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ANL/ESD/06-6

Projection of Chinese Motor Vehicle Growth, Oil Demand, and CO_2 Emissions through 2050

Energy Systems Division

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NOTATION

The following is a list of the abbreviations, acronyms, and units of measure used in this document. (Some acronyms and abbreviations used only in tables may be defined only in those tables.)

GENERAL ACRONYMS AND ABBREVIATIONS

3-W RV	three-wheeled rural vehicle
4-W RV	four-wheeled rural vehicle
CAFE	Corporate Average Fuel Economy
CATARC	China Automotive Technology and Research Center
CKD	Completely Knocked Down
CO_2	carbon dioxide
DRCCSC	Development Research Center of China State Council
DV	displacement volume
EC-DGET	European Commission, Directorate General for Energy and Transport
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
GDP	gross domestic product
GVW	gross vehicle weight
HDB	heavy-duty bus
HDT	heavy-duty truck
HWV	highway vehicle
IEEE	Institute of Electrical & Electronics Engineers
JACENR	Japan's Advisory Committee for Energy and Natural Resources
JAIRA	Japanese Automobile Inspection and Registration Association
JAMA	Japanese Automobile Manufacturer's Association
KAMA	Korean Automobile Manufacturer's Association
LC	large car
LDB	light-duty bus
LDT	light-duty truck
MC	motorcycle
MDB	medium-duty bus

MDT	medium-duty truck
MiniB	mini bus
MiniT	mini truck
MIRVDRC	Machinery Industry Rural Vehicle Development Research Center of China
MMIC	Ministry of Machinery Industry of China
MY	model year
NAS	National Academy of Sciences
NRAGCSA	National Reality Analysis Group of China Science Academy
PTW	pump-to-wheels
RGAID	Research Group of Automotive Industry Development
RGCES	Research Group of China Energy Strategies
RMB	RenMinBi
RMC	rural motorcycle
RV	rural vehicle
SC	small car
SETCC	State Economic and Trade Commission of China
SR	survival rate
SSBC	State Statistical Bureau of China.
TRB	Transportation Research Board
TVL	total vehicle length
UKDT	United Kingdom Department for Transport
UMC	urban motorcycle
USD	U.S. dollars
USFHWA	U.S. Federal Highway Administration
USNRC	U.S. National Research Council
VMT	vehicle miles traveled
WTW	well-to-wheels

UNITS OF MEASURE

gal	gallon(s)
kg	kilogram(s)
km	kilometer(s)
L	liter(s)
m	meter(s)
MPG	mile(s) per gallon
yr	year(s)

PROJECTION OF CHINESE MOTOR VEHICLE GROWTH, OIL DEMAND, AND CO_2 EMISSIONS THROUGH 2050

by

Michael Wang, Hong Huo, Larry Johnson, and Dongquan He

ABSTRACT

As the vehicle population in China increases, oil consumption and carbon dioxide (CO_2) emissions associated with on-road transportation are rising dramatically. During this study, we developed a methodology to project trends in the growth of the vehicle population, oil demand, and CO_2 emissions associated with on-road transportation in China. By using this methodology, we projected — separately — the number of highway vehicles, motorcycles, and rural vehicles in China through 2050. We used three scenarios of highway vehicle growth (high-, mid-, and low-growth) to reflect patterns of motor vehicle growth that have occurred in different parts of the world (i.e., Europe and Asia). All are essentially business-as-usual scenarios in that almost none of the countries we examined has made concerted efforts to manage vehicle growth or to offer serious alternative transportation means to satisfy people's mobility needs. With this caveat, our projections showed that by 2030, China could have more highway vehicles than the United States has today, and by 2035, it could have the largest number of highway vehicles in the world. By 2050, China could have 486–662 million highway vehicles, 44 million motorcycles, and 28 million rural vehicles. These numbers, which assume essentially unmanaged vehicle growth, would result in potentially disastrous effects on the urban infrastructure, resources, and other social and ecological aspects of life in China.

We designed three fuel economy scenarios, from conservative to aggressive, on the basis of current policy efforts and expectations of near-future policies in China and in developed countries. It should be noted that these current and near-future policies have not taken into consideration the significant potential for further fuel economy improvements offered by advanced technologies such as electric drive technologies (e.g., hybrid electric vehicles and fuel-cell vehicles).

By using vehicle growth projections and potential vehicle fuel economy, we projected that China's on-road vehicles could consume approximately 614–1,016 million metric tons of oil per year (12.4–20.6 million barrels per day) and could emit 1.9–3.2 billion metric tons of CO_2 per year in 2050, which will put tremendous pressure on the balance of the Chinese and world oil supply and demand and could have significant implications on climate change.

Our analysis shows that, while improvements in vehicle fuel economy are crucial for reducing transportation energy use, containing the growth of the vehicle population could have an even more profound effect on oil use and CO_2 emissions. This benefit is in addition to other societal and environmental benefits — such as reduced congestion, land use, and urban air pollution — that will result from containing vehicle population growth. Developing public transportation systems for personal travel and rail and other modes for freight transportation will be important for containing the growth of motor vehicles in China.

Although the population of passenger cars will far exceed that of all truck types in China in the future, our analysis shows that oil use by and CO_2 emissions from the Chinese truck fleet will be far larger than those related to Chinese passenger cars because trucks are very use intensive (more vehicle miles traveled per year) and energy intensive (lower fuel economy). Unfortunately, the potential for improving fuel economy and reducing air pollutant emissions for trucks has not been fully explored; such efforts are needed.

Considering the rapid depletion of the world's oil reserve, the heightened global interest in addressing greenhouse gas emissions, and the geopolitical complications of global oil supply and demand, the study results suggest that unmanaged vehicle growth and limited improvements in vehicle fuel efficiency will lead to an unsustainable and unstable transportation system in China.

In other words, while our projections do not definitively indicate what *will* happen in the Chinese transportation sector by 2050, they do demonstrate that by allowing uncontained growth in the number of motor vehicles and pursuing only incremental improvements in fuel economy, China may face severe consequences in terms of oil use and CO_2 emissions. Many argue that China — and, in fact, the world — will not be able to accommodate such uncontained vehicle growth. The potential problems related to transportation energy use and CO_2 emissions in China are, indeed, global problems; solving these problems will require international collaboration.

Key Words: Chinese on-road vehicles, vehicle stock, oil consumption, fuel economy, CO_2 emissions

1 INTRODUCTION

Over the past two and a half decades, China has experienced rapid growth in the population of motor vehicles on its roads. The annual rate of growth in China's vehicle stock has been over 10%, and this trend will continue. As a result, oil consumption and carbon dioxide (CO_2) emissions associated with on-road transportation are rapidly increasing. Since the late 1990s, the growth in oil demand by and the increase in CO_2 emissions from motor vehicles in China have been a focus of interest for many research institutions — domestic and international, academic and governmental. Researchers have conducted many studies to estimate and forecast the demand for oil by China's on-road vehicles, and some have tried to formulate feasible policies to mitigate the trend of China's rapidly increasing oil demand. The Chinese government is also paying close attention to oil demand — expending considerable effort to improve vehicle fuel efficiency and save oil. For example, in 2004, China adopted its first national fuel consumption standard for passenger vehicles (GB19578-2004) (Jin et al. 2005).

Forecasting oil demand is important because it forces decision makers to develop strategies to prevent more serious impacts in the future. According to recent studies, the amount of oil consumed by China's on-road vehicles will grow rapidly — at an annual rate of 6% — and consumption will reach 280–360 million metric tons by 2030 (He et al. 2005). In light of the shortage of oil resources, both in China and globally, the rising demand for oil in China will severely strain the balance of national and international oil supply and demand. Mounting scientific evidence shows that increases in global CO_2 emissions may result in global climate change. Oil use and CO_2 emissions have become major international concerns.

We developed a methodology and a model to simulate the growth in the population of Chinese vehicles and resulting oil consumption and CO_2 emissions through 2050. This effort extends a study conducted by two of the authors in 2002 to project Chinese vehicle growth (Wang and He 2000). Our ultimate goal in conducting this study is to establish a base for formulating effective policies so that the disastrous consequences of uncontained vehicle growth in China can be avoided.

Although the number of Chinese on-highway vehicles has increased at a tremendous rate in recent years, China still has a large population of motorcycles (MCs) and rural vehicles (RVs). In our study, we included all three vehicle types and their fuel use and CO_2 emissions.

2 METHODOLOGY AND DATA

The traditional method used to forecast on-road vehicle oil demand and CO_2 emissions includes three steps: (1) determine the number of on-road vehicles; (2) determine vehicle use, such as the distance driven annually by each vehicle (i.e., vehicle miles traveled [VMT]); and (3) determine fuel consumption rates (i.e., the amount of fuel consumed per hundred kilometers traveled [L/100 km]) or fuel economy (kilometers per liter [km/L] or miles per gallon [MPG] of fuel). Various studies have addressed these three steps by employing different approaches. For studies related to China, researchers tend to use simplified methods because of the lack of data in the three areas. He et al. (2005) used the elasticity method to project vehicle population and the growth in total traffic demand to generate vehicle use; they ultimately used these projections to predict vehicle population and usage intensity from 1997 to 2030. Wang and He (2000) projected the growth in vehicle population, future VMT, and rate of fuel consumption from 2000 to 2030 by examining historical trends in developed countries. Kobos et al. (2003) used a dynamic model to simulate the growth in the number of passenger vehicles in China up to 2025 by province. Ng and Schipper (2006) projected Chinese passenger car population through 2020 by assuming that the car ownership rate per unit of gross domestic product (GDP) in China in 2020 would be at the level of Korea's car ownership (per unit of GDP) in the 1990s.

Because rapid growth in the vehicle population in China occurred only recently, the period for vehicle data to accumulate in China is much shorter than in developed countries. Also, because China has unique ways of classifying its vehicle stock and vehicle use, projecting vehicle population growth, consequent energy use, and CO_2 emissions is especially challenging. Although some modeling approaches have been developed and used extensively in other countries, their application in China is often problematic, primarily because of limited data. In this study, we project Chinese vehicle population growth, vehicle usage intensity, and vehicle fuel consumption rates by considering (1) data availability in China, (2) assumptions that are based on international experiences and are applicable to China, and (3) scenarios reflecting important parameters regarding Chinese motor vehicle growth and usage.

2.1 CHINESE VEHICLE CLASSIFICATION

In Chinese statistics, vehicles are often classified as "civil" or "special" vehicles according to their function. Civil vehicles include passenger vehicles and trucks that provide commercial transportation services, vehicles belonging to private enterprises and government institutions, and private vehicles. Special vehicles include those for special purposes, such as fire trucks, municipal sanitation vehicles, and military fleets. Our study considers only civil vehicles. The number of special vehicles is small, and it may not increase significantly in the future.

Figure 1 shows the Chinese classification for civil vehicle types included in this study. Chinese civil vehicles are grouped into highway vehicles (HWVs), MCs, and RVs. On the basis of Chinese statistical protocol[1], HWVs include cars, trucks, and buses. Trucks are further classified into heavy-duty trucks (HDTs), medium-duty trucks (MDTs), light-duty trucks (LDTs), and mini trucks (MiniTs). Buses are classified into heavy-duty buses (HDBs), medium-duty buses (MDBs), light-duty buses (LDBs), and mini buses (MiniBs). Cars are classified into large cars (LCs) and small cars (SCs)[2]. MCs are classified into urban motorcycles (UMCs) and rural motorcycles (RMCs), and RVs are classified into three-wheeled (3-W RVs) and four-wheeled (4-W RVs). Cars, truck types, and bus types can be further classified into gasoline and diesel vehicles. All MCs are fueled with gasoline, and all RVs are fueled with diesel.

2.2 PROJECTION OF HWV STOCK

The number and age of on-road vehicles are key factors in determining oil use and CO_2 emissions in the transportation sector. Because vehicle technologies improve over time — as a result of either government requirements or market competition — and these improvements could increase vehicle fuel economy, fuel economy rates generally vary according to the age of on-road vehicle fleets. In China, where vehicle technologies are less advanced, the variation in vehicle fuel economy among different model-year (MY) vehicles could be substantial. Therefore, an accurate projection of oil use and CO_2 emissions needs to take into account differences in the fuel economy of different MY vehicles on the road in a given calendar year. In other words, information concerning HWV stocks by MY, as well as total HWV stock, is needed. In this study, we first projected the HWV ownership per 1,000 people by using the Gompertz function (as explained in Section 2.2.1) to obtain total HWV population with projected human population in China. Then, we back-calculated annual sales of vehicles to match the projected total HWV stock in a given year by considering vehicle survival rates and market shares by vehicle type. Note that in this step, the total HWV stock was also broken down into different vehicle types by using their market shares. Finally, we established HWV stocks by MY and by type on the basis of HWV sales, survival rates, and market shares.

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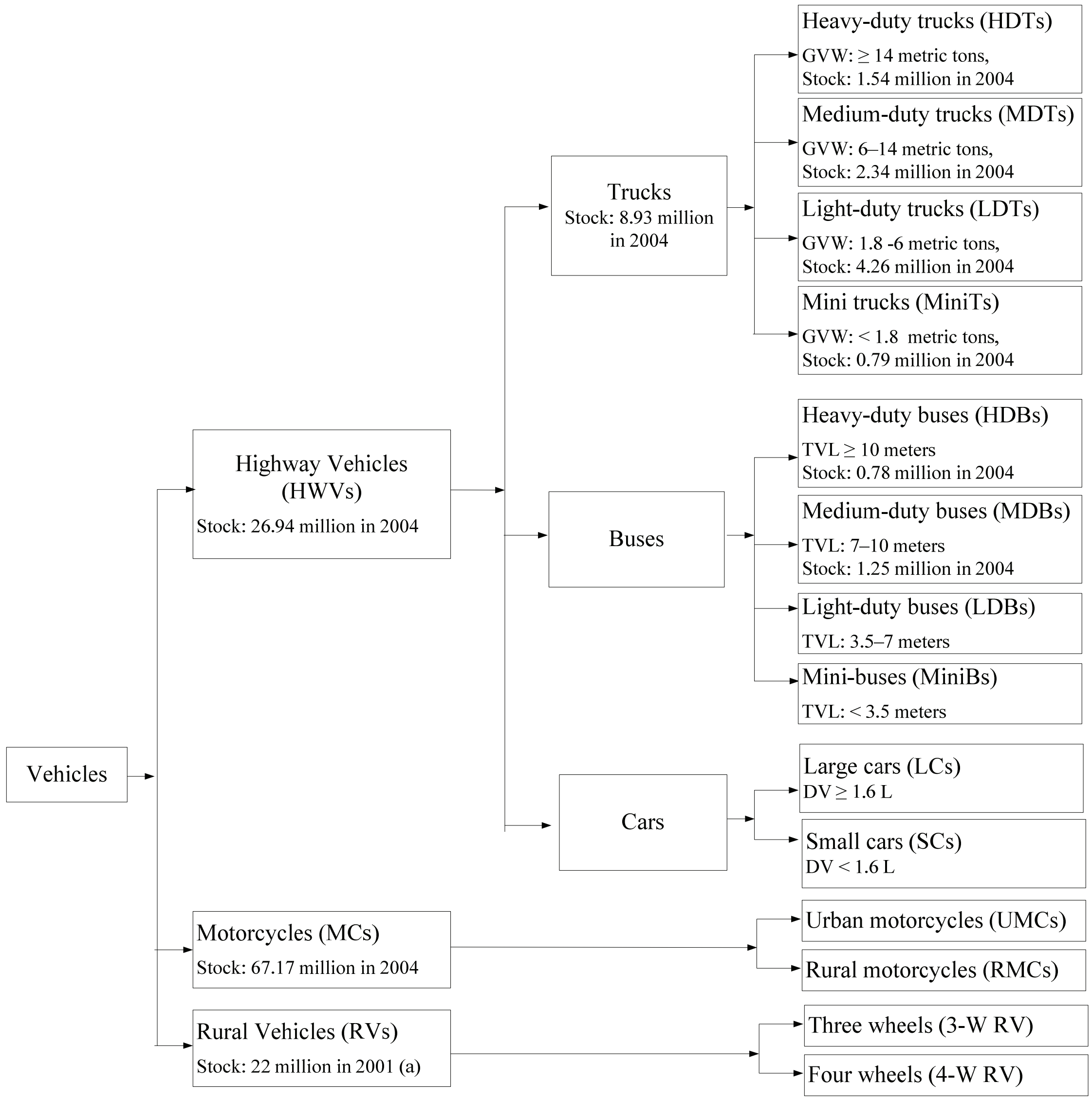
[1] The Chinese national standards for vehicle classification have been updated several times during the past two decades. The latest standards that define vehicle classification are GB/T 15089-2001 for HWVs and GB 7258-2004 for RVs. To increase data availability and consistency, we based the vehicle classifications in this study on the previous national classification standards (GB 9417-1989 and GB 18320-2001).

[2] Classification of trucks in China is based on gross vehicle weight (GVW). HDTs have a GVW of greater than or equal to 14 metric tons, MDTs of 6–14 metric tons, LDTs of 1.8–6 metric tons, and MiniTs of less than 1.8 metric tons. Classification of buses is based on total vehicle length (TVL). HDBs have a TVL of greater than or equal to 10 m, MDBs of 7–10 m, LDBs of 3.5–7 m, and MiniBs of less than 3.5 m. Classification of cars is based on engine displacement volume (DV). LCs have a DV of greater than or equal to 1.6 L and SCs of less than 1.6 L.



Note: The stock data are from CATARC (2005), except RV data (a), which are from CATARC (2002). Stock data are not presented here for buses and cars because the stock data reported in CATARC (2005) combined buses and cars together as passenger vehicles.

FIGURE 1 Classification of Chinese Civil Vehicles

2.2.1 Total HWV Stock

Numerous studies have been conducted to project vehicle stock in major countries. De Jong et al. (2004) provided a thorough review of the passenger car ownership models described in recent literature (the models reviewed can be applied to simulate vehicle types other than cars). The authors classified available projection models into nine types, the first of which is the "Aggregate Time Series Models." These models relate vehicle ownership to certain economic parameters (usually national GDP, per-capita GDP, per-capita income, and/or per-household income) by using a sigmoid-shape function, which assumes that the long-term trend in vehicle growth follows an S-shape curve, with three phases: a slow-growth period in the beginning (when economic levels are low), a boom period, and a saturated period (when vehicle population growth approaches the saturation level). The data requirements for the Aggregate Time Series Models are less intensive than those for other types of car ownership models. Therefore, these models are widely used to simulate the vehicle stock in the developing world, where detailed data are often not available or are proprietary. A number of sigmoid functions for simulating vehicle stocks have been demonstrated: the modified logistic function by Button et al. (1993) and Ingram and Liu (1997), as well as the Gompertz function by Dargay and Gately (1999) and Zachariadis et al. (1995). In this study, we chose to use the Gompertz function to simulate the growth of the total HWV stock in China.

