Assessment of private car stock and its environmental impacts in China from 2000 to 2020

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A R T I C L E   I N F O

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A B S T R A C T

Economic growth and the rising demand for mobility in developing countries are leading to increased car ownership, with associated environmental problems. To develop appropriate policies to cope with this situation, reliable forecasts are needed of the stock of vehicles and its environmental impacts. This paper looks at the potential for car ownership increase in China's 31 provinces and considers its likely effect on atmospheric pollution (notably, CO₂, CH₄, NMVOC, NOₓ, and SO₂) up to 2020. The effects will continue to be spatially variable with a heavy concentration of car use and pollution in urban areas. At the meso level, the South and North Coast regions will have the highest levels of vehicle ownership and will be the most adversely affected by environmental damage.

1. Introduction

The private car stock in a country or region is often an indicator of car use, and as cars rely heavily on fossil fuel, this has major impacts for the local and global environment. Private car use is growing most rapidly in developing countries; for example, the stock in China increased 2.9 times between 2000 and 2005, compared with a per capita GDP increase of only 1.2 times (National Bureau of Statistics, 2006; Department of Urban and Rural Society and Economic Statistics, 2006).

Globally, a good deal of research has been done in this area. The World Business Council for Sustainable Development (2004) extrapolated car stock trajectories by regions up to 2030 on the basis of region-specific starting conditions and estimated the consequent emissions. The International Energy Agency (2001) built up scenarios to predict automobile ownership and its implications for the oil market and CO₂ emissions in three large Asian economies up to 2020. Potoglou and Kanaroglou (2008) examined the influence of family structure, socio-economic characteristics and accessibility of the place of residence on the number of cars owned by a household, and modeled car ownership in urban areas of Hamilton city through a disaggregate model. Meyer et al. (2007) projected passenger car stocks and associated CO₂ emissions from 11 world regions using a multi-model approach. Kuhns et al. (2004) assessed the air pollutant emission factors for on-road gasoline and diesel vehicles in Las Vegas, US based on remote sensing techniques. In China, He (2005) employed a scenario analysis to estimate road transport development and CO₂ emissions under different strategy scenarios. Wang et al. (2006) used the International Vehicle Emission (IVE) model to estimate vehicle pollutant emissions in Shanghai. Cai and Xie (2007) used the COPERT III (Computer Program to Calculate Emissions from Road Transport) model to evaluate motor vehicle emissions from 1980 to 2005. However, most such studies treat transport evolution in a country or region as a whole and project the observed trends by elasticity-based methods. This kind of extrapolation is more dubious in developing countries where historical data are scarce but current development is rapid. Taking China as an example, wide socio-economic inequalities exist between the eastern and western regions and between urban and rural areas. In general, eastern and urban parts of China are
more developed, with relatively high levels of income and motorization, while the situation in western and rural parts is the reverse.

2. Study area and data

As pointed out in many studies, car stocks have a strong relation to economic level (International Energy Agency, 2001; World Business Council for Sustainable Development, 2004; Das and Parikh, 2004). Accordingly, in order to estimate private car stocks and associated air pollutant emissions, this study defines a hierarchical country-region-province structure for China, noting that the country is made up of regions and that each region has a number of provinces. Following the regional clusters proposed by the Development Research Center of State Council of China (2005), we divide China’s 31 provinces into 8 regions according to economic homogeneity (Fig. 1). It is evident that regional development is significantly unbalanced. During 1995–2005, the eastern and coastal regions (NE, NC, EC and SC), making up only 20% of the country’s territory accounted for 43% of the total population and generated 63% of GDP. On the other hand, the western and inland regions (SW and NW), occupying over 50% of the territory, contained only 24% of the population and generated only 14% of GDP.

