2.92. A gap of 20 Mt between demand and supply of gasoline may appear around 2019.

1. Introduction

Most gasoline and diesel are obtained from the oil refinery industry in China. Passenger cars consumed 86.3 Mt gasoline in 2014, and it is about 83 % of the total gasoline consumption (National Bureau of Statistics of the People's Republic of China, 2014). Ratio of gasoline to diesel decreased in both the production and consumption sections from 2004 to 2014. The sale volume and total stock of passenger cars will increase rapidly in the future. However, the development rate of economy in China will slow down. That means the trend that the ratio of gasoline to diesel will not change in the future. When the consumption ratio of gasoline to diesel meets the minimum production ratio of gasoline to diesel, the oil refinery industry only follows the production one. The balance of production and consumption of gasoline will be broken. This paper does not consider the price effect of diesel and gasoline directly. The effect of diesel price is included in the setting of demand growth rate of diesel. The effect of gasoline price is included in the setting of the proportion of other passenger cars.

In the aspect of gasoline consumption trend in China, Ou et al. (2010) analysed the energy consumption in transport section and carbon emission trend. Huo et al. (2012) analysed the influence of fuel economy, dieselization, electric and fuel diversification on the energy consumption in the transport section and pollutant emission. However, there is little accurate modelling for gasoline consumption calculation in passenger car section and little analysis of fuel economy and average annual mileage in the energy consumption calculation for passenger cars. In the calculation and forecast of gasoline consumption in passenger car section, few researches consider how the ratio of gasoline to diesel in refinery affects gasoline supply.

This paper aims at predicting the changing range of the ratio of gasoline to diesel based on the present refinery industry in China and then calculating the maximum gasoline production for passenger cars. Based on the growth model of passenger cars, the gasoline consumption in passenger car section up to 2030 is predicated. Comparing the predicated gasoline production and consumption, this paper aims to estimate whether the future consumption exceeds the production.

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2. Forecast of gasoline and diesel yield from China's refining sector

2.1 Virtual refinery model

The refining processes in China can be divided into three parts: primary process, secondary process and extended process. Extended process is a deepening processing procedure, mainly to produce chemicals. As this paper mainly aims at the productivity of gasoline and diesel, only primary and secondary processes are considered. Adding up all the primary and secondary processing technologies, a virtual refinery model at the national level is built, in which the capacity of each unit is the summation of all corresponding unit capacities in the whole country. Figure 1 presents the virtual model. The connections between units include all feasible connections based on actual refining processes and satisfy the basic physic rules. Crude is inputted into the virtual refinery to get primary crude fraction. Primary process is a physical procedure, so the yields of primary products are decided by the crude property. Secondary process takes primary crude fraction as raw material to obtain the final end products. The yields of end products from each unit are set to a range according to the actual production of refinery. All the yields of end products are mutually restricted due to mass conservation. Setting the yields of the end products except gasoline and diesel into a reasonable range is necessary to optimize the yield of gasoline and diesel. When the crude volume, capacity of each unit and the demand for end products except gasoline and diesel are given, the minimum and maximum gasoline and diesel production and the flexibility can be calculated.

Primary crude fraction mainly contains Naphtha, Diesel and Kerosene, Vacuum gas oil and Vacuum residuum. This paper does not consider the energy required by refineries. The proportion of coke and refinery gas as the energy for refineries becomes larger and larger, so coke and refinery gas can substitute a large part of residuum; the demand of crude in China mainly depends on import, so the situation of fuel for engines and resource for chemical industry is serious; considering the energy security, residuum and light dydrocarbon should not be used as resources for refineries. Additionally, energy saving of refineries is taken seriously, so the proportion of residuum as the fuel for refineries is smaller (Hua, 2005). The crude for refineries in China is a mixture of domestic crude and import crude. The proportion of import crude is 59 % in 2014 (National Bureau of Statistics of the People's Republic of China, 2014). The average crude fraction ratio is obtained by weighted average of domestic crude and import crude. The quality of the import crude will be controlled for the matching between crude quality and domestic refining technologies, so crude fraction ratio of 2014 is taken up to 2030 in this paper for convenience. The capacity of primary processing will reach 940 Mt in 2030 (Economic and Technical Research Institute of CNPC, 2014). The capacity of secondary processing is obtained by an extrapolation based on average annual growth rate of primary and secondary processing capacity from 2010 to 2014. The yield range of other end products is set based on the maximum and minimum yields from 2010 to 2014.