The Gompertz function can be expressed as:

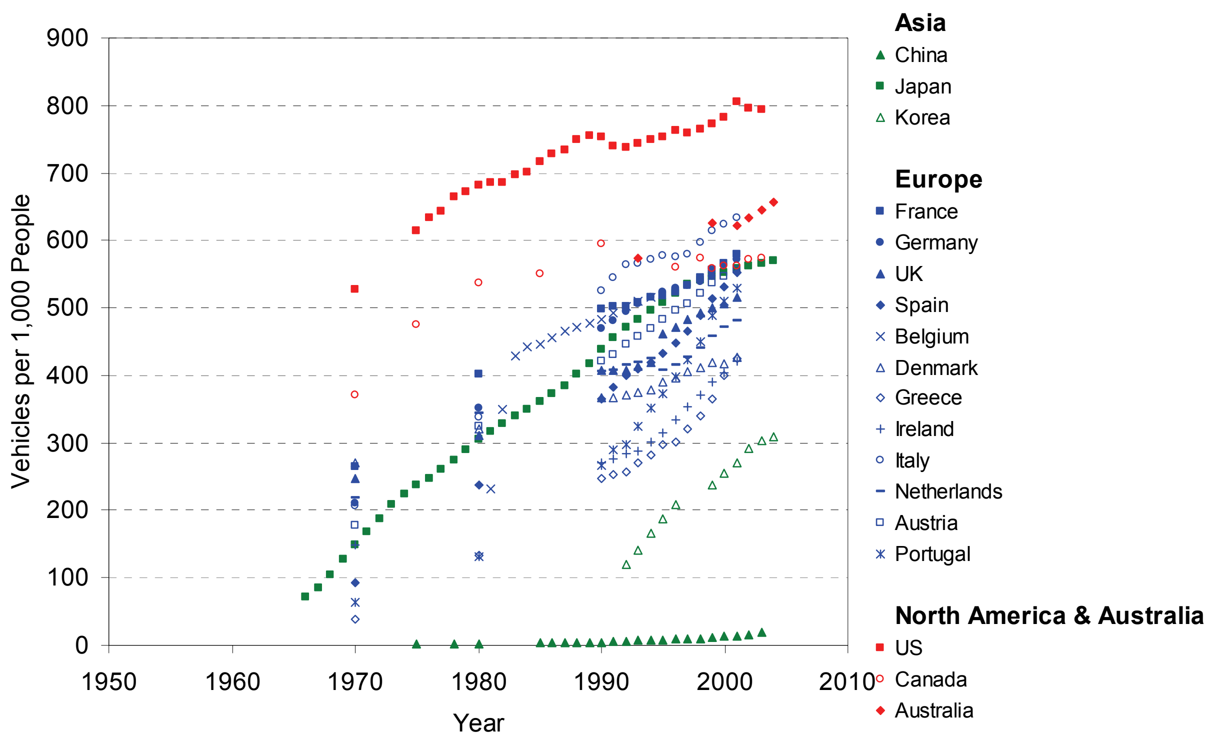
$$V_i = V^* \times e^{\alpha e^{\beta EF_i}} \tag{1}$$

Where:

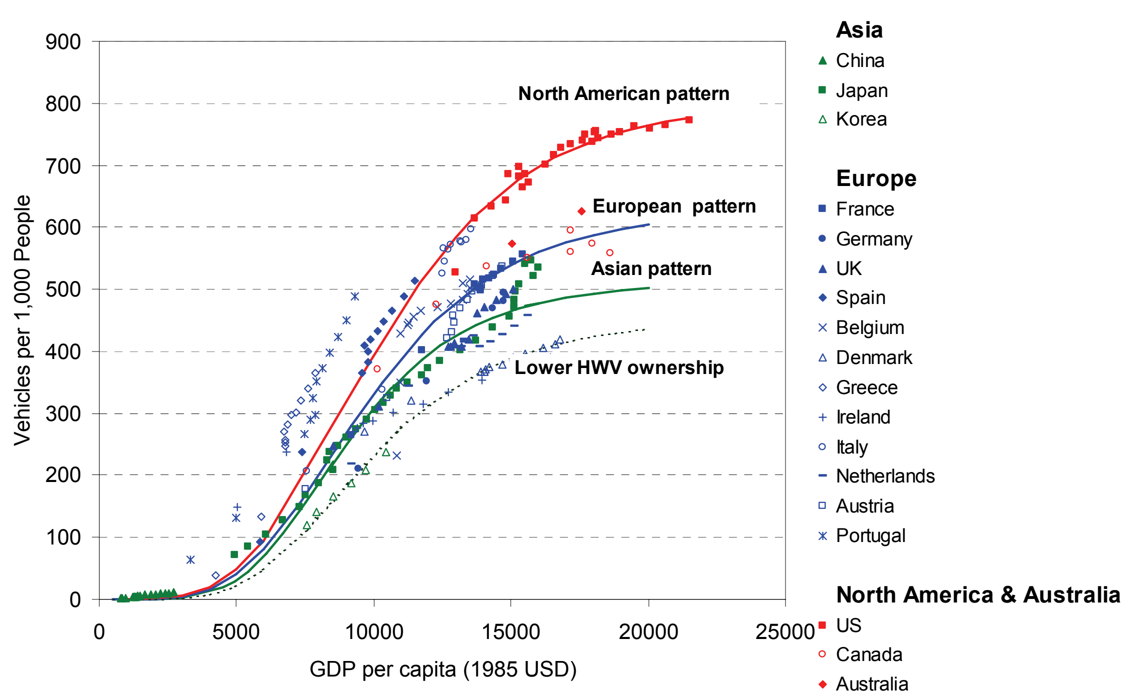
- V_i – Vehicle ownership in year i (vehicles per 1,000 people);
- V^* – Ultimate saturation level of vehicle ownership (vehicles per 1,000 people);
- EF_i – An economic indicator; we used per-capita GDP to simulate the growth of HWVs; and
- α and β – The two parameters that determine the shape of the S-shape curve of vehicle ownership growth over economic growth.

As Equation (1) shows, the Gompertz function predicts vehicle ownership per 1,000 people on the basis of economic growth. Thus, with projected total population, total vehicle stock in China can be predicted from the projected vehicles per 1,000 people.

Figure 2(A) illustrates the HWV ownership over time in 18 countries, while Figure 2(B) plots the HWV ownership versus per-capita GDP in the same 18 countries. In Figures 2(A) and 2(B), vehicle stock data for the European countries are from EC-DGET (2003); those for Korea are from Lee (1997) and KAMA (2006); those for China are from SSBC (2005); and those for other countries are from Davis and Diegel (2006). Per-capita GDP data are from Easterly (2001), and population data are from the U.S Census Bureau (2006).



(A) Vehicle Ownership over Time in 18 Countries



(B) Vehicle Ownership versus Per-Capita GDP in 18 Countries

FIGURE 2 Growth Trend of Vehicle Ownership in Selected Countries

Figure 2(A) shows that the rate of growth in ownership (i.e., the slope of the growth curve) of HWVs per 1,000 people over time in different countries follows nearly the same pattern during the period before growth reaches the saturation points. As Figure 2(B) shows, in the long-term relationship of per-capita GDP and vehicle ownership per 1,000 people, the HWV growth patterns can be grouped into three categories. The first category is the North American pattern (with the United States as its representative), in which the HWV fleet grows most rapidly as per-capita GDP increases. Ownership reaches a saturation level of as high as 800 per 1,000 people when per-capita GDP is at 20,000 U.S. dollars (USD) (1985 price). The second pattern is the European pattern, in which the growth rate of the HWV fleet versus per-capita GDP is a little slower than that of the North American pattern. This is true for both the slope of the growth curve and the saturation level. This finding could be partially attributable to the denser population and compact urban development in European countries. The saturation level for the European pattern is about 600 per 1,000 people. The third pattern is the Asian pattern, with Japan as its representative. The saturation level of HWV ownership in Japan is relatively lower — about 550 per 1,000 people; this low saturation level is partly caused by the high population density and the extensive public transportation system in Japan. Countries such as Korea, Denmark, and Ireland show even lower HWV ownership.

The saturation level of vehicle ownership per 1,000 people is a key factor in estimating total vehicle population. Dargay and Gately (1999) assumed a saturation level of 850 of all vehicles per 1,000 people and 620 cars per 1,000 people for the 26 countries (including China) that they studied. However, Kobos et al. (2003) believed that it was impossible for China — a highly populated country — to support such a high level of vehicle ownership. Instead, they used a saturation level of 292 passenger vehicles per 1,000 people. Button et al. (1993) established a range of 300–450 cars per 1,000 people for low-income countries such as China. On the basis of historic trends in HWV growth in developed countries, we established three scenarios for the growth of Chinese HWVs. The first is a high-growth scenario in which the growth of HWV ownership in China will follow the European growth pattern, with a saturation level of 600 HWVs per 1,000 people. The second is a mid-growth scenario, in which the growth of HWV ownership in China will follow the Asian pattern, with a saturation level of 500 HWVs per 1,000 people. The third is a low-growth scenario, with a saturation level of 400 HWVs per 1,000 people. Note that our assumptions are for all HWVs, including passenger cars, buses, and trucks.

We obtained other necessary data (such as future GDP growth and national demographic forecasts up to 2050) from the published official targets and academic forecasts for China. The current Chinese government's plan is to increase its GDP four times between 2000 and 2020 and to reach a per-capita GDP of 10,000 USD by 2050. On the basis of these projections and other available references (Zhou et al. 2003; Li et al. 2002; Hu 1999; NRAGCSA 1995), we assumed annual GDP growth rates in China of 8.0% between 2006 and 2010 and of 6.0%, 4.7%, 4.0%, and 3.0% during each 10-year period from 2011 to 2050.

Thus, with projected total human population, we can predict total HWV stock in China from the projected vehicles per 1,000 people. The Chinese population is assumed to increase from the current 1.30 billion to 1.45 billion by 2050 (Zhou et al. 2003; United Nations 2005; RGCES 1996). For comparison purposes, Figure 3 presents the historical Chinese GDP and population growth rates (SSBC 2005).

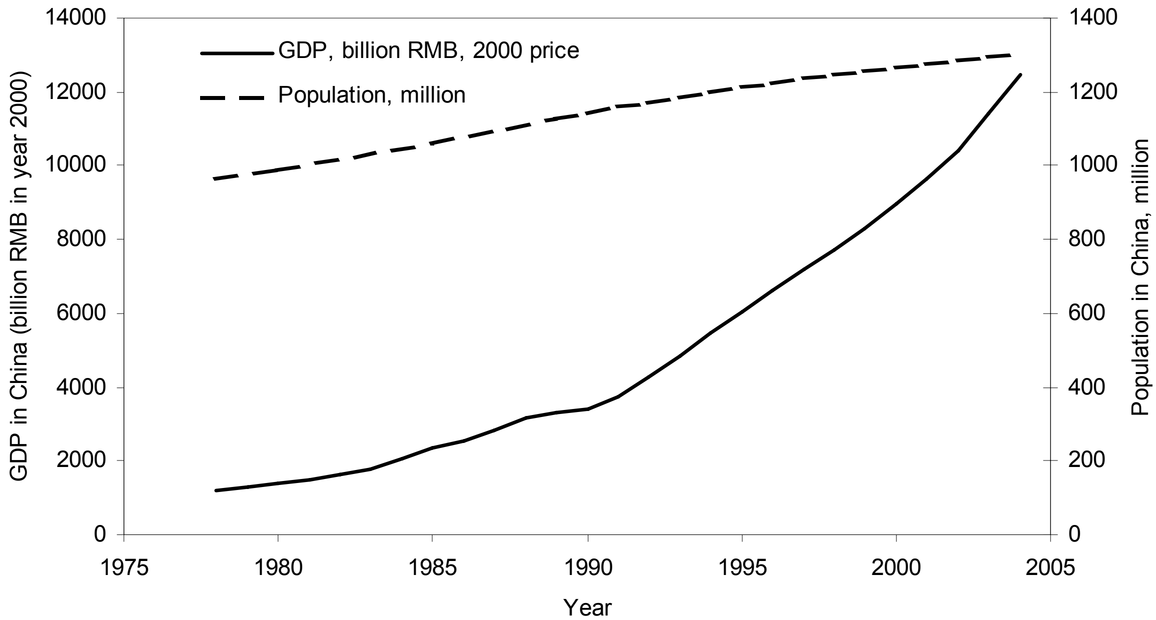


FIGURE 3 Historical Growth of GDP and Population in China

2.2.2 HWV Sales and HWV Stock by Model Year

Assuming that China's vehicle stock in a given year consists of the portion of the HWVs sold during all previous MYs that are still on the road, the total vehicle population can be expressed by Equation (2). Given the survival rates and market shares of vehicles by type, we use this equation to back-calculate annual vehicle sales to match our already-projected total HWV.

$$VP_i = \sum_j \sum_{k=0}^{\sigma} \left(Sales_{i-k} \times Market_{i-k,j} \times SR_{k,j} \right) \quad (2)$$

Where:

- σ – The possible longest service period of the vehicles (in years);
- k – Age in k years for vehicles;
- VP_i – Vehicle population in year i (million units);
- $Sales_{i-k}$ – Sales of all vehicle types in model year $i–k$ (million units);
- $Market_{i-k,j}$ – Market share of vehicle type j in model year $i–k$ (%);
- $SR_{k,j}$ – Survival rate of vehicle type j at age k (%); the proportion of still-operating vehicles (in sales) in certain years. (Generally, the survival rate decreases non-linearly as vehicles get older.)

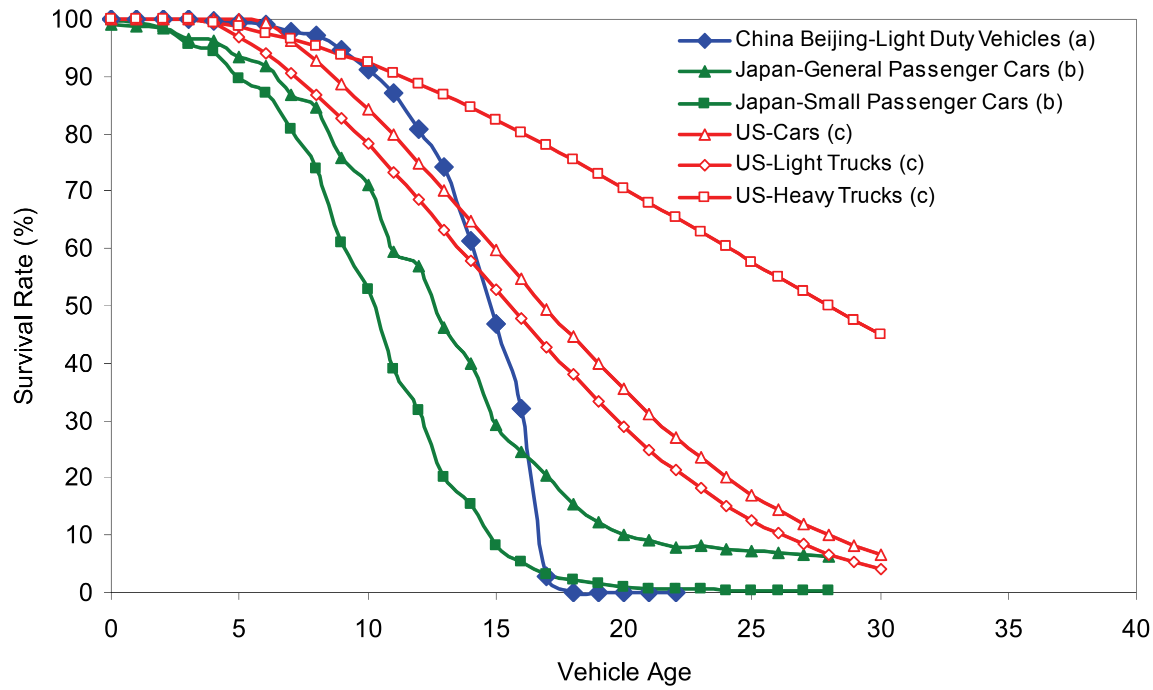
Equation (2) provides a different, detailed way to project vehicle population in a given year on the basis of projected annual vehicle sales over a period of time. This approach was categorized as an "Aggregate Car Market Model" in De Jong's review (De Jong et al. 2004). This approach was taken in the VISION model developed by Argonne National Laboratory to analyze the energy and emission effects associated with advanced vehicle technologies (Singh et al. 2003).

To use Equation (2), survival rates and market shares (by vehicle types sold in a given year) are needed.

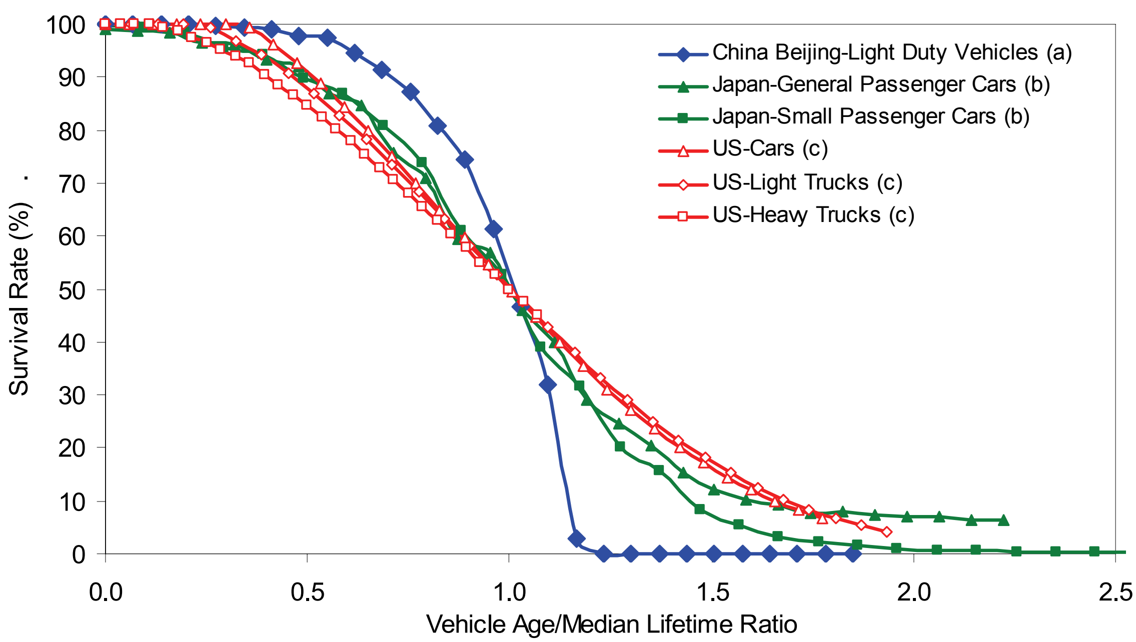
2.2.2.1 Survival Rates

The determination of vehicle survival rates normally requires substantive historical information about vehicle fleets. Because they have had a long period to accumulate registration information and survey data, the United States and other developed countries have been able to generate survival rates for their vehicle fleets. In Zachariadis et al.'s 1995 study, the survival rates were simulated by using a Weibull distribution. Yang et al. (2003) made efforts to develop a methodology to generate the survival rates for light-duty vehicles in Beijing by using the total number of (1) registered vehicles, (2) newly registered vehicles, and (3) scrapped vehicles. However, in most Chinese regions, information such as the number of scrapped vehicles of each type in each year is not easy to obtain. Figure 4(A) shows the vehicle survival rates in Beijing, China; Japan; and the United States. The data for the United States and Japan seem to indicate that heavy vehicles survive longer than lighter ones. Because vehicle lifetimes in the three places are different, Figure 4(B) introduces, for purposes of comparison, the definition of "median lifetime," which is the vehicle age when the survival rate equals 50%. For example, the median lifetimes of the Japanese passenger cars, Japanese small passenger cars, U.S. cars, U.S. light trucks, U.S. heavy trucks, and Beijing light-duty vehicles, which are depicted in Figure 4(A), are 12.6, 10.2, 16.9, 15.5, 28.0, 14.6 years, respectively. Figure 4(B) depicts the survival rates as a function of vehicle age, but with age normalized with median lifetimes for different vehicle types (in order to show survival rates of different vehicle types at the same scale). We can see that the survival rate curve of China's vehicle fleet is somewhat different than that of the other countries. The survival rate of the Chinese light-duty vehicle fleets remains near 1 during the early years and suddenly drops to 0 after a certain age (15 years). This pattern reflects Chinese national scrappage standards that determine which vehicles should be scrapped when they reach a certain age or mileage — causing a sudden decline in the survival rate curve around the age when they must be scrapped.

According to the Automobile Scrappage Standards issued in 2000, 1998, and 1997 by the State Economic and Trade Commission of China, the China State Planning Commission, the Ministry of Public Security of China, and the China State Environmental Protection Administration, the scrappage age of not-for-revenue passenger vehicles with nine seats or fewer is 15 years; this period can be extended if the vehicles can meet certain stringent national requirements for vehicle safety and emissions. The scrappage age of for-revenue



(A) Survival Rate vs. Vehicle Age



(B) Survival Rate vs. Vehicle Age/Median Lifetime

Sources: (a) Yang et al. 2003.
(b) JAIRA 2006.
(c) Davis and Diegel 2004 (the survival rates are for 1990s MY vehicles).

FIGURE 4 Comparison of Vehicle Survival Rates in Different Countries

passenger vehicles and not-for-revenue passenger vehicles[3] with more than nine seats is 10 years (8 years for taxis); this period can be extended up to 10 additional years if the vehicles can meet stringent national requirements for safety and emissions. Trucks should be scrapped when they reach 400,000 km of accumulated travel distance or 10 years of service (300,000 km and 8 years for MiniTs). For HDTs, MDTs, and LDTs, the scrappage period can be extended 5 additional years if these vehicles meet national requirements. Some provincial authorities have been implementing more stringent scrappage standards. For example, Beijing requires that taxis with engine DVs of less than 1 L and small urban public buses (equivalent to LDBs) be scrapped after 6 years of service; no extension is allowed. China is considering the implementation of new scrappage standards that emphasize safety and performance rather than mileage and service period. For example, the Chinese government is planning to withdraw the scrappage requirement for private passenger cars. Table 1 lists the vehicle scrappage requirements in China. Besides service period and mileage, scrappage standards also regulate other conditions under which vehicles must be scrapped; such conditions include serious damage, high oil consumption rates, and high emission levels.

