24. PRIVATE CAR AND ITS ENVIRONMENTAL IMPACTS: EVIDENCE FROM THE RAPIDLY URBANIZING CHINA

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With the further growth of economy and rising demand for mobility, private car is booming at a surprising speed especially in developing countries. To grasp its increasing potential and environmental impacts so that proper policies could be made, this paper develops a system dynamics model to project the regionalized private car stock and associated vehicular emissions in China's 31 provinces with an urban and rural division. It is found that from 2000 to 2020, the total private car stock and generated vehicular pollutants such as CO_2, CH_4, CO, NMVOC, NO_x and SO_2 are expected to grow at 18%, 16.4%, 15.8%, 15.8%, 15.8%, 16.6% and 17.5% annually, and touch 36.7 million, 258.1, 0.07, 26.9, 5.1, 2.3 and 0.2 million tons respectively at the end of 2020. However, their spatial distributions are so unbalanced with total amount lowering from coastal to inland regions. In 2020, over 80% of private car and 75% of emissions will concentrate in urban areas. South coast and north coast regions will be the top two regions holding 28% and 20% of total private car, and 25% and 21% of total emissions respectively.

Key Words : *private car, system dynamics model, China*

1. INTRODUCTION

Private car stock is often used as a indicator of private car use in a region or country and is also a key sector relying heavily on fossil fuel that has been issuing great challenges for local and global environment. Due to the increasing mobility demand from globalization as well as the rapid growth of socio-economic activity, the use of private car is expected to soar especially in developing countries like China. Specifically, since the beginning of 21st century, the private car stock in China has increased by 2.9 times from 1.4 million in 2000 to 4.1 million in 2005, while the per capita GDP increased by only 1.2 times in the same period[1)]. It is reasonable to imagine that when the per capita GDP in China approaches the level of developed countries, the private car stock and associated vehicular pollutant emissions will reach a significant level. In the worldwide context of conservation of energy and mitigation of green house gas emissions, it is becoming increasingly important to evaluate the private car stock change and its environmental impacts so that proper policies could be made to achieve a sustainable development.

In the international scope, the World Business Council for Sustainable Development (2004)[2)] extrapolated the regionalized car stock trajectory till 2030 by using region-specific starting conditions and estimated the related emissions. International Energy Agency (2001)[3)] built scenarios to predict automobile ownership and its implications for oil market and CO_2 emissions in three large Asian economies till 2020. Meyer at al. (2007)[4)] projected passenger car stock and associated CO_2 emissions from 11 world regions by adopting a multi-model approach. Kuhns et al. (2004)[5)] assessed the air pollutant emission factors for on-road gasoline and diesel engine vehicles in Las Vegas of USA based on remote sensing techniques. In China, He (2005)[6)] employed a scenario analysis to estimate the road transport development and CO_2 emissions inventories under different strategies. Wang et al. (2006)[7)] used the International Vehicle Emission

(IVE) model to estimated vehicular pollutants emissions in Shanghai city. Cai and Xie (2007)[8] used the Computer Program to Calculate Emissions from Road Transport (COPERT) III model to evaluate motor vehicle's emissions from 1980 to 2005. However, most of the studies treat the transport evolution in a country or region as a whole and project the trend by elasticity-based methods. This kind of extrapolation is more doubtable for those developing countries with less historical data but rapid development. Taking China as an example, socio-economic inequalities exist widely between the eastern and western and between the urban and rural areas. Urban and eastern parts of China are more developed with relatively high income and motorization level, while the situation in rural and western areas is the other way round.

2. HISTORICAL TRENDS IN CAR STOCK

(1) Automobile production in China

Motorization in China is growing rapidly since economic reform and opening up in 1978. The auto production has been booming in the past decades (Fig.1). After 2001, its annual growth rate was around 26%. This may partly due to the policy support. For example, in 1978 Chairman Deng Xiaoping approved joint venture management in automobile industry. Since then, lots of joint venture auto companies appeared including Shanghai Volkswagen, Guangzhou Peugeot, Guangzhou Honda, and Tianjin Toyota, etc. In 1996, the General Office of the State Council issued an order that local governments should not restrict the usage of economy cars. After China's entrance to WTO in 2001, the price of imported automobile in 2006 decreased by 30% compared to that in 2001. And in 2004, Policy on Development of Automobile Industry was implemented to promote the purchase of private car, to encourage research and development of environmental friendly automobiles, and to speed the regroup of automobile companies.