All the analysis data are collected at the provincial level, with an internal division into urban and rural areas. More exactly, annual socio-economic data such as GDP, per capita income, population, inter-province and intra-province migration etc. are taken from the “China Statistical Yearbook” (National Bureau of Statistics, 1996–2006) and the “Tabulated Population Census of the People’s Republic of China” (National Bureau of Statistics, 1993, 2002). Data on private cars such as private car stocks per hundred households, the share of private car costs in annual per capita expenditure, the car price index etc. are obtained from the “China Urban Life and Price Yearbook” (Department of Urban Society and Economic Statistics, 1996–2006) and the “China Yearbook of Rural Household Surveys” (Department of Rural Society and Economic Statistics, 1996–2006). Fig. 2 shows private car stocks and per capita incomes in urban and rural areas for China’s 8 regions in 2000. Overall the private car stock is higher in the urban and coastal parts than in the rural and inland ones, while the overall level is far below the world average. For example, in the wealthiest areas (South Coast urban areas, SC-u) the private car stock per 100 people was 0.35, while in the least developed areas (Northwest rural areas, NW-r) it was only 0.04. But for comparison, there were over 70 private cars per 100 people in the USA at this time, 40 in Japan and 35–50 in Europe.

3. Methodology and model setting

3.1. Projection of private car stock

For Chinese statistics, a “private car” means a licensed four-wheeler passenger vehicle with a capacity of 2–8 persons. It serves personal uses only and can be further classified into gasoline and diesel types. In this study, instead of extrapolating the historical trend into the future, we treat private cars as consumer goods and use a linear expenditure projection, namely the Stone-Geary model. The base year is 2000, with 2005 used for validation, and 2020 as the target year. As set out in Eq. (1), the consumer aims to obtain maximum utility from the consumption of goods purchased, under the restriction of a limited income.

\[
\begin{align*}
\max & \quad U_{n,it} = \alpha_{n,it} \ln NPC_{n,it} + (1 - \alpha_{n,it}) \ln (G_{n,it} - \beta) \\
\text{s.t.} & \quad Y_{n,it} = p_{NPC_{n,it}} \cdot NPC_{n,it} + p_{G_{n,it}} \cdot G_{n,it} \\
\end{align*}
\]

where subscript \(n\) refers to either urban or rural areas; \(i\) and \(t\) denote the province and year; \(U\) is consumer utility; \(NPC\) is newly purchased private cars per capita; \(G\) is a generic good representing all other consumer goods; \(\alpha\) is the budget share of private cars in annual per capita expenditure; \(\beta\) is the subsistence level of the good. As suggested by Meyer et al. (2007), the

Fig. 1. The eight regions of China.
First, we discuss the estimation of economic development. Since the economic reforms in 1978, China has been experiencing a dramatic changeover from central planning to market mechanism, accompanied by rapid socio-economic development. The issue of whether or not economic convergence will occur across China’s provinces has attracted wide attention, because the promotion of harmonious regional development has been singled out as one of the key targets for future development. The issue of economic development between regions: the less developed a region is, the smaller is its economic growth rate. On these hypotheses, the economy in each province will converge in the following way.

Using Lagrangean and first order conditions to solve Eq. (1), we obtain

$$\text{NPC}_{ni,t} = \frac{1}{2} \sum_{i} \frac{Y_{ni,t}}{\text{NPC}_{ni,t}}$$

(2)

The private car stock per capita is a function of NPC and cars owned the previous year after subtraction of scrapped cars.

$$\text{PC}_{ni,t} = \text{NPC}_{ni,t} + \text{PC}_{ni,t-1} \cdot (1 - \sigma_{ni,t-1})$$

(3)

where PC is the private car stock per capita; \(\sigma\) is the scrapping rate for private cars, which may vary with the different stages of economic development between regions: the less developed a region is, the smaller \(\sigma\) will be. In 2002, the annual scrapping rate for private cars was only 4.6%, although this is expected to increase substantially (Zhang and Zong, 2008). In this projection, we set it at 5% for 2000–2010 and 6% for 2011–2020.

By inputting the PC, \(z\) and \(Y\) data for the urban and rural areas in each province for 1999 and 2000, we obtain the price of a private car and of the generic good respectively. The private car stock per capita is a function of NPC and cars owned the previous year after subtraction of scrapped cars.