On the basis of the scrappage requirements and dynamics of vehicle fleets in China and trends in the variation of survival rates in the developed countries, the following four assumptions were made to obtain survival rates for Chinese vehicle fleets. First, the survival

TABLE 1 Vehicle Scrappage Regulations in China

Category	Vehicle Type	Scrappage Mileage (km)[a]	Scrappage Period (yr)[a]	Additional Extension Allowed
HDTs, MDTs, LDTs		400,000	10	Up to 5 yr
MiniTs		300,000	8	None
For-revenue passenger vehicles	Tourist travel buses[b]		10	Up to 10 yr
	Taxis	500,000	8	None
	Other purposes	500,000	10	Up to 5 yr
Not-for-revenue passenger vehicles	With more than nine seats (HDBs, MDBs, part of LDBs)		10	Up to 10 yr
	With nine or fewer seats (cars, MiniBs, and some LDBs)		15	Varied

[a] Vehicles that meet *either* the scrappage period or scrappage mileage criterion should be scrapped.

[b] Vehicles that are owned by authorized travel service agencies and used for transporting tourists.

[3] Not-for-revenue vehicles include vehicles used by individuals and companies to transport people or goods but not for generating revenue; for-revenue vehicles include vehicles that provide commercial transport service for generating revenue, such as urban public buses, long-distance passenger buses, taxis, buses in the travel service sector, etc.

rates of all vehicle types in China closely follow the China-Beijing pattern in Figure 4, but with a different median lifetime. Second, the median lifetime of each vehicle type is determined on the basis of its required scrappage period. For HDTs, MDTs, and LDTs, which are subject to the same scrappage requirements, the heavier vehicles are assumed to survive longer than the lighter ones. Third, for the same vehicle type, the survival rates of diesel and gasoline vehicles are assumed to be the same. Finally, the trend in the variation of survival rates over time is similar to that observed in the United States, where the median lifetime of cars increased from 11.5 years for 1970s MY cars, to 12.5 years for 1980s MY cars, to 16.9 years for 1990s MY cars. In contrast, the median lifetime of light trucks in the United States did not vary much, and that of heavy trucks fluctuated substantially (Davis and Diegel 2004). On the basis of these assumptions and considering that passenger cars in China can survive longer because they will not be subject to the scrappage requirements in the future, we assumed an increase of 2–3 years in the median lifetime for cars, MiniBs, and LDBs between now and MYs after 2020 in China. The survival rates of other Chinese fleets were assumed to remain unchanged over time. Figure 5 shows the survival rates of Chinese vehicle fleets. Note that the actual survival rates of each vehicle type vary irregularly within a small range over time.

2.2.2.2 Market Share by Vehicle Type

We searched numerous relevant sources (including yearbooks, automobile technical reports, and market data released by industry associations or posted at Internet Web sites) for historic HWV sales data for the period between 1980 and 2004.

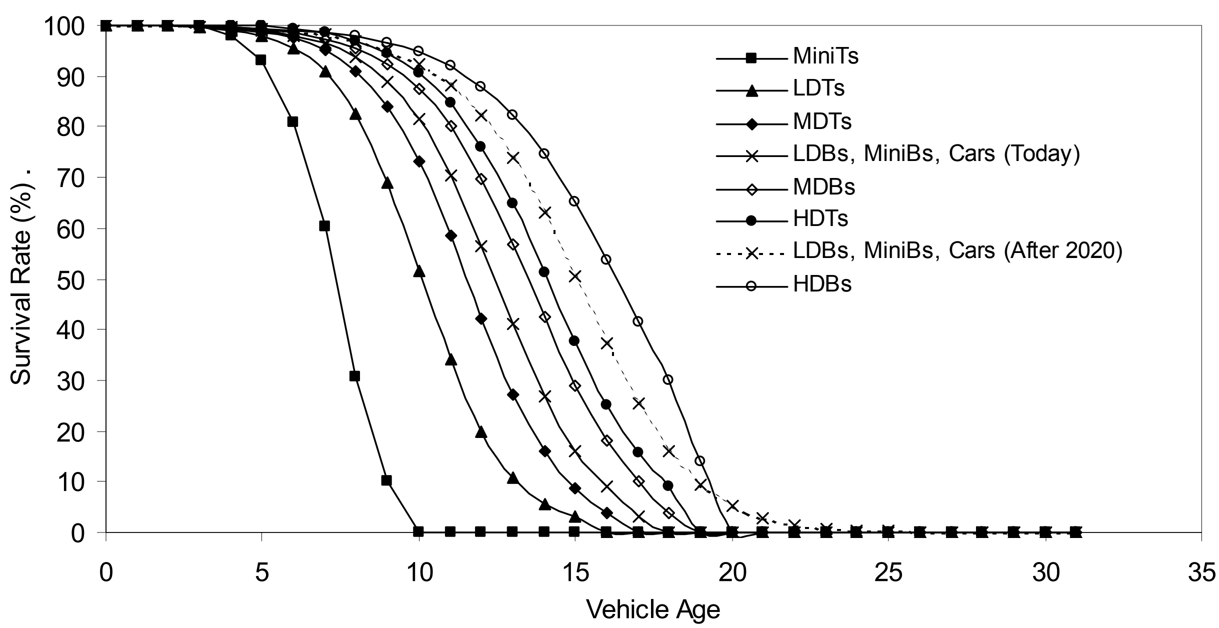


FIGURE 5 Survival Rates of Chinese Vehicle Fleets

Sales data for the period between 1992 and 2004 were taken from the *China Automotive Industry Yearbooks* (CATARC 1991, 1993–2005) and related automobile industry statistics. The Chinese sources report sales of domestically produced vehicles and domestically assembled vehicles with imported components, called CKD (completely knocked down) (these are also taken into account in imported vehicle statistics). In our study, we also took into account import of assembled vehicles.[4]

Data for sales before 1992 were not available. We calculated the sales during this period by using Equation (3). Because CKD vehicles were counted in both domestic production and import statistics, they need to be subtracted from the production data.

$$Sales_i = Production_i - CKD_i \quad Export_i + Import_i \tag{3}$$

Where:

i – Years, i = 1980–1991;
$Sales_i$ – Sales of HWVs in year i;
CKD_i – Domestically assembled vehicles with imported components in year i, which were taken into account in both domestic production and import statistics;
$Production_i$ – Domestic production volume of HWVs in year i;
$Export_i$ – Exported volume of HWVs in year i; and
$Import_i$ – Imported volume of HWVs in year i.

Figure 6 shows the historical growth trend of vehicle sales in China. During the past two decades, the average annual growth rate of new HWV sales in China was around 15%. Because the Chinese automobile market is far from saturation, it is conceivable that this high rate of growth in vehicle sales will continue for the next 15 years.

The market share by vehicle type during the period from 1992 through 2004 was taken from *China Automotive Industry Yearbooks* and related automobile industry statistics (CATARC 1991, 1993–2005). For the period before 1992, only production data were available. Because of the limited data, we assumed that the sales shares of different types of vehicles were the same as the production shares. For the period before 1988, neither production data nor sales data could be found for some vehicle types. In this case, we estimated vehicle sales (by type) by interpolating data from the years when data were available.

The next step is to determine the market share for each vehicle type in the future. The composition of the Chinese HWV population is now undergoing enormous changes. Trends in vehicle composition were projected according to government policies, the development plan of

[4] In Chinese statistics, import vehicles include assembled vehicles and components. During the 1980s and early 1990s, import vehicles represented a large percentage of the vehicle market in China. The import peak occurred in 1985, with the number of imported vehicles at 354,000 — representing a market share of 44.4%. During the early 1990s, imported vehicles accounted for about 18% of the vehicle market, and this value has declined to 2–3% since 1997. The percentage of assembled vehicles in the total number of imports (vehicles and parts together) has been decreasing in recent years, from 72.9% in 1988 to 63.1% in 1990 to 30.0% in 1995.

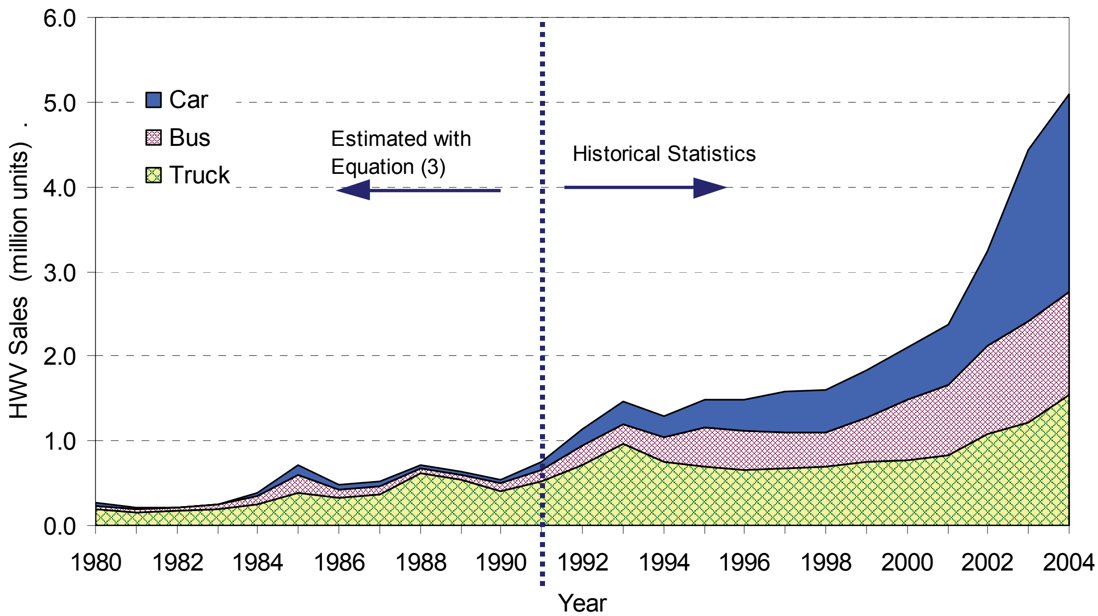


FIGURE 6 Historical HWV Sales in China

the Chinese automobile industry (RGAID 2001), and historical trends in some developed countries. The following factors were taken into account to determine the composition of the HWV population in China.

First, sales of passenger cars will continue to increase. The most obvious change in Chinese HWV sales is the rapid increase in the proportion of cars sold, from 1.4% in 1985 to 46.6% in 2005. At present, the percentage of cars in the total vehicle population is still relatively low compared with that in developed countries, and passenger car ownership in China is far from the saturation level.

Second, the proportion of smaller passenger vehicles (including small cars and MiniBs) will gradually increase. Although the proportion of small cars in the Chinese HWV fleet decreased in recent years from about 70–85% in 2000 to 55–65% in 2005 (data are from different industrial statistical sources), these cars could capture an increased share of the market because of three factors: (1) lower purchase prices, (2) low rates of fuel consumption (resulting in lower operating costs), and (3) middle- and low-income customers entering the passenger car market. This trend toward smaller cars has already been observed in Japan, Korea, and European countries. In Japan, sales of small cars and mini-cars (with engine DVs of less than 2.0 L) accounted for 85% of car sales in 2002 (JAMA 2006). In fact, recent Chinese government fiscal policies were designed to encourage purchase of small, rather than large, cars. For example, in

April 1, 2006, the Chinese central government established the following national sales excise tax rates for passenger cars to encourage small car and discourage large car sales:

- Engine size ≤ 1.5 L: 3% excise tax
- Engine size 1.5–2.0 L: 5% excise tax
- Engine size 2.0–2.5 L: 8% excise tax
- Engine size 2.5–3.0 L: 11% excise tax
- Engine size 3.0–4.0 L: 14% excise tax
- Engine size ≥ 4.0L: 20% excise tax

Third, the share of truck sales will gradually decrease according to the general historical trend in developed countries.

Fourth, shares of diesel vehicles in the Chinese vehicle population could increase. In the past 20 years, the rate of Chinese truck dieselization has accelerated — the share of diesel trucks in the total truck population in China has increased from 13.8% in 1980, to 21.3% in 1990, to 53.0% in 2000 (Liu 2001). In the *Tenth Five-Year Plan of the Chinese Automotive Industry*, the Chinese government set a goal that all heavy- to medium-duty trucks produced by 2005 would be fueled with diesel (SETCC 2001). In Japan, the dieselization of trucks that weigh more than 2,000 kg was almost 100% in 2004 (JAIRA 2006).

Table 2 shows the projected market share of each vehicle type.

2.2.2.3 Annual Vehicle Sales Projection

As discussed in Section 2.2, our vehicle projection was based on a reverse, aggregate approach. In other words, given the assumed vehicle ownership per 1,000 people at different per-capita GDP levels and projected GDP growth over time, we projected total vehicle population (VP_i in Equation [2]). We then used Equation (2) to back-calculate annual vehicle sales to match our already-projected total vehicle population.

We developed Equation (4) from Equation (2) to estimate annual vehicle sales. As shown in Equation (4), sales in year *i* can be calculated by using the vehicle population in year *i* and the surviving vehicles sold in all previous MYs. Because we had already obtained the sales data for the period between 1980 and 2004, we calculated annual sales between 2005 and 2050 (year by year) by using Equation (4).

$$Sales_i = \frac{VP_i - \sum_j \sum_{k=1}^{\sigma} \left(Sales_{i-k} \times Market_{i-k,j} \times SR_{k,j}\right)}{\sum_j \left(Market_{i,j} \times SR_{0,j}\right)} \tag{4}$$

The variables and notations in Equation (4) are defined in Equation (2). The denominator ($\sum Market_{i,j} \times SR_{0,j}$) represents the portion of the vehicles sold in the given year *i* that survived in that year.

TABLE 2 Projected Market Share of Each Vehicle Type (%)

	Year					
Vehicle Type	1990	2000	2005	2010	2030	2050
Trucks	78.7	36.4	31.4	26.4	19.5	19.0
HDT	3.9	4.0	4.5	4.6	4.6	5.3
MDT	37.6	7.5	4.5	3.9	3.1	3.2
LDT	32.0	18.6	17.7	14.9	10.9	10.6
MiniT	5.3	6.4	4.7	3.2	1.0	0.0
Buses	9.9	34.0	21.6	13.0	4.0	1.0
HDB	1.1	0.4	0.5	0.7	1.5	0.8
MDB	0.5	1.7	0.9	0.5	0.3	0.1
LDB	8.0	12.0	8.6	5.1	1.1	0.1
MiniB	0.3	19.9	11.7	6.7	1.2	0.1
Cars	11.4	29.6	47.0	60.6	76.5	80.0
Small Car	9.7	22.2	28.2	37.3	50.5	56.0
Large Car	1.7	7.4	18.8	23.3	26.0	24.0

2.2.2.4 HWV Stock by Model Year

For a given year *i,* the number of vehicles at a certain age *k* is calculated by using Equation (5):

$$Vintage_{i,k,j} = Sales_{i-k} \times Market_{i-k,j} \times SR_{k,j} \tag{5}$$

Where:

- $Vintage_{i,k,j}$ – Number of type *j* vehicles at age *k* in year *i* (million units);
- $Sales_{i-k}$ – Vehicle sales in year *i–k* (million units);
- $Market_{i-k,j}$ – Market share of vehicle type *j* sold, out of total vehicle sales in year *i–k* (%); and
- $SR_{k,j}$ – Survival rate of vehicles type *j* at age *k*.

2.3 MOTORCYCLE STOCK

The MC population has been increasing at an annual rate of 17% in China over the past 15 years. In 2004, the MC stock in China was about 67 million, or 52 MCs per 1,000 people (SSBC 1995–2005). Figure 7 shows the growth in MC ownership in some countries (UKDT 2005; JAIRA 2006). Unlike the ownership growth trends for HWVs, the MC ownership growth trends in different countries are completely different. The growth in MC ownership could be influenced by many factors besides economic factors, which increases the difficulty in

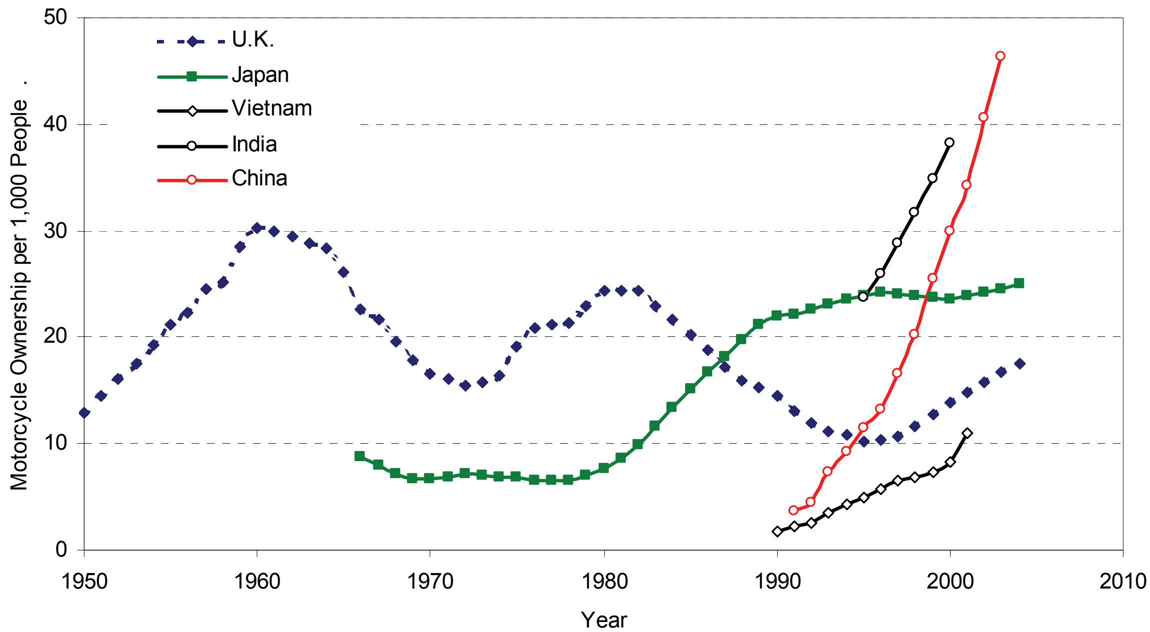


FIGURE 7 MC Ownership in Selected Countries

simulating these trends. In fact, some may argue that, as income increases, people will switch from MCs to passenger cars. We grouped these factors into three categories: (1) economic factors, (2) geographical factors, and (3) other factors. Each is described in the following sections.

2.3.1 Economic Factors

Rising income will undoubtedly increase the demand for MCs; however, as income rises to a certain level, MC owners may prefer a more comfortable transportation mode, such as a car.

Figure 8 shows the results of a survey of urban families with different income levels in China who own MCs and HWVs (SSBC 1998–2005). MC ownership in families with per-capita income below 20,000 RenMinBi (RMB[5]) (2003 price) is rising as per-capita income increases. On the other hand, when per-capita income reaches 20,000–30,000 RMB (2003 price), the growth rate of MC ownership per 1,000 people appears to slow down to a saturation level. Also at this income level, car ownership per 1,000 people begins to increase rapidly, suggesting that the switch from MCs to passenger cars occurs in urban families with high income levels. Although it is still unclear how HWV and MC ownership levels in China will change when per-capita income increases to more than 30,000 RMB, MC ownership may start to decline as income continues to increase. As people climb from one income level to the next, average MC ownership per 1,000 people can vary greatly. In our study, we assumed that within a given income level, MC ownership per 1,000 people will be the same. Total MC population is projected by the distribution of income levels.

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[5] RMB is Chinese currency; 1 USD≈8.3 RMB in 2003.

