

POLICY RESEARCH WORKING PAPER

WPS 2042

2042

Determinants of Motorization and Road Provision

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National and urban motor vehicle ownership increases at about the same rate as income, whereas road length increases with income mainly at the national level. So, urban congestion grows with income. Controlling vehicle fleet growth and use would require high taxes that increase faster than income — or there could be congestion tolls.

The World Bank
Research Advisory Staff
and
Transport, Water, and Urban Development Department
Transport Division
January 1999



Summary findings

Ingram and Liu survey past trends in vehicle ownership and road network expansion to analyze determinants of their growth at the national and urban level.

Surprisingly, they find that:

- Nationally, income is a major determinant of *both* vehicle ownership and road length.
- Nationally, paved road length and vehicle ownership has been increasing about as fast as income, while total road length is increasing less rapidly than income.
- In urban areas vehicle ownership increases as fast as income while road length increases very slowly with income.

Because national paved road networks are expanding about as fast as national motor vehicle fleets, national congestion is unlikely to be worsening. But because urban road length is growing much more slowly than the number of urban motor vehicles, urban congestion is rising with income over time. Increased urban congestion is stimulating decentralized urban growth.

Income elasticities are greater than price elasticities in absolute terms, for both vehicle ownership and use — an

important finding because prices are often used as an instrument to control motor vehicle ownership and use. If price elasticities are half as large as income elasticities, prices would have to grow twice as fast as incomes to stabilize vehicle ownership.

Breaking the link between income growth, rising congestion, and urban decentralization will be difficult: Restraining auto ownership in urban areas requires high tax rates, and increasing the supply of urban roads is costly.

Elasticity estimates vary, but a good point estimate for the income elasticity of fleet growth is 1. This means country motor vehicle fleets grow in proportion to country incomes. More than half the world's annual increase in motor vehicles is likely to occur in high-income countries until 2025 (assuming GNP growth of 3 percent in high-income countries, 5 percent in low- and middle-income countries). The motor vehicle fleet in low- and middle-income countries is not projected to exceed that in high-income countries until after 2050.

Carbon dioxide emissions are likely to be distributed similarly.

This paper — a joint product of the Research Advisory Staff and the Transport Division, Transport, Water, and Urban Development Department — is part of a research project on motorization and roads. Copies of this paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Jean Ponchamni, room MC4-382, telephone 202-473-1022, fax 202-522-0304, Internet address jponchamni@worldbank.org. The authors may be contacted at gingram@worldbank.org or zliu@worldbank.org. January 1999. (29 pages)

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The authors are grateful to Chiaki Yamamoto for research assistance and to Esra Bennathan, Kenneth Button, Marianne Fay, Tony Gomez-Ibanez, Reuben Gronau, Kenneth Gwilliam, David D. Li, Lant Pritchett, Louis Thompson, and Clifford Winston for helpful comments on earlier versions of this paper.

This paper is a product of a research project on motorization and roads that is being carried out jointly by the Research Advisory Staff and the Transport, Water, and Urban Development Department.

1. Introduction

The number of motor vehicles in the world is growing rapidly. Between 1980 and 1995—just fifteen years—the global fleet of cars, trucks, and buses increased by 60 percent, with a third of the increase in developing countries. The increasing number of vehicles brings many benefits but is associated with worsening negative externalities including congestion and air pollution. In addition, motor vehicles need roads, and road networks have been expanding to accommodate the increasing number of vehicles. Roads are costly to build and maintain, and they also produce externalities. For example, road network expansion is a major determinant of development patterns, particularly in urban areas. Opinions are divided on the desirability of increased motorization. The effects of the growth of motor vehicle use and road networks are viewed by some commentators as inevitably adverse,¹ while others argue that national patterns of motor vehicle use are sustainable.²

The analysis presented here reviews past trends in vehicle ownership and road network expansion. It analyzes the determinants of past growth so that we can better understand what future patterns of motor vehicle and road network growth are likely to be, and how policy interventions can influence future growth. Because motorization raises different issues at the urban and national levels, city-level and national patterns are analyzed using data from a sample of cities and countries covering all income levels.

Motor vehicles are central to policy debates on urban transport because their increased use causes congestion, contributes to low-density development, and reduces transit use.³ Some analysts have argued that urban development densities must be increased to reduce auto dependence and promote transit use.⁴ Moreover, vehicular emissions have contributed to the degradation of the air quality in many cities, particularly in developing countries.

Motor vehicle use and road provision are concerns at the national level because large investments are needed for road infrastructure, and because countries want to ensure that their national transport policy reflects the comparative advantages of each transport mode (road, rail, water, and air). And at the national and global levels, emissions from

¹ "Taming the Beast--A Survey on Living with the Car," *The Economist* (22 June 1996), p. 1-18.