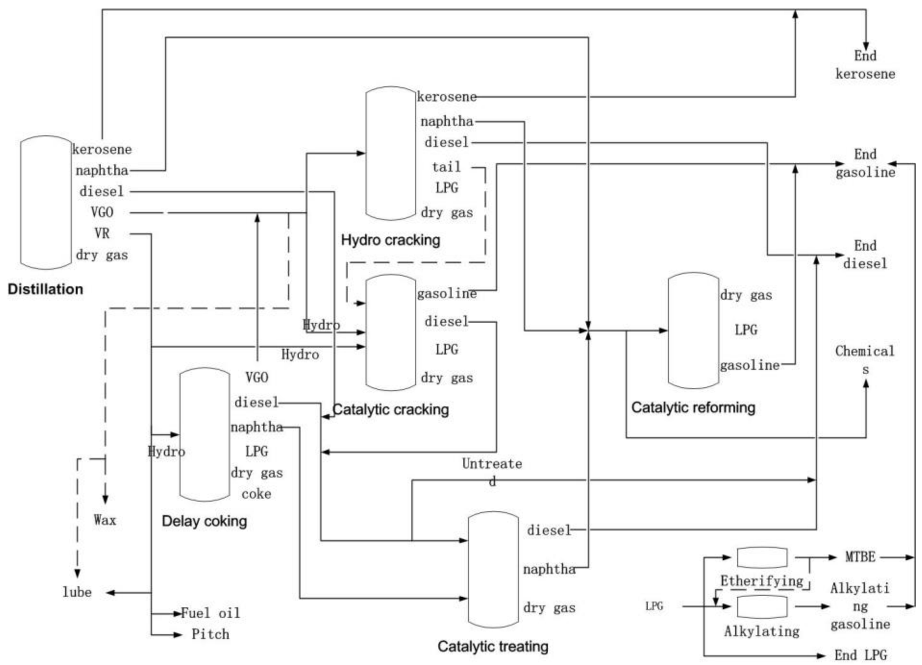

Figure 1: The structure of virtual refinery model at the national level in China

2.2 Results analysis

According to the results of model calculation, the adjustment range of gasoline and diesel ratio is 1.27~2.92. When the ratio reaches the minimum number 1.27, the gasoline yield is about 25.5 %, and the diesel yield is about 32.4 %. Assuming the diesel production volume is equal to consumption volume, the maximum gasoline supply volume for passenger cars can be calculated through dividing the demand of diesel by the minimum ratio of gasoline to diesel and subtracts the demand of gasoline in other sections apart from passenger car section. The report of Economic and Technical Research Institute of CNPC (2014) showed that crude oil consumption increases with a low growth rate and high gasoline consumption and low diesel consumption will be the new trend in the future; considering many factors, the researches of Li and Yuan (2015) and Resources and Environmental Policy Research Institute under the State Council Development Research Center (2013) showed that the growth rate of diesel consumption will slow down in the future. This paper sets the growth of diesel demand between 2015 and 2020, 2020 and 2025, 2025 and 2030 are 1.5 %, 1.2 % and 1.0 %. The demand of gasoline in other sections is relatively small compared with passenger car section. The result shows that the maximum gasoline supply for passenger cars is 150 Mt.