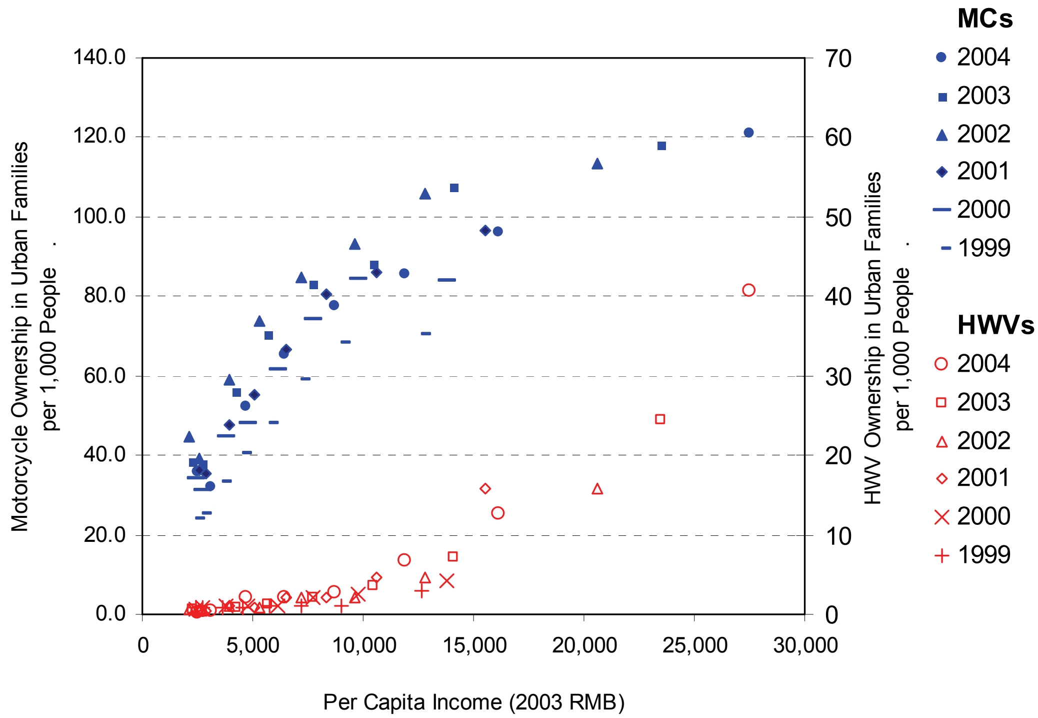
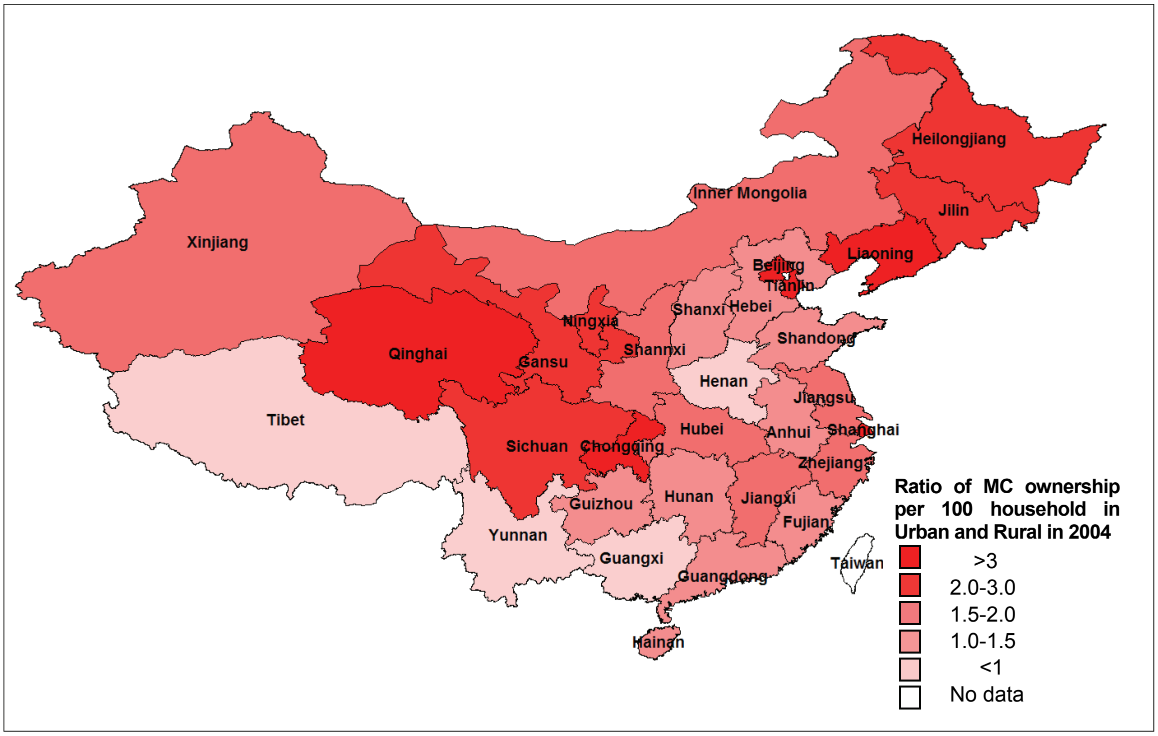


FIGURE 8 MC and HWV Ownership in Urban Families with Different Income Levels in China

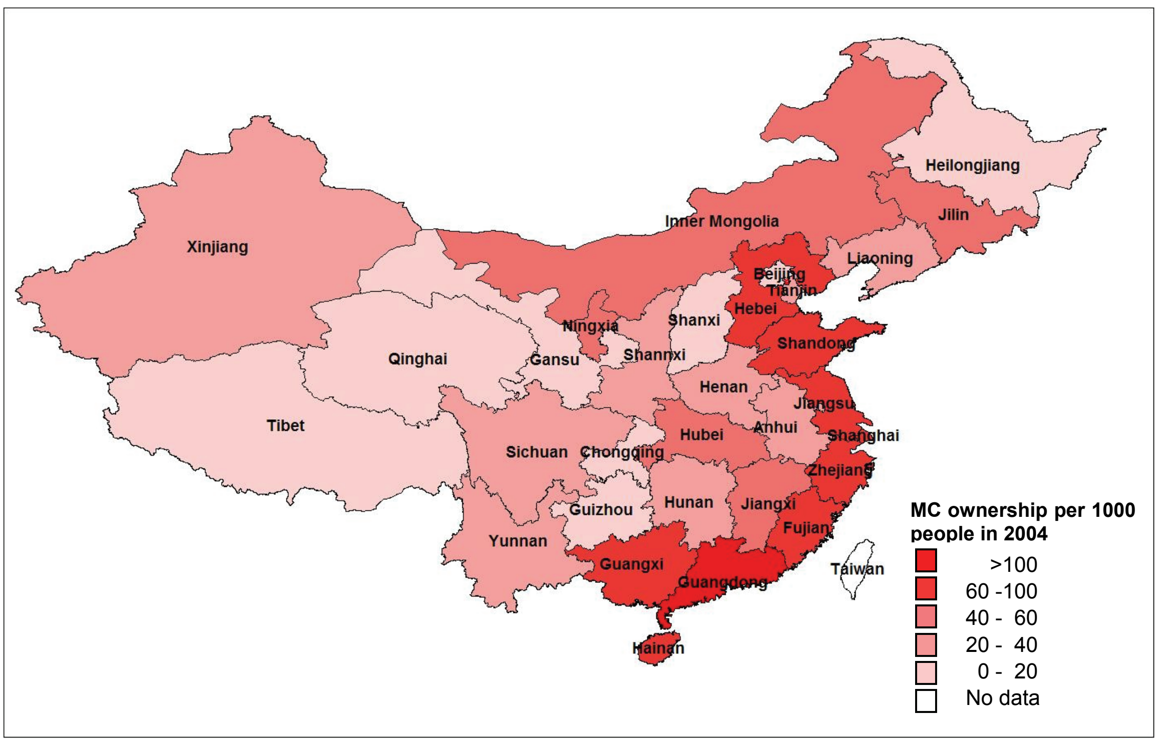
2.3.2 Geographical Factors

Geographical features are another important factor influencing MC stock. Nagai et al. (2003) examined the trend associated with MC ownership in Asian countries and found that MC ownership tends to increase as per-capita GDP grows, except in several geographically unique countries and areas, such as Bangladesh, where the land is unconnected because of the numerous rivers; the Philippines, which is archipelagic; and Singapore, which is a city-state. In China, because geographical features vary dramatically throughout the country, MC ownership is different from region to region. For example, the level of MC ownership in the Hainan province is 64 per 1,000 people and is still growing at an annual rate of 17%, while in Sichuan, the level of MC ownership has stabilized at only 9.2 per 1,000 people (see Figure 9). Note that per-capita income in the two provinces is similar. Generally, the geographical distribution of MC ownership in China has the following characteristics.

First, MC ownership by rural families is generally higher than that by urban families, as shown in Figure 9. In most provinces, MC ownership in rural areas per 100 households is higher than that in urban areas (in some places such as Shanghai, Beijing, and Tianjin, the ratio of rural to urban MCs could be 10 to 1). This huge difference between rural and urban MCs is not the result only of geographical factors; it is also partly attributable to policies in major Chinese cities to limit, and even ban, the registration and use of MCs. The difference is also related to the desire of Chinese citizens to switch from MCs to cars as their incomes increase. One implication is that the population of rural MCs has a greater potential for growth than that for urban MCs in the foreseeable future.



(A) Ratio of MC Ownership per 100 Households in Urban and Rural Areas



(B) MC Ownership per 1,000 People

FIGURE 9 MC Ownership in China in 2004 (SSBC 2005)

Second, MC ownership in China's southern regions is generally higher than in the northern regions because the warmer southern climate makes riding MCs more comfortable. In some southern provinces, such as Guangdong and Hainan, MC ownership can be as high as 60 or more per 100 households.

Third, MC ownership in the western provinces is much lower than in the eastern provinces because of lower incomes and mountainous geography in the west.

We divided the 31 provinces in China into three regions: the northern, the southern, and the western. In addition, because of the distinct differences between rural and urban MC ownership, we projected urban and rural MC stocks separately.

2.3.3 Other Factors

Other factors that influence MC ownership in China include (1) policy restrictions that affect the use of MCs or cars in cities; (2) operational costs that are affected by fuel prices and other maintenance costs; and (3) some other factors. The fluctuation of MC ownership in the United Kingdom is a typical example. As Figure 7 shows, the first downtrend in MC ownership in the United Kingdom in the 1960s was attributed to the replacement of MCs by cars.

Duffy and Robinson (2004) stated that the second growth period of MCs during the two oil crises in the 1970s in the United Kingdom was probably related, to some extent, to lower fuel consumption by MCs. They also considered that the upswing in MC ownership in the United Kingdom since the mid-1990s might be the result of recent government efforts to inhibit car use in major cities in order to relieve congestion. The 2006 surge in MC sales in the United States is also likely attributable to the high gasoline prices at the time this paper was prepared. These factors are difficult to specify when projecting MC stock — some are even unpredictable. In our study, we take into account only the quantifiable factors, such as the above-mentioned restrictions on MC registration and use in urban areas in China.

Total MC ownership per 1,000 people is related to the distribution of per-capita income levels and MC ownership in each income level. Geographical features and government policies also affect MC ownership; we used Equation (6) to simulate the MC ownership in each of the three regions in China:

$$MC_i = \sum_j \left[Inc\_Dis_j \times M*_j \times (1 - Res_i) \right] \tag{6}$$

Where:

MC_i – MC ownership per 1,000 people in year i;

j – Income level j (we classified per-capita income into 11 income levels, with more levels at lower incomes because MC ownership is more sensitive to income at lower income levels. The first to sixth income levels were from 0 through 15,000 RMB per capita in 2,500-RMB increments; the seventh through ninth income levels were from 15,000 to 30,000 RMB in 5,000-RMB increments; the tenth level was from 30,000 to 50,000 RMB; and the eleventh level was above 50,000 RMB.);

Inc_Dis_j– Share (%) of the population within income level *j* out of total population (we used the lognormal distribution to simulate the income distribution among people in future years. The necessary data [i.e., urban and rural population split, per-capita income, and income disparity between the eastern and western regions] were taken from studies conducted by Chinese and international academic institutions to project urbanization trends and urban and rural income levels in China [Toth et al. 2003; Li 1997; Zhou et al. 2003]. Table 3 shows the projection of urban population shares, and Table 4 shows distribution of income group by region.);

M^*_j– MC ownership per 1,000 people for the population within income level *j* (we assumed that MC ownership per 1,000 people within a certain income level would be constant for a given region. On the basis of available statistics, historical trends of MC stock, and other survey studies [SSBC 1998–2005; Zhang and Zhu 1996], we set *M** for the first through ninth income levels for the six regions, as Figure 10 shows. For income levels 10 and 11, we took into account the switching potential from MCs to cars at higher income levels — establishing switching factors of 80% and 30%, respectively, for each of these two income levels [which means MC ownership at income levels 10 and 11 will be 20% and 70% lower, respectively, than those at income level 9].); and

Res_i– Restriction factors in year *i*, which reflect the effect of possible policies to restrict the use of MCs. In this study, we assumed that *M** will be reduced by 20% of total MC population in urban areas after 2020, another 5% after 2030, and another 5% in 2040 as a result of potential policy intervention.

TABLE 3 Projection of Chinese Regional Urban Population Shares (%)

Year	National	Northern Region	Southern Region	Western Region
2005	34.4	36.3	36.1	28.0
2010	43.9	46.4	44.6	38.4
2015	51.9	54.9	53.7	43.6
2020	57.9	60.2	61.5	47.6
2030	64.7	70.9	74.6	58.1
2040	69.5	75.2	78.0	62.7
2050	73.5	79.4	81.4	67.4

TABLE 4 Income Distribution by Region in China

		Income Level										
		1	2	3	4	5	6	7	8	9	10	11
	2003 RMB	0–2,500	2,500–5,000	5,000–7,500	7,500–10,000	10,000–12,500	12,500–15,000	15,000–20,000	20,000–25,000	25,000–30,000	30,000–50,000	>50,000
Northern Urban	2000	5.1	26.4	26.1	17.3	10.3	5.9	5.5	2.0	0.8	0.6	0.0
	2010	0.0	1.5	7.9	14.6	17.2	15.3	21.5	11.5	5.5	4.8	0.3
	2030	0.0	0.0	0.0	0.0	0.0	0.1	0.8	3.2	7.3	50.5	38.1
	2050	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	97.6
Southern Urban	2000	12.1	37.2	25.3	12.7	6.2	3.0	2.4	0.7	0.2	0.1	0.0
	2010	0.0	0.5	4.1	9.7	13.0	14.3	24.1	15.2	8.8	9.4	0.9
	2030	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.9	3.0	36.5	59.5
	2050	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	99.5
Western Urban	2000	25.8	43.4	18.8	7.1	2.7	1.1	0.7	0.2	0.0	0.0	0.0
	2010	0.2	6.5	19.4	22.7	18.3	12.6	12.9	4.7	1.7	1.0	0.0
	2030	0.0	0.0	0.0	0.0	0.0	0.1	0.8	3.4	7.4	51.0	37.3
	2050	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	98.5
Northern Rural	2000	38.5	38.1	14.1	5.3	2.2	1.0	0.7	0.2	0.1	0.0	0.0
	2010	7.8	38.0	28.8	13.9	6.3	2.8	1.8	0.4	0.1	0.1	0.0
	2030	0.0	0.0	0.1	0.7	2.8	5.6	19.3	22.3	18.4	27.5	3.2
	2050	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.7	26.4	71.2
Southern Rural	2000	78.3	18.1	2.8	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.0
	2010	3.7	27.8	29.9	18.3	9.8	5.0	3.9	1.1	0.3	0.2	0.0
	2030	0.0	0.0	0.0	0.4	1.6	3.9	14.8	20.4	19.1	34.3	5.5
	2050	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.4	24.3	73.7
Western Rural	2000	93.9	5.6	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2010	34.4	47.3	13.6	3.4	0.9	0.3	0.1	0.0	0.0	0.0	0.0
	2030	0.0	0.0	1.3	5.8	12.2	15.4	29.6	18.7	9.4	7.3	0.3
	2050	0.0	0.0	0.0	0.0	0.0	0.1	0.9	3.5	7.1	47.4	40.9

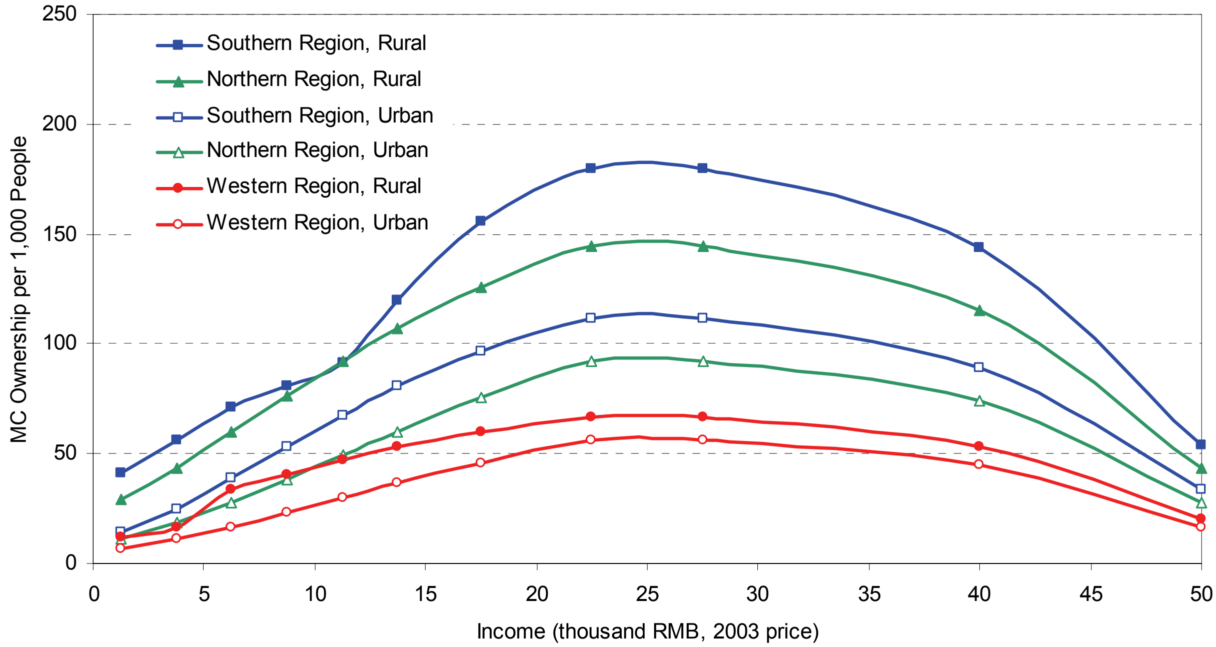


FIGURE 10 MC Ownership per 1,000 People within Each Income Level

2.4 RURAL VEHICLE STOCK

With a rural population of 925 million people, China has a large population of RVs — about 22 million in 2001 (CATARC 2002). RVs are a special type of vehicle used in China and in some other developing countries. They are owned mainly by rural families and used for various functions, including agricultural field work and transportation of goods and people. Because China changes the definition of RVs quite often and the registration requirements are weak, the statistical data from different official sources for these vehicles are so inconsistent that they may not provide accurate information about Chinese RVs. We relied mainly on the information released by the Chinese RV industry and related organizations, such as the China Automotive Technology and Research Center, the Chinese Ministry of Machinery Industry, and other organizations.

The production of RVs in China increased at an annual rate of 38% between 1985 and 2000 — a rate that is even faster than that for HWVs. This rapid growth was caused partly by the much more lenient requirements and weaker regulations for RVs versus HWVs. The growth of RV production in China has slowed down in recent years, probably as a result of slower growth in the income of rural families, the poor product structure of RVs, and new stringent regulatory conditions for using RVs (Tang 2003).

Problems related to RV safety and pollution have already raised government concerns. Efforts are under way to enforce the regulation of RVs — from production to registration — and to improve the safety and emissions technology of these vehicles, which will certainly affect production and the RV market. Nevertheless, the Chinese RV stock still shows a huge potential for growth because of its low rate of ownership: 9.3 RVs per 100 rural households in 2001

(CATARC 2002). The increase in per-rural-family income and improvements in the condition of rural roads will be the major causes for the growth of the RV population in China. According to a survey conducted by authorities in over 20 provinces, 5% of rural families were willing to purchase an RV in the next 3 years (Yu and Xiao 2005).

Like MCs, RVs are a kind of transitional transportation because of their much lower price. When their per-capita income increases, rural families will turn to more powerful modes, such as LDTs. Therefore, we projected RV stock by using the same method as that used for projecting MC stock. RV ownership per 1,000 rural people was estimated for 11 income levels on the basis of the limited available data (MMIC 1997), as shown in Table 5. A switching factor was established in our simulations to reflect the potential of buyers to switch from RVs to LDTs or MDTs at income levels 5 through 11.

As for MCs, we established a restriction factor for RV ownership for our simulations. This restriction factor reflects the influence of policies on the ownership of RVs. There are several factors — such as price differences, RV power needs, and geographic features — that influence a consumer's choice between 3-W RVs and 4-W RVs. The ownership split between 3-W RVs and 4-W RVs was about 80% to 20% in 2000 (MIRVDRC 2001). According to current Chinese government policy guidance, 4-W RVs will be subjected to more stringent requirements; therefore, we assumed higher restriction factors for 4-W RVs. The restriction factors were set at 10% for 3-W RVs and at 15% for 4-W RVs in 2010.

2.5 VEHICLE MILES TRAVELED

The VMT data in China are not readily available or published. Some VMT data were obtained from the available literature. These data, although limited, can provide some helpful information about the characteristics of VMT by the Chinese vehicle fleet.