² Remy Prud'homme, Richard Darbera, David Newbery, Achim Diekmann, and Bent Elbeck, *Is Our Present Transport System Sustainable?* (Observatoire de l'Economie et des Institutions Locales, Université de Paris, 1997).

³ For a summary of these arguments, see John R. Meyer and Jose A. Gomez-Ibanez, *Auto, Transit, and Cities* (Harvard University Press, 1981).

⁴ See, for example, Peter Newman and Jeffrey Kenworthy, *Cities and Automobile Dependence* (Aldershot, England: Gower Publishing Company Limited, 1989).

transport are a growing source of carbon dioxide emissions. Motor vehicles produced 22 percent of global anthropogenic carbon dioxide emissions in 1990 (their *share* of emissions is also growing), and roughly 70 percent of motor vehicle carbon dioxide emissions are produced in high-income countries.⁵

Most motor vehicles are privately owned in market economies, and most of the roads they use are publicly owned. Relatively little is known about how road provision varies across countries or with vehicle ownership, and few analysts have examined the provision of roads at the national or urban level. In urbanized areas road construction has high economic costs and is politically contentious. The resettlement of households residing in the right of way of planned urban roads is a concern in both high income and developing countries.

As reported in many studies, this paper confirms that income is a strong determinant of vehicle ownership at both the country and city level, and that both national and urban motor vehicle ownership increase at about the same rate as income. More surprisingly, this paper also finds that income is a major determinant of the length of roads at the national level: national paved road length has also been increasing at about the same rate as income, and total road length less rapidly than income. Because national paved road networks are expanding at about the same rate as national motor vehicle fleets, congestion on them is unlikely to be worsening. But at the urban level, road length is growing much more slowly than income—and much more slowly than the number of motor vehicles. Urban congestion is therefore rising with income over time, and the increase in urban congestion is stimulating decentralized urban growth. Breaking the link between income growth, rising congestion, and decentralization at the urban level will be very difficult. Restraining auto ownership in urban areas requires very high tax rates, increasing the supply of roads in urban areas is very costly, and increasing the supply of transit alternatives is costly and has little effect on congestion in the few cases where it has been studied.

The paper outlines some basic economic hypotheses about motorization and road provision and then evaluates these hypotheses with some simple summary statistics compiled at the national and city level in high income and developing countries. Next, it surveys more sophisticated empirical work on motorization and on road provision and summarizes this knowledge as stylized facts. It then examines the production of motor vehicle transport services—passenger and freight transport that uses vehicles and roads as inputs—and ends with a prognosis and issues that need to be addressed.

2. Economic hypotheses concerning motorization and road provision

Economic reasoning produces a number of hypotheses about the relationships among motor vehicle ownership, road provision, and the production of motor vehicle

⁵ World Resource Institute, *World Resources 1996-97* (New York: Oxford University Press, 1996).

transport services. Although the vehicle fleet will grow with income, the number of cars should increase more rapidly than trucks. This is because the production of services grows faster with income than do freight volumes and the production of goods. And as incomes rise, labor costs rise relative to capital costs, leading to an increase in average truck size, capacity, and load, thereby reducing the number of trucks needed to produce a given number of ton-miles of freight transport.

Passenger travel for all purposes (work, shopping, social, etc.) also grows with income, but car ownership may grow even more quickly than travel. Income growth raises the value of time, shifting demand from slower, cheaper modes of transportation to faster, costlier modes, such as the automobile. In urban areas, as demand shifts from transit to cars and transit passenger volumes decline, transit service often degrades, prompting more riders to abandon transit. Increases in the value of time also make the circuitous routing required to serve multiple passengers by car more costly, which lowers the number of passengers per car and raises the demand for cars. For both freight and passenger travel, however, the presence of competing modes such as railways and transit should reduce demand for both trucks and cars.

The nature of demand for roads is likely to differ at the national and urban levels. The road network at the national level primarily connects urban centers and provides access to rural areas. It links human settlements and economic activities distributed across the nation and is rarely congested. The extent of national road networks and the total length of national roads should increase with output, allowing increased accessibility to the whole country. If other variables are held constant, urbanization's effect on the national road network is difficult to predict. Urbanization might raise the demand for non-urban roads, because the specialization of production in individual cities associated with urbanization may increase demand for roads between cities.

Urban growth should increase the demand for urban roads, although the presence of competing modes, particularly railways and transit, should temper demand and reduce the need for roads. Urban road networks are much more heavily used than rural roads, are frequently congested, and exist not only to connect locations but also to provide traffic carrying capacity. Providing roads in urban areas is usually more costly than providing roads nationally. These higher costs may lead to a lower ratio of urban road length to population and a slower rate of urban road network expansion than at the national level.

