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Urban Transport and CO2 Emissions: Some Evidence from Chinese Cities

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PREFACE

The work presented below was conducted as part of the World Bank's economic and sector work titled "Urban Transport and Climate Change." It is first a compendium of data— most of it collected as part of the "China-GEF-World Bank Urban Transport Partnership Program"— and also provides a preliminary analysis of urban transport characteristics, energy use and greenhouse gas (GHG) emissions for a diverse set of cities in China. This working paper is not in itself intended to be a strategy for urban transport and climate change in China. It is the view of the authors that it could be an input towards the development of such a strategy in China and more broadly.[1]

While transport in general, and urban transport in particular, is acknowledged to be an important and growing source of greenhouse gas emissions, work still needs to be done to develop robust and standardized datasets and frameworks to support a decision-making process. The paper is intended as a background document to support ongoing discussions about a climate change strategy and to establish a dataset to be made available as a platform for future studies and further refinement. It is hoped that others will take advantage of the dataset created for this study and use it as a basis for projections, comparative analysis and to test their own hypothesis. Reviewers of this paper have also raised many specific possibilities and interesting ideas for further work, which are summarized in the conclusions.[2]

The authors would particularly like to thank AusAID (the Australian Government's overseas aid program), ESMAP (Energy Sector Management Assistance Program), and GEF (Global Environment Facility) who provided partial financing for this work. The authors would also like to acknowledge the management of the World Bank's Sustainable Development units in East Asia & Pacific Region and Latin American & the Caribbean Region for their support.

[1] All judgments and interpretations in this paper are those of the authors and do not necessarily represent the views of the World Bank, its Executive Directors, or the countries they represent.
[2] The authors particularly thank the following reviewers for the comments and suggestions received to date: Brian Dawson (AusAID); and from the World Bank: Sameer Akbar, Ranjan Bose, Elisabeth Goller, Roger Gorham, Ajay Kumar, Aurelio Menendez, Brian McCollum, and Samuel Zimmerman.

1. INTRODUCTION

This working paper provides a bottom-up estimate of energy use and GHG emissions for the transport sector based on data available at the city and municipal levels. For urban transport in China, GHG emissions primarily consist of carbon dioxide (CO2), so these terms are used interchangeably. Energy use and CO2 emissions are also highly correlated based on the predominance of fossil fuels in transport. A database of self-reported indicators was developed and verified for the 14 participating cities of the China World Bank-GEF Urban Transport Partnership Program.[3] Other supplemental sources were also used to enrich the dataset for urban transport and energy analysis, namely the most recent China City Statistical Yearbooks. Beijing and Shanghai were also included where data was available from existing studies given their relevance in broad comparison of Chinese cities. Wuhan was included in a limited number of analyses where data was available from an ongoing Bank operation in that city.

Section 2 discusses the general demographic and economic trends in the sample of cities that may be influencing the sector. Section 3 points to stylized facts about the most relevant urban transport demand, supply and performance characteristics in recent years and suggests how they may be driving energy consumption and GHG emissions. Section 4 is the analysis and forecast of energy use and GHG emissions using the urban transport drivers identified. Finally, general conclusions and next steps are suggested in Section 5, as well as additional details on the data, methodology, definitions, and a map of China with the 17 selected cities in the annexes.

2. DEMOGRAPHIC AND ECONOMIC TRENDS

The selected cities represent a significant share and wide spectrum of Chinese urban areas and municipalities. The sample of 17 cities and municipalities comprises roughly 143 million inhabitants or nearly 11% of the China's population, and 21% of the GDP in 2006. Beijing, Shanghai (both province-level municipalities), and Guangzhou (capital of Guangdong Province) are the largest metropolises in China, situated in the more populous and prosperous Eastern and Southern coasts, while Chongqing (a province-level municipality), Xi'an (capital of Shaanxi Province), and Wuhan (capital of Hubei Province) are amongst the largest cities in China's less developed Central and Western regions. The medium cities in the dataset with populations between four million and 1 million inhabitants are scattered geographically throughout the country and include Jinan (capital of Shandong Province), Zhengzhou (capital of Henan Province), Nanchang (capital of Jiangxi Province), Urumqi (capital of Xinjiang Province), and Luoyang (in Henan Province). Finally, Dongguan (in Guangdong Province), Xianyang (in Shaanxi Province), Jiaozou (in Henan Province), Weihai (in Shandong Province), Linfen (in Shanxi Province), and Changzhi (in Shanxi Province), represent relatively smaller cities with city-proper populations ranging between 0.5 and 1 million. The distribution between larger, medium, and smaller cities based on urban population estimates for 2006 are reflected in FTable 1.

[3] Annex 1 describes the template and methodology used to compile and verify the data from 14 cities participating in the China World Bank-GEF Urban Transport Partnership Program: Changzhi, Chongqing, Dongguan, Guangzhou, Jiaozuo, Jinan, Linfen, Luoyang, Nanchang, Urumqi, Weihai, Xi'an, Xianyang, and Zhengzhou.

Table 1: Distribution of Cities by Population, Land Area and Density

2006 Estimates		Urban Population ('000)	Urban Land Area (km sq.)	Population Density (person/km sq.)
Larger Cities (>4 million pop.)	Shanghai	12,901	820	15,733
	Beijing	9,600	1,085	8,848
	Guangzhou	7,601	1,444	5,264
	Chongqing	6,590	2,616	2,519
	Xi'an	5,410	3,582	1,510
	Wuhan	5,012	1,615	3,104
Medium Cities	Jinan	3,513	3,257	1,079
	Zhengzhou	3,090	1,010	3,059
	Nanchang	2,213	617	3,587
	Urumqi	1,587	1,600	992
	Luoyang	1,510	544	2,776
Smaller Cities (<1 million pop.)	Dongguan	882	233	3,785
	Xianyang	856	523	1,637
	Jiaozuo	819	424	1,930
	Linfen	756	1,316	574
	Weihai	620	769	806
	Changzhi	531	334	1,589

For the purposes of this paper, two geographic boundaries are used to define the cities. Urban or "city-proper" refers to the urbanized areas of a city. By contrast, "municipality" (also known as "prefecture") is a larger, formal administrative division within the country, often including vast suburban and rural areas in addition to the urban areas. [4]

The population of the sample cities grew above the national average. Population in all urban areas sampled (except for Beijing) has increased since 1993 and at an average year-on-year rate of 2.5%. The year-on-year growth rate from 2002 to 2006 for the sample was about 2.0%, which is above the national average for that period of 0.6%. This is consistent with China's continued urbanization. Urban population as a share of total population stood at 42% in 2006 (World Bank development data). Figure 1 presents the population and population density trends in these cities between 1993 and 2006.

Nearly all of the cities exhibited growth in population and population density at the municipal level. This phenomenon was less evident in urban areas because decentralization can be the policy or the unintended consequence of land development decisions. There is evidence from the larger and more developed cities like Guangzhou, Beijing and Shanghai that the suburban areas are growing faster than the central areas. In Beijing, for example, the population in the central urban area has actually decreased from 2.115 million in 2000 to 2.061 million in 2006, but increased in the suburban areas from 6.388 million to 7.736 million over the same period. Population density and job density are important and favorable condition to support cost-effective public transport operations and other sustainable transport strategies (Kenworthy and Hu, 2002), but are also crude indicators for urban transport planning.[5]

The most populous municipalities tend to be the most urbanized, since the urban population is a greater share of the total municipal population. The exceptions are Urumqi and Chongqing, as shown

[4] Additional information about the distinction between "municipal" and "city-proper" is available in Annex 2.
[5] More effective indicators of the quality and spatial distribution of land uses have been suggested, such as population or job centrality and jobs-housing balance (Bento, Cropper, et al. 2003), but the present dataset does not lend itself to such spatial structure analyses at the micro-urban level.

in Figure 2. Urbanization can vary greatly because the land area within the administrative boundaries of a municipality can include significant tracts of suburban and rural lands. In the case of Chongqing, the municipality was greatly expanded in 1997 to cover a vast and sparsely populated area of 82,000 square kilometers with 30 million inhabitants, so only its city-proper population is shown in Figure 1. Urumqi appears to be highly urbanized because it is the major urban center in a sparsely-populated and arid region of the country.

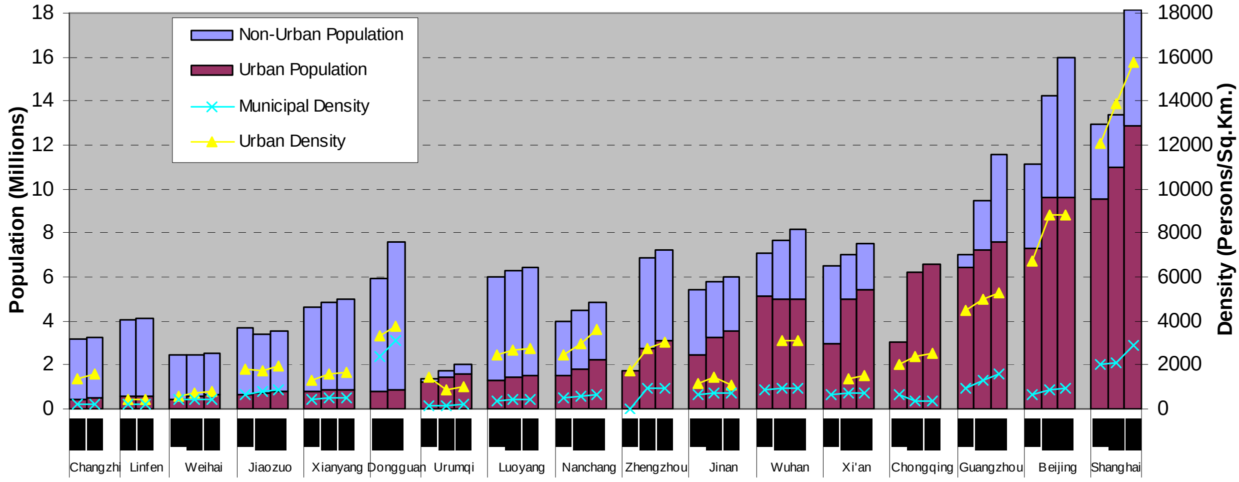

Figure 1: Population and Population Density Trends

The urban population densities in larger cities tend to be higher than in smaller cities. This relationship is less clear with municipal population densities because municipal areas are usually much larger and can include suburban and rural lands. Shanghai exhibits the highest density of any urban area in the Chinese mainland, while the urban areas of Linfen and Weihai are among the least dense in the sample. Figure 1 also shows that population density has generally been increasing faster for the urban areas than for municipal areas of smaller cities, while this is this trend is not as clear for larger cities. The urban density in larger cities is often influenced by specific city policies towards decentralization, such as the location of public buildings and new land for development.

The larger, coastal cities tend to have the highest GDP per capita. This measure of normalized economic output, as shown in Figure 3, can vary in smaller and medium cities for numerous reasons including natural resources, local industries and historical factors. Weihai, for example, is a smaller city with a GDP per capita approaching that of the largest cities because of an important seaport and local industries. Beyond size and geographical differences, the sample includes China's wealthiest large and medium cities such as Beijing, Shanghai, Guangzhou and Dongguan, as well as less developed cities like Linfen, Changzhi, and Jiaozuo.

All cities in the sample exhibited remarkable economic growth, and most were above the national average. Figure 2 shows the GDP growth in all of the sample cities, particularly from 2002 to 2006 when the national average was around 10 percent per year for China. Urban and municipal GDP per capita also grew in all cases since 1993. The average year-on-year growth rate for GDP per capita in the sample of 17 municipalities was 8% from 1993 to 2002, and an extraordinary 15% from 2002 to 2006.

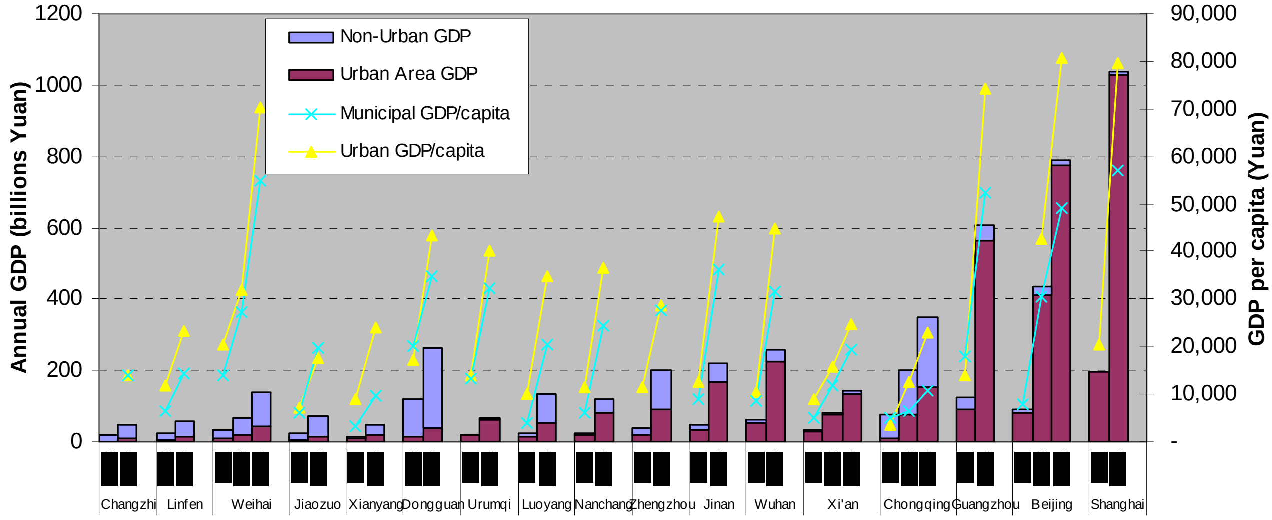

Figure 2: Growth in Economic Output

Annual salaries and disposable incomes also saw remarkable increases for all cities. Figure 3 shows the average annual increase in disposable income was around 7.8% from 2002 to 2006. Such economic growth can fuel tremendous changes in the way city residents live and consume basic services, like transport.

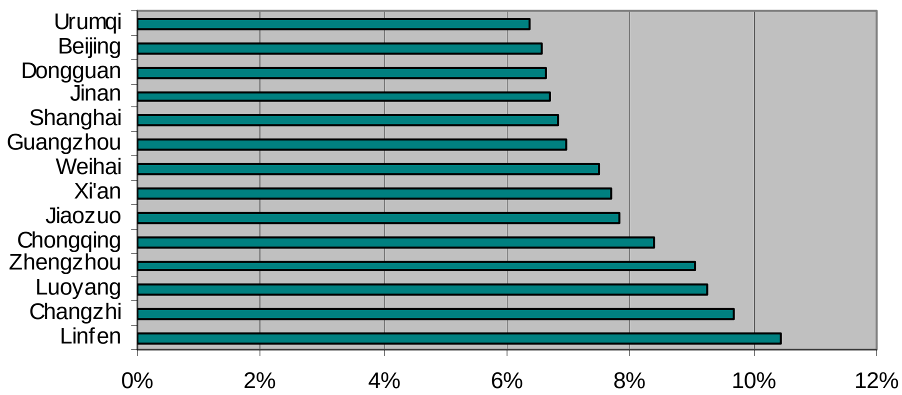

Figure 3: Average Annual Change in Disposable Income, 2002-2006

3. URBAN TRANSPORT DRIVERS

A number of factors in urban transport contribute directly or indirectly to the potential growth in energy use and CO2 emissions. Energy use or emissions by urban transport, *E*, can be described by the following identities, and where *i* is the mode of transport. Since CO2 emissions are directly proportional to energy use, the same identities apply but with a different coefficient for the carbon content of the fuel.[6] For instance, identity (1) below is defined by the number of vehicles, the vehicle use or vehicle-kilometers traveled (VKT), and the vehicle efficiency and fuel content (E/VKT). Identity (2), however, is defined by the number of person-trips, the distance of the trips, the number of persons in each vehicle (i.e., occupancy), and the energy or emissions content of the fuel per VKT.

$$\Sigma\, E(i) = (vehicles)i*(VKT/year)i*(E\ /VKT)i \qquad (1)$$

$$\Sigma\, E(i) = (trips)i*(trip\ distances)i*(1/vehicle\ occupancy)i*(E\ /VKT)i \qquad (2)$$

These identities and others[7] are useful in characterizing the potential urban transport characteristics driving changes in energy use or emissions. Figure 4 decomposes the absolute change in CO2 emissions using identity (1) showing that the vast majority of the growth for each city from 1993 to 2002 and 2002 to 2006 can be attributed to the increase in the vehicle fleet. Both VKT/year and E/VKT were mostly negative drivers of emissions as explosive growth in new vehicles moderated the use of individual vehicles (while aggregate VKT increased) and introduced more efficient technologies.