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By inputting the PC, \(z\) and \(Y\) data for the urban and rural areas in each province for 1999 and 2000, we obtain the price of a private car and of the generic good respectively. The programs implemented in recent years under the “Develop-the-West Strategy” and the “Eleventh Five-year Plan” are well known. The promotion of harmonious regional development has been singled out as one of the key targets for future development. For this reason, regional economic convergence must be taken into account in modeling.

Two hypotheses have been made for the projection: (a) other things being equal, per capita GDP growth rate will be higher in regions with a lower per capita GDP. (b) Per capita income will occupy a constant proportion of per capita GDP: they have the same growth rate. On these hypotheses, the income in each province will converge in the following way.

$$r_i = r^* - \delta_i \cdot \lambda \cdot \ln(Y_i/Y)$$

s.t. $GR_{\text{China},t} = \left[ \frac{\sum_i \left(\text{GDPP}_{i,t-1} \cdot (1 + r_{i,t}) \cdot \text{POP}_{i,t} \right)}{\sum_i \left(\text{GDPP}_{i,t-1} \cdot \text{POP}_{i,t-1} \right)} - 1 \right] \cdot 100\%$  

(4)

where \(r_i\) is the growth rate of per capita income \((Y)\) and per capita GDP \((\text{GDPP})\) in province \(i\); \(r^*\) is the corresponding growth rate in the province concerned; \(\text{POP}\) is the province’s population. The choice of the province ought to be arbitrary because the annual national GDP growth rate \((GR_{\text{China}})\), predicted from the various values for each province, can be expected to match the rate given exogenously. In accordance with the previsions of the Development Research Center of State Council of China (2005), \(GR_{\text{China}}\) is set at 7% for 2000–2010 and 6% from 2011 to 2020. The parameter \(\lambda\) is set at 2.5% (Barro and Sala-i-Martin, 2003). \(\delta_i\) is the economic convergence parameter of province \(i\), which varies from −1 (divergence) to +1 (convergence).
Considering the economic performance of the eight regions, \( \delta_i \) is assigned as 1.0 for EC, 0.9 for SC, 0.8 for NE and NC, 0.7 for MYR, MCR and NW, and 0.6 for SW.

Second, we discuss the estimation of migration and population change. Population growth in province \( i \) can be divided up into natural growth and net inter-provincial migration.

\[
\text{POP}_{i,t} = \text{POP}_{i,t-1} \cdot (1 + \phi_{i,t}) + \text{NETM}_{i,t}
\]  
(5)

where \( \phi \) is the natural population growth rate; \( \text{NETM} \) is the net immigration to province \( i \).

The estimation of \( \text{NETM} \) starts from Lowry’s gravity model (Lowry, 1966)

\[
M_{ij} = \frac{k \text{UE}_i \text{W}_j}{\text{UE}_j \text{W}_i} \frac{L_i I_j}{D_{ij}}
\]  
(6)

where \( M_{ij} \) is migration from province \( i \) to \( j \); \( \text{UE} \) is the unemployment rate; \( W \) is the average wage in the manufacturing sector; \( L \) is the labor force; \( D_{ij} \) is the distance between provinces \( i \) and \( j \); \( k \) is a constant.

Eq. (6) can also be modified by substituting some of these variables such as wage and labor force by more readily available data such as per capita income and population, respectively.

\[
M_{ij} = \frac{k \text{UE}_i \text{Y}_j}{\text{UE}_j \text{Y}_i} \frac{\text{POP}_i \cdot \text{POP}_j}{D_{ij}}
\]  
(7)

After the first order approximation and ignoring the second-order effect of population change due to migration and unemployment change, we obtain

\[
\text{NETM}_{i,t} = \sum_{j \neq i}(M_{ji} - M_{ij})_t
\]

\[
= \text{NETM}_{i,t-1} + \sum_{j \neq i}(M_{ji} + M_{ij})_{t-1} \left( \frac{\Delta Y_i}{\text{Y}_{i,t-1}} \frac{\Delta Y_i}{\text{Y}_{j,t-1}} \right)
\]  
(8)