The higher costs of urban roads may be offset by their larger benefits, however, because increasing urban road capacity can reduce congestion and travel time—benefits that become more valuable as incomes increase. In congested urban areas, more vehicles increase congestion and travel times. Because the value of travel time increases with income and is a component of travel costs, in urban areas the cost per kilometer of motor vehicle transport services increases with income, and may be greater than at the national level where average speeds are higher. Income growth increases the benefits from urban roads and may stimulate additional road provision to relieve congestion and raise speeds.

Such a response would tend to reduce the ratio of motor vehicles to roads in urban areas with high income levels.

The relative prices of motor vehicle services and roads are also likely to change with development because motor vehicles are traded goods (whose prices are reasonably constant around the world), and roads are nontraded goods (whose prices vary with wage levels across countries). The ratio of the prices of nontraded to traded goods rises with wage levels and income. Hence roads become more costly relative to vehicle services as incomes rise (assuming minimal congestion at the national level), and the ratio of motor vehicles to national roads should rise with income as traffic volumes increase on national road networks.

Finally, road quality is also an issue. Motor vehicle speeds rise and operating costs fall as road quality improves, so arguments based on economic efficiency suggest that road quality—particularly the share of roads that are paved—should increase as the value of time (related to income) and the intensity of road use rise.

Of course, these hypotheses stem from economic principles. Because public road providers face few market incentives, however, a substantial question is whether predictions based on economic reasoning have any predictive power.

3. Summary Statistics

Summary statistics on vehicle ownership and road provision at the national and urban levels for developing and high income countries, shown in table 1, provide a crude test of the hypotheses based on economic reasoning. The cross-country data set and cross-urban area data set summarized in table 1 cover a wide range of country income levels, ranging in 1990 from \$260 to \$28,000 per capita in 1987 US dollars at market exchange rates.⁶ The national and urban samples summarized in table 1 do not overlap precisely in geographical terms or in time, but they provide a useful comparison of urban and national measures for developing countries and high-income countries.

Relative to countries as a whole, urban areas in both developing and high-income countries obviously have much higher population densities, higher road network densities, somewhat more vehicles per thousand persons, much less road length per person, and more motor vehicles per kilometer of road. Although it is used here as a rough proxy for the volume-to-capacity ratio frequently used in traffic analysis, the number of motor vehicles per kilometer of road is an imperfect measure because it does not contain information on average vehicle utilization and traffic peaking. However, the large difference between

⁶ National data on population, vehicles, and road length include urban and rural areas. Data on urban road length are from a variety of sources and are not broken down into paved and unpaved categories, as are national data. Typically a greater proportion of urban roads than of national roads are paved, so the analysis of urban roads may be more comparable to the analysis of national paved roads than total roads.

Table 1. Sample summary averages, 1980

Item	Developing economies		High-income economies*	
	National (31 countries)	Urban (9 cities)	National (19 countries)	Urban (26 cities)
Per capita GNP in 1987 US\$ ^b	546	1,589	14,247	15,037
Population per sq. km	86	14,982	125	3,989
Motor vehicles per 1000 persons	41	60	379	482
Autos as percent of total fleet	60	61	86	82
Kilometers of road per sq. km	0.2	5.9	1.2	10.9
Percent of roads paved	34	—	77	—
Meters of road per capita	3.7	0.5	16.5	4.5
Meters of paved road per capita	1.0	—	11.2	—
Motor vehicles per km of road	12	142	31	152
Motor vehicles per paved km	41	—	41	—

— Not available.

a. In 1980 high-income countries had a GNP per capita over \$4,800 (World Bank, 1992).

b. Average weighted by population.

Source: Ingram and Liu (1998).

the national and urban levels shown in table 1 suggests that, on average, non-urban national road systems are uncongested whereas urban road systems are congested. Compared with high-income countries, at the national level developing countries have a lower share of cars in their vehicle fleets, a lower share of paved roads, fewer motor vehicles per kilometer of total roads, fewer meters of paved road per capita, and similar numbers of motor vehicles per kilometer of paved road.

The summary averages also show some key differences between cities in developing and high-income countries. Cities in developing countries have much higher population densities, lower road network densities, many fewer motor vehicles per thousand people, and much less road length per person than do cities in high-income countries. The result is the relatively small difference in motor vehicles per kilometer of road between developing and high-income cities.

The overall patterns evident in table 1 are consistent with many of the hypotheses based on simple economic reasoning sketched earlier. For example, the number of vehicles per kilometer of total road at the national level is greater in high-income than in developing countries but similar at the urban level. And autos make up a higher share of motor vehicle fleets in high income than developing countries. These patterns suggest that economic behavior may be an important determinant of motorization and road provision across countries.