The evidence strongly suggests that changes in travel behavior that increase energy use or emissions are overwhelming any gains made by vehicle technology or fuel improvements. Figure 5 presents the relative change in major urban transport drivers under identity (2), which further suggests that the growth in energy use and emissions is being driven by changes in behavior. Specifically, increases in trip rates (trips per person per day), increases in distance of motorized trips (VKT/trip), and decreases in vehicle size or occupancy are driving emissions higher, despite significant improvements in the technology of the vehicle fleet in most cities. The level and type of infrastructure investment is also potentially an indirect driver of energy use and emissions.

The following sections and Annex 3 provide a more detailed discussion of the urban transport characteristics. Although detailed statistical analysis of each variable to develop and test an energy use model were not performed because of data limitations or the scope of this work, the findings do suggest how these drivers may be indicators of the energy or carbon-intensity pathway for urban transport in Chinese cities.

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[6] The emissions of CO2 and quantity of fuel consumed are very closely correlated because the carbon content of the most common transport fuels does not vary greatly.

[7] Such as "Activity-Share of Mode-Intensity-Fuel Content" (ASIF) by Schipper, et al. (2000)

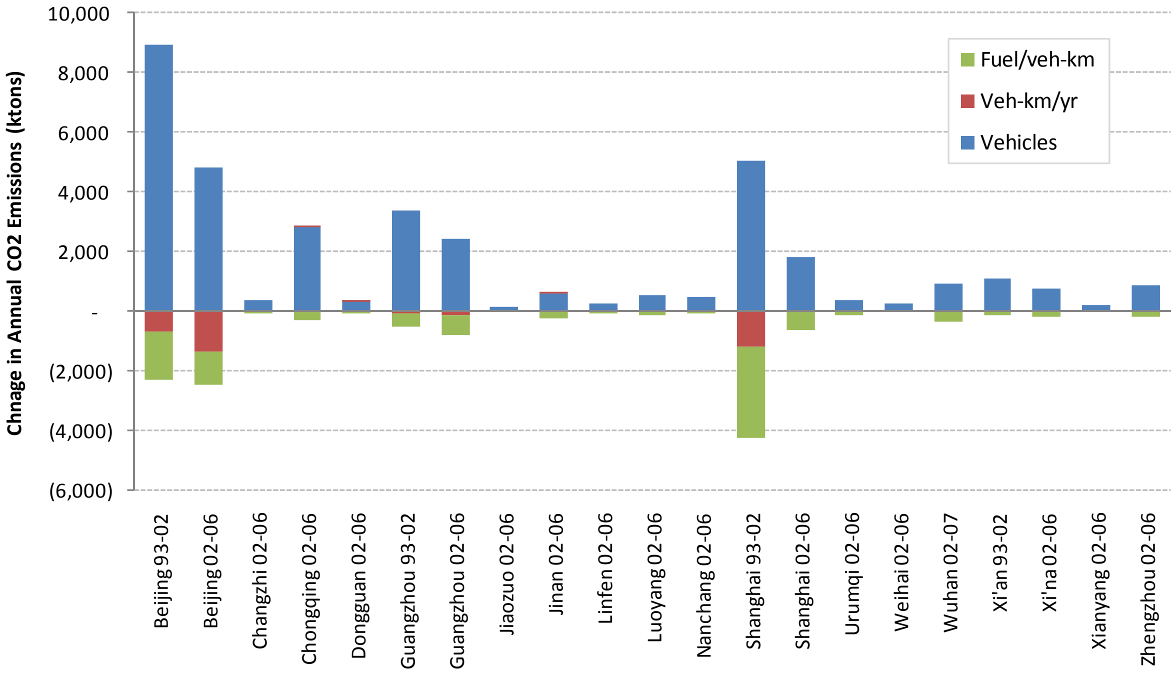

Figure 4: Decomposition of Major Drivers of CO2 Emissions under Identity (1)

3.1 Increase in trip-making

The aggregate number of trips per day has been increasing primarily as a result of population and income growth. In fact, the average growth in overall trips was above 5% per year in a sample of 11 urban areas, which was higher than population growth and just below income growth. It follows that the trip rate (daily person-trips per capita) has increased measurably in all of the cities analyzed, by at least 2% per year in most cases. This is also consistent with the literature that shows a slight to moderate increase in aggregate travel demand in developed and developing countries with rising incomes.

The expected growth in population and personal income for most if not all urban areas will contribute to continued growth in aggregate number of trips. In turn, this has a direct implication on energy use and emissions as many of the new trips are made on motorized modes. As shown in Figure 6, the growth in the trip rate is particularly pronounced for motorized trips per capita (public transport, taxi, motorcycle, passenger cars, and others). Although the absolute values of the trips rates may not be comparable across cities because of varying methodologies (discussed in Annex 2), the relative growth is significant.

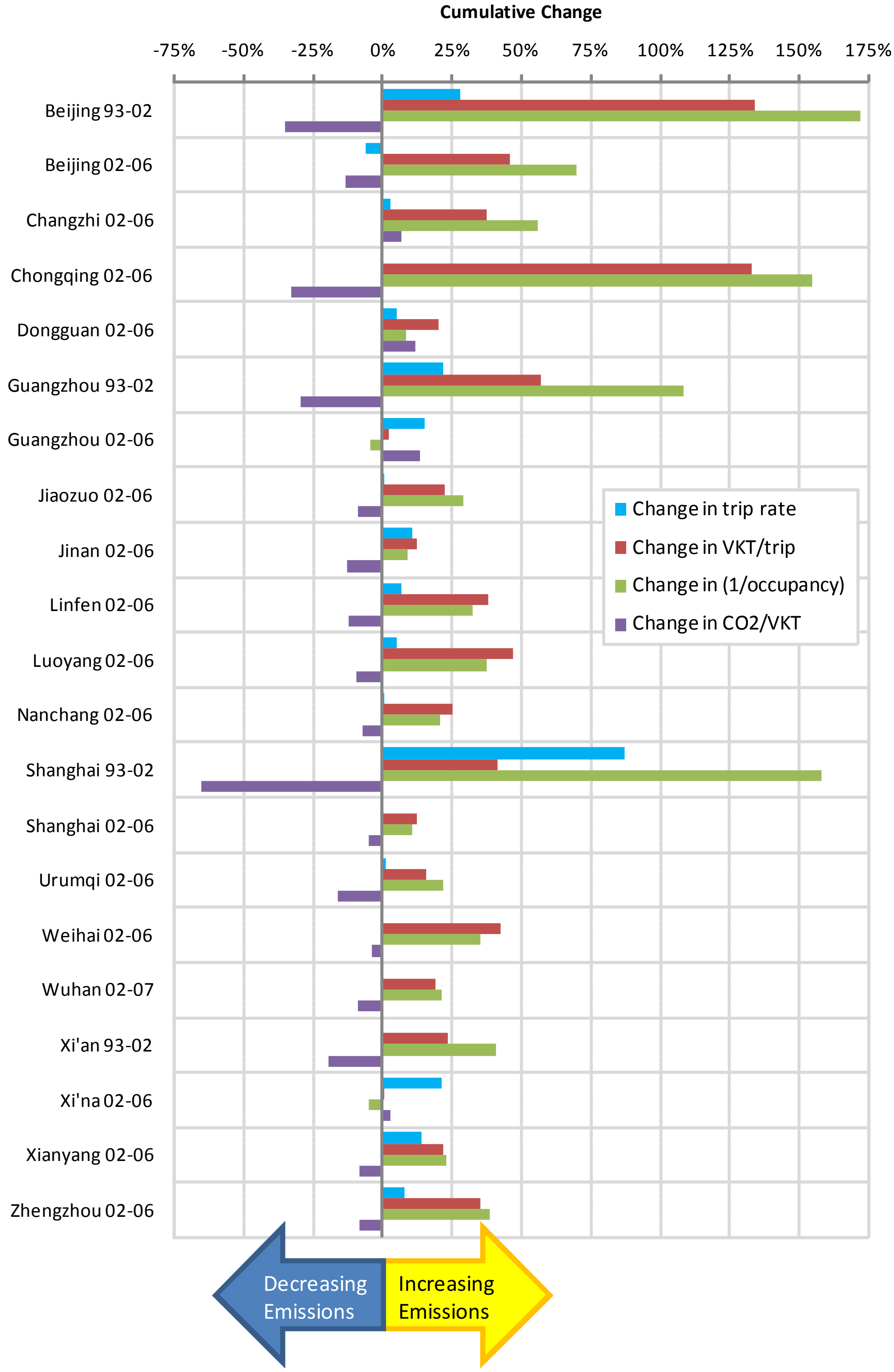

Figure 5: Change in Major Urban Transport Drivers under Identity (2)

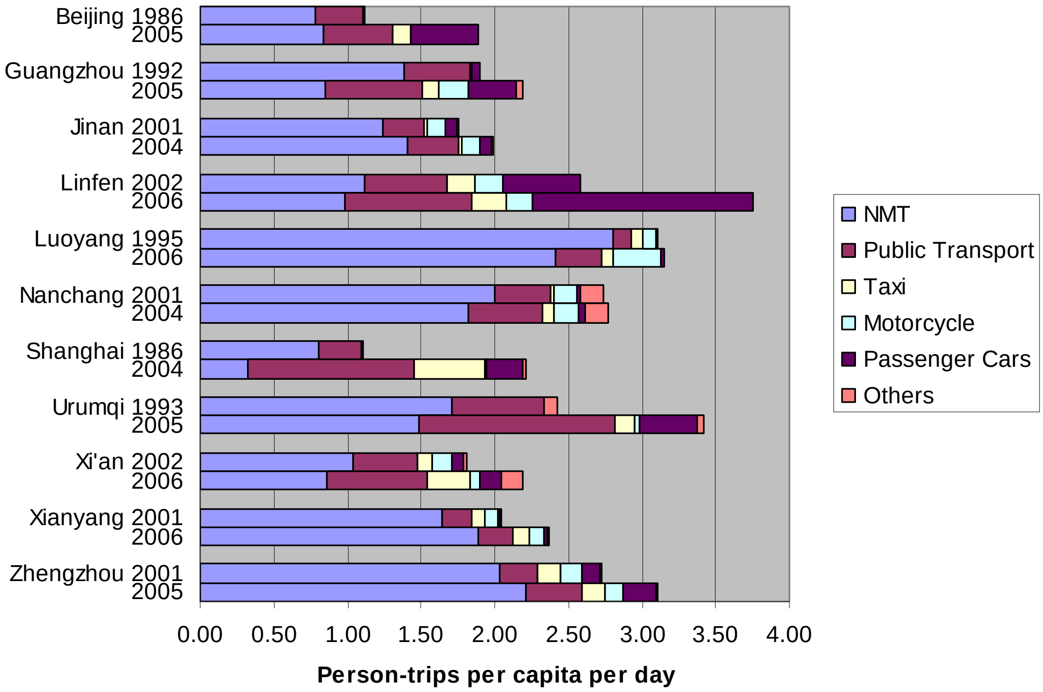

Figure 6: Trends in Trip Rates by Mode

3.2 Increase in travel distances

Increasing trip lengths is a driver of energy consumption. Among 8 sample cities, bus/trolleybus and passenger car trips tend to be the longest, as presented in Table 2. Although time series data was lacking to statistically test trends, average trip distances have been increasing in Chinese cities due to a number of factors. China's transition to open markets generated tremendous economic growth and urban expansion, along with great changes in the development pattern of urban areas. The break-up of the *danwei* system (or work unit compounds) and the long-term land leasing system, further described in Annex 3, have at least contributed to the increase in trip rates and trip distances. Many urban Chinese no longer live where they work, resulting in more and often longer commutes. As a result, distances between centers of trip generation (housing) and trip attraction (work sites, shopping, services, etc.) have increased, often requiring motorized transport.

Trip distances for motorized modes are likely to be increasing because of "urban sprawl" even as trends in population density were mixed. Better indicators of sprawl (i.e., unfavorable spatial development patterns) include trends in employment centrality and the distribution of land uses (mix of jobs-housing-services). Unfortunately, these data were not available with this dataset. However, recent survey data for Nanchang (presented in Table 2) is indicative of the potential growth in trip lengths for motorized modes. The largest increases were for taxis, which are usually a small share of all trips. Perhaps more significant considering the mode shares are the increases for bus/trolleybus and cars. Average trip distances in Beijing have also increased significantly from 8 km in 2000 to 9.3 km in 2005. Combining this with the increase in overall trips, as described above, means that total travel distance in Beijing over the period has increased by about one-third (Beijing TDM Study, 2008).

Table 2: Average Trip Distances by Mode

	Average of 8 Cities (km)	Nanchang in 2005 (km)	Change in Nanchang from 2002 to 2005
Walk	1.5	1.1	-2%
Bicycle	3.8	6.6	0%
Motorcycle	6.2	11.5	8%
Taxi	7.0	10.0	88%
Bus and Trolleybus	8.8	15.3	16%
Passenger Cars	10.1	16.2	6%

3.3 Shift towards motorized, lower-capacity modes

Non-motorized travel (NMT), including walking and bicycle trips, continues to decline in favor of motorized trips on both public and private modes. This is evident from the evolution of mode shares in Figure 7. Even as public transport (PT) fleets and mode shares increased in some cities, private vehicle mode share increased in all cities, mostly at the expense of higher-occupancy PT modes (primarily bus). Moreover, the passenger load of private modes is decreasing in some cities as vehicle ownership levels increase and households begin owning multiple cars. For example, average vehicle occupancy per trip in Beijing declined from 1.56 in 2000 to 1.26 persons in 2007 indicating an increase in drive-alone car use over the period (Beijing TDM Study, 2008).