The variation between the urban and the rural population can be estimated from the following equation:

\[
\text{POP}_{u,t} = \text{POP}_{u,t-1} \cdot \text{UBASE}_{i,t} + \text{NETM}_{u,t}
\]

\[
\text{POP}_{r,t} = \text{POP}_{r,t-1} - \text{POP}_{u,t}
\]  
(9)

where \( \text{POP}_u \) and \( \text{POP}_r \) are the urban and rural populations in province \( i \); \( \text{NETM}_u \) is the net immigration into urban areas; \( \text{UBASE} \) is the urbanization level projected by extrapolating the historical trajectory.

Similarly to the case of Eq. (8), the net immigration into urban areas is estimated from

\[
\text{NETM}_{u,t} = -\text{NETM}_{r,t} = (M_{ru} - M_{ur})_t
\]

\[
= \text{NETM}_{u,t-1} + (M_{ru} + M_{ur})_{t-1} \left( \frac{\Delta Y_u}{\text{Y}_{u,t-1}} \frac{\Delta Y_r}{\text{Y}_{r,t-1}} \right)
\]  
(10)

where \( M_{ru} \) is the net rural-to-urban migration; \( Y_u \), \( Y_r \) are the urban and rural per capita incomes.

3.2. Estimation of environmental impacts

In order to estimate the environmental impacts of private car use such as carbon dioxide and other pollutant emissions, two more factors related to the private car stock are needed—the annual distance traveled by a private car (DTC) and fuel intensity (FI).

Since there are no published statistical data for DTC in China, we assume that the larger the private car stock in a region, the less intensively each car will be used. Noting that DTC in developed countries with a high stock of private cars lies mainly in a range of 10,000–18,000 km, we assume that DTC in China will converge on 14,000 km per annum and propose a logistic function to measure the DTC change (Fig. 3).

Fuel intensity is usually determined by numerous local factors such as fuel quality, engine type, driver habits and road conditions. However, due to the limited availability of data, we assume here that FI will be the same for private cars in each region. In recent years, the Chinese government has been implementing intensive transport policies to encourage the use of light vehicles and to improve fuel economy. Notably, in 2004, the Standardization Administration of the People’s Republic of China (2004) issued “Maximum Limits of Fuel Consumption for Passenger Cars” stressing the target of a 15% decrease in fuel consumption for cars and light duty vehicles in 2006–2010 compared with current levels. In this context and taking the existing literature as a base, we project FI and the proportions of gasoline and diesel cars (Table 1).

In this study, the assessment of the environmental influences of private car use covers two main aspects. One concerns the global impact of the greenhouse gases CO\(_2\) and CH\(_4\), and the other the mainly local impact of CO, non-methane volatile organic compounds (NMVOC), NO\(_x\) and SO\(_2\). Eq. (11) is used for estimating vehicle emissions in province \( i \).
Fig. 3. Relationship between DTC and per capita private car stock.

Table 1
Fuel intensity and proportion of private cars by fuel type

<table>
<thead>
<tr>
<th>Year</th>
<th>Proportion (%)</th>
<th>Fuel intensity (l/100 km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gasoline cars</td>
<td>Diesel cars</td>
</tr>
<tr>
<td>2000</td>
<td>99.91</td>
<td>0.09</td>
</tr>
<tr>
<td>2005</td>
<td>97.48</td>
<td>2.52</td>
</tr>
<tr>
<td>2010</td>
<td>95.02</td>
<td>4.98</td>
</tr>
<tr>
<td>2015</td>
<td>92.49</td>
<td>7.51</td>
</tr>
<tr>
<td>2020</td>
<td>90.01</td>
<td>9.99</td>
</tr>
</tbody>
</table>