4. Motorization

What have analysts discovered about the determinants of motor vehicle ownership? Because vehicles are mainly privately produced and purchased, vehicle ownership is usually analyzed in the traditional economic demand framework. Knowledge about the effects of income, prices, demographic trends, and transport policy on car ownership is needed to predict the effect that specific policies might have on vehicle ownership patterns.

During the last four decades, many empirical studies have modeled and forecast the trends of motor vehicle ownership and use in various countries.⁷ These studies fall into three categories, based on the type of data used. In the first category are models that analyze motorization using time series data (trends over time in a city or country) or attempt to extrapolate national or regional motor vehicle ownership trends to future years under the explicit assumption of a saturation level.⁸ The second category of models uses cross-section data (data from a single point in time where variations are analyzed across households, cities, or countries). Some of these studies use aggregate data to produce long-run income elasticity estimates while others use disaggregate household level data to explain household car ownership behavior.⁹ The third category of models uses panel data,

⁷ For a concise survey of the commonly used methodologies, see Juan de Dios Ortuzar and Luis G. Willumsen, *Modeling Transport* (New York: John Wiley & Sons, 1994), pp. 405-13. For more thorough discussions of the econometric techniques, see Stephen Glaister, *Fundamentals of Transport Economics* (New York: St. Martin's Press, 1981); Kenneth Button, A. D. Pearman, and A. S. Fowkes, *Car Ownership Modeling and Forecasting* (London: Gower Publishing Company Ltd., 1982); M. J. H. Mogridge, *The Car Market: A Study of the Statics and Dynamics of Supply-Demand Equilibrium* (London: Pion, 1983); and Kenneth E. Train, *Qualitative Choice Analysis: Theory, Econometrics and An Application to Automobile Demand* (Cambridge, Mass.: MIT Press, 1986).

⁸ See, for example, S. Wildhorn and others, *How to Save Gasoline* (Santa Monica, Calif.: Rand Corporation, 1974); J. L. Sweeney, *Energy Policy and Automobile Use of Gasoline* (Palo Alto, Calif.: Stanford University Press, 1978); Anthony Chin and Peter Smith, "Automobile Ownership and Government Policy: the Economics of Singapore's Vehicle Quota Scheme," *Transportation Research A*, Vol. 31, No. 2, pp. 129-40. The time series models that extrapolate motor vehicle ownership trends assume that the number of vehicles per person has an upper limit, beyond which changes in income or other attributes will have no effect on vehicle ownership. This upper limit is termed a saturation level. For examples of these models, see J. C. Tanner, "Forecasts of Future Numbers of Vehicles in Great Britain," *Roads and Road Construction*, vol. 40 (1962), pp. 236-74; J. C. Tanner, "Long Term Forecasting of Vehicle Ownership and Road Traffic," *Journal of the Royal Statistical Society*, vol. 141A, no. 1 (1978), pp. 14-63; M. J. H. Mogridge, "The Prediction of Car Ownership," *Journal of Transport Economics and Policy*, vol. 1 (January 1967), pp. 52-74; and M. J. H. Mogridge, "The Prediction of Car Ownership and Use Revisited," *Journal of Transport Economics and Policy*, vol. 23 (January 1989), pp. 55-74.

⁹ For studies using aggregate data, see Michael E. Beesley and John F. Kain, "Urban Form, Car Ownership and Public Policy: An Appraisal of Traffic in Towns," *Urban Studies*, vol. 1, no. 2 (November 1964), pp. 174-203; Aubrey Silberston, "Automobile Use and the Standard of Living in East and West," *Journal of Transport Economics and Policy*, vol. 4 (January 1970), pp. 3-14; William C. Wheaton, "The Long-Run Structure of Transportation and Gasoline Demand," *The Bell Journal of Economics*, vol. 13 (Autumn 1982), pp. 439-54; and John F. Kain and Zhi Liu, "Efficiency and Locational Consequences of Government Transport Policies and Spending in Chile," Harvard Project on Urbanization in Chile (Harvard University, 1994). Studies using disaggregate household level data include D. A. Quarmby and J. J. Bates, "An

which includes both cross-sectional and time series information.¹⁰ Studies of all three types measure the effects of economic, demographic, and geographic variables on the levels and rates of motorization, using variables such as per capita income, vehicle prices, fuel prices, population density, degree of urbanization, and availability and prices of competing transport modes.