TABLE 5 RV Ownership per 1,000 People at Each Income Level[a]

Income Level No.	Income Level (in thousand 2003 RMB)	3-W RVs	4-W RVs
1	0–2.5	10.6	3.5
2	2.5–5.0	34.8	11.6
3	5.0–7.5	56.5	18.8
4	7.5–10.0	77.4	25.8
5	10.0–12.5	85.1	28.4
6	12.5–15.0	92.8	30.9
7	15.0–20.0	77.4	25.8
8	20.0–25.0	77.4	25.8
9	25.0–30.0	77.4	25.8
10	30.0–50.0	77.4	25.8
11	>50.0	77.4	25.8

[a] RV ownership at income levels 5 through 11 was calculated by using a switching factor (see text for more detailed explanation).

2.5.1 Cars

According to the *Annual Reports of Urban Road Transport Development* released by urban transport planning institutes and surveys conducted by universities (Wang et al. 2002; Huo 2005), the annual VMT by cars in cities has been about 24,000–27,000 km in the past few years. Urban taxis show much higher VMT, with a daily travel mileage of around 280–350 km and an annual travel mileage of about 90,000–115,000 km. Other private and business cars travel about 16,000–18,000 km per year. Compared with other developed countries, the VMT of the current Chinese car fleet is much higher. For example, the VMT of cars in Japan, France, and Germany was about 10,000–14,000 km per year between 1970 and 1990 (Schipper 1995). The high percentage of taxis in the Chinese car fleet (16.4% in 2002 and 10.1% in 2004) and their high annual mileage are the main reasons for the high annual VMT by the Chinese car fleet. We assumed that, as the number of private cars grows rapidly and the car fleet gradually matures, the annual VMT by cars will decrease and eventually reach a level of 12,000 km per year in 2050, which is about the current level in Western Europe, as shown in Table 6.

2.5.2 Trucks and Buses

He et al. (2005) determined the VMT for trucks and buses by using traffic demand (freight and passenger traffic volumes). According to that study, HDTs currently travel about 50,000 km annually, while MDTs and LDTs travel 20,000–25,000 km each year. Other researchers reported that heavy-duty vehicles in China travel 20,000 km annually (Wang et al. 2002; Wang and He 2000). Heavier commercial trucks tend to have higher VMTs than lighter commercial trucks because they are mainly business-owned and most are used for long-distance transport. In Japan, the annual mileage rates of commercial trucks with vehicle weights of 4, 5–6, 7–8, and 10 metric tons are 30,000, 40,000, 50,000, and 78,000 km, respectively (Minato and Hirota 2003). In the United States, trucks with weights of less than 2.7, 2.7–4.5, 4.5–11.8, and greater than 11.8 metric tons travel 19,000, 20,000, 21,000, and 71,000 km per year, respectively (Davis and Diegel 2004). In this study, we projected an increasing annual VMT trend for HDTs and a stabilized annual VMT trend for LDTs and MDTs, as shown in Table 6.

The annual VMTs for buses are somewhat similar to those for trucks. That is, larger buses tend to travel farther than smaller ones.

2.5.3 MCs

Because MCs are not suitable for long-distance travel, their annual VMT is usually low. Previous research has found that the current annual VMT for Chinese MCs ranges from 4,000 to 10,000 km (Yang and Yu 2004; Wang et al. 2002; Hao et al. 2000). Worldwide, the annual VMT for MCs varies from 1,700 km in France; to 3,000–4,000 km in the United States, Mexico, and Germany; to 6,700 km in the United Kingdom during the 1990s (USFHWA 1993–2004). We assumed that annual VMT for Chinese MCs will decrease from 9,000 km in 2000 to 4,000 km in 2050.

TABLE 6 Comparison of Annual Chinese VMT Projections with Those in Some Other Countries[a]

Country		China[b]			Japan[c]	United States[d]	United Kingdom[f]	France[f]	Germany[f]
Year		2000	2030	2050	1999	2002	1999	1999	1998
Cars		24	13	12	8	19	17	15	12
Trucks	HDTs	40	50	55	78	71	25	20	13
	MDTs	25	24	24	50	21			
	LDTs	21	20	20	30-40	20			
	MiniTs	20	15	14		19			
Buses	HDBs	40	35	35	13	20[e]	60	29	44
	LDBs	35	20	20					
MCs		9	5	4		3.1[e]	6.7	1.7	3.4
RVs	3-W	15	15	15					
	4-W	28	28	28					

[a] Values are in 1,000 km.

[b] The GVWs of MiniTs, LDTs, MDTs, and HDTs in China are less than 1.8 metric tons, 1.8–6 metric tons, 6–14 metric tons, and greater than or equal to 14 metric tons, respectively.

[c] From Minato and Hirota (2003). Trucks here are commercial trucks; the GVWs of LDTs, MDTs, and HDTs in Japan are 4–6 metric tons, 7–8 metric tons, and greater than 10 metric tons, respectively.

[d] From Davis and Diegel (2004), pp. 5–6. The GVWs of MiniTs, LDTs, MDTs, and HDTs in the United States are less than or equal to 2.7 metric tons (6,000 lb), 2.7–4.5 metric tons (6,001–10,000 lb), 4.5–11.8 metric tons (10,001–26,000 lb), and greater than 11.8 metric tons (26,000 lb), respectively.

[e] From USFHWA (1993–2004), 2001 data.

[f] From USFHWA (1993–2004).

2.5.4 RVs

We estimated the annual VMT of current RVs by using their scrappage mileage (Sperling et al. 2004) and their average scrappage age. We further assumed that the annual VMT of RVs will be constant in the future at 15,000 km per year for 3-W RVs, and 28,000 km per year for 4-W RVs.

Table 6 compares the annual VMT of the vehicle types projected in this study and in some other countries.

2.6 FUEL ECONOMY

2.6.1 Fuel Economy of New Vehicles

In 2004, China issued two-phase, weight-based national fuel consumption standards for passenger vehicles — Passenger Vehicle Fuel Consumption Limits (GB19578-2004) — as shown in Table 7. The standards apply to newly produced M1 vehicles (which, by definition, include passenger cars, minivans with fewer than nine seats, and sport-utility vehicles [SUVs]; the standards also cover cars, MiniBs, and some LDBs in this study) beginning in July 2005. The Chinese standards are based primarily on the Path One Scenario of fuel efficiency technologies presented in the National Academy of Sciences (NAS) study for estimating the potential costs and benefits of improvements in fuel economy (USNRC 2002)[6]. After the implementation of the two-phase standards, the fuel consumption rates of M1 vehicles could be reduced by about 15% compared with those of MY2002 Chinese M1 vehicles (Jin et al. 2005).

Table 8 lists the fuel economy values of vehicles produced before MY2005. To estimate these values, we used the data in He et al.'s 2005 study, which applied the labeled fuel economy and adjustment factors to calculate on-road fuel economy (He et al. 2005). Data on fuel economy rates for RVs are taken from two reports (DRCCSC et al. 2001; Sperling et al. 2004).

To project the fuel consumption rates of future motor vehicles in China, we designed three fuel economy scenarios: a conservative scenario, a moderate scenario, and an aggressive scenario. Under the conservative scenario, potential improvements in fuel economy corresponding to NAS's Path One were assumed for cars and LDTs in the next 3 years, and regulations equivalent to the fuel consumption limits of new Japanese heavy-duty vehicles were assumed for Chinese heavy-duty vehicles (including MDTs, HDTs, MDBs, and HDBs) in the next 20 years (JACENR 2005). Under the moderate scenario, improvements in fuel economy corresponding to NAS's Path Two were assumed for Chinese passenger cars and LDTs in the next 15 years, and regulations equivalent to the fuel consumption limits of new Japanese heavy-duty vehicles were assumed for Chinese heavy-duty vehicles 4 years sooner than in the conservative scenario. Under the aggressive scenario, potential improvements in fuel economy corresponding to NAS's Path Three were assumed for Chinese passenger cars and LDTs. Fuel consumption regulations that are 20% more stringent than those for Japanese HDTs were assumed for Chinese HDTs, as listed in Table 9. Figure 11 compares the fuel economy of some

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[6] NAS designed three paths for improving fuel economy on the basis of the market potentials of fuel economy improvement technologies and economic/regulatory conditions. Path One assumes likely market-responsive or competition-driven advances in fuel economy using production-intended technologies that may be possible under the current economic and regulatory conditions in the United States and could be introduced within the next 10 years. Path Two assumes more aggressive improvements in fuel economy that employ more costly production-intended technologies but that are technically feasible for introduction within the next 10 years if economic and/or regulatory conditions justify their use. Path Three assumes even greater gains in fuel economy, which would necessitate the introduction of emerging technologies that have the potential for substantial market penetration within 10–15 years. These technologies require further development in critical aspects of the total system before commercial introduction.

TABLE 7 Fuel Consumption Limits for Chinese M1 Vehicles[a]

	Phase 1	Phase 2	Phase 1[b]	Phase 2[b]
Effective Date	July 2005	Jan. 2008	July 2005	Jan. 2008
GVW (kg)				
≤750	7.2	6.2	7.6	6.6
750<GVW≤865	7.2	6.5	7.6	6.9
865<GVW≤980	7.7	7.0	8.2	7.4
980<GVW≤1,090	8.3	7.5	8.8	8.0
1,090<GVW≤1,205	8.9	8.1	9.4	8.6
1,205<GVW≤1,320	9.5	8.6	10.1	9.1
1,320<GVW≤1,430	10.1	9.2	10.7	9.8
1,430<GVW≤1,540	10.7	9.7	11.3	10.3
1,540<GVW≤1,660	11.3	10.2	12.0	10.8
1,660<GVW≤1,770	11.9	10.7	12.6	11.3
1,770<GVW≤1,880	12.4	11.1	13.1	11.8
1,880<GVW≤2,000	12.8	11.5	13.6	12.2
2,000<GVW≤2,110	13.2	11.9	14.0	12.6
2,110<GVW≤2,280	13.7	12.3	14.5	13.0
2,280<GVW≤2,510	14.6	13.1	15.5	13.9
>2,510	15.5	13.9	16.4	14.7

[a] Fuel consumption limits are in L/100 km.

[b] Fuel consumption limits are for vehicles with one or more of the following characteristics: (1) automatic transmission; (2) three or more rows of seats; or (3) Type M1G (SUVs), as specified in China's GB/T 15089-2001.

TABLE 8 On-Road Fuel Economy of Vehicles Produced before MY2005[a]

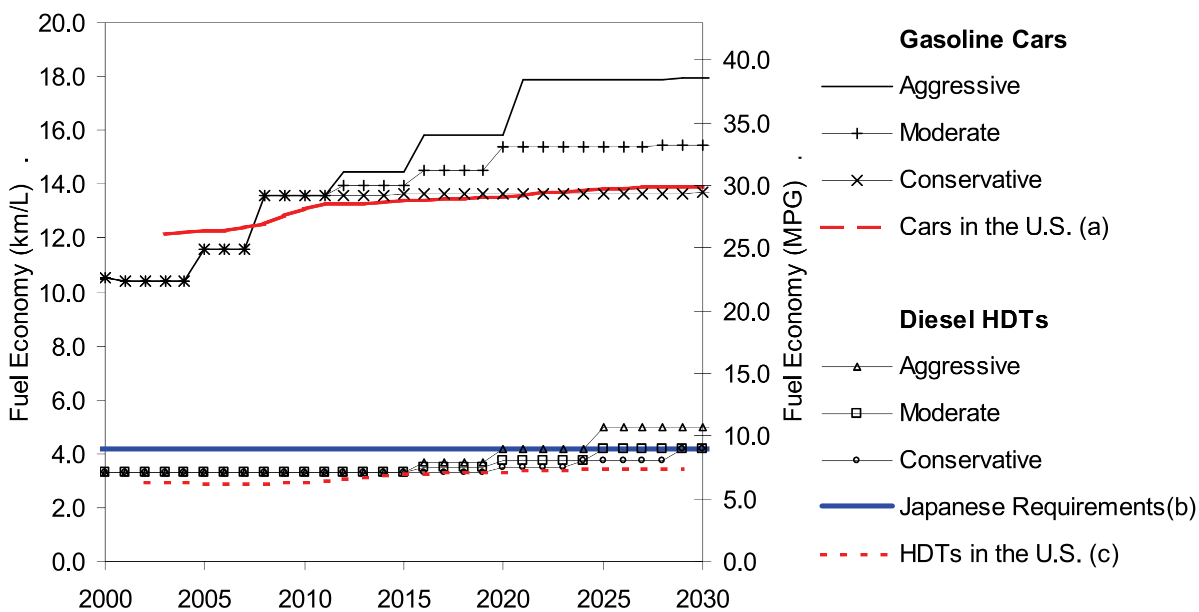
	Fuel Type	Fuel Economy		Fuel Type	Fuel Economy
Truck			Bus		
HDT	Diesel	3.32	HDB	Diesel	3.02
HDT	Gasoline	–[b]	HDB	Gasoline	2.21
MDT	Diesel	4.28	MDB	Diesel	3.91
MDT	Gasoline	2.99	MDB	Gasoline	2.68
LDT	Diesel	6.53	LDB	Diesel	8.82
LDT	Gasoline	5.90	LDB	Gasoline	7.90
MiniT	Diesel	–[b]	MiniB	Diesel	–[b]
MiniT	Gasoline	11.54	MiniB	Gasoline	11.9
Car	Gasoline	11.03	3-W RV	Diesel	26.79
MC	Gasoline	36.77	4-W RV	Diesel	11.54

[a] Fuel economy values are in km/L and are based on the volume of each fuel type (i.e., gasoline and diesel).

[b] No data because the current stock of these vehicle types is zero.

TABLE 9 Fuel Economy Scenarios for Chinese HWVs

	LDBs, MiniBs, Cars	LDTs, MiniTs	HDBs, MDBs, HDTs, MDTs
Conservative Scenario	NAS's Path One technologies began in 2005 in China	NAS's Path One technologies will begin in 2008 in China	Japanese HDT fuel consumption requirements will begin in 2020 in China
Moderate Scenario	NAS's Path One technologies began in 2005 in China; NAS's Path Two technologies will begin in 2012 in China	NAS's Path One technologies will begin in 2008 in China; NAS's Path Two technologies will begin in 2016 in China	Japanese HDT fuel consumption requirements will begin in 2016 in China
Aggressive Scenario	NAS's Path One technologies began in 2005 in China; NAS's Path Three technologies will begin in 2012 in China	NAS's Path One technologies will begin in 2008 in China; NAS's Path Three technologies will begin in 2016 in China	Fuel consumption requirements 20% more stringent than those for Japanese HDT will begin in 2016



Sources: (a) EIA 2006
(b) JACENR 2005; truck weight of 16–20 metric tons
(c) EIA 2006; Class 7&8 truck with a weight of 11.8 metric tons (26,000 lb)

FIGURE 11 Fuel Economy of Various Vehicle Types under Three Scenarios

vehicle types under the three scenarios in China and other countries. Under the conservative scenarios, the average fuel economy of new cars in China will be equivalent to the fuel economy of new cars in the United States by 2030.

2.6.2 Fleet Average Fuel Economy

The average fuel economy of a given fleet was calculated by using the following equation:

$$AFE_{i,j} = \frac{\sum_{k=0}^{\sigma}\left(Vintage_{i,k,j} \times FE_{i,j}\right)}{VP_{i,j}} \tag{7}$$

Where:

i –	Year i;
j –	Vehicle type j;
k –	Vehicle age k;
σ –	Longest possible service period of the vehicles (in years);
$AFE_{i,j}$ –	Average fuel economy of in-use vehicle type j in year i (km/L);
$FE_{i,k,j}$ –	Fuel economy of model year i–k vehicle type j in year i (km/L);
$Vintage_{i,k,j}$ –	Number of vehicles of type j at age k in year i (million units); and
VP_i –	Vehicle stock in year i (million units).

2.7 CALCULATION OF OIL USE AND CO_2 EMISSIONS

Oil use was calculated by using the following equation:

$$Oil_i = \sum_j \left(VP_{i,j} \times VMT_{i,j} \times Den_{i,j} / AFE_{i.j}\right) \tag{8}$$

Where:

i –	Year i;
j –	Vehicle type j;
$VP_{i,j}$ –	Stock of vehicle type j in year i (million units);
$AFE_{i,j}$ –	Average fuel economy of vehicle type j in year i (km/L);
Oil_i –	Oil use in year i (million metric tons);
$VMT_{i,j}$ –	Annual per-vehicle VMT of vehicle type j in year i (1,000 km); and
$Den_{i,j}$ –	Density of the fuel of vehicle type j in year i (kg/L) (0.732 for gasoline and 0.875 for diesel).

CO_2 emissions were calculated on the basis of the assumption that all the carbon in fuels will be transformed to CO_2 eventually. So CO_2 results in this study are the so-called pump-to-wheels (PTW) results. To take into account CO_2 emissions during production and delivery of gasoline and diesel, researchers can use well-to-wheels (WTW) CO_2 emission factors per unit of fuel used. Usually, WTW CO_2 emissions are 20% higher than PTW CO_2 emissions.

3 RESULTS AND ANALYSIS

3.1 PROJECTED TOTAL CHINESE VEHICLE STOCK

Figure 12 shows the Chinese HWV stock projected under each of the three HWV growth scenarios (low-, mid-, and high-growth). Our projections of Chinese on-road vehicle stock show an annual growth rate of about 10% until 2020. By 2050, the HWV stock is projected to reach between 486 million and 662 million. Chinese HWV ownership will be 335, 398, and 456 per 1,000 people in 2050 under the low; mid-, and high-growth scenarios, respectively.

Figure 12 also compares the projected HWV stock in China with current (2004) vehicle stock in the United States. The HWV stock in China will match current U.S. vehicle stock between 2027 and 2028. By 2035, the Chinese HWV stock will reach 321–391 million, which will be similar to the U.S. vehicle stock level of 330 million in 2030, as projected by the Energy Information Administration in its 2006 *Annual Energy Outlook* (EIA 2006). After 2035, China will potentially have the largest HWV fleet in the world, even under the low-growth scenario. Moreover, even by 2050, the number of HWVs per 1,000 people in China will not reach the saturation point assumed earlier in this report for each of the three vehicle growth scenarios — meaning that the Chinese HWV stock still has potential to increase after 2050.

Table 10 and Figure 13 show the projected vehicle stock by type. The number of vehicles in the Chinese passenger car fleet is expected to dramatically increase in the future. Under the low-growth scenario, the total number of cars in China will match the current U.S. car population by around 2020. By 2030, the Chinese car population will reach 186–217 million — 30 times the

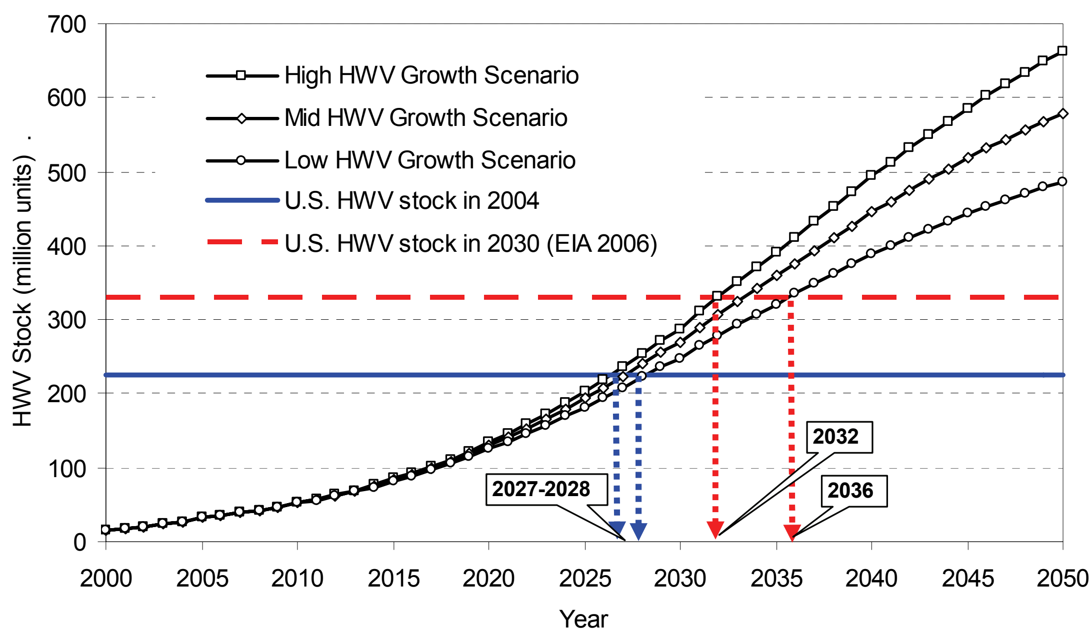


FIGURE 12 Projected Chinese HWV Stock between 2000 and 2050

TABLE 10 Projected Chinese Vehicle Stocks (in millions)

	2000	2010	2020	2030	2040	2050
Low-growth scenario						
Total highway vehicles	16	52	125	247	389	486
Cars	4	26	87	186	306	391
Trucks	7	15	27	47	70	86
Buses	4	11	11	13	13	10
HWVs/1,000 people	13	39	90	174	270	335
Mid-growth scenario						
Total highway vehicles	16	52	130	269	446	578
Cars	4	26	91	203	350	464
Trucks	7	15	28	52	80	103
Buses	4	11	12	14	15	11
HWVs/1,000 people	13	39	94	189	309	398
High-growth scenario						
Total highway vehicles	16	53	134	287	495	662
Cars	4	27	93	217	389	532
Trucks	7	15	29	55	89	118
Buses	4	11	12	15	17	13
HWVs/1,000 people	13	39	97	202	344	456
Total MCs (millions)	44	77	95	92	61	44
MCs/1,000 people	35	58	69	65	42	30
Total RVs (millions)	21	40	45	41	32	28
RVs/1,000 rural people	23	53	76	90	81	83

current Chinese car population. On the basis of our projections, under the conservative scenario, China will increase its total number of cars from 100 million to 200 million in only 8–10 years; it will take the European Union (15 Western European countries) more than 25 years to do so. Thus, even under the low-growth scenario, the increase in the absolute number of cars in China will be extraordinarily high as a result of significant growth in the GDP and China's large population. Note that Ng and Schipper (2006) projected a Chinese car population of 145.7 million by 2020 under the business-as-usual scenario and 72–131 million under alternative vehicle-constraining scenarios. Their projected car population is much larger than our projected car population of 87–93 million in 2020.