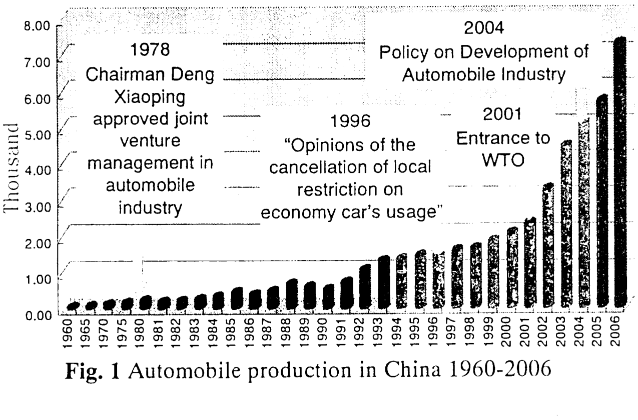

Fig. 1 Automobile production in China 1960-2006

(2) Regional characteristics

In order to make an proper prediction of private car stock in China, the regional characteristics must be understood and taken into accout in modeling. In this study, China is divided into 8 regions according to the economic homogeneity[9] as shown in Fig.2.

Fig. 2 Eight regions in China

All the data used for analysis are collected at the provincial level with urban and rural division. In detail, annual socio-economic data such as GDP, per capita income, population, inter-province and intra-province migration etc. are taken from "China Statistical Yearbook"[1] and "Tabulation on the Population Census of the People's Republic of China"[10]. Generally, the development among the 8 regions are unbalanced. The eastern and coastal regions (NE, NC, EC and SC) cover only 20% of whole country's territory. However, they accommodate 43% of total population and create 63% of GDP in China. On the contrary, the western and inland regions (SW and NW) share over 50% of area while only 24% of population concentrates there and 14% of GDP are created.

Data on private car such as private car stock per hundred households, budget share of private car in annual per capita expenditure and car price index etc. are complied from "China Urban Life and Price Yearbook"[11] and "China Yearbook of Rural Household Survey"[12]. Fig.3 shows the private car stock and per capita income in urban and rural areas of China's 8 regions in 2000. Overall the private car stock in urban and coastal regions is higher than that in rural and inland areas, with the level far below the world average. For example, in the wealthiest region (south coast urban area, SC-u), the private car stock per 100 people was 0.35. While in the least developed region (northwest rural area, NW-r), it was only 0.04. By comparison, there are over 70 private cars per 100 people in US, 40 in Japan and 35-50 in Europe.

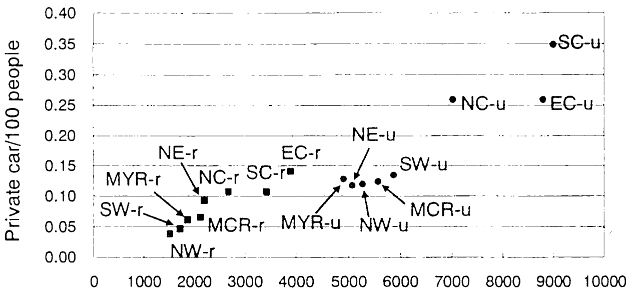

Fig.3 Regional private car stock in 2000

Note: "u" and "r" refers to urban and rural area respectively.

3. METHODOLOGY

(1) Framework of system dynamics model

The implementation of some specific policies, economic growth, migration and urbanization are expected to cause a substantial increase of private car stock and related vehicular emissions. Thus, a system dynamics approach is adopted rather than extrapolation of historical data, for it can describe the complicated connections among each element of a complicated system. Fig.4 shows the model framework. Dynamics of the model are determined by the feedback loops in the causal loop diagram. Each arrow of the causal loop diagram indicates the influence of one element on the other. The influence is considered positive (+) if an increase in one element causes an increase in another, or negative (-) in the opposite case. The base year of projection is 2000, while 2020 is set as the target year by taking into account the reliability of projection results.