4.1 Income elasticities of motor vehicle ownership and use¹¹

Because most motor vehicles are purchased by individuals, households, or firms and are privately owned, per capita income is perhaps the most important economic variable that determines the level of motorization. Representative estimates of income elasticities of motor vehicle ownership and use from previous studies are summarized in table 2. Many estimates indicate that motorization increases rapidly with income, though the elasticities vary. Some of the variation in income elasticities relates to income definition, but income elasticities also vary depending on the types of data and the methodologies used.¹²

Econometric Method of Car Ownership Forecasting in Discrete Areas," *MAU Notes 219*, (London: Department of Environment, 1970); J. J. Bates, H. F. Gunn, and M. Roberts, "A Model of Household Car Ownership," *Traffic Engineering and Control*, vol. 19 (November/December 1978), pp. 486-91, 562-66; Fred Mannering and Clifford Winston, "A Dynamic Empirical Analysis of Household Vehicle Ownership and Utilization," *Rand Journal of Economics*, vol. 16 (summer 1985), pp. 215-36; Train, *Qualitative Choice Analysis*; and David A. Hensher, Frank W. Milthorpe, and Nariida C. Smith, "The Demand for Vehicle Use in the Urban Household Sector," *Journal of Transport Economics and Policy*, vol. 17, no. 3 (1990), pp. 119-37.

¹⁰ Robert Pindyck, *The Structure of World Energy Demand* (Cambridge, Mass: MIT Press, 1979); Kenneth Button, Ndoh Ngoe, and John Hine, "Modeling Vehicle Ownership and Use in Low-Income Countries," *Journal of Transport Economic and Policy*, vol. 27 (January 1993), pp.51-67; Olof Johansson and Lee Schipper, "Measuring the Long-Run Fuel Demand of Cars," *Journal of Transport Economics and Policy*, vol. 31 (September 1997), pp. 277-92; Gregory K. Ingram and Zhi Liu, "Motorization and the Provision of Roads in Countries and Cities," Policy Research Working Paper 1842 (Washington, D.C.: World Bank, 1997); and Gregory K. Ingram and Zhi Liu, "Vehicles, Roads, and Road Use: Alternative Empirical Specifications," Policy Research Working Paper 2036 (Washington, D.C.: World Bank, 1998).

¹¹ These income elasticities measure the percentage change in vehicle ownership or use when income changes by one percent. An elasticity greater than one means that vehicle ownership or use changes more rapidly than income.

¹² Cross-country per capita income can be measured on the basis of market exchange rates or purchasing power parity (PPP) exchange rates. Income measured at market exchange rates may be more relevant for cross-country studies of motorization because vehicles are traded goods, and market exchange rate income measures the ability of an economy to purchase traded goods. Income at PPP exchange rates spans a narrower range than income defined at market exchange rates, because PPP-based income substantially exceeds market-rate based income for low-income countries. Thus income elasticities estimated using income at market exchange rates tend to be smaller than those using income at PPP exchange rates. For a discussion of purchasing power parity exchange rates, see Robert Summers and Alan Heston, "The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950-1988," *Quarterly Journal of Economics*, vol. 56 (May 1991), pp. 327-368.