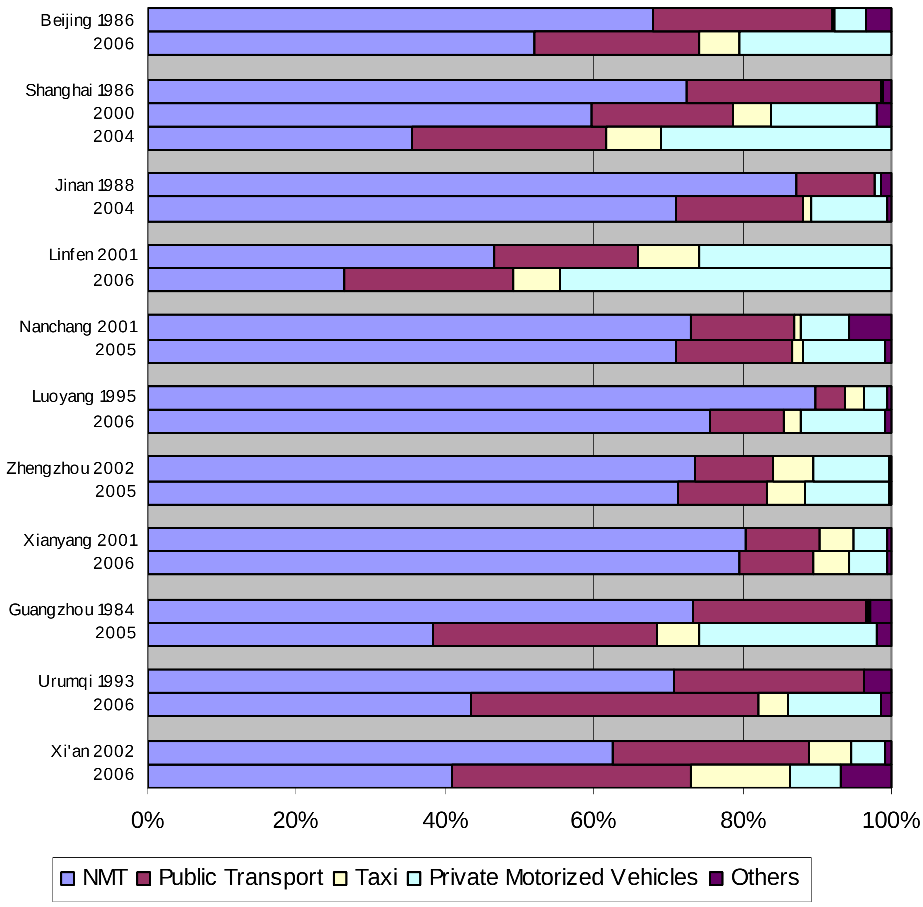

Figure 7: Evolution of Mode Shares by Person-Trips

Estimates of vehicle-kilometers traveled (VKT) show increases in all cities and surpassing GDP per capita growth in a few cities. Travel demand, as measured by VKT, is a major driver of energy use and emissions. As shown in Figure 8, VKT growth was closely related or "coupled" with GDP growth in the 1993-2002 period, but less so in the 2002-2006 period that saw extraordinary economic growth in most of the cities. Although the intensity of vehicle use in terms of VKT per vehicle per year tends to decrease slightly as motorization levels (vehicles per capita) increase, this is greatly overwhelmed by the growth of the vehicle fleet in all cities. The result has been an average year-on-year increase in total VKT and VKT per capita of over 11% and 8%, respectively. A description of the data and methodology used is available in the following section and Annex 3.

Among the potential drivers or enablers of VKT growth suggested in the literature are private vehicle ownership, road density, and public transport supply. As a suggested next step in this research, a careful multivariate analysis may show that these and other variables explain at least in part the differences in mode share and demand between cities. It is also important to point out that other, higher-order factors may also explain part of the variance between cities. For example, extreme winter weather in Urumqi tends to increase the use of motorized vehicles and discourage non-motorized modes.

Private vehicle ownership in terms of passenger cars per capita, which is closely correlated to personal income, has generally been outpacing GDP or income growth as the prices for small cars have come down relative to income. When motorcycles are included in this measure, the growth is not as significant since motorcycles are restricted in many Chinese cities. According to the IEA, the spectacular growth in the private vehicle fleet in China in recent years obscures huge differences between cities and provinces. The average vehicle ownership in wealthier coastal provinces is at least twice as high as in inland provinces. Vehicle ownership in Beijing, one of the wealthiest cities, is five times more than the national average and equal to that of South Korea about 6 years earlier. Some of the poorest inland provinces and cities have one-tenth of the level of vehicle ownership of Beijing because of differences in personal income, infrastructure development, urban planning and an array of other factors (IEA, 2007). Inland provinces have a higher share of trucks and tractors than coastal provinces, where cars represent two-thirds of vehicles. Shanghai, the wealthiest region of China, has a vehicle ownership of less than one-third that of Beijing (around 65 vehicles per 1,000 people), arguably reflecting local policies that restrict the number of driving licenses, certain vehicle types, and promote public transport investment. The contrast between Beijing and Shanghai is further explored in Box 1 and 2.

Investment by local governments in transport infrastructure has been growing in nearly all cities where such data was reported. Road density, as measured by the percentage of the urban area occupied by paved travel lanes, varied between 3% and 11% in 12 cities sampled, but no correlation to VKT was evident perhaps because of other explaining factors. However, road density is increasing in all of these cities and at an average rate of 9% per year. Road space per capita has also been increasing, as shown in Figure 8. As shown in Figure 8, urban buses per capita as a measure of PT supply increased in all cities except Shanghai, which already has the largest bus fleet and exhibits some of the highest levels of this index in China. Table 3 shows that public transport infrastructure in most cases has been outpacing total infrastructure investment, reflecting both the need and opportunity to develop these kinds of services in Chinese cities. Figure 9 shows that the PT share of public infrastructure investment varies widely by city and may not be closely related to the level of PT demand or mode share in every city. Again, there may be numerous other factors involved, such as climate, terrain and socio-economic conditions that should be explored in more detail in future research.

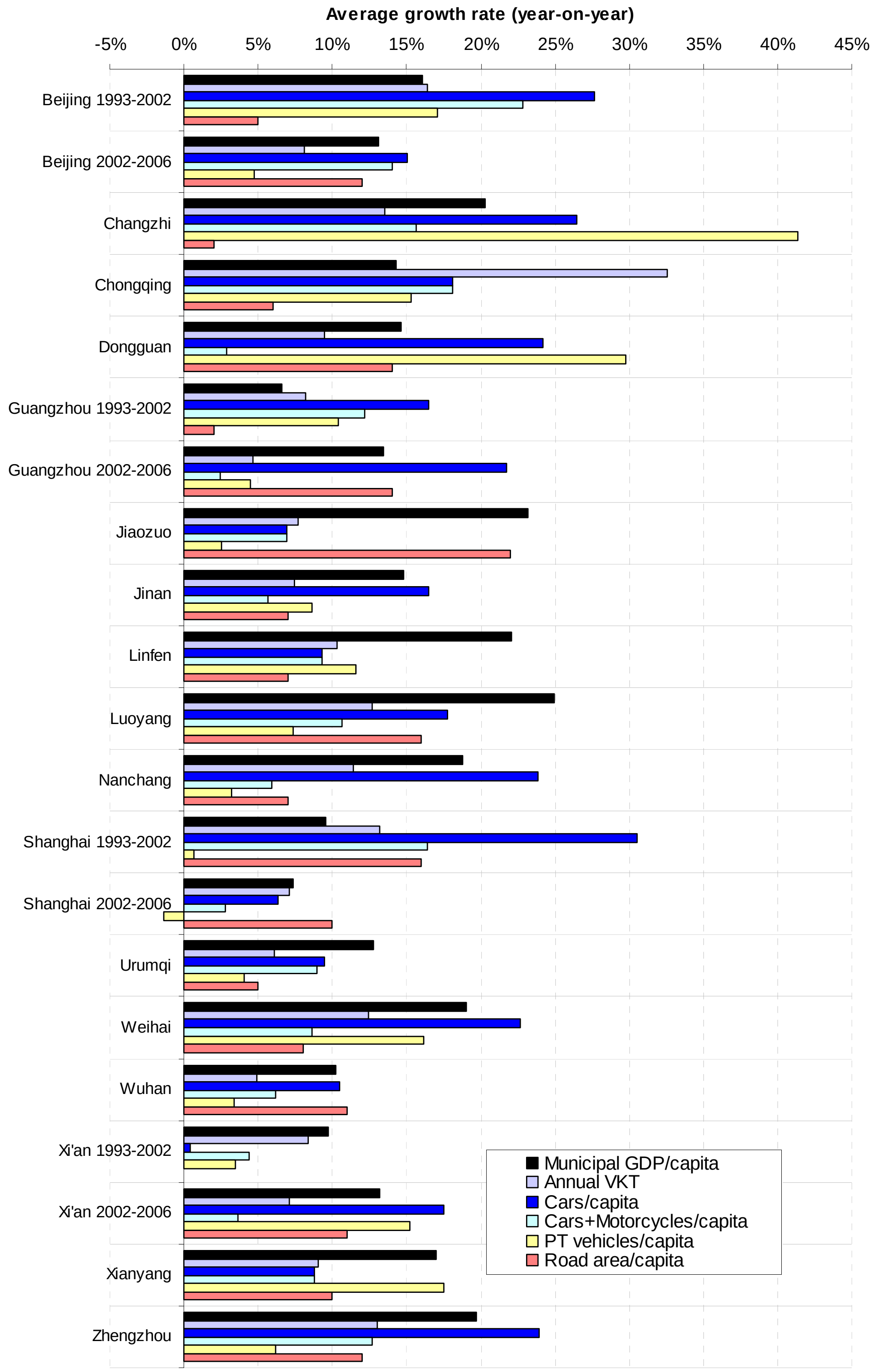

Figure 8: Vehicle-Km Growth and Potential Drivers

Table 3: Growth in Infrastructure Investment by City

Average Annual % Growth	Public Transport Infrastructure Investment	All Transport Infrastructure Investment	Period
Jiaozuo	170%	52%	2001-2006
Dongguan	149%	11%	2001-2006
Changzhi	42%	40%	2001-2006
Linfen	38%	40%	2002-2006
Guangzhou	34%	7%	2004-2005
Shanghai	30%	23%	2004-2006
Xianyang	21%	-1%	2001-2006
Luoyang	10%	91%	2001-2006
Weihai	16%	29%	2001-2006

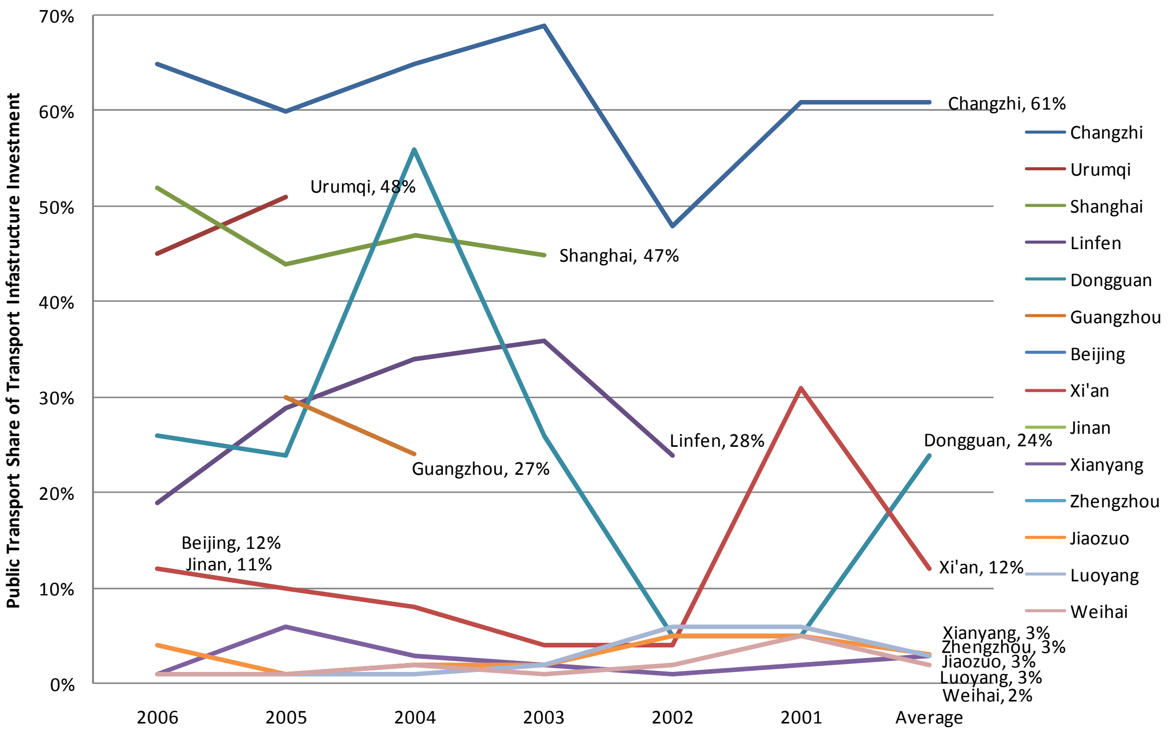

Figure 9: Shares of Government Infrastructure Investment in Public Transport

3.4 Improving vehicle efficiency and fuel content

China has recently implemented one of the strictest efficiency standards for new vehicles, which basically trails the EU standard with a lag of a few years. National fuel-efficiency standards for cars, sport-utility vehicles and minibuses were introduced in two phases in 2005 and 2008. The standards set maximum fuel consumption levels for 16 weight classes, using the New European Driving Cycle. The Chinese standard is currently surpassed by standards in the EU and Japan, as can be observed in Figure 13. China has also tightened vehicle emission standards, which in most provinces equate to Euro II standards first adopted in Europe in 1996. More current Euro III standards have been adopted in a few other cities such as Beijing and Guangzhou.

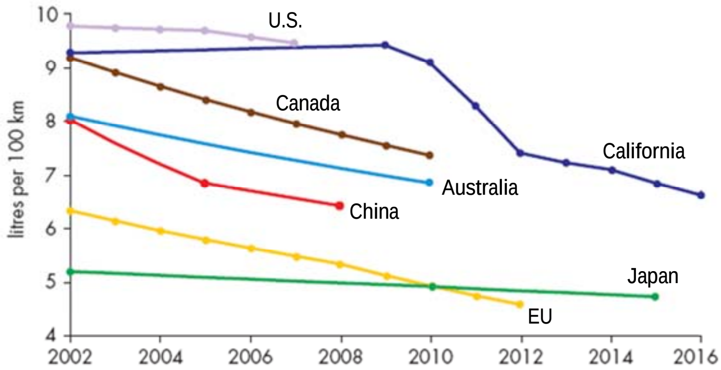

Figure 13: Average New Vehicle Fuel Efficiency Standards

(Source: IEA World Energy Outlook, 2007)

Many countries also require additives or bio-fuels to be sold or blended into transport fuels for improved performance, energy security, or other reasons. Often these can be produced with domestic crops, but the energy efficiency of the process is highly dependent on the source of the fuel. In the US, the primarily source has been corn, which is a major food crop and requires more resources to produce sugar cane-based ethanol in Brazil. The Chinese government supports the use of alternative fuels, notably bio-fuels and compressed natural gas (IEA World Economic Outlook, 2007). In 2005, ethanol consumption was 1 billion liters (0.5 Mtoe or megatons of oil equivalent). Production and consumption is concentrated in the few provinces that have been granted financial support by the Chinese government for production of E10, a gasoline blend with 10% ethanol. The government has set non-mandatory targets of 6 Mtoe for ethanol and 1.9 Mtoe for biodiesel by 2020. However, ethanol is not expected to become a major fuel for transport in the long-term, because of supply constraints. Natural gas-powered vehicles, mainly buses, consumed 0.1 Mtoe in 2005. China already has a fleet of more than 110,000 gas-powered buses and taxis in use in more than ten cities. The small number of filling stations and limited availability of natural gas supply are the main constraints to the further development of gas as an alternative fuel.

4. ENERGY ANALYSIS AND CARBON FOOTPRINTING

4.1 Data and Methodology

The urban transport data collected from the 14 GEF cities were generally self-reported using the template provided in Annex 1. These data were then analyzed for inconsistencies and corrected or supplemented as necessary through two rounds of inquiries with city representatives with coordination assistance by the national-level GEF implementation unit, the Chinese Institute of Comprehensive Transport. These data were also verified to the extent possible using independent data sources from the public domain. Data for the three additional reference cities, Beijing, Shanghai and Wuhan, were gathered primarily through other sources such as the China City Statistical Yearbook, World Bank project reports, and other recent studies.

As described earlier, the following methodology was used to estimate the energy use or CO2 emissions:

- **Vehicle fleet numbers** were self-reported by the GEF cities based on municipal and district registration records and supplemented by other available data sources and studies. These data were verified whenever possible with independent studies and the China City Statistical Yearbook.