(2) Model settings

a) Projection of socio-economic driving forces

In this part, we consider economic convergence, urban/rural income difference, natural demographic change and net migration between China's provinces and rural-urban areas. Two socio-economic driving forces, population and per capita income, are formulated as important input variables for the projection of private car stock. The detailed derivation can be found in Han et al. (2006)[13].

b) Projection of private car stock

We adopt a linear expenditure system, notably the Stone-Geary model for projecting private car stock. As described in Eq. (1), consumer aims at getting a maximum utility from consuming goods with the restriction of limited income.

$$\begin{aligned} & Max\, U_{n,i,t} = \alpha_{n,i,t} \ln \mathrm{PC}_{n,i,t} + (1-\alpha_{n,i,t}) \ln (G_{n,i,t} - \beta) \\ & s.t.\;\; Y_{n,i,t} = p_{\mathrm{PC}n,i,t} \cdot \mathrm{PC}_{n,i,t} + p_{Gn,i,t} \cdot G_{n,i,t} \end{aligned} \tag{1}$$

where, subscript n refers to urban or rural area; i and t denote province and year; U is consumer utility; PC is private car stock per capita; G is a generic good, which represents all the other consumable goods; α is the budget share of private car in annual per capita expenditure; β is the subsistence level of generic good, which is the necessary amount of consumption irrespective of consumer's budget or good's price. As suggested by Meyer et al. (2007)[4], the definition of β is same with that of poverty. We follow their study and set β as 50% of one unit generic good for empirical analysis. Y is the per capita disposable income; p_{PC} and p_G are the prices of private car and generic good respectively.

Using Lagrangean and the first order conditions to solve Eq. (1), yielding

$$\mathrm{PC}_{n,i,t} = \frac{\alpha_{n,i,t}}{2-\alpha_{n,i,t}} \cdot \frac{Y_{n,i,t}}{p_{\mathrm{PC}n,i,t}} \tag{2}$$

Per capita private car stock is therefore a function of annual per capita income, price and budget share of private car. By inputting the data of PC, α and Y for urban and rural areas of each province in 2000, we derive the private car price in 2000 as the starting value and use the average growth rate of car price during 1995-2000 to estimate the future price change up to 2020. Budget share of private car is quite small in 2000, with a national average of 1.5% in urban area and 0.8% in rural area. However, with the increase of income level share is expected to increase correspondingly[14]. Based on the existing literature, we set the annual growth rate of budget share in both urban and rural areas as 8% from 2000 to 2020[15].

c) Projection of vehicular emissions

In order to estimate the vehicular emissions of private car, two more factors are needed—annual distance traveled by private car (DTC) and fuel intensity (FI).

Since there is no published statistical data on DTC in China, we follow the scenario analysis results conducted by Wang et al. (2007)[16], and assume that the more private car stock is in a region the less intensively each car is used. We define that the DTC in China will converge to 14000 km per annum.

According to the "Maximum Limits of Fuel consumption for Passenger Cars" issued by the Standardization Administration of China in 2004[17], in which it stressed the realization of target that the fuel consumption per 100 km of car and light duty vehicles could decrease 15% in 2006-2010 than the current level, we project the FI and proportion of gasoline and diesel cars (Table 1).

We use IPCC (1997)'s methodology[18] to estimate vehicular emissions including CO_2 and CH_4 of global impact, and CO, Non-Methane Volatile Organic Compounds (NMVOC), NO_x, SO_2 of local effect.