Table 2. Income Elasticities of Motor Vehicle Ownership and Usage

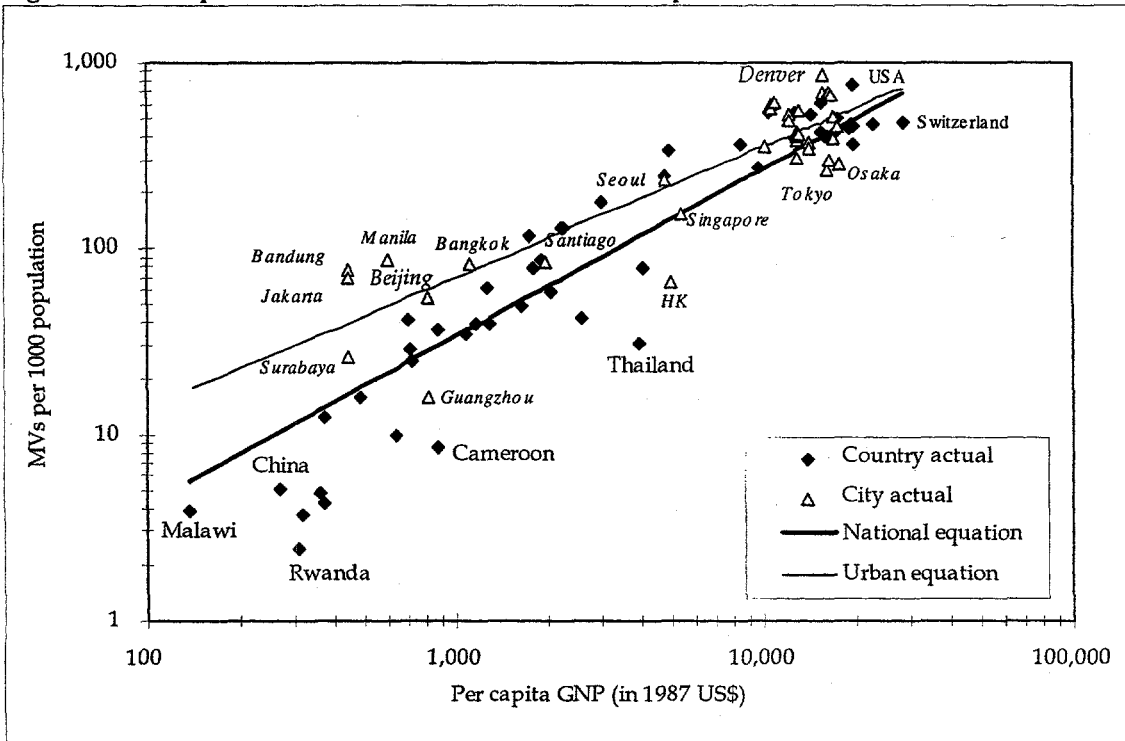
<i>Study</i>	<i>Sample</i>	<i>Cross section</i>	<i>Time series</i>	<i>Panel data</i>
<i>Vehicle ownership at the national level</i>				
Silberston (1970)	38 free-market countries, 1965, cars	1.14		
	38 free-market countries, 1965, total vehicles	1.09		
	46 countries, 1965, cars	1.21		
Wildhorn and others (1974)	United States, 1950-73		0.88	
Sweeney (1978)	United States, 1950-73		0.82	
Pindyck (1979)	11 Western countries, 1955-73			0.30
Wheaton (1982)	25 countries, early 1970s, cars	1.38		
	25 countries, early 1970s, total vehicles	1.19		
	42 countries, early 1970s, cars	1.43		
Kain (1983)	23 OECD countries, 1958	1.95		
	23 OECD countries, 1968	1.59		
	98 non-communist countries, 1977	1.30		
Button and others (1993)	58 developing countries, 1968-87, cars			0.53 ~ 1.12
	29 developing countries, 1968-87, commercial vehicles.			0.84 ~ 1.50
Kain and Liu (1994) ^a	52 countries, 1990, cars	1.58		
	52 countries, 1990, commercial vehicles	1.15		
	Chile, 1960-90		0.56 ~ 0.92	
Ingram and Liu (1997, 1998)	50 countries, 1970, 1980, 1990, cars	1.02 ~ 1.21		1.12
	50 countries, 1970, 1980, 1990, commercial vehicles	0.64 ~ 0.94		1.12
	50 countries, 1970, 1980, 1990, total vehicles	0.90 ~ 1.09		0.98
Johansson and Schipper (1997)	12 OECD countries, 1973-92			0.75 ~ 1.25
<i>Vehicle ownership at the urban level</i>				
Beesley and Kain (1964)	45 U.S. cities, 1960	0.73		
Kain and Liu (1994) ^a	60 world cities, 1980, cars	1.02		
Chin and Smith (1997)	Singapore, 1968-89		0.53 ~ 0.61	
Ingram and Liu (1997)	35 urban areas, 2 points in time, cars	0.50 ~ 0.91		1.83 ~ 1.88
	35 urban areas, 2 points in time, commercial vehicles	0.37 ~ 0.60		0.53
	35 urban areas, 2 points in time, total vehicles	0.52 ~ 0.83		1.01 ~ 1.03
<i>Vehicle usage at the national level</i>				
Pindyck (1979)	11 Western countries, 1955-73			0.66
Wheaton (1982)	25 countries, early 1970s, cars	0.54		
	25 countries, early 1970s, total vehicles	0.53		
	42 countries, early 1970s, cars	0.33		
Button and others (1993)	58 developing countries, 1968-87, cars			0.71
	29 developing countries, 1968-87, commercial vehicles			0.52
Johansson and Schipper (1997)	12 OECD countries, 1973-92			-0.10 ~ 0.35
<i>Vehicle usage at the household level</i>				
Mannering and Winston (1985)	U.S., more than 1,000 households, 1978-80			
	households with one vehicle	0.06		
	households with two vehicles	0.11		
Train (1986)	California, 105 households, 1976-80	0.29		
Hensher and others (1990)	Sydney, 1172 households, 1981-82	0.05 ~ 0.14		

a. Kain and Liu (1994) used per capita GDP at purchasing power parity exchange rates.