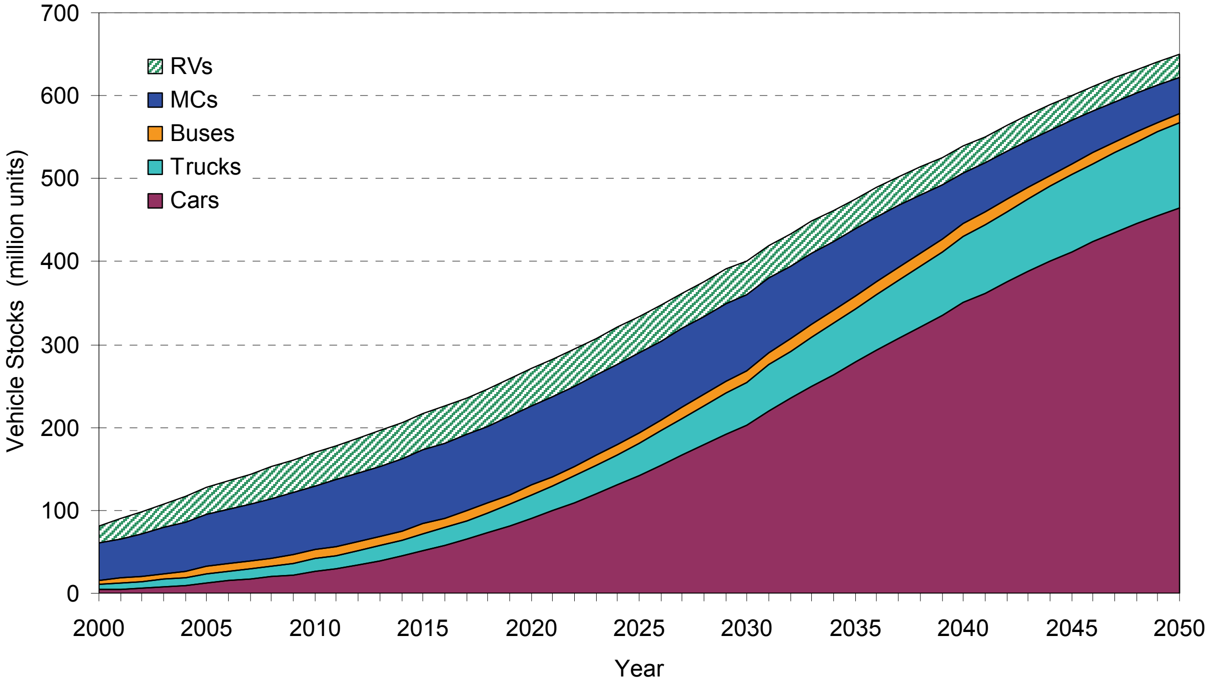


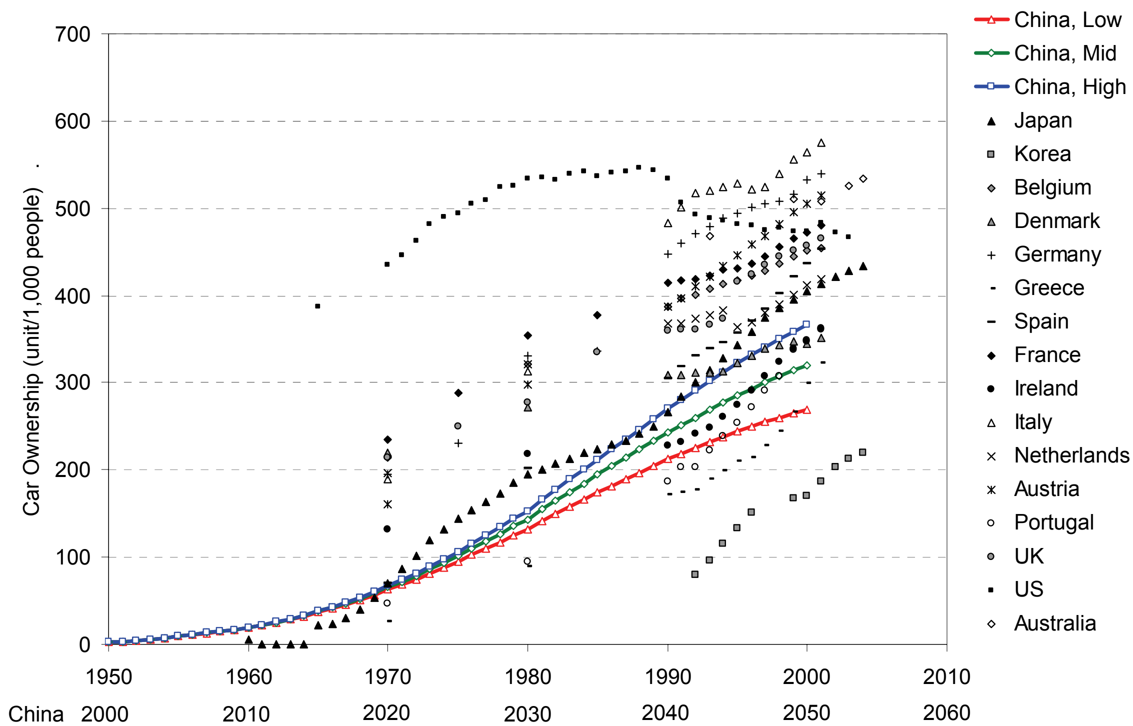
Figure 13 Projected Chinese Vehicle Stock under the Mid Vehicle Growth Scenario

The number of trucks in China will also increase at an annual rate of 5.0–5.7% through 2050 and will reach 86–118 million by 2050.

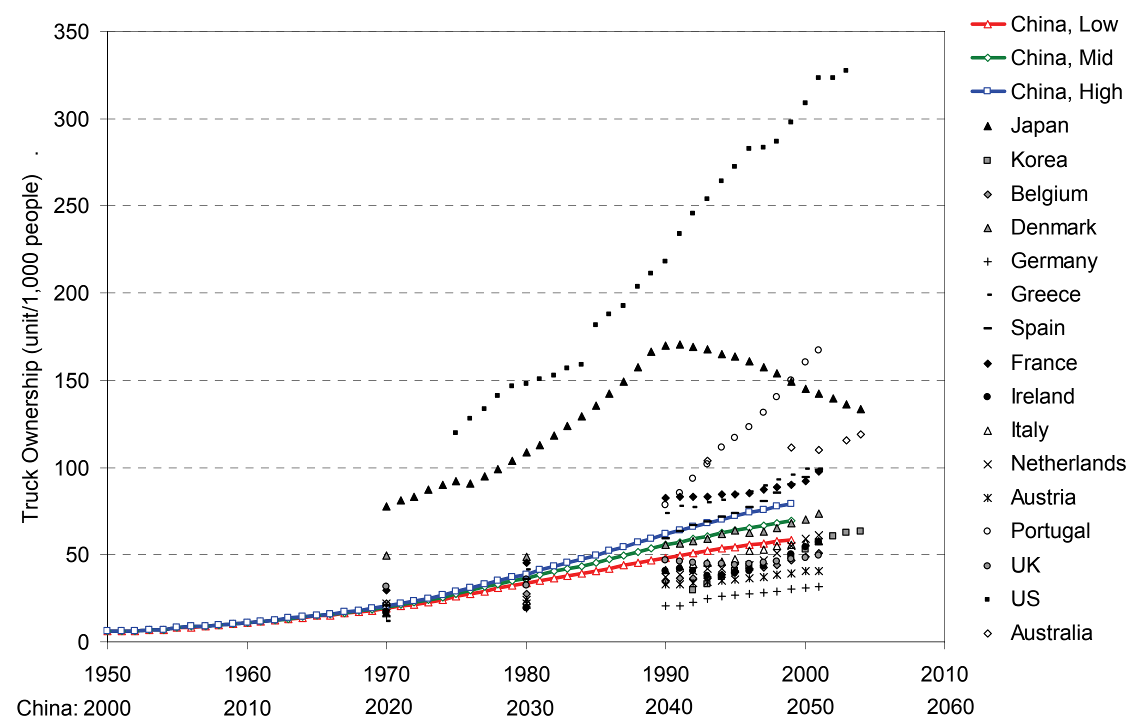
The number of MCs (the largest vehicle fleet in China at present) will continue to grow over the next 20–25 years, reaching 92 million around 2030. Then the number will gradually decline as a result of a rise in family income in China and the consequent switch from MCs to cars. This trend was driven by our assumption that MC ownership will decline at higher income levels. By 2050, China will have 44 million MCs.

The population of RVs will steadily increase to 45 million by 2020, then gradually decrease to 28 million by 2050; this number is almost 1.3 times the current stock.

Figure 14 and Table 11 compare the composition of truck and car fleets in China (under the low-growth scenario) with those in other countries (USFHWA 1993–2004; JAIRA 2006; EC-DGET 2003; U.S Census Bureau 2006). The trend in the growth of the Chinese vehicle population may follow a pattern similar to that in Japan and in European countries, but with a lag of 40–50 years. On the other hand, Chinese car ownership is about 35 years behind the ownership level in Korea. By 2050, cars will account for 80% of the total HWVs in China. (We note that the proportion of passenger cars to total vehicles in the United States is low because fuel is relatively inexpensive and because fuel economy and emissions regulations are lenient for LDTs versus passenger cars, so there has been a steady migration from passenger cars to LDTs in the U.S. market in the past 20 years). We assumed many similarities between the current Japanese fleet composition and the future Chinese fleet composition, except that there is a larger percentage of MDTs and HDTs in China than in Japan.



(A) Car Ownership



(B) Truck Ownership

Figure 14 HWV Ownership in Selected Countries

TABLE 11 Comparison of Chinese HWV Fleet Structure Projected in this Study with Those in Other Countries

		HWV Fleet Composition (%)			Truck Fleet Composition (%)				Car Fleet Composition (%)	
Country	Year	Trucks	Buses	Cars	MiniTs	LDTs	MDTs	HDTs	SCs	LCs
China[a]	2000	46.3	27.9	25.8	11.2	45.9	35.9	7.0		
	2030	19.2	5.1	75.7	4.5	53.7	15.5	26.3		
	2050	17.7	1.9	80.3	0.6	50.9	16.8	31.7	69.9	30.1
Japan[b]	2005	24.7	0.3	75.0	59.1	33.1	5.1	2.7	75.9[c]	24.1[c]
United States	2002	40.5	0.3	59.2	61.0[e]	32.9[e]	3.4[e]	2.7[e]	20.0[d]	80.0[d]
United Kingdom[f]	2000–2001	9.6	0.3	90.1	94.6	3.5	1.2	0.7		
France[f]	2000–2001	16.8	0.2	82.9	93.2	3.0	3.2	0.6		
Germany[f]	2000–2001	5.5	0.2	94.3	83.8	10.1	4.1	2.0		
Spain[f]	2000–2001	17.8	0.3	81.9	88.9	3.6	2.8	4.8		
Denmark[f]	2000–2001	17.2	0.6	82.2	92.7	3.5	2.7	1.1		
Greece[f]	2000–2001	23.3	0.7	76.1						

a The GVWs of MiniTs, LDTs, MDTs, and HDTs in China are less than 1.8 metric tons, 1.8–6 metric tons, 6–14 metric tons, and greater than or equal to 14 metric tons, respectively.

b From JAIRA (2006). The GVWs of MiniTs, LDTs, MDTs, and HDTs in Japan are less than 2 metric tons, 2–6 metric tons, 6–12 metric tons, and greater than 12 metric tons, respectively.

c From JAMA (2006). Small cars in Japan are passenger cars with engine DVs of less than 2.0 L; large cars are passenger cars with engine DVs of greater than or equal to 2.0 L.

d From Davis and Diegel (2004), pp. 3–7. Small cars in the United States include two-seaters, mini-compact cars, and subcompact cars. Large cars include compact cars, mid-size cars, and large-size cars.

e From Davis and Diegel (2004), pp. 5–6 (2002 data). The GVWs of MiniTs, LDTs, MDTs, and HDTs in the United States are less than or equal to 2.7 metric tons (less than or equal to 6,000 lb), 2.7–4.5 metric tons (6,001–10,000 lb), 4.5–11.8 metric tons (10,001–26,000 lb), and greater than 11.8 metric tons (greater than 26,000 lb), respectively.

f From EC-DGET (2003). The carrying capacities of MiniTs, LDTs, MDTs, and HDTs in European countries are less than 3 metric tons, 3–7 metric tons, 7–15 metric tons, and greater than 15 metric tons, respectively.

3.2 PROJECTED ANNUAL HIGHWAY VEHICLE SALES

As discussed in Section 2, annual vehicle sales by vehicle type were estimated to match the total vehicle stocks projected on the basis of per-1,000 people vehicle ownership and GDP growth. Figure 15 presents the annual HWV sales in China between 2000 and 2050.

By 2050, annual sales of HWVs will reach 42–59 million, which is about 10 times today's annual sales level. By 2022–2023, annual HWV sales will reach 20 million, and in fewer than 10 years, annual sales will reach at least 30 million. In comparison, the annual vehicle sales total in the United States is 17 million: 7.5 million passenger cars and 9.5 million trucks (Ward's Communications 2006).

Figure 16 presents the composition of annual HWV sales projected for the mid-growth scenario. The chart shows that, starting in 2007, passenger car sales will exceed sales of trucks and buses combined. Annual car sales could reach 10 million by 2017, 20 million by 2027, 30 million by 2036, and 40 million by 2050.

3.3 PROJECTED ANNUAL OIL DEMAND AND CO_2 EMISSIONS

Figure 17 shows the projected oil demand by Chinese motor vehicles (including HWVs, RVs, and MCs) over the next 45 years under nine combinations of the three vehicle growth scenarios and the three fuel economy improvement scenarios. In 2005, on-road Chinese vehicles consumed a total of 108.6 million metric tons of oil, which was about one-third of total national oil consumption. The oil demand for Chinese road transportation will rise rapidly, with an annual growth rate of 3.9–5.1% between 2005 and 2050, reaching 614–1,016 million metric tons a year (or 12.4–20.6 million barrels per day) by 2050. This potential growth in oil demand will put tremendous pressure on the balance of Chinese — and global — oil supply and demand.

According to Figure 17, the oil demand by the road transportation sector in China will match that in the United States by 2030 under the high vehicle growth and conservative fuel economy improvement scenarios, by 2034 under the mid vehicle growth and moderate fuel economy improvement scenarios, or by 2041 under the low vehicle growth and aggressive fuel economy improvement scenarios. Relative to the growth pattern of the vehicle population (see Figure 12), it will take some additional years for China to match the oil demand of road transportation in the United States. This is because (we assume) Chinese vehicles are smaller and have lower energy intensity than U.S. vehicles.

The combination of the high vehicle growth scenario and the conservative fuel economy improvement scenario results in the highest oil demand in 2050 — 65% higher than that under the combination of the low vehicle growth scenario and the aggressive fuel economy improvement scenario (the combination with the lowest oil demand). In a way, the difference between these two combinations shows the potential offered by efforts to contain Chinese vehicle population growth and improve vehicle fuel economy.

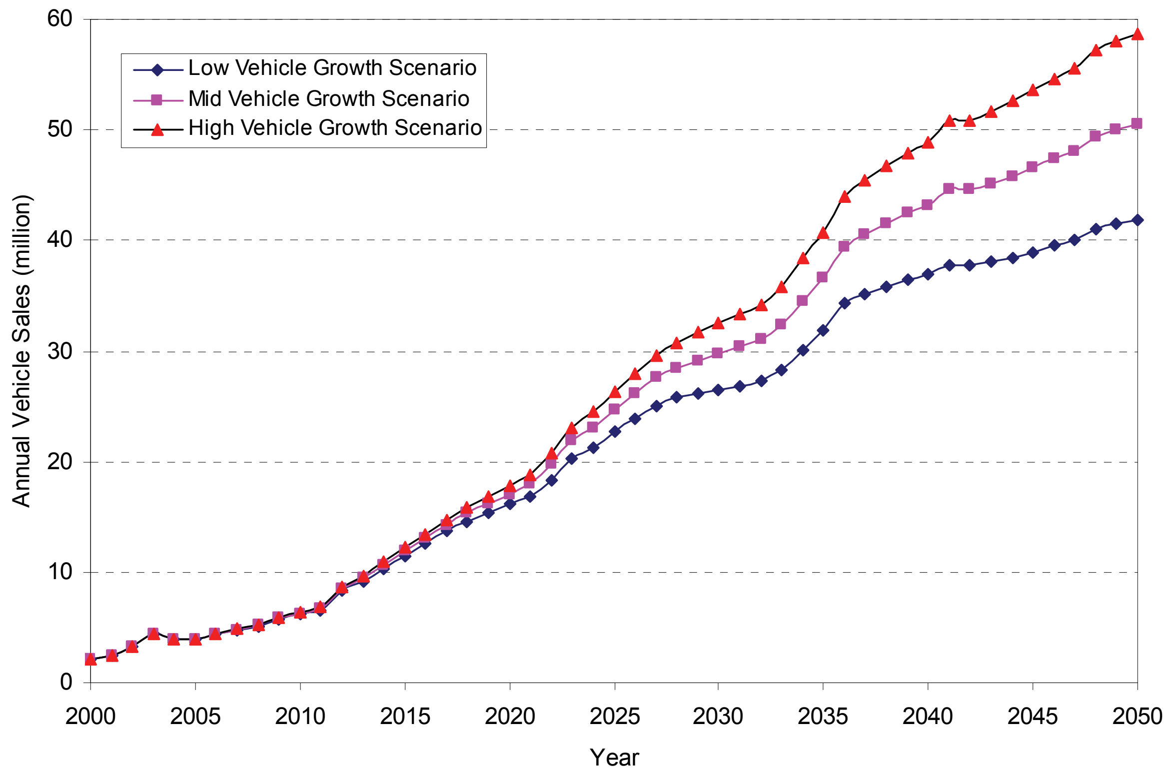


FIGURE 15 Projected Annual HWV Sales in China

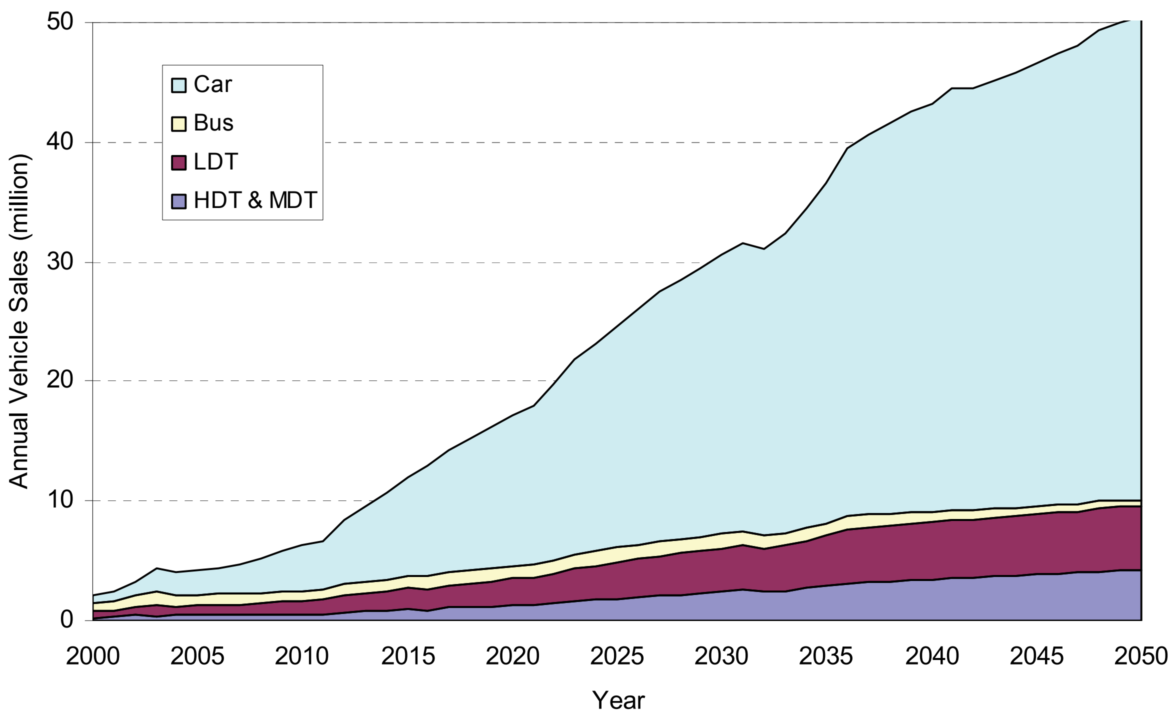


FIGURE 16 Projected Annual HWV Sales in China (by Type) under the Mid Vehicle Growth Scenario