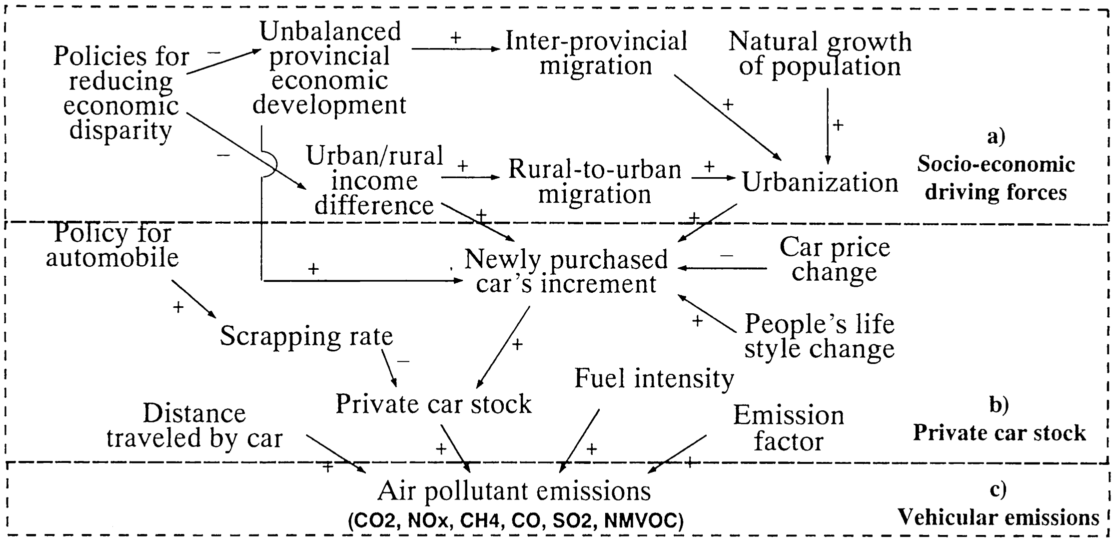

Fig.4 Framework of system dynamics model

Table 1 Fuel intensity and proportion of private car

	2000	2005	2010	2015	2020
Proportion (%)					
Gasoline car	99.91	97.48	95.02	92.49	90.01
Diesel car	0.09	2.52	4.98	7.51	9.99
Fuel intensity (*l*/100 km)					
Gasoline car	16.2	15.56	14.94	14.35	13.78
Diesel car	16.2	15.56	14.94	14.35	13.78

$$\mathbf{EC}_{m,i,t} = \sum_{n} \mathbf{PC}_{n,i,t} \cdot \mathbf{POP}_{n,i,t} \cdot S_{m,t} \cdot \mathbf{DTC}_{n,i,t} \cdot \mathbf{FI}_{m,t} \cdot a_m \qquad (3)$$

$$\mathbf{EM}_{q,i,t} = \sum_{m} \mathbf{EC}_{m,i,t} \cdot b_{q,m}$$

where, subscripts m and q denote fuel type and pollutants respectively; EC is energy consumption; EM is vehicular emissions; S is proportion of private car using different fuel; a is heat conversion factor, which takes value as 3.2×107 J/l for gasoline and 3.6×107 J/l for diesel; b is emission factor per unit heat generation in road transport sector[18] (Table 2).

Table 2 Emission factor for each pollutant in kg/TJ

	CO_2	CH_4	CO	NMVOC	NO_x	SO_2
Gasoline car	68607	20	8000	1500	600	4.65E-05
Diesel car	73326	5	1000	200	800	1.41E-04

4. RESULTS

Based on the model projection, we illustrates the future trends of private car stock and its urban-rural share in China till 2020 in Fig. 5. It shows that the total amount will touch 36.7 million at the end of 2020, with an annual average growth rate around 18%. The shares of private car in urban and rural area are nearly at the same level in 2000. However, with the development of unbalanced economy and for seeking better lives, large amount of people in China will move across regions and particularly from rural to urban area, which stimulates the boom of city economy and increases the level of motorization. Accordingly, the urban private car stock grows faster than that in rural area and makes more contribution to the total scale change. In 2020, over 80% of private car is expected to concentrate in China's urban area while the rest 20% will be in rural region.