Four stylized facts emerge in the income elasticity estimates shown in table 2:

- First, income elasticities from time series data are typically smaller than those from cross-section data. This is because cross-section analyses produce long-run elasticities, and long-run behavior is generally more responsive to income changes than short-run behavior. Roughly speaking, long-run income elasticities of motor vehicle (especially car) ownership are greater than 1, while short-run income elasticities are less than 1.
- Second, income elasticities from urban-level data are similar to or smaller than those from country-level data largely because there are more competing modes of transportation and greater congestion in urban areas, both of which reduce the attraction of motor vehicles. In fact, the long-run elasticities from urban-level data are closer to those from country-level data than are the short-run elasticities. Using the data sets summarized in table 1, figure 1 indicates that motor vehicle ownership increases somewhat more rapidly with income at the national level than at the urban level.
- Third, income elasticities are generally larger for automobiles than for commercial vehicles, supporting the economic hypothesis that the share of passenger cars in the motor vehicle fleet increases with income.
- Finally, income elasticities of motor vehicle use are less than unity, smaller than long-run income elasticities of motor vehicle ownership, and smaller for households

Figure 1. Per Capita Income and Motor Vehicle Ownership in 50 Countries and 35 Cities



Note: Both Axes are in logarithms, and the slope of a line on such a diagram is the elasticity. A straight line indicates a constant elasticity.

Source: Ingram and Liu, "Vehicles, Roads, and Road Use."

with one vehicle than two, indicating that motor vehicle use increases less rapidly than motor vehicle ownership.

These findings also support the earlier economic hypotheses.

4.2 *Price elasticities of motor vehicle ownership and use*¹³

Motor vehicle prices affect individuals' decisions to own a vehicle. The fleet comprises a variety of vehicle types, however, which makes it difficult to construct an average price index for the entire fleet. Because of this problem, only a few empirical studies include vehicle prices as an explanatory variable for vehicle ownership.¹⁴ Increases in vehicle prices were found to reduce vehicle registrations and prolong vehicle life—which reduces vehicle depreciation rates (table 3).¹⁵

Unlike vehicle prices, gasoline prices are generally available and thus are included in many studies. Although some analysts found that increases in gasoline prices reduce vehicle ownership,¹⁶ others found that gasoline prices had little effect on vehicle ownership.¹⁷ The effect on vehicle use is clear, however: an increase in gasoline prices decreases vehicle usage and increases the average fuel efficiency of the vehicle stock by encouraging the purchase of more fuel-efficient vehicles.¹⁸ When facing higher operating costs, households with two or more cars reduce usage less than one-car households by shifting usage to their more efficient car. These results are summarized in table 3.

A comparison of available estimates suggests that income elasticities are greater than price elasticities in absolute terms for both motor vehicle ownership and use. This finding has an important policy implication because prices are often suggested or used as an instrument to control motor vehicle ownership and use. If price elasticities are half as large as income elasticities, prices would have to grow twice as fast as incomes to stabilize vehicle ownership. In fact, prices have not increased much in real terms.

¹³ These price elasticities measures the percentage change in vehicle ownership or use when its price changes by one percent. A price increase usually reduces demand, so price elasticities are normally negative.

¹⁴ The absence of vehicle prices in a vehicle ownership model may cause bias to the income elasticity estimates. For a treatment of the problem, see Mogridge, "The Prediction of Car Ownership." Mogridge adjusted the income variable to "car purchasing income" by the cost of motoring before fitting the vehicle ownership equations.

¹⁵ Pindyck, *The Structure of World Energy Demand*.

¹⁶ Wildhorn and others, *How to Save Gasoline*; Pindyck, *The Structure of World Energy Demand*; and Ingram and Liu, "Vehicles, Roads, and Road Use."

¹⁷ Wheaton, "The Long-Run Structure of Transportation and Gasoline Demand;" and Johansson and Schipper, "Measuring the Long-Run Fuel Demand of Cars."

¹⁸ Wildhorn and others, *How to Save Gasoline*; Pindyck, *The Structure of World Energy Demand*; Wheaton, "The Long-Run Structure of Transportation and Gasoline Demand;" and Johansson and Schipper, "Measuring the Long-Run Fuel Demand of Cars."