Table 2
Emission factors for each air pollutant in kg/TJ by fuel type

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Gasoline cars</th>
<th>Diesel cars</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>68607</td>
<td>73326</td>
</tr>
<tr>
<td>CH4</td>
<td>20</td>
<td>70</td>
</tr>
<tr>
<td>CO</td>
<td>8000</td>
<td>1000</td>
</tr>
<tr>
<td>NMVOC</td>
<td>1500</td>
<td>200</td>
</tr>
<tr>
<td>NOx</td>
<td>600</td>
<td>800</td>
</tr>
<tr>
<td>SO2</td>
<td>4.65E-05</td>
<td>1.41E-04</td>
</tr>
</tbody>
</table>

\[
EC_{m,i} = \sum_{n} PC_{n,i} \cdot POP_{n,i} \cdot S_{m,i} \cdot DTC_{n,i} \cdot F_{m,i} \cdot a_{m} \\
EM_{q,i} = \sum_{m} EC_{m,i} \cdot b_{q,m}
\]

where subscripts \( m \) and \( q \) denote fuel type and air pollutants respectively; \( EC \) is energy consumption; \( EM \) is vehicular emissions; \( S \) is the proportion of private car using each type of fuel; \( a \) is a heat conversion factor, with a value of \( 3.2 \times 10^7 \) J/L for gasoline and \( 3.6 \times 10^7 \) J/L for diesel; \( b \) is an emission factor per unit heat generation in the road transport sector, which is calculated from the revised IPCC 1996 guidelines for national GHG inventories (Intergovernmental Panel on Climate Change, 1997) (Table 2).

4. Results

Fig. 4 shows trend projections for the private car stock in China and urban and rural shares up to 2020. It predicts that the total number of cars will reach 42.1 million by the end of 2020, with an annual average growth rate around 18%. The shares of private car ownership in urban and rural areas were nearly the same in 2000. However, with the unbalanced development of the economy, large numbers of people will continue to migrate between regions in search of a better lifestyle, with an even more pronounced movement from rural into urban areas. This in turn will stimulate the booming city economies and increasing urban levels of motorization. Moreover, because of the large body of private car stock in the urban areas during the past decades, the private car stock will continue to grow faster in the cities than in the rural areas and contribute more to the overall scale of change in the near future. By 2020, over 80% of private cars are expected to be concentrated in China’s urban areas and only 20% in the rural ones.

Projections of private car emissions are summarized in Table 3. During the period 2000–2020, the total volume of CO\(_2\), CH\(_4\), CO, NMVOC, NO\(_x\) and SO\(_2\) emissions will increase sharply with annual average growth rates of 16.5%, 15.9%, 15.8%, 15.8%, 16.6% and 17.6% respectively. By the end of 2020, the volumes of these emissions will be 281.2, 0.07, 29.3, 5.5, 2.5 and 0.2 million tons, respectively, for totals of around 16–20 times the levels in 2000. The massive growth of the private
Fig. 4. Private car stock with urban and rural shares in China 2000–2020.