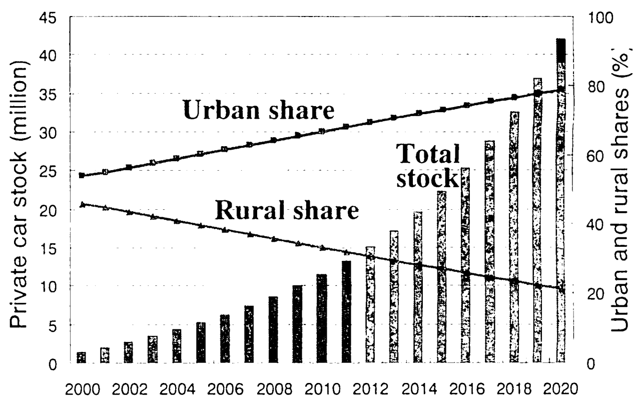

Fig.5 Private car stock and urban-rural share 2000-2020

The projected vehicular emissions are summarized in Table 3. During the period of 2000-2020, the total volume of CO_2, CH_4, CO, NMVOC, NO_x and SO_2 increases sharply with an annual average growth rate of 16.4%, 15.8%, 15.8%, 15.8%, 16.6% and 17.5% respectively. The massive growth of the private car stock is the major cause. Furthermore, due to the unbalanced growth of private car stock in urban and rural areas, the increment of vehicular emission budgets in urban area is also much faster than that in rural domain. In 2000 around 50% of air pollutants from private car will remain in urban regions, while at the end of 2020 the said proportion rise to 75%.

Table 3 Annual emissions with urban-rural division in China 2000-2020 (million tons)

	Urban area				Rural area				China			
	2000	2010	2020	AGR	2000	2010	2020	AGR	2000	2010	2020	AGR
CO_2	6.28	35.63	194.20	18.7%	6.12	20.18	63.89	12.4%	12.40	55.82	258.09	16.4%
CH_4	0.002	0.010	0.051	18.2%	0.002	0.006	0.017	11.9%	0.004	0.016	0.068	15.8%
CO	0.73	3.93	20.27	18.1%	0.71	2.23	6.67	11.8%	1.44	6.16	26.93	15.8%
NMVOC	0.14	0.74	3.80	18.1%	0.13	0.42	1.25	11.8%	0.27	1.16	5.06	15.8%
NO_x	0.05	0.32	1.75	18.9%	0.05	0.18	0.58	12.6%	0.11	0.50	2.32	16.6%
SO_2	0.004	0.027	0.160	19.9%	0.004	0.015	0.053	13.6%	0.008	0.042	0.213	17.5%

Note: AGR denotes the annual average growth rate of pollutant emissions from 2000 to 2020.