3. Forecast growth model of passenger car considering alternative fuel

3.1 Forecasting model

A prediction of total passenger cars is a base of the predication of the total gasoline consumption. If the total stock $TSTOCK_N$ and $TSTOCK_{N+1}$ in N^{th} year and $N+1^{th}$ year is known, their difference is the net increase of total passenger car stock. For passenger cars using fuel j, the difference between the N^{th} year stock and the $N+1^{th}$ year survival out of the total sale in previous N year is the number of scrap for passenger cars using fuel j. Summing all the number of scrap in $N+1^{th}$ year no matter what fuel to get the total scrap number, the $N+1^{th}$ year sales can be calculated by adding the total scrap number and the net increase of total passenger car stock. According to the sales ratio of passenger cars using difference fuel, the sales of passenger cars using fuel j in $N+1^{th}$ can be calculated. Combined with the sales in previous N year, the sales in previous N+1 year can be obtained. Then $N+1^{th}$ year stock of passenger cars using fuel j can be calculated considering the survival rate. The input parameters for this model are total stock of passenger cars, passenger car survival rate and the sale proportion of passenger cars using different fuel. Here the total stock is not distinguished by different fuels but only forecasting the demand of passenger cars.

3.2 Preparation of input parameters

Passenger cars are divided into private cars, business cars and taxis. The stock of private cars is mainly decided by purchasing ability and purchasing desire. Here the annual disposable income is used to represent the purchasing ability. There is a positive correlation between the desire to purchase a car and the private car ownership. The calculation for private passenger car ownership is described as follows:

$$TSTOCK_{private} = \frac{PL(t)}{1000} \int_0^{\infty} F(x) S(x) dx \quad (1)$$

PL(t) is the population of China and it is a function of time. F(x) is the distribution of annual disposable income in China which obeys the law of lognormal distribution (Shen, 2006). S(x) is a Gompertz function which matches the growth of private passenger car ownership per thousand people related to annual disposable income. The effect of price and purchasing desire is covered in S(x).

There is good linear correlation between ownership of business passenger cars and GDP：

$$TSTOCK_{business} = 18.553 GDP(t) + 85.264 \quad (2)$$

The stock of taxis is controlled based on related policies. The stock of taxis is related with urbanization rate. Assuming that taxi stock and urbanization rate meet the linear relationship, the equation is as follow:

$$TSTOCK_{Taxi} = 111.28 UR + 44.13 \quad (3)$$

The stock of passenger cars in Nth year consists of the sales of Nth year and cars sold before which are still working. Improvements of fuel economy and the use of alternative fuels can only be completed by car replacement. Based on existing research (Hao et al., 2011), Weibull distribution is used to describe the survival rule of passenger cars and Table 1 shows the parameters for the equation:

$$SR(t) = e^{-\left(\frac{t}{T}\right)^k} \quad (4)$$

Table 1: Parameters for survival function of passenger car in China

Parameters	Private	Business	Taxi
T	14.46	13.11	6
k	4.79	5.33	∞

Li et al. (2015) considered eight options of alternative fuels. Based on the technical maturity and the development level, the alternative fuels considered here mainly consists of electric power, natural gas, ethanol and methanol. The ratio of passenger cars using mixed fuel with ethanol and methanol has no effect on the total stock of passenger cars using gasoline. However, the substitution amount of ethanol and methanol will affect the total demand of gasoline. In this part, only the electric power, natural gas are considered as the alternative fuels to calculate the stock of passenger cars using different fuels.

The whole country has been divided into 3 groups in electric vehicle (EV) and plug-in hybrid electric vehicle (PHEV) promotion for private and business electric power passenger cars based on the economy and the environment in different regions. First group covers 10 provinces, such as Beijing, Shanghai which are in heavy atmospheric pollution or are well developed and their sale targets are no less than 3 %, 4 %, 5 %, 8 % and 10 % from 2016 to 2020. Second group covers midland provinces including Anhui et al. whose sale targets are 2 %, 3 %, 4 %, 5 % and 6 %. Other provinces are in the 3rd group whose sale targets are 0.5 %, 1 %, 1.5 %, 2 % and 3 % (Ministry of Science and Technology, 2016). The forecast from 2020 to 2030 can be obtained by extrapolation. The annual passenger car sales ratio nationwide of different groups are needed to obtain the national average of electric passenger car sales ratio. In the sales of electric passenger cars, in 2014 EV accounted for 60 % and in 2015 the proportion was 66 % (China Automotive Technology Research Centre and China Automobile Industry Association, 2014). With the gradual improvement of the charging infrastructure and the development of EV, the proportion of PHEV will gradually reduce. This section assumes the proportion of PHEV decrease at a rate of 2 % a year with a criterion in 2015 up to 2030.