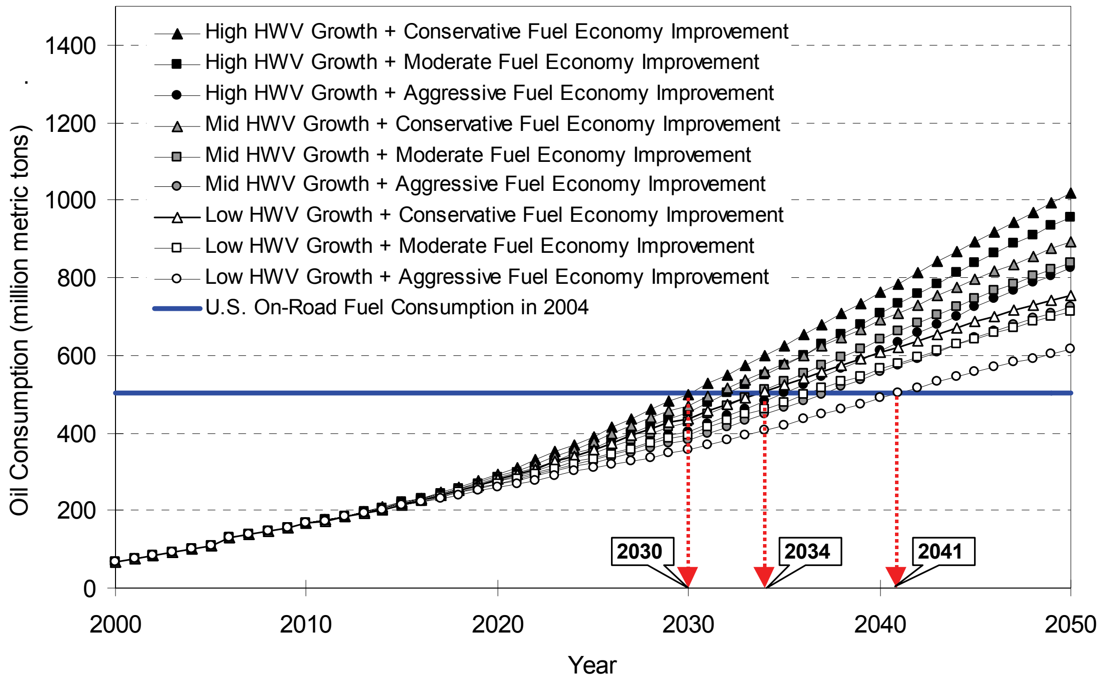


Figure 17 Projected Annual Oil Demand by Chinese Motor Vehicles under the Nine Combinations of Scenarios

On the other hand, under any of the vehicle growth scenarios, oil demand under the aggressive and moderate fuel economy improvement scenarios in 2050 is 23% and 6% lower, respectively, than under the conservative scenario, which results in a savings of 141–192 million tons and 45–61 million metric tons of oil, respectively, by 2050.

In 2005, the demand for gasoline was 44 million metric tons, and the demand for diesel was 65 million metric tons for on-road vehicles in China. In the United States, gasoline consumption by HWVs was 112.0 billion gallons, and diesel consumption was 34.8 billion gallons in 2002 (Davis and Diegel 2004); gasoline accounted for 76% of fuel consumption, and this percentage is projected to be 72% by 2030. In China, the demand for diesel by motor vehicles increases much more rapidly than does the demand for gasoline. In China, the demand for gasoline will steadily increase (by 3–6 times) from 2005 through 2050 under the nine scenarios, while the demand for diesel will increase by 6–10 times during the same period. In 2050, the demand for gasoline will be 179–317 million metric tons, and the demand for diesel will be 435–699 million metric tons. The share of diesel in terms of total oil demand by Chinese on-road vehicles will be about two-thirds of total transport oil demand by 2050.

Figure 18 shows the oil demand by vehicle type under the mid-growth (vehicle population) and the moderate fuel economy improvement scenarios. Tables 12 through 14 summarize projected oil demand by and CO_2 emissions from Chinese motor vehicles by vehicle type under the nine combinations of scenarios (low-, mid-, and high-growth for vehicle population and conservative, moderate, and aggressive for fuel economy improvement). In 2005,

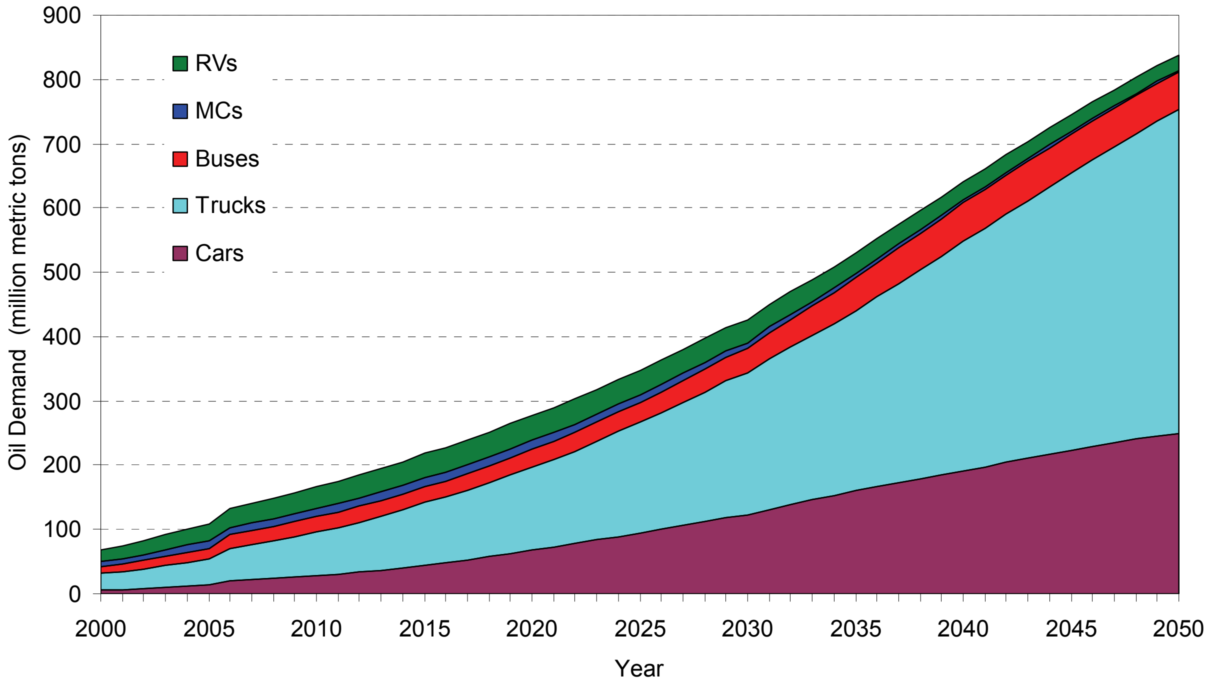


FIGURE 18 Projected Annual Oil Demand by Chinese Motor Vehicle Types under the Mid Vehicle Growth Scenario and the Moderate Fuel Economy Improvement Scenario

oil consumption by cars, buses, trucks, MCs, and RVs was 13.4%, 15.9%, 35.7%, 10.0%, and 25.0%, respectively. Our projection shows that cars and trucks will be the largest consumers of oil in Chinese road transportation in the next half century. Cars have already been targeted for oil savings worldwide. The proportion of cars in the total HWV population in China will increase from 25% in 2000 to 80% in 2050, and the oil consumption share by cars will account for 30–31% of the total oil demand by HWVs in 2050. On the other hand, although the proportion of trucks in the total HWV population will decrease to below 25% by around 2015, all trucks together will still be the largest consumers of oil through 2050 — suggesting that China needs to implement some effective measures to control oil consumption by trucks.

With a declining share of MC stock, the percentage of oil demand by MCs will decline from 10% in 2005 to below 0.3–0.6% in 2050. RVs have been largely ignored in addressing energy use by and emissions from motor vehicles in China. In fact, because of their large population, RVs consume a significant amount of oil: 18 and 27 million metric tons of diesel in 2000 and 2005, respectively — accounting for more than 40% of total diesel used in road transportation. In 2050, RVs will consume 24 million metric tons of diesel, accounting for 3.4–5.6% of total diesel consumption for road transportation in China. Some other studies report that RVs consumed about 14–19 million metric tons of diesel in 2000 (Sperling et al. 2004; Ke and Shang 2000; Yang 2001); these findings are quite close to the results of our study.

TABLE 12 Projected Annual Oil Consumption by and CO_2 Emissions from Chinese Motor Vehicles: Low Vehicle Growth Scenario[a]

Scenario	2000	2010	2020	2030	2040	2050
Conservative Fuel Economy Scenario						
Total HWVs	42.6	119.8	226.5	391.0	574.1	727.9
Cars	6.1	28.5	69.4	126.1	187.2	234.3
Buses	10.7	23.6	28.1	39.2	54.8	49.6
Trucks	25.8	67.7	129.0	225.7	332.1	444.0
MCs	8.0	12.3	14.2	9.1	4.9	3.5
RVs	17.5	33.7	38.8	35.8	27.9	24.2
Total oil consumption	68.0	165.7	279.5	435.9	606.9	755.6
Gasoline	31.8	61.6	102.1	147.4	198.8	234.7
Diesel	36.2	104.2	177.5	288.5	408.1	520.8
Total oil consumption (billion gal)	22.4	53.7	90.5	140.5	195.2	242.3
Total CO_2 emissions	215.2	521.5	878.4	1,368.7	1,904.2	2,370.0
Moderate Fuel Economy Scenario						
Total HWVs	42.6	119.8	216.3	350.8	531.4	683.2
Cars	6.1	28.5	65.6	112.4	167.2	210.4
Buses	10.7	23.6	26.7	35.1	52.6	49.1
Trucks	25.8	67.7	124.1	203.3	311.7	423.7
MCs	8.0	12.3	14.2	9.1	4.9	3.5
RVs	17.5	33.7	38.8	35.8	27.9	24.2
Total oil consumption	68.0	165.7	269.3	395.8	564.2	710.9
Gasoline	31.8	61.6	97.3	130.4	174.3	205.5
Diesel	36.2	104.2	172.1	265.4	389.9	505.4
Total oil consumption (billion gal)	22.4	53.7	87.2	127.4	180.9	227.1
Total CO_2 emissions	215.2	521.5	846.4	1,242.7	1,770.2	2,230.0
Aggressive Fuel Economy Scenario						
Total HWVs	42.6	119.8	208.5	309.3	456.9	586.6
Cars	6.1	28.5	62.3	98.8	146.2	184.9
Buses	10.7	23.6	25.7	30.5	44.4	41.1
Trucks	25.8	67.7	120.6	180.0	266.4	360.6
MCs	8.0	12.3	14.2	9.1	4.9	3.5
RVs	17.5	33.7	38.8	35.8	27.9	24.2
Total oil consumption	68.0	165.7	261.5	354.3	489.7	614.3
Gasoline	31.8	61.6	93.4	115.6	152.0	178.9
Diesel	36.2	104.2	168.1	238.6	337.7	435.4
Total oil consumption (billion gal)	22.4	53.7	84.6	113.9	157.0	196.3
Total CO_2 emissions	215.2	521.5	822.0	1,112.6	1,536.7	1,927.2

[a] Units are in million metric tons, except as noted.

TABLE 13 Projected Annual Oil Consumption by and CO_2 Emissions from Chinese Motor Vehicles: Mid Vehicle Growth Scenario[a]

Scenario	2000	2010	2020	2030	2040	2050
Conservative Fuel Economy Scenario						
Total HWVs	42.6	120.8	235.3	424.9	656.5	864.1
Cars	6.1	28.7	72.3	137.4	214.4	278.4
Buses	10.7	23.7	29.2	42.6	62.2	58.4
Trucks	25.8	68.3	133.9	244.9	379.9	527.2
MCs	8.0	12.3	14.2	9.1	4.9	3.5
RVs	17.5	33.7	38.8	35.8	27.9	24.2
Total oil consumption	68.0	166.8	288.3	469.8	689.3	891.7
Gasoline	31.8	62.0	105.6	159.7	227.0	278.3
Diesel	36.2	104.8	182.7	310.1	462.3	613.5
Total oil consumption (billion gal)	22.4	54.1	93.4	151.5	221.8	286.1
Total CO_2 emissions	215.2	524.7	906.1	1,474.9	2,162.6	2,797.0
Moderate Fuel Economy Scenario						
Total HWVs	42.6	120.8	224.6	381.1	607.7	811.0
Cars	6.1	28.7	68.3	122.4	191.5	250.1
Buses	10.7	23.7	27.7	38.2	59.7	57.9
Trucks	25.8	68.3	128.7	220.5	356.5	503.0
MCs	8.0	12.3	14.2	9.1	4.9	3.5
RVs	17.5	33.7	38.8	35.8	27.9	24.2
Total oil consumption	68.0	166.8	277.6	426.1	640.5	838.6
Gasoline	31.8	62.0	100.6	141.1	198.9	243.5
Diesel	36.2	104.8	177.0	285.0	441.6	595.1
Total oil consumption (billion gal)	22.4	54.1	89.9	137.2	205.4	267.9
Total CO_2 emissions	215.2	524.7	872.5	1,337.8	2,009.5	2,630.4
Aggressive Fuel Economy Scenario						
Total HWVs	42.6	120.8	216.4	335.8	522.6	696.4
Cars	6.1	28.7	64.8	107.6	167.4	219.7
Buses	10.7	23.7	26.6	33.2	50.4	48.5
Trucks	25.8	68.3	125.0	195.1	304.8	428.2
MCs	8.0	12.3	14.2	9.1	4.9	3.5
RVs	17.5	33.7	38.8	35.8	27.9	24.2
Total oil consumption	68.0	166.8	269.4	380.8	555.4	724.0
Gasoline	31.8	62.0	96.5	125.1	173.4	211.9
Diesel	36.2	104.8	172.9	255.8	382.0	512.1
Total oil consumption (billion gal)	22.4	54.1	87.2	122.5	178.1	231.4
Total CO_2 emissions	215.2	524.7	846.8	1,195.8	1,742.6	2,271.1

[a] Units are in million metric tons, except as noted.

TABLE 14 Projected Annual Oil Consumption by and CO_2 Emissions from Chinese Motor Vehicles: High Vehicle Growth Scenario[a]

Scenario	2000	2010	2020	2030	2040	2050
Conservative Fuel Economy Scenario						
Total HWVs	42.6	121.6	242.2	452.6	728.5	989.0
Cars	6.1	29.0	74.5	146.7	238.2	318.9
Buses	10.7	23.9	30.0	45.3	68.6	66.5
Trucks	25.8	68.8	137.7	260.6	421.6	603.6
MCs	8.0	12.3	14.2	9.1	4.9	3.5
RVs	17.5	33.7	38.8	35.8	27.9	24.2
Total oil consumption	68.0	167.6	295.2	497.6	761.3	1016.7
Gasoline	31.8	62.3	108.4	169.8	251.6	318.3
Diesel	36.2	105.2	186.8	327.8	509.6	698.4
Total oil consumption (billion gal)	22.4	54.3	95.6	160.5	245.0	326.2
Total CO_2 emissions	215.2	527.2	927.5	1561.9	2388.2	3188.7
Moderate Fuel Economy Scenario						
Total HWVs	42.6	121.6	231.1	406.0	674.4	928.1
Cars	6.1	29.0	70.3	130.6	212.7	286.5
Buses	10.7	23.9	28.4	40.7	65.9	65.9
Trucks	25.8	68.8	132.3	234.6	395.8	575.8
MCs	8.0	12.3	14.2	9.1	4.9	3.5
RVs	17.5	33.7	38.8	35.8	27.9	24.2
Total oil consumption	68.0	167.6	284.1	450.9	707.2	955.8
Gasoline	31.8	62.3	103.2	150.0	220.4	278.5
Diesel	36.2	105.2	180.9	301.0	486.8	677.3
Total oil consumption (billion gal)	22.4	54.3	92.0	145.2	226.8	305.4
Total CO_2 emissions	215.2	527.2	892.7	1415.6	2218.5	2997.7
Aggressive Fuel Economy Scenario						
Total HWVs	42.6	121.6	222.6	357.6	579.9	797.0
Cars	6.1	29.0	66.8	114.8	186.0	251.7
Buses	10.7	23.9	27.4	35.3	55.6	55.2
Trucks	25.8	68.8	128.4	207.5	338.3	490.2
MCs	8.0	12.3	14.2	9.1	4.9	3.5
RVs	17.5	33.7	38.8	35.8	27.9	24.2
Total oil consumption	68.0	167.6	275.6	402.6	612.7	824.7
Gasoline	31.8	62.3	99.0	132.8	192.0	242.3
Diesel	36.2	105.2	176.6	269.8	420.7	582.4
Total oil consumption (billion gal)	22.4	54.3	89.2	129.6	196.6	263.6
Total CO_2 emissions	215.2	527.2	866.1	1264.0	1922.4	2586.7

[a] Units are in million metric tons, except as noted.

By 2050, Chinese motor vehicles could emit 1.9–3.2 billion metric tons of CO_2 under the nine combinations of scenarios, which is 6–10 times today's CO_2 emissions from Chinese motor vehicles. Figure 19 compares the CO_2 emissions under the combinations of scenarios in the future. The CO_2 emissions of motor vehicles in China will match those of today's motor vehicles in the United States (EPA 2006) by 2028 under the high vehicle growth and conservative fuel economy improvement scenarios, by 2033 under the mid vehicle growth and moderate fuel economy improvement scenarios, and by 2037 under the low vehicle growth and aggressive fuel economy improvement scenarios.