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

<table>
<thead>
<tr>
<th></th>
<th>Urban areas</th>
<th></th>
<th></th>
<th></th>
<th>Rural areas</th>
<th></th>
<th></th>
<th></th>
<th>National totals</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>7.17</td>
<td>60.85</td>
<td>214.73</td>
<td>18.53</td>
<td>6.13</td>
<td>31.59</td>
<td>64.92</td>
<td>12.53</td>
<td>13.30</td>
<td>92.43</td>
<td>279.66</td>
<td>16.45</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.002</td>
<td>0.02</td>
<td>0.06</td>
<td>17.97</td>
<td>0.002</td>
<td>0.01</td>
<td>0.02</td>
<td>11.99</td>
<td>0.004</td>
<td>0.03</td>
<td>0.07</td>
<td>15.90</td>
</tr>
<tr>
<td>CO</td>
<td>0.84</td>
<td>6.72</td>
<td>22.41</td>
<td>17.88</td>
<td>0.71</td>
<td>3.49</td>
<td>6.78</td>
<td>11.91</td>
<td>1.55</td>
<td>10.21</td>
<td>29.18</td>
<td>15.81</td>
</tr>
<tr>
<td>NMVOC</td>
<td>0.16</td>
<td>1.26</td>
<td>4.21</td>
<td>17.88</td>
<td>0.13</td>
<td>0.65</td>
<td>1.27</td>
<td>11.91</td>
<td>0.29</td>
<td>1.91</td>
<td>5.48</td>
<td>15.82</td>
</tr>
<tr>
<td>NOₓ</td>
<td>0.06</td>
<td>0.54</td>
<td>1.93</td>
<td>17.70</td>
<td>0.05</td>
<td>0.28</td>
<td>0.58</td>
<td>12.69</td>
<td>0.12</td>
<td>0.82</td>
<td>2.52</td>
<td>16.62</td>
</tr>
<tr>
<td>SO₂</td>
<td>0.005</td>
<td>0.05</td>
<td>0.18</td>
<td>19.69</td>
<td>0.004</td>
<td>0.02</td>
<td>0.05</td>
<td>13.63</td>
<td>0.01</td>
<td>0.07</td>
<td>0.23</td>
<td>17.59</td>
</tr>
</tbody>
</table>

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

Fig. 5. Spatial distribution of economic levels, private car stocks and vehicular emissions in 2020.
car stock will be the major reason for this. Further, due to the imbalance in growth between urban and rural areas, the annual increase in vehicle emissions will also be much larger in the urban areas. In 2000, cities accounted for around 54% of all the emissions, but by the end of 2020 this proportion will rise to 77%.

For a better understanding of the spatial distribution of private car stocks and related pollutant emissions, Fig. 5 shows maps for GDP, per capita incomes, private car stocks and emissions of six air pollutants based on province-level forecasts for 2020. Generally, the distribution of private car stocks and vehicle emissions is quite uneven, with clines of considerable decrease from the eastern and coastal regions to the western and inland ones. This is consistent with the expected imbalance in economic development among regions. In 2020, the SC region is predicted to have the largest private car stock and the largest share of national vehicle emissions (28% and 26%, respectively), followed by the NC region (22% and 21%), while the NW region will have only 2% of the private car stock and likewise account for just 2% of pollutants. The gap between regions will thus be in the order of 11 to 14 times. Similarly, the SC and NC regions will contribute 14% and 19% to the national GDP, and the NW region only 3%.

The economy of the EC region is predicted to grow at an annual rate of 7%, making the largest regional unit (20% of GDP) by 2020, while its private car stock is predicted to increase 25 times and to account for 11% of China's stock. In contrast with the SC region, the growth rate of GDP will be about 6.6% per annum but the rise in the private car stock will be 30 times. This disproportion between car ownership and GDP may be explained by the differences in the vehicle policies between these regions. For example, Shanghai city, the largest municipality in the EC region, has been strictly controlling the increase in private car ownership through the auctioning of license plates for new cars. In Guangdong province in the SC region, on the other hand, there is no extra charge for car license plates and the government is actively encouraging purchases of private cars.

To verify the accuracy of the model and of the parameter settings, provincial statistical data for 2005 were also fed in for comparison with the model projections. Fig. 6 shows the results. $R^2$ in each case is close to 1.0, indicating that the model’s performance is reasonable.

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**Fig. 6.** Verification of model results.
5. Conclusions

This paper has looked at the private car stock in China and its regional environmental impacts. In contrast with previous works, we have highlighted the modeling of the macroscopic driving forces behind change in the private car stock, especially against the background of the current phase of rapid socio-economic transition. Factors usually ignored in the existing literature, such as the economic imparities among regions, population migration, policy influences and their interactions, were investigated to allow a appropriate projections of private car stocks in urban and rural areas taken separately. The results indicate that the total number of private cars, but also the volume of related pollutant emissions will shoot up to considerably higher levels in the near future if recent behavioral trends and the present technical aspects of private car use persist. Despite the introduction of stricter controls on private car purchase and pollutant emissions, China will come under much greater pressure to cut back on emissions.

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