Private and business CNG passenger cars develop well in Sichuan, Chongqing, Xinjiang and Shandong because of the rich resource of natural gas and low price. Considering that electric power cars are in key promotion, the sale of private and business CNG passenger cars in other provinces is assumed to zero. According to historical data, annual private and business CNG passenger car sales ratio is 3 % in total passenger car sales nationwide.

Based on the above analysis, this section assumes that Beijing, Shanghai and Shenzhen mainly develop electric power taxis. The other provinces mainly develop natural gas taxis follow the present trend and policy. This section assumes that the proportion of electric power taxis changes linearly and reaches 15 % in 2030 and the remaining is natural gas taxis. The trend of natural gas taxis is obtained by extrapolating present trend.

3.3 Calculation results

This section divides private and business passenger cars into one group because the respective ratio of private and business passenger cars is difficult to obtain and the total stock of business passenger cars is relatively small compared to private passenger cars.

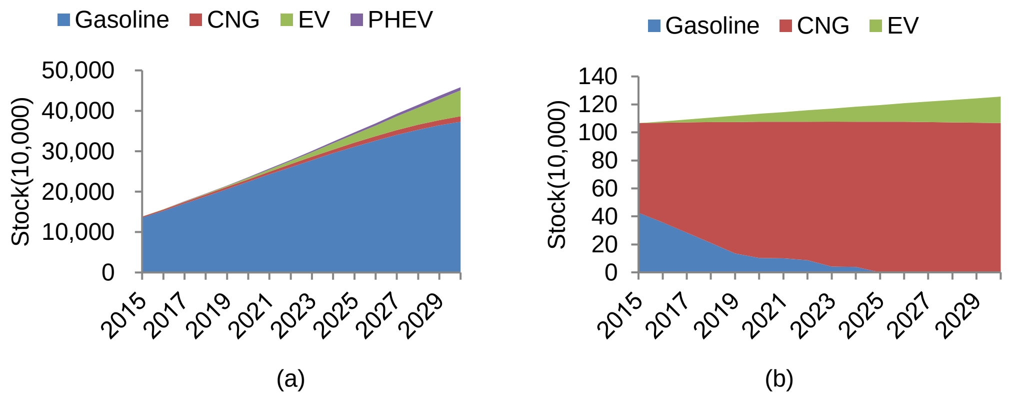

Figure 2: (a) Stock of private and business passenger cars from 2015 to 2030 and (b) Stock of taxi from 2015 to 2030

The results indicate that the sale ratio of gasoline passenger car is 68.4 %, the 3 % of CNG, 27.4 % of PE and 1.1 % of PHEV in 2030. Figure 2(a) and Figure 2(b) show the calculation results. The result shows that in private and business car sector, gasoline cars still account for most percentage of the total stock and the total stock reaches 450 M in 2030. In taxi sector, gasoline taxi decreases year by year and will disappear in 2025.

4. Gasoline consumption calculation based on the passenger car growth model

4.1 Preparation of Parameters

The gasoline consumption of passenger cars in Nth year is equal to a product subtracting the demand of alternative fuel, such as fuel ethanol and fuel methanol. The product is equal to the Nth year stock of passenger cars using gasoline multiplies actual gasoline consumption rate per passenger car in Nth year and average annual mileage of all passenger cars in Nth year.

The consumption of gasoline per car is expressed by nominal gasoline consumption per hundred km. Since 2003 the average nominal gasoline consumption per hundred km of passenger cars decreased from the 9.11 L/100 km down to 7.31 L/100 km in 2013 resulted from the government policy (Innovation Centre for Energy and Transportation, 2014). The average nominal gasoline consumption per hundred km from 2020 to 2030 is assumed decreasing from 5.0 L/100 km to 4.0 L/100 km referring to the target of developed country.

The actual gasoline consumption is generally higher than nominal gasoline consumption because traffic congestion becomes serious with the increasing of passenger car stock. This section represents traffic congestion using stock of passenger cars per thousand people. Gasoline consumption ratio of actual and nominal for passenger cars increased from 1.12 to 1.27 between 2008 and 2014 (Innovation Centre for Energy and Transportation, 2015). The maximum of gasoline consumption ratio of actual and nominal is assumed to 1.4 considering the urban conditions and bad driving habits.