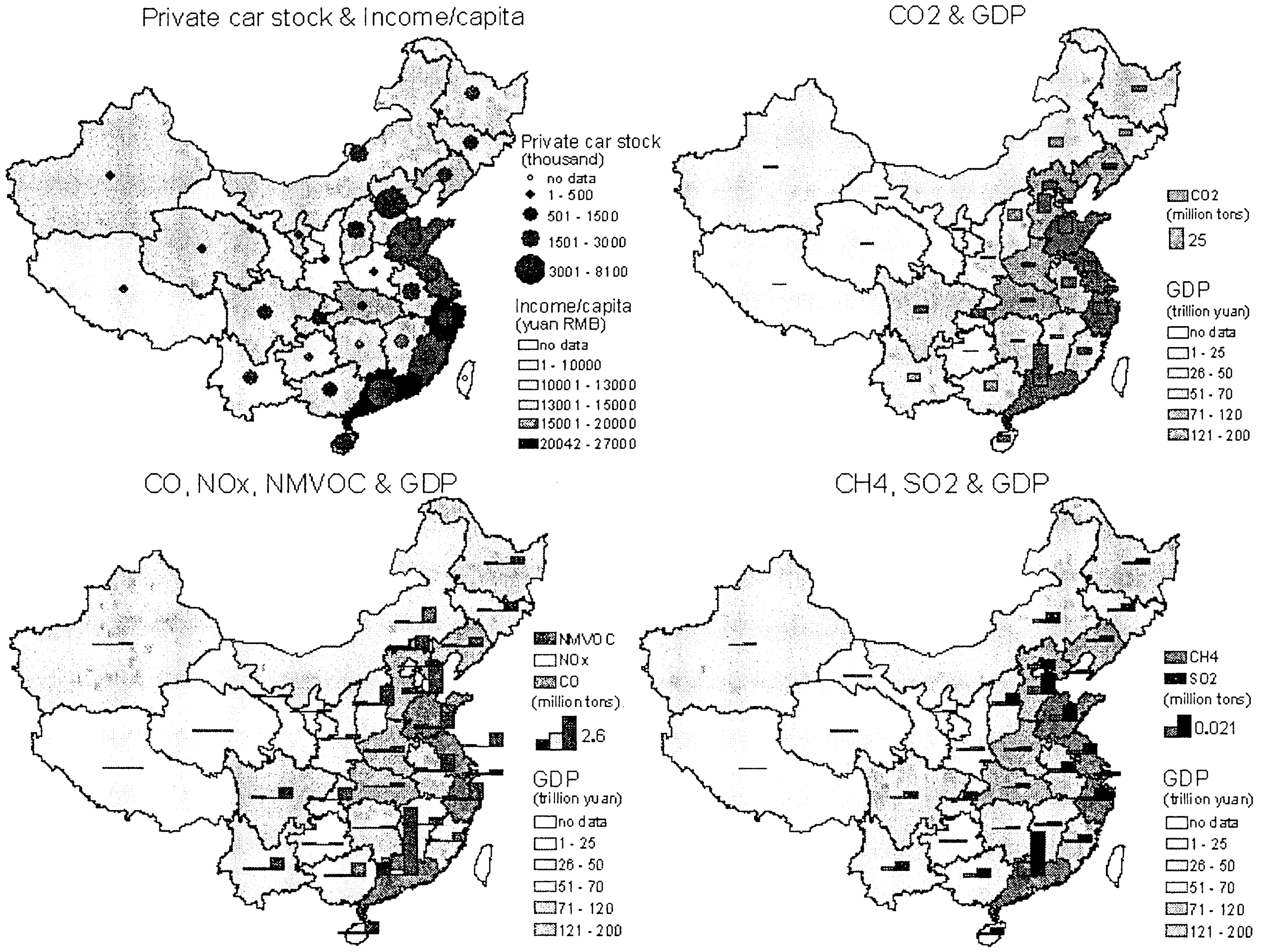

Fig. 6 Spatial distribution of economic level, private car stock and vehicular emissions in 2020

To better understand the spatial distribution of private car stock and associated air pollutant emissions, Fig. 6 depicts a map of GDP, per capita income, private car stock and six air pollutants emissions based on provincial level budgets in 2020. Generally the distribution of private car stock and vehicular emissions is quite uneven, with the scale lowers significantly from the eastern and coastal parts to the western and inland China. This is consistent with the characteristics of unbalanced economic development among the regions. In 2020, the south coast region is supposed to have the largest private car stock and vehicular emissions (28% and 25% of national total respectively), followed by the north coast region (20% and 21% of national total). While the northwest region only has 2% of total private car stock and thus emits just 2% of total air pollutants. The gap is about 10-14 folds. Similarly the south coast and north coast regions contribute to 14% and 19% of national GDP, while the northwest region only produces 3% of total GDP.

Moreover, it is noticeable that GDP of the east coast region will grow at an annual rate of 7% and contribute to the largest share (20%) of national total in 2020, while its private car stock is supposed to increase by 17 times and account for 10% of China's total in 2020. Comparing with the situation in south coast region, the growth rate of GDP is about 6.6% per annum but its private car will rise 40 times, which makes it the region with largest private car stock in 2020. The disproportionate development of private car and GDP could be explained by different vehicle policies among these regions. For example, Shanghai city, a municipality in east coast region, has been strictly controlling the private car increase through auctioning license tag of new car. While in Guangdong province of south coast region, there is no extra charge for car license tag and the government encourages the purchase of private car.

5. CONCLUSIONS

Looking at the regionalized private car stock in China and projecting its future dynamics as well as the environmental implications in 31 provinces especially with an urban and rural division, we find the total amount of private car will grow at a rate of 18% per annum and amount to 36.7 million in 2020. The associated vehicular emissions such as CO_2, CH_4, CO, NMVOC, NO_x and SO_2 are also expected to be booming, with total volumes increasing at an annual rate of 16.4%, 15.8%, 15.8%, 15.8%, 16.6% and 17.5%, and reaching 258.1, 0.07, 26.9, 5.1, 2.3 and 0.2 million tons respectively at the end of 2020.

Consistent with the uneven distribution of economic development among China provinces, private car stock and its generated air pollutant emissions mainly concentrate in the developed coastal and urban regions of China. In 2020, urban areas will accommodate over 80% of total private car and 75% of total emissions. South coast and north coast regions will be the top two regions holding 28% and 20% of total private car, and 25% and 21% of total emissions respectively.

To reduce the vehicular pollutant emissions and achieve a sustainable development of environment, the policy implication is that controlling the over boom of private car and associated pollutant emissions is necessary in China, especially for the south coast region.

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