- **Vehicle kilometers traveled** for passenger cars and motorcycles was estimated using self-reported data on the number of vehicles by type multiplied by the average VKT per year for each. All cities also reported VKTs for managed vehicle fleets such as buses and taxis, which were verified against independent data sources where available. These results were then verified and reconciled whenever possible using the following methods:
  - Comparing to other, independent sources of traffic counts, survey of odometer readings, or vehicle inspection records. Field survey data of car odometer readings and/or traffic counts to derive actual vehicle use were available only in Beijing, Shanghai, Xian, and Guangzhou. Where city data was not available or deemed not comparable because of varying methodologies, a national urban average of VKT per year of 20,000 per passenger car or truck and 9,000 per motorcycle was used (He et al., 2005).
  - Comparing to the aggregate number of trips by mode multiplied by the average trip distances measured through household travel surveys or user surveys for the development of transport models;
  - Comparing to a national average for VKT per year by vehicle type (20,000 per passenger car or truck and 9,000 per motorcycle according to He et al., 2005) and expected levels of vehicle ownership according to average income level;
- **Energy use or CO2 per VKT** was estimated for cities using self-reported, on-the-road average fuel efficiency figures by mode from survey data or inspection records. When this was not available, a national average fuel efficiency measure by vehicle type was used and based on industry and government data as estimated by He et al (2005). For Beijing and Shanghai, detailed survey data was available from the International Vehicle Emissions Model.[8] Total transport fuel consumption data was provided by only a few cities and was used to perform a top-down verification of fuel economy and VKT figures.

4.2 Indicators

The total estimated contribution of urban transport in 2006 for the sample of 17 cities is about 54 Mtons of CO2 or 17.7 Mtoe of energy consumed. Figure 11 presents the first two indicators for each city, CO2 emitted and energy consumed by urban transport, on two directly related horizontal axes. Not surprisingly, the larger cities of Beijing, Shanghai, Guangzhou, Chongqing, and Wuhan are predominant. It is also evident that cars and trucks tend to be the largest contributors. The larger cities with large industrial sectors or ports, such as Guangzhou, Chongqing, and Wuhan, tend to have at least half of their energy use and CO2 emission coming from trucks. For other large cities with very developed service, financial, and government sectors, such as Beijing and Shanghai, cars tend to contribute about half of the energy use and CO2 missions. The other modes, including public transport, motorcycles and taxis, contribute 10-20% in most cities.

In all sample cities, the energy consumed or CO2 emitted increased from 1993 to 2002 and from 2002 to 2006. On average, the increase from 2002 to 2006 was 6% year-on-year (YOY) and ranged from 2% to 22% from city to city. Estimates were available for only 4 cities from 1993 to 2002, which showed an apparent decrease in the annual growth rate of energy use and GHG emissions, presented in Table 4.

The share of CO2 emissions and energy use by urban transport is significant and likely to grow in most if not all of the cities. The total 17-city estimate represents about 40% of the national estimate for the entire road transport sector estimated by IEA World Energy Outlook (2007). This figure is higher than expected because of the inclusion of all trucks in registered in municipalities, which account for about 36% of all CO2 emissions and energy consumption but rarely travel on roads in the urban areas. If trucks are excluded, the 17-city estimate is more in line with national estimates for urban transport.

[8] *http://www.issrc.org/ive*

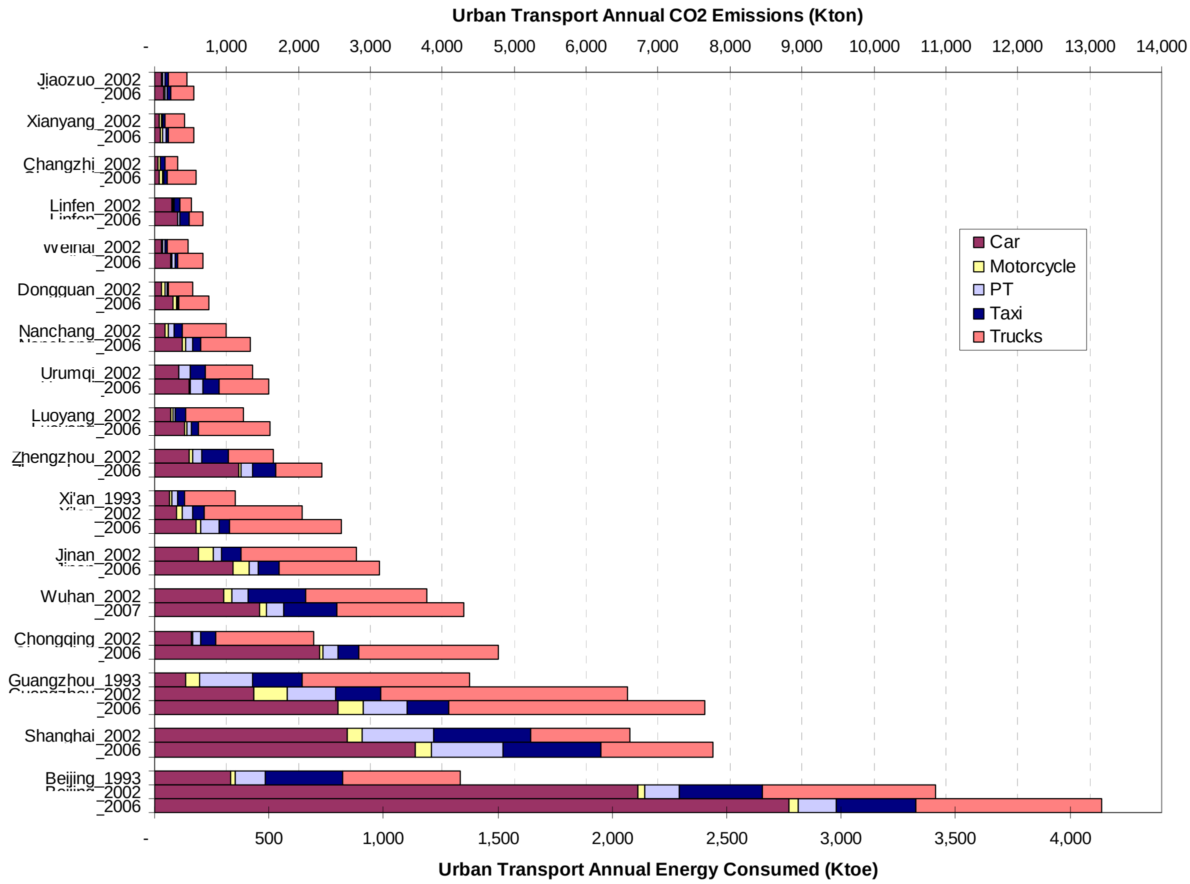

Figure 11: Annual CO2 Emissions and Energy Consumed in Urban Area

Table 4: Average Annual Growth in Energy Use and GHG emissions

Year-on-year % growth	1993 to 2002	2002 to 2006
Beijing	11%	5%
Guangzhou	5%	5%
Shanghai	9%	4%
Xian	7%	6%

Transport's share of total energy use or CO2 emissions at the urban or municipal level is significant and varies greatly by city. On a global scale, transport accounts for around 20% of energy use (World Energy Outlook, 2007). At the city level, the estimates in the literature typically range from 10-30% depending on the level of travel demand, transport supply, technologies, urban form, economic structure, industrial output, and other characteristics of each city. Energy or GHG emissions inventories were available only for Beijing and Shanghai (Dhakal, 2008), where the estimated contribution of urban transport is about 20% and less that 10%, respectively. In developing world cities with high transport demand and an overreliance on inefficient transport systems, this share can be as high as 50% as is the case in Mexico City according to their GHG emissions inventory (2002). In developed cities with very high travel demand and good transport systems, the share can still be around 20%, as is the case in London and New York City according to their most recent GHG emissions inventories.

There is currently no consensus on the most appropriate indicators for comparison of CO2 emissions between cities. Energy use or emissions are normalized in order to control for potential factors, including population, economic activity, and travel demand. However, normalizing may also distort the magnitude of the output of interest, in this case CO2 emissions. For these reasons, a set of indicators is presented in this paper considering the advantages and disadvantages of each. For instance, the emissions per GDP or emissions per GDP/capita are useful for extrapolating estimates with the projected economic growth. Disaggregate GDP or personal income would present certain advantages but was not available or not reliable for all cities. Emissions per VKT or passenger-km would have the drawback of distorting the contribution from non-motorized modes, so emissions per person-trip is presented instead.

CO2 emissions per capita varied widely between the 17 cities, even within the groups of smaller, medium and larger cities. As presented in Figure 12, the annual per capita emissions for all cities in 2006 ranged between 500 and 1,400 kg/person, with Beijing being the highest. This result is not surprising given Beijing's current level of motorization in comparison with the other cities. The higher than average motorization and truck traffic in cities like Linfen, Luoyang and Changzhi contributed to elevated levels of this indicator. An average for all 17 cities was determined to be around 876 kg/person per year with about 40% coming from cars, about 40% coming from trucks, and the remaining 20% from public transport, motorcycles and taxis.

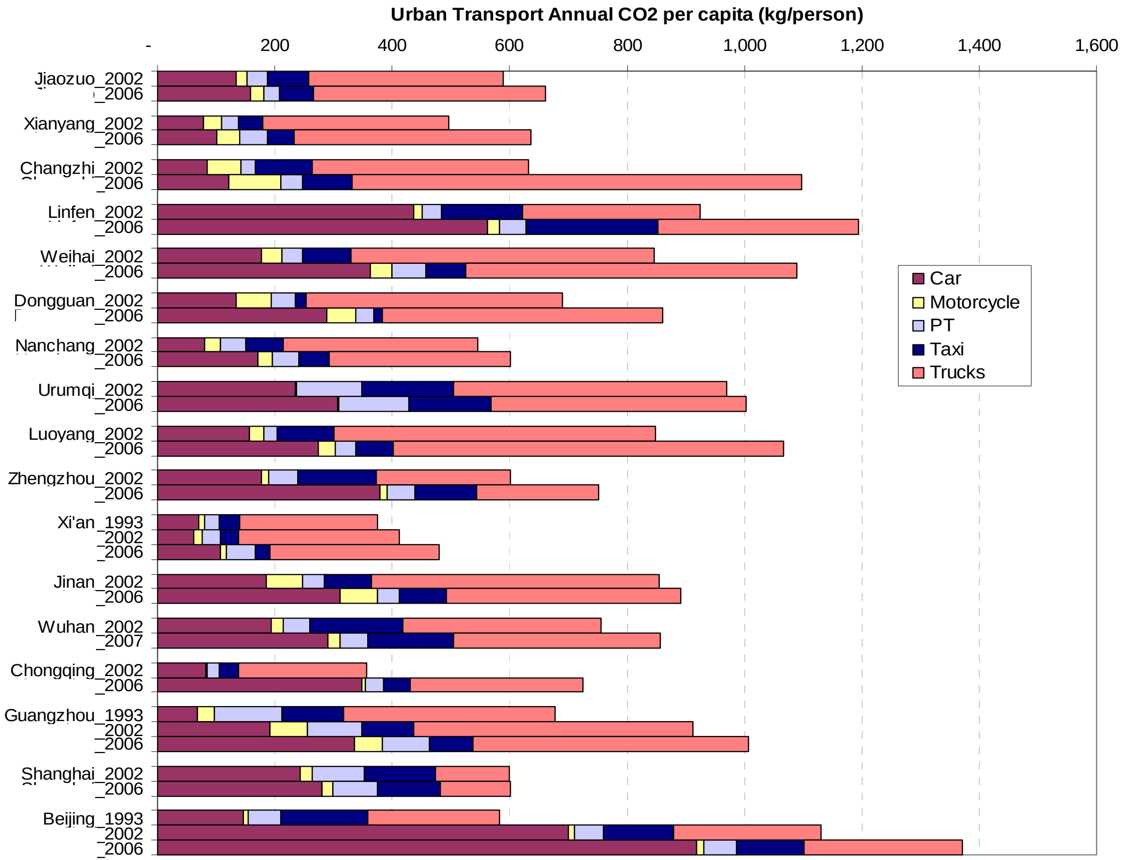

Figure 12: Annual Per Capita CO2 Emissions in Urban Areas

All sample cities exhibited growth in GHG emission and energy use per capita, but the rates varied widely. The results for each city are presented in Figure 12 and may be a reasonable indicator in the short-run of how much an additional city inhabitant may contribute on average. The average increase of this indicator for all cities between 2002 and 2006 was 5% year-on-year and it ranged from less than 1% (YOY) in Shanghai and Urumqi from 2002-2006 to above 14% (YOY) in Changzhi and Chongqing in the same period. In cities where this indicator was low, VKT growth was outpaced by population growth or the increase in mode share of more efficient modes (such as public transport).

Some normalized indicators of energy use and GHG emissions are trending in opposite directions. As shown in Figure 13, estimates of CO2 emissions per municipal GDP (i.e., controlling for economic growth) are decreasing while they are increasing on a person-trip basis (i.e., controlling for differences in trip-making characteristics). Again, Beijing is the city producing the highest emission from an average trip, in part because trip distances are longer than in many other cities, but also due to explosion of private motor vehicles in the past two decades. A few smaller and medium cities such as Jinan, Linfen and Weihai are above the average of about 500 grams per trip, while cities such as Xian and Xianyang appear to be well below the average. These variances between cities may be explained by differences in the urban transport drivers and other factors discussed earlier, but further analysis is needed. In the case of Linfen, private motor vehicles are a large share of all trips (45%), which significantly drives the estimate. By contrast, in Jinan private motor trips are a relatively small share (13%) but tend to be longer than average. One also notes in Figure 13 the contrast between the indicator paths for Shanghai and the other comparable cities, the potential factors of which are explored further in Box 2.

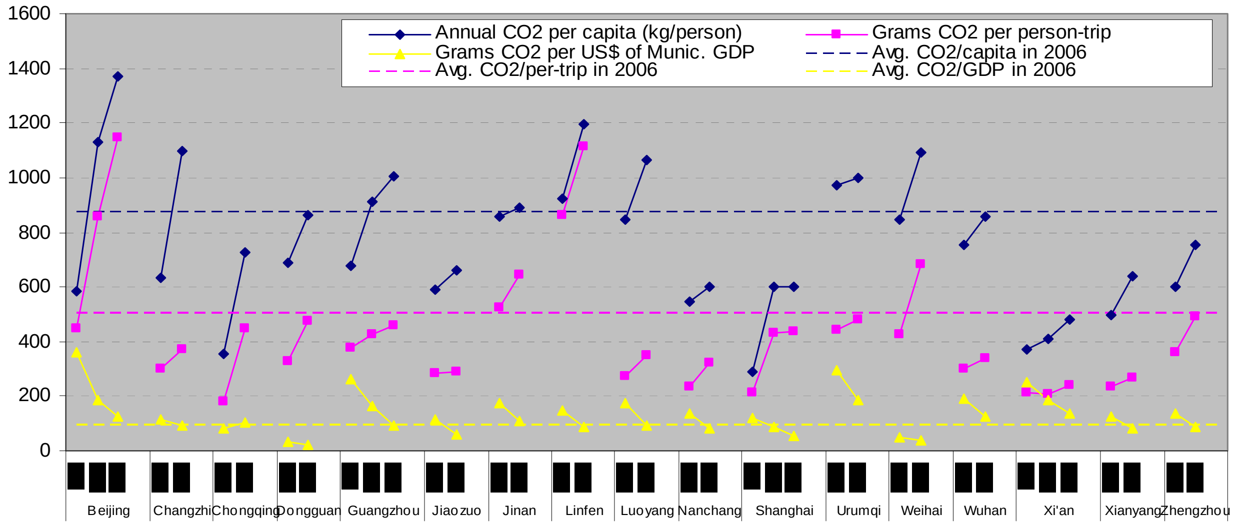

Figure 13: Comparison of Normalized Indicators of CO2 Emissions

The energy and CO2 intensity of urban transport as measured per unit of GDP is decreasing in nearly all cities. The only exception is Chongqing, which has a very vast and hilly terrain that has likely influenced the growth in motorized modes. In fact, the preliminary evidence from the three most developed cities (Beijing, Shanghai, and Guangzhou) is that the growth in CO2 emission per capita may be stabilizing as GDP per capita continues to increase. Figure 14 is a scatter plot of a panel dataset for 1993, 2002 and 2006 relating two critical indicators: CO2 per capita and GDP per capita or the efficiency of the urban transport system to generate welfare in the form of GDP/capita per output of CO2 emissions.