The average mileage per year of taxi is 100,000 km (Huo et al., 2012). The average annual mileage of private and business passenger cars decreased from 29,000 km in 2004 to 10,000 km in 2011 and trended to stabilize. The average annual mileage of private and business passenger cars is assumed to 9,500 km considering the traffic congestion and government policy to limit driving.

When the gasoline consumption of passenger cars is calculated, the demand of alternative fuel should be subtracted by converting to the demand of gasoline. The production of fuel ethanol is not so large, and present volume is about 2 Mt. The production of fuel ethanol up to 2030 is obtained by extrapolation of the current trend. In 2030 the volume of fuel ethanol is 4.25 Mt and the volume of converted gasoline is 2.71 Mt. From the experience in the use of fuel methanol worldwide, the engine of car should be redesigned. Therefore, the possibility of large-scale development in the short term is difficult. This section assumes that the volume of methanol is the same with 2014 up to 2030. In 2030 the volume of fuel methanol is 4 Mt and the volume of converted gasoline is 1.95 Mt.

4.2 Calculation result

Based on the analysis and calculation above, Figure 3 presents the total gasoline consumption and the maximum gasoline supply. Total gasoline consumption of passenger cars increased rapidly from 2009 and this trend slows down in 2022. The peak appears in 2028. Compared the gasoline consumption and the maximum gasoline supply, it is clear that the consumption exceeds the limit from 2019 to 2030 and the maximum exceeding volume is 20 Mt.

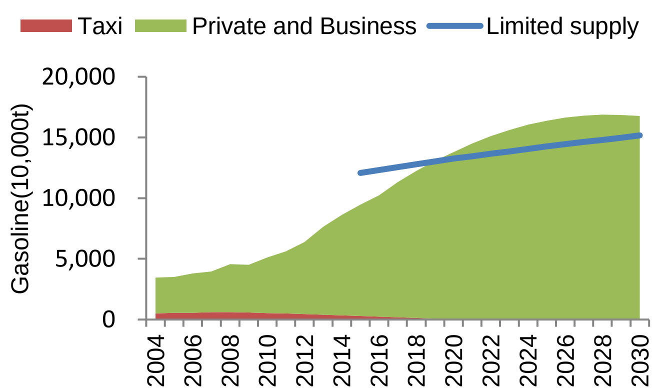

Figure 3: Comparison between gasoline consumption and the maximum gasoline supply

5. Conclusions

Based on the model and calculation above, the range of the ratio of gasoline to diesel is 1.27 between 2.92. When the ratio of gasoline to diesel is 1.27, the yield of gasoline is 25.5 % and the yield of diesel is 32.4 %. The rate of gasoline consumption of passenger cars increases quickly after 2015 and it will slow down in 2022. The gasoline consumption of passenger cars will meet the supply limit in 2019 and the consumption exceeds the limit up to 2030.The maximum exceeding volume is 20 Mt. Aiming at the exceeding, this paper gives several suggestions to relieve the pressure.

(1) The stock of passenger cars using gasoline is determined by the total passenger cars and the ratio of gasoline passenger cars. Controlling the increasing rate of gasoline private and business passenger cars is an efficient measure to reduce gasoline consumption. However, this measure will dissatisfy the purchasing demand and in some degree harm car market; (2) another measure is to decrease the ratio of gasoline passenger cars, that is, promoting the development of new energy passenger car. This measure can reduce gasoline consumption meanwhile no harm to the purchasing demand and car market; (3) the survival rate of gasoline passenger cars can affect the gasoline consumption and the effect is accumulated. The survival rate of new energy passenger cars has little effect on the gasoline consumption. Speeding up the obsolescence rate of gasoline passenger cars is efficient to reduce gasoline consumption; (4) if the consumption meets the limit, the average annual mileage of passenger cars has to decrease to 8,300 km from 2020 to 2025. However, this is difficult to realize.

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