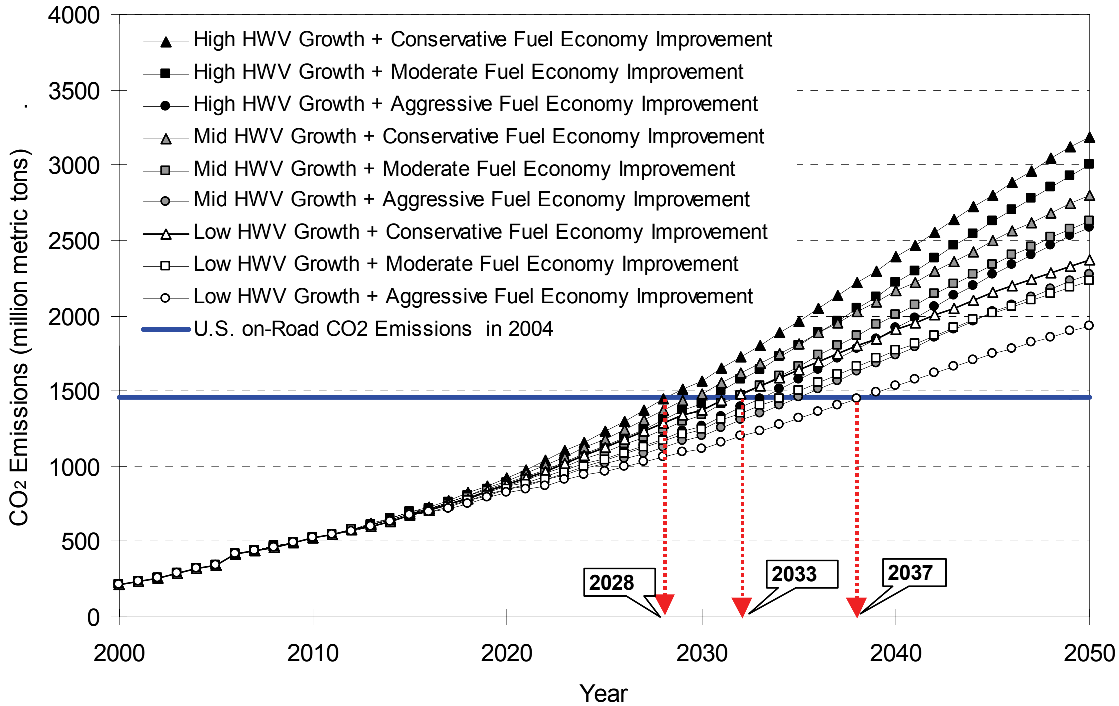


FIGURE 19 Projected Annual CO_2 Emissions of Chinese Motor Vehicles under the Nine Combinations of Scenarios

4 CONCLUSIONS AND DISCUSSION

China has experienced rapid growth in the population of its motor vehicles during the past two and half decades. As Argonne and others have projected, this trend will continue into the future. Consequently, oil consumption, CO_2 emissions, and other environmental problems associated with the transportation sector are rapidly increasing in China. Although the growth of the Chinese vehicle population and the country's increased oil use and CO_2 emissions have been reported in publications and the news media, the details about such projections are often lacking. Consequently, China may not have the information required to formulate targeted, effective policies to manage vehicle growth and the resulting increase in oil demand and GHG emissions.

During this study, we developed a model to project total HWV, MC, and RV populations in China through 2050. HWVs were further separated into passenger cars, trucks, and buses. To address the uncertainties associated with the growth in the number of Chinese vehicles and China's potential to improve vehicle fuel economy, we developed two sets of scenarios: one covering the range of vehicle growth rates and the other the range of potential improvements in vehicle fuel economy. While the vehicle growth scenarios established in this study reflect patterns in other parts of the world, all are essentially business-as-usual scenarios in that almost none of the countries we examined has made concerted efforts to manage vehicle growth or to offer serious alternative transportation means to satisfy people's mobility needs. The vehicle fuel economy scenarios developed in this study reflect current policy efforts and expectations of near-future policies in China and in developed countries. The current and near-future policies in China do not take into consideration the significant potential for further fuel economy improvements offered by advanced technologies such as electric drive technologies (e.g., hybrid electric vehicles and fuel-cell vehicles).

By using the methodology developed in this study, we projected Chinese vehicle population, annual vehicle sales, and annual oil use and CO_2 emissions through 2050. By 2030, China could have more HWVs than the United States has today, and by 2035, it will likely have more HWVs than any country in the world. Chinese HWV stock could reach 486–662 million by 2050. During the projection period of 2000 through 2050, China's stock of MCs and RVs will increase, stabilize, and then decrease. The peak period for MCs and RVs will probably occur during the 2030s. Decreases in the populations of both types of vehicles after the 2030s reflect the switch from MCs to passenger cars and from RVs to LDTs. By 2050, the number of MCs will be 44 million, and the number of RVs will be 28 million.

By 2050, annual sales of HWVs in China could reach 42–59 million, which is about 10 times the annual sales level in China today. By 2022–2023, annual HWV sales will reach 20 million, and in fewer than 10 years, annual sales will reach at least 30 million (in comparison, the annual vehicle sales total in the United States is currently about 17 million). Beginning in 2007, passenger car sales will exceed the sales of trucks and buses combined. Annual passenger car sales could reach 10 million by 2017, 20 million by 2027, 30 million by 2036, and 40 million by 2050. The vehicle growth patterns projected for China reflect the fundamental assumption that was used for our study: that China will follow the lifestyle patterns (e.g., methods of meeting personal transportation needs and desires) that have occurred in developed countries over the past 50 or so years. Some — including ourselves, as the authors of this study — seriously question this assumption.

On the basis of scenarios projecting the growth of vehicle stock and improvements in fuel economy, on-road vehicles in China could consume 614–1,016 million metric tons of oil per year (or 12.4–20.6 million barrels of oil per day) and emit 1.9–3.2 billion metric tons of CO_2 a year in 2050 — putting tremendous pressure on the balance of Chinese (and, indeed, international) oil supply and demand. Another result will be serious concerns about the potential effects of Chinese motor vehicles on global climate change. Considering the rapid depletion of the world's oil reserve, the heightened global interest in addressing GHG emissions, and the geopolitical complications of global oil supply and demand, the study results suggest that unmanaged vehicle growth and only incremental improvements in vehicle efficiency will lead to an unsustainable and unstable transportation system in China.

Our findings show that, although the population of Chinese HWVs could match that of HWVs currently in the United States before 2030, oil consumption by Chinese vehicles will match that of the current U.S. vehicle population between 2030 and 2040 (depending on vehicle growth and fuel economy improvement scenarios). The apparent lag in oil consumption growth versus vehicle population growth in China, in comparison with that in the United States, is largely the result of differences in vehicle fleet composition between the two countries. In China, the vehicle fleet consists of smaller vehicles than those in the U.S. vehicle fleet, so the Chinese vehicle fleet uses less oil than the U.S. fleet. The difference in oil consumption demonstrates the importance of introducing small, efficient vehicles — which is indeed encouraged by recently adopted Chinese policies that impose excise taxes on vehicle sales.

While improvements in vehicle fuel economy are crucial for reducing transportation energy use, our simulations show that, with our assumptions, containing the growth of the vehicle population could have an even more profound effect on oil use and CO_2 emissions. This benefit is in addition to other societal and environmental benefits — such as reduced congestion, land use, and urban air pollution — that will result from containing vehicle population growth. Developing public transportation systems for personal travel and rail and other modes for freight transportation will be important to containing the growth of motor vehicles in China.

Although the population of passenger cars will far exceed that of all truck types in China in the future, oil use by and CO_2 emissions from the Chinese truck fleet will be far larger than those related to Chinese passenger cars because trucks are very use intensive (higher VMT per year) and energy intensive (lower fuel economy). Unfortunately, fuel economy regulations for trucks are weak worldwide. Only very recently did Japan adopt fuel economy standards for HDTs. Chinese organizations also recently began to evaluate potential fuel economy standards for heavy-duty vehicles. Such standards, with a timely implementation schedule, are urgently needed to control energy use by the Chinese truck fleet in the future.

The Chinese government faces major challenges in terms of developing alternative transportation fuels to control China's importation of oil. We have not considered the future use of alternative fuels in China in this study. The use of alternative fuels may not reduce CO_2 emissions if they are produced from fossil energy sources (such as coal). Only if alternative fuels are produced from renewable sources (such as biomass) will their use help reduce CO_2 emissions and oil consumption.

We have not analyzed China's conventional air pollution problems (such as urban ozone) and problems with particulate matter caused by the rapidly expanding Chinese motor vehicle population. Urban air pollution caused by motor vehicles has been and will continue to be a major concern in China. Tightening per-vehicle emission standards under an urgent implementation schedule, together with containing vehicle population growth, will certainly help to alleviate urban air pollution caused by motor vehicles.

Because of the lack of adequate data, the projections of MC and RV stocks in this study need further refinement. In addition, our study might underestimate the restrictions on these two types of vehicles by governments at all levels in China. However, the total demand for transportation vehicles will continue to increase, even if the use of MCs and RVs will be severely restricted in the future. If the transportation needs of low-income groups are taken into consideration, these modes could be replaced unintentionally by other energy-intensive modes of transportation (passenger cars for MCs and LDTs and MDTs for RVs), which might further increase oil use by Chinese vehicle fleets.

Our projected oil demand by the Chinese road transportation sector is enormous. Readers may wonder how such demands will be met, especially given that global conventional oil production may reach its peak before 2050. As stated previously in this report, our intention was to develop a business-as-usual case (with incremental changes in vehicle growth and small improvements in vehicle fuel economy) to show the potential consequences of uncontained vehicle growth and limited, incremental improvements in vehicle efficiency. Our results show that, if China makes no effort to address oil use by and CO_2 emissions from on-road vehicles, its transportation sector will have disastrous effects on global oil use and CO_2 emissions. In other words, while our projections do not definitively indicate what *will* happen in the Chinese transportation sector by 2050, they do demonstrate that by allowing uncontained growth in the number of motor vehicles and pursuing only incremental improvements in fuel economy, China may face severe consequences in terms of oil use and CO_2 emissions. Many argue that China — and, in fact, the world — will not be able to accommodate such uncontained vehicle growth. The potential problems related to transportation energy use and CO_2 emissions in China are, indeed, global problems; solving these problems will require international collaboration.

On the other hand, we are hopeful that China is making efforts to address these issues by improving per-vehicle energy efficiency, promoting the use of alternative transportation fuels, and encouraging the use of more efficient transportation modes (such as public transportation systems). Nevertheless, with rapid economic growth, a huge population, and its citizens' desire for increased mobility, the Chinese transportation sector faces significant challenges in terms of sustainable resource supply and environmental protection. Meeting such challenges will require coordinated efforts both within China and between China and the international community.

5 REFERENCES

Button, K., N. Ngoe, and J. Hine, 1993, "Modeling Vehicle Ownership and Use in Low Income Countries," *Journal of Transport Economics and Policy* 27(1):51–67.

CATARC: see China Automotive Technology and Research Center.

China Automotive Technology and Research Center, 1991, 1993–2005, Chinese Automotive Manufacturers Association*, China Automotive Industry Yearbook* (various issues).

Dargay, J., and D. Gately, 1999, "Income's Effect on Car and Vehicle Ownership, Worldwide: 1960–2015," *Transportation Research Part A* 33(2):101–138.

Davis, C.S., and W.S. Diegel, 2006, *Transportation Energy Data Book*, 25th Edition, prepared for the U.S. Department of Energy, Washington, D.C.

Davis, C.S., and W.S. Diegel, 2004, *Transportation Energy Data Book*, 24th Edition, prepared for the U.S. Department of Energy, Washington, D.C.

De Jong, G., et al., 2004, "Comparison of Car Ownership Models," *Transport Reviews* 24(4):379–408.

Development Research Center of China State Council, Department of Environmental Science and Engineering, Tsinghua University, et al., 2001, *Background Report of Vehicular Fuel Economy in China*, prepared for the U.S.-Based Energy Foundation, http://www.efchina.org/documents/China_FuelEcon_Backgd.pdf, accessed Dec. 2005.

DRCCSC et al.: see Development Research Center of China State Council, Department of Environmental Science and Engineering, Tsinghua University, et al.

Duffy, M., and T. Robinson, 2004, "An Econometric Analysis of Motorcycle Ownership in the UK," *International Journal of Transport Management* 2(2004): 111–121.

Easterly, R.W., 2001, Global Development Network Growth Database, World Bank Web site, http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0, contentMDK: 20701055~pagePK:64214825~piPK:64214943~theSitePK:469382,00.html, accessed Jan. 2006.

EC-DGET: see European Commission, Directorate General for Energy and Transport.

EIA: see Energy Information Administration.

Energy Information Administration, 2006, *Annual Energy Outlook 2006,* DOE/EIA-0383 (2006).

EPA: see U.S. Environmental Protection Agency.

European Commission, Directorate General for Energy and Transport, 2003, "European Union Energy & Transport in Figures," http://ec.europa.eu/dgs/energy_transport/figures/pocketbook/2003_en.htm, accessed Jan. 2006.

Hao, J., et al., 2000, *Urban Vehicular Pollution Control*, China Environmental Science Press, Beijing, China.

He, K., et al., 2005, "Oil Consumption and CO_2 Emissions in China's Road Transport: Current Status, Future Trends, and Policy Implications," *Energy Policy* 33 (2005):1499–1507.

Hu, A., 1999, "Current Status, Near-Term Perspective, and Long-Term Trend of China's Economic Growth," *Strategy and Management* 3, 27–34 (in Chinese).

Huo, H., 2005, *Study on Links Light-Duty Vehicle Emissions Based on Traffic Characteristics,* Doctoral Thesis, Tsinghua University, Beijing, China.

Ingram, G.K., and Z. Liu, 1997, *Motorization and Road Provision in Countries and Cities,* Policy Research Working Paper 1842, World Bank, http://siteresources.worldbank.org/INTURBANTRANSPORT/Resources/wps1842.pdf, accessed Jan. 2006.

JACENR: see Japan's Advisory Committee for Energy and Natural Resources.

JAIRA: see Japanese Automobile Inspection and Registration Association.

JAMA: see Japanese Automobile Manufacturer's Association

Japan's Advisory Committee for Energy and Natural Resources, 2005, *Final Summary on the Workshop of Fuel Economy Standards of Heavy-Duty Vehicles*, http://www.mlit.go.jp/jidosha/juuryoushanenpi/saishuu.pdf (in Japanese).

Japanese Automobile Inspection and Registration Association, 2006, http://www.aira.or.jp/, accessed Jan. 2006 (in Japanese).

Japanese Automobile Manufacturer's Association, 2006, http://www.jama-english.jp/, accessed Jan. 2006 (in Japanese).

Jin, Y., W. Wu, B. Xu, Z. Wang, D. He, C. Pera, M. Wang, F. An, and M. Walsh, 2005, *Development of Fuel Consumption Standards for Chinese Light-Duty Vehicles*, SAE Technical Paper 2005-01-0534, Society for Automotive Engineers, Warrendale, Penn.

KAMA: see Korean Automobile Manufacturer's Association.

Ke, X., and C. Shang, 2000, "Development Trend of Domestic Civil Vehicles and its Influences on Supply of Oil Product," *Petro-Chemistry Technology Economics* 16(4):31–36 (in Chinese).

Kobos, P., J. Erickson, and T. Drennen, 2003, "Scenario Analysis of Chinese Passenger Vehicle Growth," *Contemporary Economic Policy* 21(2):200–217.

Korean Automobile Manufacturer's Association, 2006, http://www.kama.or.kr/, accessed Jan. 2006

Lee, D., 1997, *Korean Automotive Industry in Transition*, https://dspace.mit.edu/handle/1721.1/1453, accessed Feb. 2006.

Li, J., 1997, "Prospective and Projection of General Development of Economy and Society in China (1996–2020)," *Management World* 4:9–17 (in Chinese).

Li, J., C. Zhong, and X. Ge, 2002, *China's Strategy of Economic Development in the 21st Century*, China City Press, Beijing, China.

Liu, J., 2001, "Development Trend of Truck Manufacture in China in the Tenth Five-Year," *Commercial Vehicle* 6:11–13 (in Chinese).

Machinery Industry Rural Vehicle Development Research Center of China, 2001, "Rural Vehicle Section in China's Rural Machinery Industry Association: The Tenth Five-Year Plan of the Chinese Rural Vehicle Industry," *China Agriculture Machinery* (Zhong guo nong ji hua bao), Nov. 29 issue.

Minato, K., and K. Hirota, 2003, "Fuel Economy Regulation of Heavy-Duty Vehicles," *JARI Research Journal* 25(3):1–4 (in Japanese).

Ministry of Machinery Industry of China, 1997, *Research and Development Strategies of China's Rural Vehicle*s (in Chinese), Beijing, China.

MIRVDRC: see Machinery Industry Rural Vehicle Development Research Center of China.

MMIC: see Ministry of Machinery Industry of China.

Nagai, Y., et al., 2003, "Two-Wheeled Vehicle Ownership Trends and Issues in the Asian Regions," *Journal of the Eastern Asia Society for Transportation Studies* 5:135–146.

National Reality Analysis Group of China Science Academy, 1995, "A Study of China's Economic Development Target by the 21st Century and Basic Development Strategy," *Management World* 5:20–30.

Ng, W.S., and L. Schipper, 2006, "China Motorization Trends: Policy Options in a World of Transport Challenges," Chapter 4 in *Growing in the Greenhouse: Protecting the Climate by Putting Development First*, World Resource Institute, Washington, D.C.

NRAGCSA: see National Reality Analysis Group of China Science Academy.

Research Group of Automotive Industry Development, 2001, "Projection of Vehicle Market during the Tenth Five-Year," *Machine-Electricity New Production Gazette* (1–2):50–57 (in Chinese).

Research Group of China Energy Strategies, 1996, *Research on China Energy Strategies 2000–2050*, China Electricity Press, Beijing, China.

RGAID: see Research Group of Automotive Industry Development.

RGCES: see Research Group of China Energy Strategies.

Schipper, L., 1995, "Determinants of Automobile Use and Energy Consumption in OECD Countries," *Annual Reviews* 20:325–386.

SETCC: see State Economic and Trade Commission of China.

Singh, M., A. Vyas, and E. Steiner, 2003, *VISION Model: Description of Model Used to Estimate the Impact of Highway Vehicle Technologies and Fuels on Energy Use and Carbon Emissions to 2050,* ANL/ESD/04-1, Argonne National Laboratory, Argonne, Ill.

Sperling, D., Z. Lin, and P. Hamilton, 2004, "Rural Vehicles in China," 2004 Transportation Research Board (TRB) Annual Meeting CD-ROM.

SSBC: see State Statistical Bureau of China.

State Economic and Trade Commission of China, 2001, *The Tenth Five-Year Plan of the Chinese Automotive Industry*, Beijing, China.

State Statistical Bureau of China, 1995–2005, *Statistical Yearbook of China* (various issues), China Statistics Press, Beijing, China.

Tang, G., 2003, "Review and Prospects of Rural Vehicle Market," *Rural Machinery Market* 2003(1):44–45 (in Chinese).

Toth, F.L., G. Cao, and E. Hizsnyik, 2003, *Regional Population Projections for China*, Interim Report IR-03-042, International Institute for Applied Systems Analysis, Laxenburg, Austria.

U.K. Department for Transport, 2005, *Transport Statistics Great Britain 2005, London: TSO*, http://www.dft.gov.uk/stellent/groups/dft_transstats/documents/divisionhomepage/031571.hcsp, accessed Jan. 2006.

UKDT: see U.K. Department for Transport.

United Nations, 2005, *World Population Prospects, the 2004 Revision: Highlights,* Department of Economic and Social Affairs, New York, http://www.un.org/esa/population/publications/WPP2004/2004Highlights_finalrevised.pdf, accessed Oct. 2005.

U.S. Census Bureau, 2006, http://www.census.gov/, accessed Oct. 2005.

U.S. Environmental Protection Agency, 2006, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2004*, EPA 430-R-06-002, Washington, D.C., April, http://epa.gov/climatechange/emissions/usinventoryreport.html, accessed April 2006.

U.S. Federal Highway Administration, 1993–2004, *Highway Statistics* (various issues), Washington, D.C.

USFHWA: see U.S Federal Highway Administration.

U.S. National Research Council, 2002, *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards,* National Academy Press, Washington, D.C.

USNRC: see U.S. National Research Council.

Wang, M., and D. He, 2000, *The Effect of Growth of Vehicle Population and its Oil Consumption on CO_2 Emissions in China in the Future 30 Years*, Conference for Background of Vehicular Fuel Economy in China, Beijing, China, Dec. 20 (in Chinese).

Wang, W., et al., 2002, *Analysis Method of Urban Transport Energy Consumption and Environmental Impact*, Science Press, Beijing, China.

Ward's Communications, 2006, *Ward's Motor Vehicle Facts and Figures 2005*, Southfield, Mich.

Yang, F., and L. Yu, 2004, "Adjusting Vehicle Mileage Accumulative Rates in Beijing Making Use of Small Sample Survey," *Journal of Northern Jiaotong University* 28(2):82–85 (in Chinese).

Yang, F., L. Yu, and G. Song, 2003, *Modeling Dynamic Vehicle Age Distribution in Beijing*, 2003 Institute of Electrical & Electronics Engineers (IEEE), 0-7803-8125-4/03.

Yang, X., 2001, "Analysis and Forecast of China's Gasoline, Kerosene, and Diesel Oil Market," *Petroleum & Petrochemical Today* 9(11):13–18 (in Chinese).

Yu, C., and J. Xiao, 2005, "Market Strategies of Mini Vehicles in Rural Areas in China," *Automotive Industry Research* 2:43–45 (in Chinese).

Zachariadis, T., Z. Samaras, and K. Zierock, 1995, "Dynamic Modeling of Vehicle Populations: An Engineering Approach for Emissions Calculations," *Technological Forecasting and Social Change* 50:135–149.

Zhang, G., and J. Zhu, 1996, "Analysis and Projection of China's Motorcycle Market," *Projection* (5):37–22 (in Chinese).

Zhou, D., et al., 2003, *China's Sustainable Energy Scenarios in 2020,* China Environmental Science Press, Beijing, China.

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