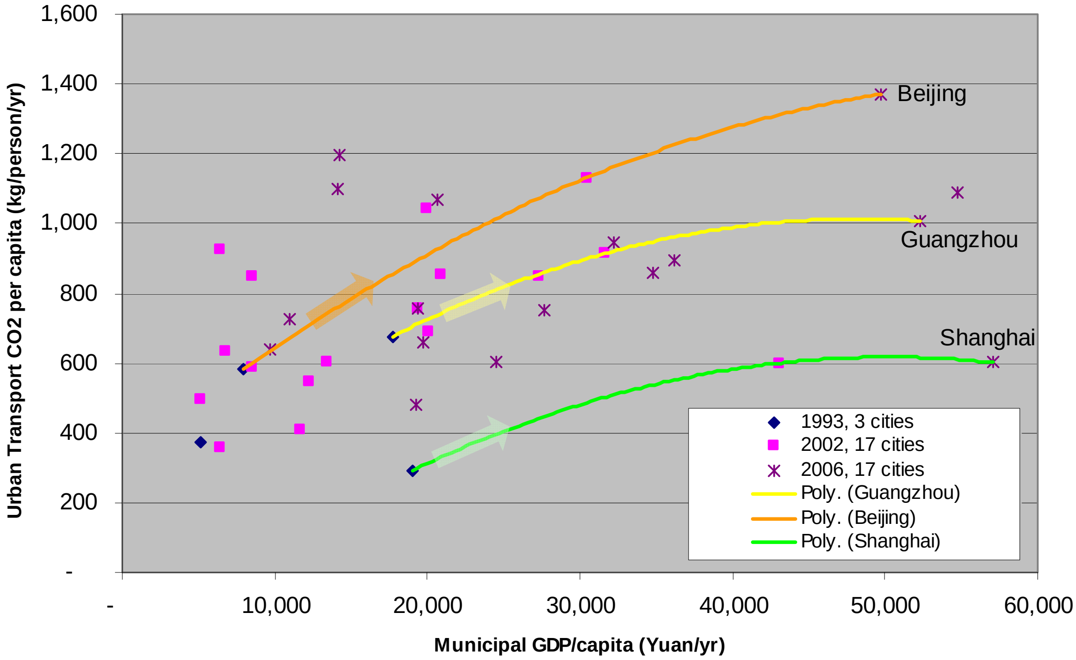

Figure 14: Potential CO2 Pathways for Urban Transport with respect to Economic Output

4.3 Projected Pathways

The plot in Figure 19 suggests that there may be a range of potential trajectories for CO2 emissions per capita in relation to economic development. The trend of the indicator for the all cities in the sample is increasing and the future growth can be projected in alternative trajectories. The key assumption is that the diverging policies and performance of the three largest and most developed cities in the past 10-15 years may suggest what is possible in the other cities in the next 10-15 years.

- Beijing may represent of the most carbon intensive path (shaded red) due to its high level of motorization considering its relative wealth, mode shares, trip distances and other urban transport characteristics. Beijing invested heavily in road network expansion in the 1990s and more recently in PT investments in preparation for the Olympics of 2008. The road investments spurred a massive expansion of the urban/suburban area and greenfield development around "ring roads," as described further in Box 1.
- On the other hand, Shanghai may represent the least carbon-intensive path (shaded green) due to its more compact development pattern, vehicle tax and licensing restrictions, and earlier investments in public transport infrastructure. It also exhibits some of the lowest levels of vehicle ownership (at least in part due to higher taxes) at a high level of economic activity. Box 2 provides a case study of the last two decades.
- At least one intermediate path (shaded yellow) is represented by Guangzhou. As a prosperous industrial port city, Guangzhou invested heavily in both road and PT expansion, and implemented some restrictions against motorcycles.

Changing the carbon-intensity pathway to conform to the historical trend in Beijing or Shanghai can have a measurable impact on energy use or CO2 emissions in the medium to long-term. The historical pathways for Beijing, Guangzhou and Shanghai were defined as non-linear functions as shown in Figure 14. The growth in population and GDP for the other cities were projected to grow at 2% p.a.

and 5% p.a., respectively, and then used as inputs to estimate project the 2020 growth from the value estimated in 2006. In other words, Figure 15 suggests that by following policies that resemble Shanghai rather than Beijing through 2020, it is estimated that other cities can save as much as 7% of CO2 emitted or energy consumed by the sector.

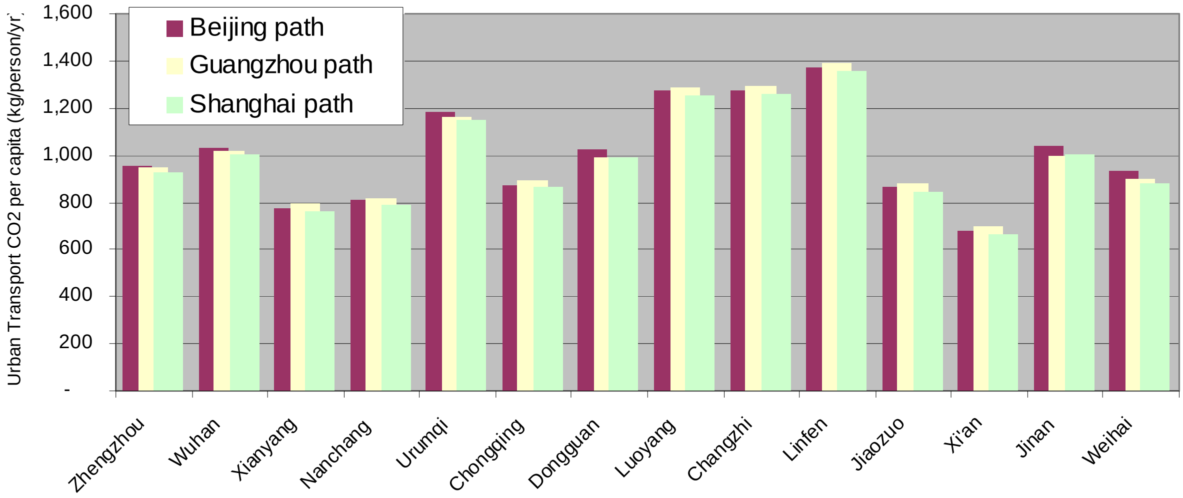

Figure 15: City Projections for 2020 under Different Carbon Pathways

Box 1: From Investment Scale-up to Mobility Management in Beijing

Beijing in the last two decades has undergone a massive transformation in urban transport, both in terms of supply and demand. Where short trips on bicycles or by foot used to dominate travel, today car ownership is being embraced by the growing middle class not just as a symbol of status, but also increasingly as a necessity. While car owners remain a minority of people, this is likely to change in the coming years as some 1,000 vehicles are added to Beijing's roads every day. Motor vehicle growth is over 10% per year and even higher for private cars. International comparisons are few but instructive. London, Paris, Tokyo and New York all experienced tremendous growth in the ownership and use of vehicles in the 20th Century, but the motorization happening in Beijing appears to be faster than in any time in history. It took Tokyo 20 years (1962 to 1982) but Beijing only 10 years (1997 to 2007) to go from 1 to 3 million motor vehicles.

On the one hand new cars in Beijing have never been more efficient and road capacity is constantly being expanded, but the growth in demand for travel has been overwhelming. Beijing built a sixth ring road in the 2000s at a distance of 15-20 km from the center of the city and an extension of some 130km which is already experiencing congestion. The ring roads have facilitated a centrifugal effect in land development patterns, increasing urban and suburban expansion to greenfield sites. Among the other trends and issues identified from a recent study of "Beijing Travel Demand Management Based on Sustainable Development" (Atkins Final Draft Report to World Bank, December 2007) are:

- Overall demand for travel is increasing as more people travel and their trips become longer
- Trip purposes are becoming more diverse and less focused on the traditional commute between the single points of home and work
- Beijing exhibits the highest road space per capita and per vehicle in China, but also the most buses per capita
- Over one-third of trips are now taken by car, with a dramatic decline in the use of cycling, and public transport mode share remaining largely unchanged

- Average vehicle occupancy per trip is 1.26 persons in 2006, a decline from 1.56 in 2000, indicating an increase in drive-alone car use
- Average travel time in the peak periods is increasing, as a result of longer trip distances and congestion; and there is evidence that the peak periods are extending into shoulder hours.

The focus on massive road investments in the 1990s and early 2000s turned to more public transport investments during the years before the 2008 Olympics, as several new subway, light rail and BRT lines were constructed. In describing a new approach for the coming years, Beijing transport officials have characterized a shift from a period of investment scale-up, when transport infrastructure investments consumed a large share of GDP, to a period of optimized operations and mobility management. While new infrastructure supply and technologies (e.g. Intelligent Transport Systems) will certainly be part of enhancing the capacity of transport systems, both transport supply and demand will be addressed for long-term success. For example, a temporary Olympic TDM regime restricting 50% of private vehicles from circulating every day based on the license plate number proved to be successful. There was popular support and political will to extend the restriction under a one-workday-per-week private vehicle restriction (20% regime) similar to what has been in place in other mega-cities such as Mexico City and São Paulo for many years.

Box 2: Policies for Balanced Investments and Automobile Restrictions in Shanghai
Excerpts from Zhou and Sperling (2001) "Transportation Scenarios for Shanghai, China"

Since the early 1990s, Shanghai also experienced one of the most remarkable periods of demographic and economic growth in modern history with the associated changes in urban transport and motorization. To limit air pollution and traffic congestion, city officials began capping the registration of all new cars and trucks in 1998 at 50,000 annually. In 1996, Shanghai capped the registration of mopeds (under 50 cc), allowing owners to transfer registrations to new mopeds but not to purchase additional mopeds, and soon after banned the use of all scooters and motorcycles (over 50 cc) from the city center. The only unrestricted motorized vehicles are two-wheelers powered by batteries.

Shanghai has responded to pressure on the urban transport system with massive infrastructure investments. From 1991 to 1998, about 14.6 percent of the city GDP was devoted to construction — and a significant percentage of that for transportation, a much higher rate than is typical for developing country megacities. The surface area of paved roads increased by 62 percent. In 1993, Shanghai spent three times more money on urban construction and maintenance than any other Chinese city, about half on roads, bridges, and mass transit. From 1991 to 1996, Shanghai spent approximately US$10 billion on transport infrastructure, including two major bridges, a tunnel, an inner ring road, and the first line of its new subway system.

The second phase of the urban transport planning effort began in 1995. It was aimed at moving housing and industry outside the city center to decentralize the metropolitan region. Shanghai's Land Use Master Plan predicts for 2020 a population of 16 million, a multi-center metropolis with a strong central business district, a new city center in Pudong New Area on the east side of the Huangpu River, and eleven satellite towns, all linked by an efficient transport network.

As described by Zhou and Sperling (2001), the scarcity of privately owned cars is related to issues of access, cost, ease of use, and quality:

- "First, it is expensive and time-consuming to acquire a driver's license. One must enroll in an official driving school at a cost of US$500, a significant expense for the typical Shanghai resident. The course involves three weeks of classroom sessions, more than a month of behind-the-wheel training, and three separate road tests.

- Second, it is very expensive to own and operate a car in Shanghai. Fuel prices are similar or higher to those in the United States, but parking costs more than US$1-3 per hour in downtown Shanghai. The greatest barrier is purchase price. According to current exchange rate, the sales price of a small, domestically produced sedan is equivalent to more than US$10,000 and the actual price is much higher. A tax of approximately 10 percent and a large local registration fee must be paid at the time of purchase. Until 1998, the registration fee was approximately US$20,000 on new cars. Under pressure from the central government, the city discarded the high fees and created a vehicle registration auction similar to the one used in Singapore to limit the number of new vehicles that could be registered. In early 2000, the auctioned registration fee was approximately US$2,500.
- A third deterrent to car ownership is limited road infrastructure and traffic congestion. Land use patterns in Shanghai evolved before motorized transport. The city grew in a very densely developed radial pattern, with narrow streets conducive to bicycle use and pedestrians. Services, schools, and jobs are well mixed with housing and within easy bicycling distance for most people. Because trips are generally short and bicycles and public transit both widely available, cars bring little extra value for everyday travel. For intercity travel, options include train, bus, or airplane."

5. CONCLUSIONS AND SUGGESTED FURTHER WORK

Significant growth is expected in urban transport energy use and CO2 emissions in the cities analyzed. An average growth of 36% to 46% is expected from 2006 to 2020 depending on pathway followed in each city. This growth will be driven in large part by travel behavioral factors, such as increases in trip-making, increases in travel distances, and a shift towards motorized, lower-capacity modes, despite improving vehicle efficiency. In addition, the following urban transport trends were noted:

- Motor vehicle demand in nearly all cities is far from saturation, and even in congested cities like Beijing more than 1,000 new cars are registered on an average day.
- Growth in PT supply by many cities is encouraging but has not been sufficient to maintain PT mode shares in many cities.
- NMT is declining in mode share in all cities. The theory of constant personal budgets for travel time and travel expenditure can explain in general the shift from NMT to motorized modes, both public and private.[9] But NMT can still have an important role for short trips and as feeders for PT facilities even as cities grow wealthier, larger and more sprawled. Shifting trips back to NMT or PT becomes more difficult as the private vehicle fleet in a city grows.

On the other hand, energy and CO2 intensity per unit of GDP is decreasing in nearly all cities, suggesting a possible "decoupling." Although this observation is based on very limited time series data for four cities and should be further analyzed and verified, the finding is consistent with the setting of national objectives for all sectors. In 2007, the Chinese national government announced a target reduction of 20% in energy intensity per unit of GDP by 2010, and 40% by 2020. These targets may be achieved for the sector if current trends continue. However, more ambitious targets for overall GHG emissions and energy use are needed to ensure sustainability in urban transport.

[9] Based on decades of evidence from dozens of cities throughout the world, the average personal time budget is 1 to 2 hours per day and the personal money budget is around 4% to 8% of one's income (Schafer, 2000). Private motorized modes are generally faster unless priority is given to PT or NMT. Private motorized modes usually are more expensive, but as income rise this tradeoff between money and time becomes increasingly feasible.

The potential impact of alternative carbon-intensity pathways to 2020 is measurable and significant. A simple projection of normalized indicators reveals that a difference between following the historical policies of Beijing versus Shanghai over a 14 year period may have a 7% impact on future CO2 emissions. To this end, the successful strategies and lessons from Beijing, Shanghai, and other cities in the last two decades should be carefully studied and applied. These include:

- An appropriate combination of private vehicle restrictions and pricing as in Shanghai— including licensing, road use (i.e., tolls or congestion charge), vehicle registration, and parking— can help mitigate the adverse impact of rapid motorization and help ensure more sustainable travel behaviors.
- Early investments in high-quality public transport infrastructure and services, as were done in Shanghai, can help attract former NMT trips and retain PT trips as incomes continue to rise. Beijing chose to focus on road investments early, but has recently invested heavily in public transport.
- Allocating road space to public transport modes is an effective strategy that becomes more difficult and costly as the mode share of private vehicles increases. It should be done early and one should bear in mind that buses are and will likely continue to be the most used PT mode, even in cities such as Beijing and Shanghai.
- Traffic congestion must be managed and is not resolved simply by expanding road networks, as is the case in Beijing. An appropriate level of road density must be complemented by a good network hierarchy and good geometric design for all users (including non-motorized transport).
- Harmonizing land use and transportation plans, as was attempted in Shanghai, to include PT links to satellite cities and new districts, the efficient location and design of major activity centers, incentives for transit-oriented development, maximizing accessibility for pedestrians and bicyclists, and other policies and strategies to promote compact cities with mixed land use, can be effective.
- Adoption of modern vehicle and fuel standards for is cost-effective and efficient, especially if the vehicle fleet is growing fast as is the case in most Chinese cities.
- Finally, it is important to emphasize the improvements to the institutional system, technical capacity, and planning processes are essential to implement and sustain good plans and policies.

A number of suggested next steps could build upon and improve the present work. Among them:

- *Improving the dataset:* The complete dataset used in this analysis will be made available via the internet as an Excel file in an effort to continuously improve the quality of the data. The remaining inconsistencies in the dataset may be corrected or supplemented with additional data as they become available.
- *Additional analysis and hypothesis testing*: The availability of data and the scope of this paper limited the amount of statistical analysis performed. These could include: (i) a comparison of trends and policies in Chinese cities with those elsewhere in both fast-growing economies like India and more mature economies like those in Europe; (ii) a comparative or multivariate analysis of different indicators that best illustrate the relationships between cities and their transport-related carbon footprint; and (iii) aggregating these data as appropriate to make national level projections of trends in urban transport-related GHG emissions in China.

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ANNEX 1: Data Collection Template

The data collected from the 14 GEF cities was self-reported using the template provided below. The inherent weaknesses in self-reporting were mitigated by several rounds of inquiries and comments with each city coordinated by the Chinese Institute of Comprehensive Transport in Beijing to clarify ambiguities, inconsistencies, and data gaps. The self-reported data for each city was also compared and verified to the extent possible with other cities and independent data sources at every round as a quality control measure. The entire raw dataset is available as an Excel file.

TABLE A1: URBAN STATISTICS FOR SELECTED CITIES

PART I. SOCIOECONOMIC DATA

Indicator	For latest available year 2001	2002	2003	2004	2005	2006
1. Population ('000)						
Municipal total						
City-proper total						
Floating population						
2. Population Growth Rate (%)						
Municipal total						
City-proper total						
Floating						
3. Area (square kilometers)						
Municipality						
City proper						
Build-up area						
4. GDP(Billion Yuan)						
Municipal total						
City-proper total						
5. GDP growth last 5 years (%)						
Municipal total						
City-proper total						
6. Average disposable income in city proper(yuan)						
7. Per Capita Income Growth (%)						
8. Financial resources spent on infrastructure development(Billion yuan)						
9. Financial resources spent on public transport infrastructure(Billion yuan)						

PART II. TRANSPORT PRICES, REVENUES AND EXPENDITURES

Indicator	Year
1. Transport Fares (Yuan)	
Metro: 4 km/8 km trip	
Premium: 4 km/8 km trip	
Standard: 4 km/8 km trip	
Minibus: 4 km/8 km trip	
Taxi: 4 km/8 km trip(**Yuan/km**)	
2. Parking Charges at Daytime (city center)	
Car (Yuan/hour)	
Motorcycle (Yuan per lot)	
Bicycle: Standard/Luxury (Yuan per lot)	
3. Parking Charges at Daytime (outside center)	
Car (Yuan/hour)	
Motorcycle (Yuan per lot)	
Bicycle: Standard/Luxury (Yuan per lot)	

PART III. ROAD NETWORK AND VEHICLE FLEET

Indicator	Latest years
1. Length of road network(km) City Proper Primary (expy, major arterial) Secondary Access 2. Length of road with protected bicycle lane 3. Length of road with exclusive bus lanes(km) Bus lanes BRT 4. Vehicle Fleet in **city proper** (number) Passenger cars Motorcycles Bus Public buses (including minibuses) Company bus Bicycles Electric bicycles Ordinary bicycles Trucks (large, and small) Other 5. Traffic accident fatalities in **city proper** Number of cyclists Number of pedestrians 6. Growth rate in 5 years in **city proper(%)** Passenger cars Motorcycles Total 7. Please list and describe any restrictions on motorcycle registration and use in the city proper.	

PART IV. PUBLIC TRANSPORT SYSTEM AND OPERATION,

Indicator	Year
1. Bus and trolley bus Number of Buses Route-kilometers Vehicle-kilometers (Million km) 2. Trolleybus Number of Trolleybuses Route-kilometers Vehicle-kilometers ('000) 3. Taxi Number of Taxis Taxi-kilometers (Billion km) 4. Metro Number of Trains Route-kilometers Car-kilometers ('000)	

PART IV CONTINUED: PUBLIC TRANSPORT CHARACTERISTICS OF THE CITIES (LATEST AVAILABLE)

UNIT OF MUNICIPALITY DEALING WITH UPT	Year
1. SERVICES Number of routes Network density(km/km2) % of population within 300 meters of a bus stop % of population within 500 meters of a bus stop 2. OPERATORS Number of operators SOE's share of buses 3. FINANCIAL DATA – REPORTED SOE Total Annual Revenue(million yuan,2006) SOE Total Annual Costs (million yuan,2006) Annual Subsidy(million yuan,2006)	

PART V. TRAVEL DEMANDS BY MODE

Indicator	Year
1. Year of Data Collection 2. Demands ('000 trips per year) Walk Bicycle Bus and Trolleybus Motorcycle Company Bus Taxi Passenger cars Metro/light rail Others	

*: Please also provide these travel demand data for 5 years ago (2001) – indicate the year

PART VI. AVERAGE TRAVEL DISTANCE BY MODE

Indicator	Year
1. Year of Data Collection 2. Demands (km per trip) Walk Bicycle Bus and Trolleybus Motorcycle Company Bus Taxi Passenger cars Metro/light rail Others	

ANNEX 2: Additional Information on Definitions and Methodology

- A city can be defined as “city proper” or “municipality” and both are specifically defined by administrative boundaries of the People’s Republic of China. “City proper” is defined as the urban area of a city, including all built-up areas. A “municipality” or “prefecture” includes not only the city proper, but also large areas of suburban are rural lands. For the purposes of this analysis, it is most appropriate to compare the city-proper areas between cities unless the corresponding data is not available.
- *Excerpt from IEA World Energy Outlook, Data and Definitions (2008):* “The definition of urban population, which is governed by Ministry of Civil Affairs in China, has been changed several times since the 1950s to serve different policy objectives at the time, starting from the household registration or Hokou system in China in early 1950s. The latest definition of urban population, adopted in 1999, is based on “Regulation of Statistics Classification on Urban and Rural Population” of the National Bureau of Statistics, and is based on a number of criteria. Cities in China are defined by an administrative boundary, they contain both urban and rural populations. Similarly, many towns whose population is accounted as urban do not belong to cities but to rural regions. The urban population represents only 32% in City of Chongqing, 82% in City of Tianjin, 94% in City of Beijing and 95% in City of Shanghai in the year 2006 (Dhakal, 2008).”
- A “trip” is the travel of a person from one mode of transport to another (unlinked trip) or from origin to destination (linked trip). Not all aggregate trip rates reported in this paper are comparable because of different or uncertain methodologies used in the travel surveys. For example, a walk trip is often defined by a minimum distance or a specific trip purpose such as work, school or shopping. In the case of Urumqi, motorcycle trips were negligible or not recorded. Non-motorized trips may also be obscured when reporting “linked” trips, or those from origin to destination requiring more than one mode. This may be the case in Guangzhou, which recorded a large decrease in the trip rate.
- Motorization is an index of the number of private motor vehicles (cars and/or motorcycles) by thousands of persons in the city. The motor vehicle fleet can also be normalized by other measures, such as the level of infrastructure (i.e., km of roads).
- As measures of public transport service, “capital productivity” is defined as the number of passengers per vehicle per day and “operational productivity” as the number of unlinked trips or boardings per vehicle kilometer.

ANNEX 3: Additional Urban Transport Analysis

1. Trip-Making

The aggregate number of trips for most if not all cities increased considerably in the past three decades, irrespective of city size, wealth, or geographical location. Figure A1 below presents the average annual percentage change of linked and unlinked trips for a sub-sample of cities.[10] The larger cities of Guangzhou, Beijing, and Shanghai experienced the largest increases, followed by the medium cities of Xi'an, Zhengzhou, and Jinan. Xianyang and Luoyang, two smaller cities, had moderate growth in aggregate trips in the past years. The largest increases were recorded in the eastern coastal cities, where most of China's development took place in the last two decades. Xi'an and Luoyang are cities in central China, where government has concentrated efforts on development in recent years. The large variation is also related to differences in data availability and time period for a few of these cities. For example, Luoyang, Urumqi, Guangzhou, Beijing, and Shanghai include data from the late 1980s and early 1990s, while percentage increases for the remaining cities are based on data from the 2000s.

Aggregate person-trips have been increasing in all cities analyzed due to several factors. First, travel demand is directly related to population, and all of the municipalities have gained in population as shown in Figure A1. Second is growth in trips per capita per day, or the trip rate, which is largely driven by changes in economic conditions, travel behavior, and development patterns. Figure A2 presents the trends in trip rates by mode for select cities.[11] Figure A3 depicts the percentage increases in trips per capita. The medium-sized cities are experiencing the highest rates of growth, particularly Jinan, Xi'an, and Zhengzhou. Although the largest cities exhibited some of the largest average annual percentage increase in aggregate trips, the growth in the trip rates was not as significant.

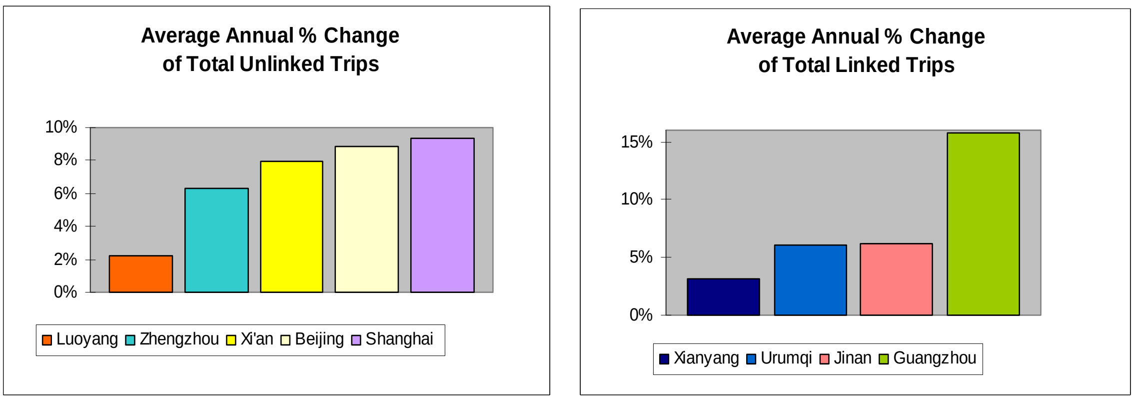


Figure A 1: Average Annual Percentage Change of Trips

[10] A "trip" is the travel of a person from an can be distinguished as "linked" or a "trip chain" if a person travels from one mode of transport to another (unlinked trip) or from origin to destination (linked trip).
[11] Not all aggregate trip rates reported are comparable because of different or uncertain methodologies used in the travel surveys. Please refer to Annex 2 for more details.

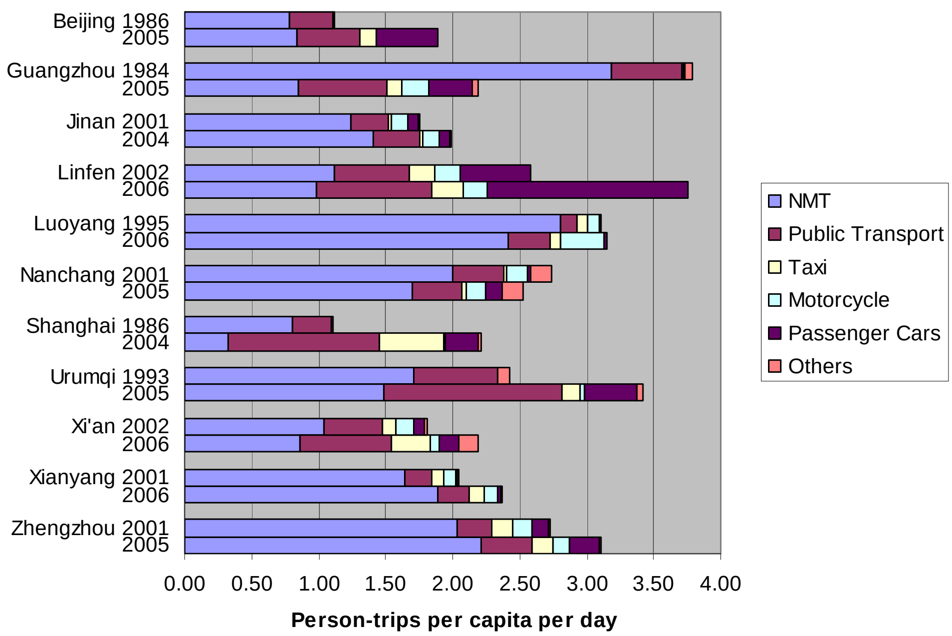
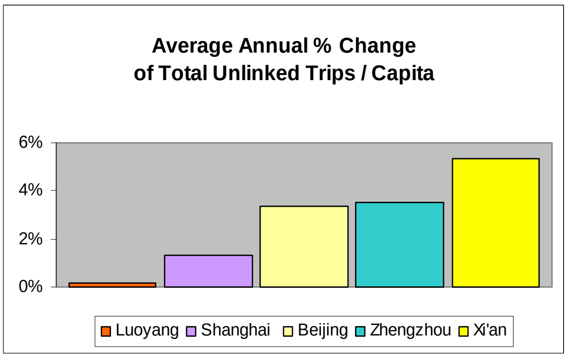


Figure A 2: Trends in Trip Rates by Mode



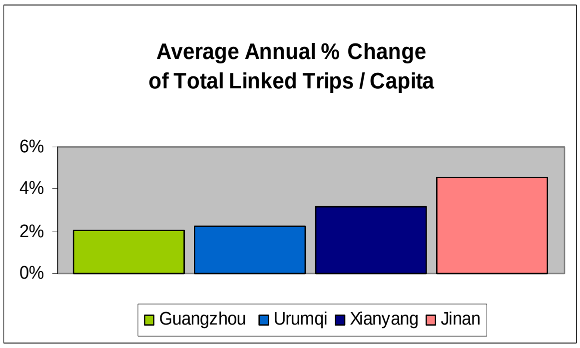


Figure A 3: Average Annual Percentage Change of Trips per Capita

2. Trip Distances

Figure A4 displays trip distances by mode in eight cities and the average for each mode. Although data was lacking to statistically test a trend, trip distances have generally been increasing in Chinese cities. Bus/trolleybus and passenger car trips tend to be the longest and also show the largest variation among the sample cities.

The increase in the trip rate and trip distances is at least in part due to the break-up of the *danwei*[12] system. China's transition to open markets generated great changes in the development pattern of urban areas. The *danwei*, or work unit compounds, popular during the 70s and 80s, were gradually replaced by urban

[12] The *danwei*, or work unit, was a walled compound organized around a state-owned enterprise or other institution such as a school or government agency which provides housing, entertainment, and other basic needs and services for its employees all reachable by walking distance.

landscapes with characteristics more typical of Western cities. Distances between productions and attractions increased from practically nil to one often requiring motorized transport: Chinese urbanites must now travel longer to access the same goods and services previously accessible by walk or bike. Many urban Chinese no longer live where they work, resulting in more and often longer commutes. The open market spurred creation of additional attraction points including large shopping and recreation areas, thereby inducing additional travel.

In addition to the disintegration of the *danwei* system, cities have growth spatially and there is evidence that trip distances have increased. Chinese cities today secure an important percentage of their financing through long term land leases. It is common for city governments to acquire rural land designated at rural land prices, then change the land use to urban land, and lease it to urban developers at higher rates. There is therefore an important incentive for the city leadership to broaden city boundaries, which often results in sprawled land uses and longer travel distances.

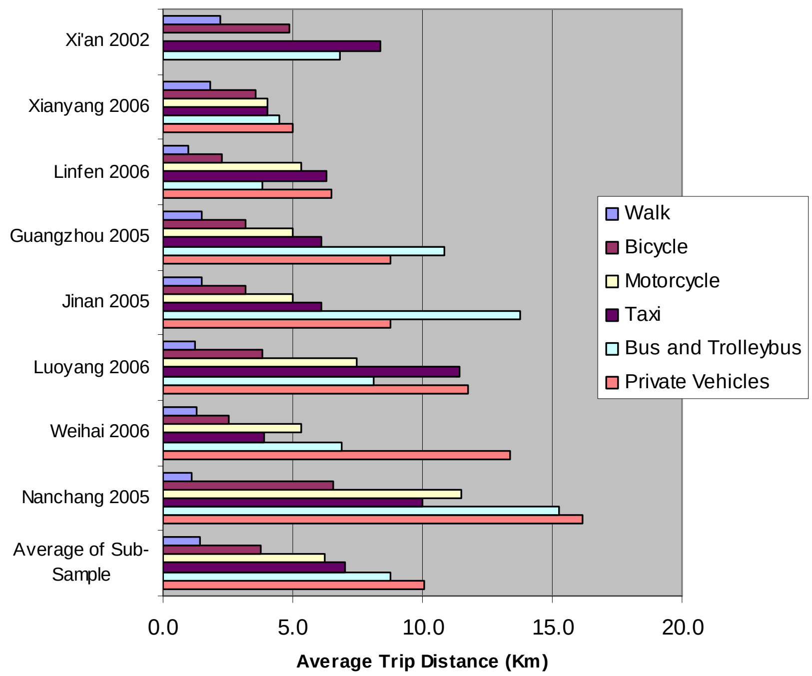


Figure A 4: Trip Distances by Mode

3. Income Elasticity of Trip-Making

Greater economic activity, particularly income growth in developing world, generates growth in travel demand. Therefore, an important driver of trip rate increases is the growth in average incomes in Chinese cities described earlier. Figure A5 clearly suggests a positively correlated relationship between income increases and increases in trip making. Table A2 is a table of the corresponding elasticities using the only consistent and available measure of income, average annual disposable income. Xi'an exhibits the highest income elasticity of 0.41, while Jinan is the lowest at 0.03. The average elasticity for the sample is 0.19, which is generally consistent with other studies of growing developing-world cities. The high variance may be due to the variability of the time period as Xi'an and Zhengzhou include data only from the 2000s, while the remaining cities include data from the 1980s and 1990s. The use of disposable income instead of total income may also influence the result. Nevertheless, these results suggest that there has been and will continue to be growing travel demand in Chinese cities.

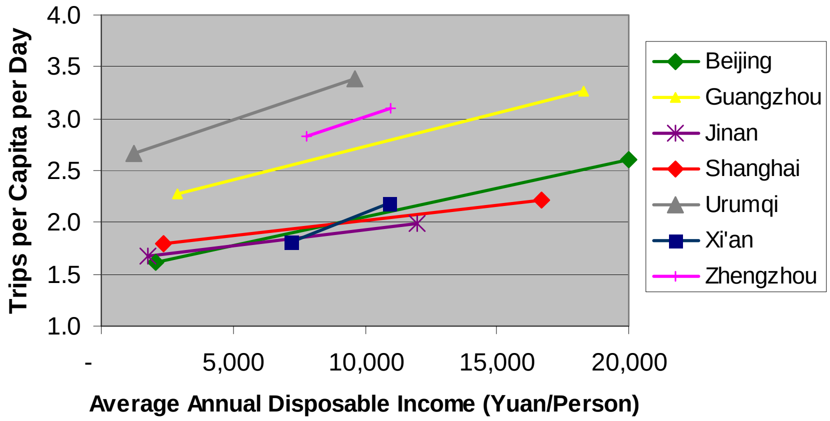


Figure A 5: Trip Rate and Income

Table A 2: Income Elasticity of Trip Rates

Xi'an 2002-2006	0.41
Zhengzhou 2001-2005	0.24
Guangzhou 1984 - 2005	0.08
Beijing 1986-2006	0.07
Urumqi 1993-2005	0.04
Shanghai 1986-2004	0.04
Jinan 1988-2004	0.03

4. Mode Shares

Figure A6-1 displays mode shares for 2005 and 2006, separated into linked and unlinked trips. The classification of modes includes non-motorized transport (NMT), consisting of walking and bicycle; public transport (public buses and trolley buses, company buses, and metro/rail transport); taxi; private motorized vehicle (passenger cars and motorcycles); and other (special and emergency vehicles, etc.).

According to Figure A6-2, the bulk of trips in Chinese cities are still made by non-motorized transport. Nine out of fourteen cities exhibit NMT mode shares higher than 40%, and only Linfen shows an NMT share below 30%. Public transport mode shares range from 39% (Urumqi) to 10% (Xianyang) for linked trips and from 26% (Shanghai) to 9% (Jiaozuo) for unlinked trips. In general the larger cities exhibit higher public transport mode share, perhaps due to longer trip distances that necessitate motorized (public) transport. These larger cities also typically have much more extensive public transport systems. The wide range in public transport mode shares across the cities may also be due to differences in the supply and quality of services among the cities, which is addressed later in this paper.

There is also a large range of mode shares for private motorized vehicles in the sample cities. Among the unlinked trips, Linfen reportedly has the highest mode share for private vehicle trips with 45%, while Jiaozuo only has a 2% mode share in this category. Among the linked trips, the wealthier cities of Dongguan, Weihai, and Guangzhou have comparatively higher mode shares for private motorized vehicles.

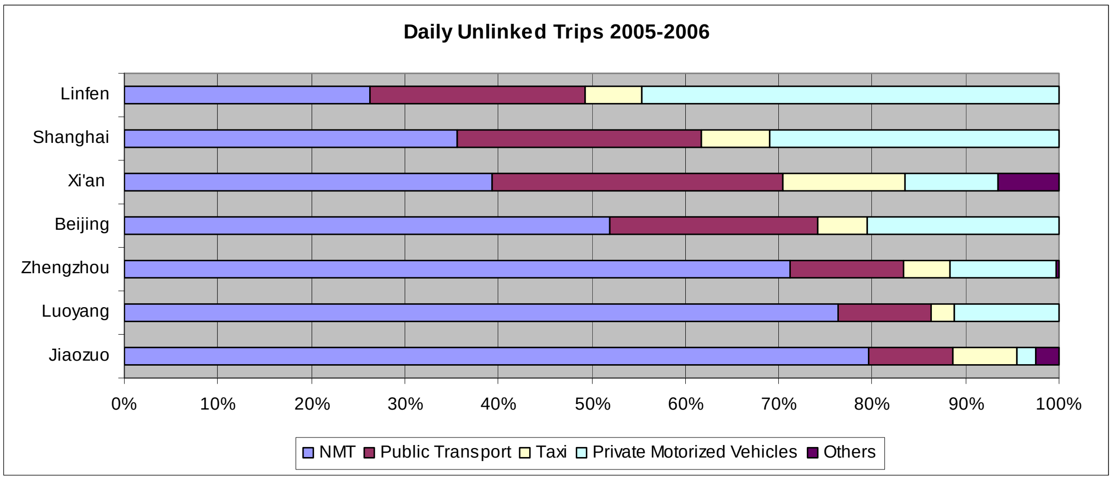


Figure A 6-1: Daily Unlinked Mode Shares of Trips in City-Proper

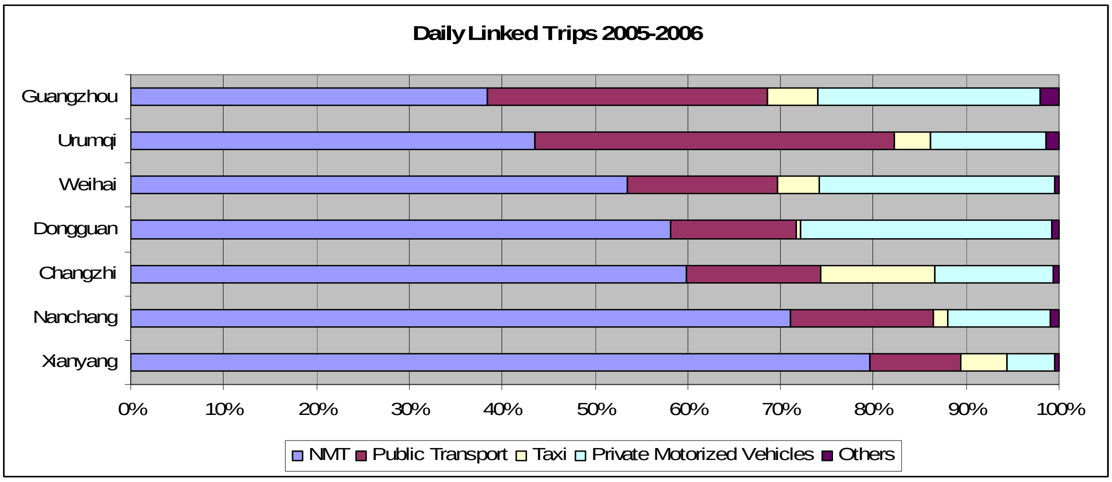


Figure A 6-2: Daily Linked Mode Shares of Trips in City-Proper

Figure A7 shows evolution of mode shares for select cities in the last three decades. Most notably, NMT share has decreased for all cities while public transport share has increased. Shanghai is perhaps the starkest example, with NMT shares falling from 72% to 36% from 1986 to 2004. It also is important to note in Figure A7 the increase in private motorized vehicle shares in all cities. Indeed, private vehicle mode share has increased in all Chinese cities in the past three decades, likely driven by increases in incomes and trip distances.

There is significant variance in the public transport (PT) mode shares. While Luoyang's PT mode share has more than doubled over a period of 11 years, in Xianyang it has remained virtually the same from 2001-2006. Perhaps most significant is the gradual decline of PT mode share in Beijing from 1986 to 2006 despite significant investments in infrastructure. Indeed, Beijing is one of the cities at the forefront of development and urban transport trends in China and its experience may foretell what may occur in the other large and medium cities as they develop further. [13]

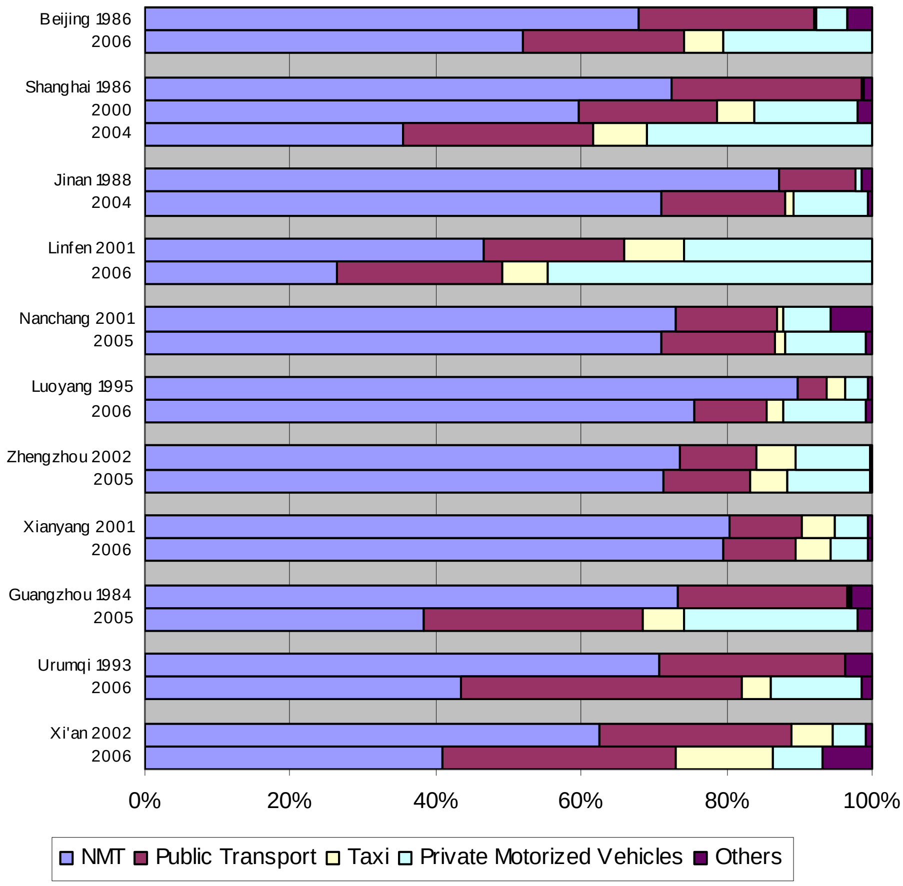


Figure A 7: Evolution of Mode Shares of Trips

5. Motorization

Figure A8 depicts the evolution of the number of personal vehicles per thousand population over time as an index for motorization. All cities have seen increases in motorization, particularly in recent years. Beijing leads the trend, reaching 131 vehicles per 1000 people in 2006,[14] followed by Guangzhou with 87.

Another important indicator of motorization is the number of private motorized vehicles as a percentage of total fleet numbers. As shown in Figure A9, for all sample cities the ratio of private motorized vehicles over total fleet has grown in recent years, ranging in 2006 from 0.09 (Zhengzhou) to 0.37 (Guangzhou).

[13] The more recent experience during the 2008 Olympic Games saw PT mode share increase from about 25% to 35% due to heavy investments in the PT network, fare subsidies, and extraordinary restrictions on private vehicle use.

[14] Atkins Beijing Travel Demand Management Study, 2008.

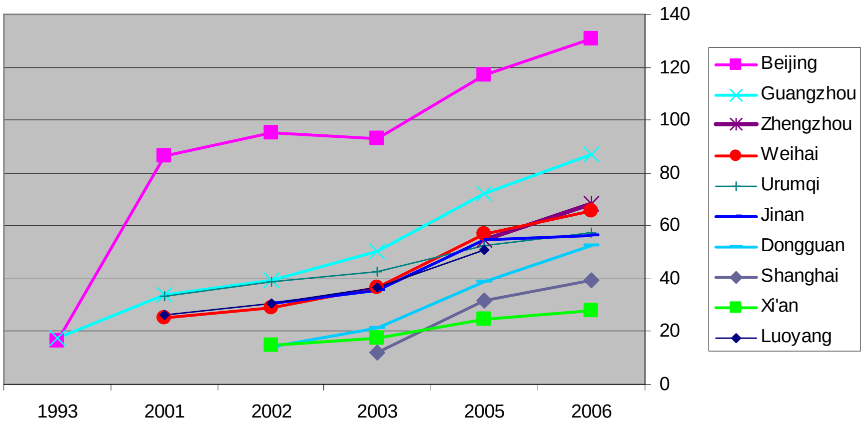


Figure A 8: Private Motorized Vehicles (including company cars) per 1000 People

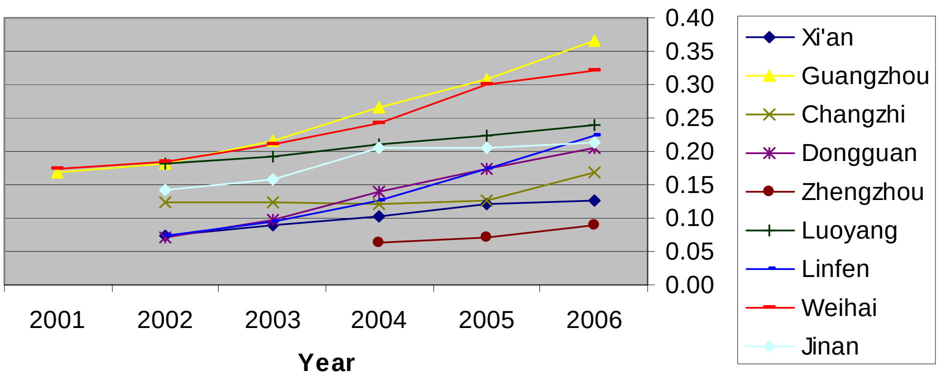


Figure A 9: Ratio of Private Motorized Vehicles (including company cars) over Total Fleet

6. Income Elasticity of Vehicle Ownership

Figure A10 is a plot of private motorized vehicles and disposable income that confirms a direct relationship between the two. Without exception, motorization in all cities is increasing with increasing incomes. Again, Beijing is at the frontier of this trend, while Shanghai exhibits much less motorization for similar levels of income. This may be in part explained by the higher costs for vehicle ownership (taxes) and use (parking) in the most populous and densest city in China.

The income elasticity (average disposable income) of vehicle ownership for all available cities is presented in Table A3. The average income elasticity for vehicle ownership for the sample cities is 1.8, which is remarkably consistent with the finding of Ingram and Liu (1997) for cars in 35 urban areas using 2 points in time. There was, however, considerable variance in the sample. Weihai displays the highest income elasticity, 2.74, while the city with lowest elasticity is Beijing with 0.7. The variance in part may be the result of using average disposable income rather than total income per capita, which was not available for all cities.

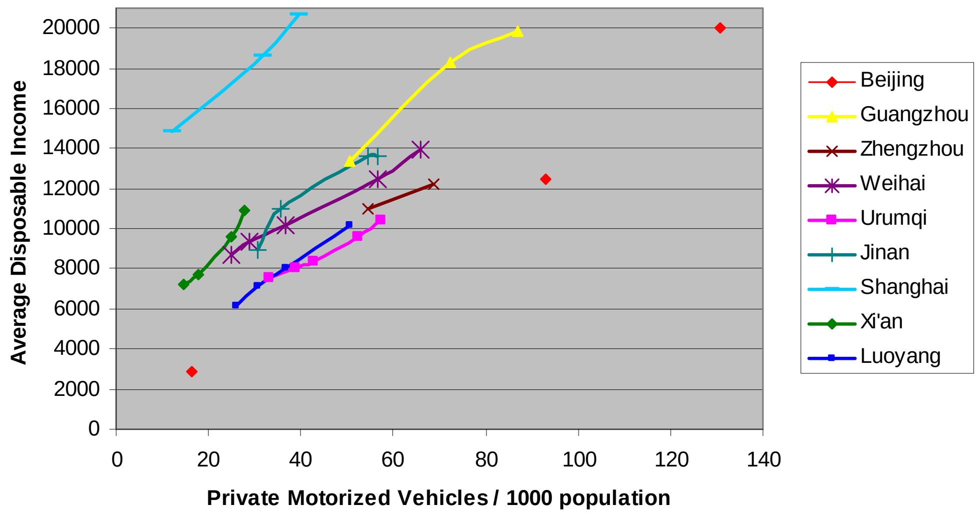


Figure A 10: Private Motorized Vehicles per 1000 Population and Average Disposable Income

Table A 3: (Average Disposable) Income Elasticity of Vehicle Ownership

Weihai 2001-2006	2.7
Zhengzhou 2005-2006	2.4
Shanghai 2005-2006	2.2
Urumqi 2001-2006	1.9
Xi'an 2002-2006	1.8
Jinan 2002-2006	1.6
Guangzhou 2003-2006	1.5
Luoyang 2001-2005	1.5
Beijing 2003-2006	0.7

7. Infrastructure

The evolution of mode shares is significant in analyzing investment decisions in infrastructure made by municipal governments in China. Since the 1990s, a high percentage of urban transport investment was allocated to construction of new roads, often high-capacity and high-velocity roadways lacking pedestrian infrastructure. For example, Shanghai's investment in roads as a percentage of total investment in urban transport was 63.9% during the period 1991-1995.[15] This trend has changed in the past few years as investment in roads decreased and investment in public transport increased. Indeed, Shanghai's investment in roads was 46.7% for the period 2001-2004, while investment in urban rail increased from 20.8% to 43.7% from 1991-1995 to 2001-2004, respectively. Renewed interest in public transport prompted upgrades and investment in many large and medium Chinese cities. At present, nearly 15 cities are building or planning metro systems or system extensions for completion by 2015, and around 17 cities are planning and/or building Bus Rapid Transit (BRT) systems.[16] Recent emphasis in public transport will address some of the needs of travelers in Chinese cities. However, there is still a sense that further investment in non-motorized transport would further benefit the bulk of Chinese city dwellers.

[15] "Urban Transport Energy Use in the APEC Region." Asia Pacific Energy Research Center (2007), page 97.
[16] China's National Development Reform Commission in an approved document by the State Council, 2006. Information provided to World Bank members in Urban Rail Mission, June 2008.

Roadway Network

Many Chinese cities have invested heavily in urban road construction. Figure A11 shows the ratio of city proper road length per thousand population. With the exception of Urumqi, which shows a slight decrease, road length per thousand population for the sample cities has increased in the period 2002-2006. Guangzhou displays the highest percentage increase, 55.5%, though the highest ratio goes to Weihai, a coastal city comparatively small in population but wealthier than most.

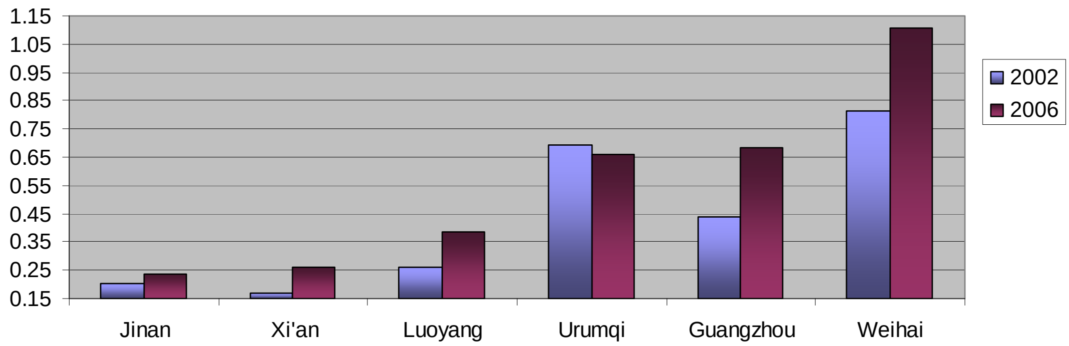


Figure A 11: Ratio of City-Proper Road Length (km) per Thousand Population

Increased road construction is taking place at the same time as (and in part as a response to) surging motorization, and it is generally not keeping pace. Figure A12 displays the ratio of private motorized vehicles to total lane kilometers in the city proper as an indicator of congestion. Beijing again shows the highest ratio by far, which is consistent with some of the highest levels of congestion in any city in China. The ratio is increasing over time for the remaining cities as well, suggesting a trend of increasing congestion.

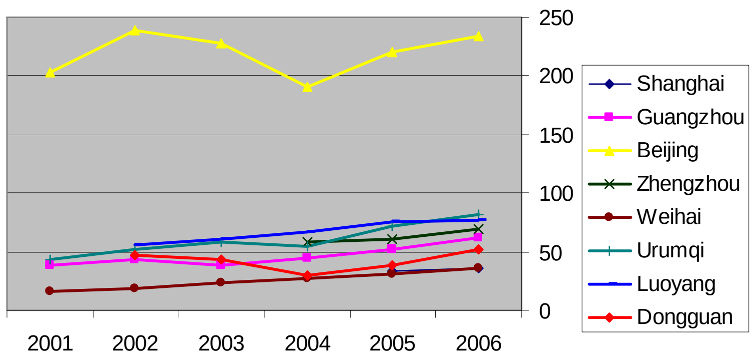


Figure A 12: Ratio of Private Motorized Vehicles versus Total Center Lane Kilometers

Public Transport

An important indicator for public transport supply is number of buses per thousand persons over the years, as shown in Figure A13. Buses are typically the mode that carries the most trips even in large, wealthy cities with urban rail systems like Beijing, Shanghai and Guangzhou. This ratio, which is an indicator of PT investment, has increased for all cities over the time periods analyzed, with Beijing, Urumqi and Shanghai displaying the highest ratios. Large increases in bus fleets in the 2000s, as is the case with Dongguan and Weihai, coincide with a Chinese government policy issued in 2005, specifically State Council Opinion # 46, which required local governments to give priority to public transport in decision making and allocation of funds. The impacts of this policy are still unfolding and should be an area of further investigation.

As expected, the cities with the highest bus fleets to population ratio also have higher PT mode shares. However, there is no evident correlation between this indicator of PT supply and the size, location, or wealth of the sample cities. Weihai, for example, has a relatively high ratio despite its smaller size, and Urumqi displays the second highest ratio despite its location in the less developed, far western region of the country.

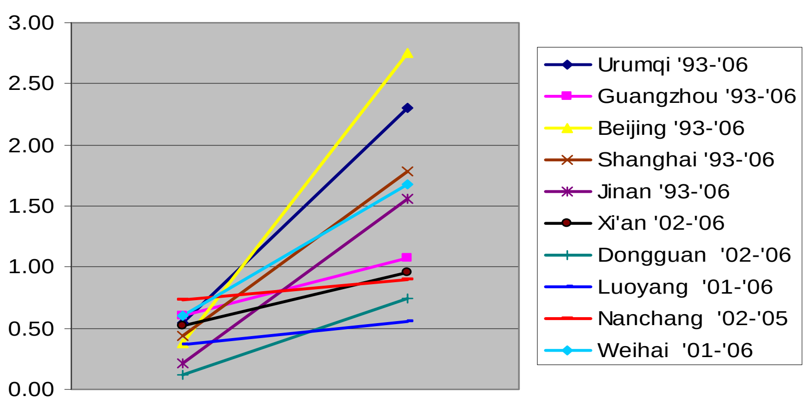


Figure A 13: Bus Fleet (including trolley buses) per 1000 Population

Exhibits A14 and A15 present two indicators of availability of public transport services in the city-proper. The first is related to network density, measured in kilometers of PT routes per square kilometer of the city-proper. The second refers to the percentage of population living within 500 meters of a bus stop. Six of the ten cities displayed have at least 80% of their population within 500 meters of a bus stop, and only two of the ten cities have less than 50% of their population within this distance.

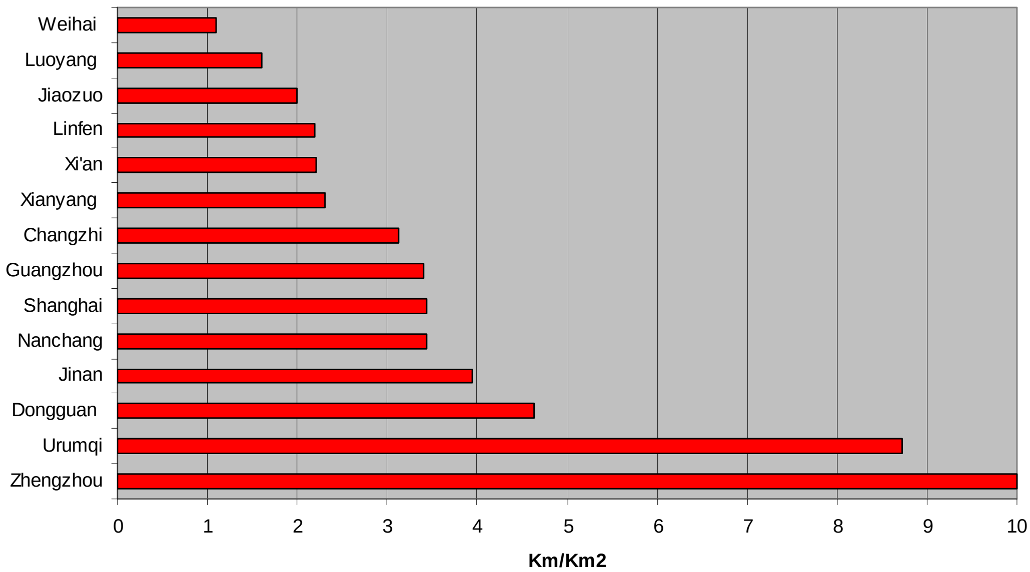


Figure A 14: Public Transit Network Density, 2005 -2006

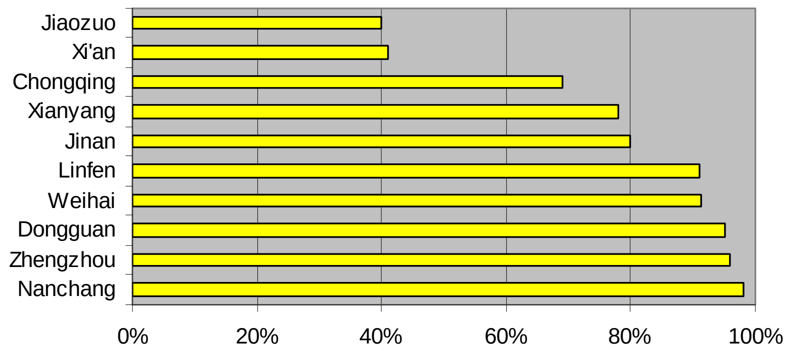


Figure A 15: Percentage of City-Proper Population within 500 Meters of a Bus Stop, 2005 -2006

Public transport performance indicators are presented in Figures A16 and A17 measuring capital and operational productivity, respectively, in recent years. Most of the cities fall within the typical range for capital productivity of 300-600 passengers per bus per day. Dongguan and Guangzhou show much higher values. There is an even bigger variance for operational productivity and measured by average bus boardings per vehicle kilometer.

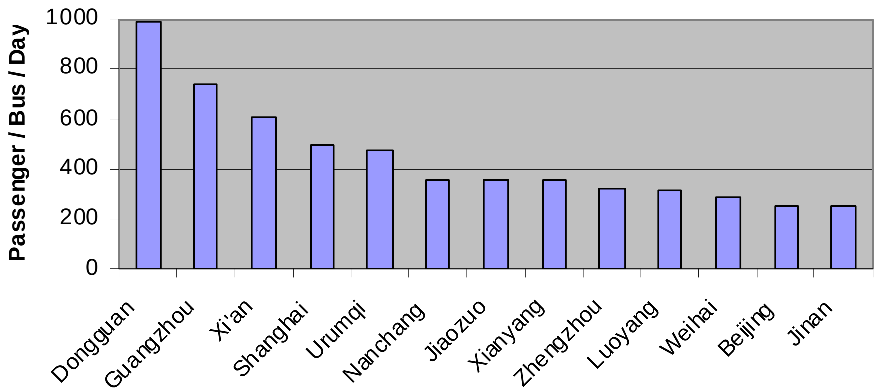


Figure A 16: Capital Productivity of Bus System, 2005-2006

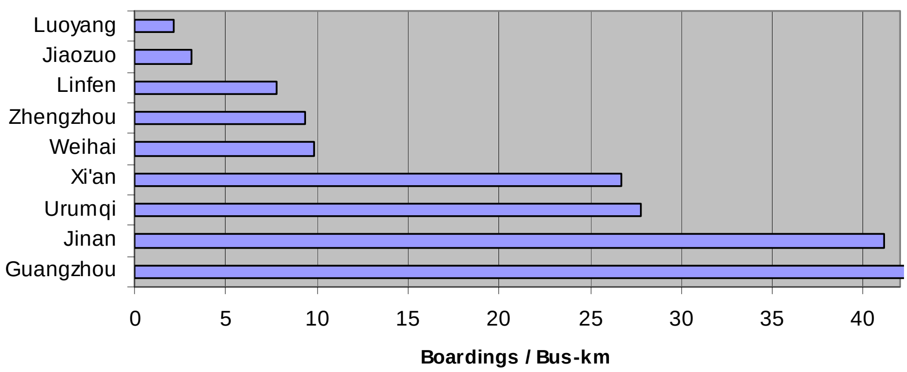


Figure A 17: Operational Productivity of Bus System, 2005-2006

ANNEX 4: Map of Chinese Cities Included in this Study