Table 3. Long-Run Price Elasticities of Motor Vehicle Ownership, Usage, and Fuel Efficiency

<i>Study</i>	<i>Vehicle ownership</i>	<i>Vehicle usage</i>	<i>Fuel efficiency</i>	<i>Vehicle depreciation</i>
<i>Vehicle price elasticities</i>				
Pindyck (1979)	-0.78	n.a.	—	-0.71
<i>Gasoline price elasticities</i>				
Wildhorn et al. (1974)	-0.25	-0.36	0.17	—
Sweeney (1978)	—	—	0.72	—
Pindyck (1979)	-0.64	—	1.43	—
Wheaton (1982)	..	-0.48 ~ -0.55	0.09 ~ 0.14	—
Train (1986)	-0.11	-0.27	—	—
Hensher et al. (1990)	n.a.	-0.22 ~ -0.39	—	—
Johansson and Schipper (1997)	-0.02 ~ 0.00	-0.35 ~ -0.05	0.45 ~ 0.35	—
<i>Operating cost elasticities</i>				
Mannerling and Winston (1985)				
one car household - short run	-0.23	—	—	—
one car household - long run	-0.28			
two car household - short run	-0.06			
two car household - long run	-0.10			
— Not available				

Vehicle prices have increased faster than income in the 1990s, but this reflects mainly increases in vehicle quality. Fuel prices have varied but have not grown as fast as income, and have actually declined from 1980 to 1995 after increasing in the 1970s. Per capita income has grown in both developing and high-income countries and is expected to continue to do so. In the future, average vehicle prices may decline as a result of lower production costs, or they may increase at a rate similar to that of income. If the past magnitudes of income and price elasticities hold for the future, global motorization can be expected to grow unless there are strong increases in the prices of—or the taxes and fees on—vehicles, fuels, and vehicle use.

4.3 *The role of population density*

At both national and urban levels, population density is a crude proxy for the spatial distribution of economic activities. Everything else being equal, low overall population density should increase average trip lengths and spur motorization. In high-density cities, congestion caused by density should impose higher costs on motoring and may reduce auto ownership and use. Empirical studies find that population density is negatively related to motor vehicle ownership both at national and urban levels, but the elasticity of motor

vehicle ownership with population density is much greater at the urban level (-0.4) than at the national level (-0.1).¹⁹

Unlike at the national level, the causal relation between population density and motorization at the urban level runs in both directions. The boundaries of countries rarely change, while most cities can expand by annexing outlying areas which have lower densities than the urban core. By increasing travel speeds, motorization can induce decentralization of both job and residential locations, which expands the urbanized area and reduces densities. The lower densities raise transit costs or reduce transit service levels, which further promotes car ownership and use. Hence motorization is both determined by and a determinant of urban density.

At the national level, the share of urban population is another proxy for the spatial distribution of economic activities, but its effect on vehicle ownership is ambiguous. On the one hand, urbanization may be negatively associated with motor vehicle ownership because motorized road transport is more attractive in rural than in urban areas.²⁰ With everything else held constant, rural households are more likely than are urban households to own motor vehicles.²¹ On the other hand, urbanization is positively associated with per capita income.²² Cross country analysis indicates that the net effect of urbanization on vehicle ownership is positive.²³

4.4 Saturation levels for motor vehicle ownership

It is often hypothesized that motor vehicle ownership in high-income countries will increase at a declining rate with per capita income growth and eventually stop increasing when a saturation level is reached. A recent study estimated ownership saturation levels for fifty countries (under a "business as usual" scenario) at 770 passenger cars and 1,180 total motor vehicles per thousand people, and for thirty-five cities at 750 passenger cars and 1,080 total motor vehicles.²⁴ These estimates exceed the maximum observed ownership levels in 1990 of roughly 574 passenger cars and 755 motor vehicles per thousand people (for the U.S.A.).

¹⁹ Ingram and Liu, "Motorization and the Provision of Roads." A small, negative, but insignificant relation between vehicle ownership and population density at the national level was found in Silberston, "Automobile Use."

²⁰ Wheaton, "The Long-Run Structure of Transportation and Gasoline Demand." He found a negative but statistically insignificant relation between the share of urban population and the level of auto ownership.

²¹ Angus Deaton, *The Demand for Personal Travel in Developing Countries* (Washington, D.C.: World Bank, 1987).

²² For a summary of empirical evidence, see Gregory K. Ingram, "Patterns of Metropolitan Development: What Have We Learned?" *Urban Studies*, vol. 35, No. 7 (June, 1998), pp. 1019-1035.

²³ Ingram and Liu, "Motorization and the Provision of Roads."

²⁴ Ingram and Liu, "Motorization and the Provision of Roads."

These estimates are larger than earlier ones.²⁵ If estimated vehicle ownership saturation levels change over time, they are of little use for forecasting. In fact, that seems to be the case as there is little direct evidence that saturation levels are stationary or that they have a straight forward behavioral interpretation. The income elasticity of motor vehicle ownership may decline as incomes rise. Estimates allowing income elasticities to vary with country income produce declining income elasticities but do not have greater explanatory power than constant elasticity specifications.²⁶

5. Road Provision

What are the determinants of road provision, or the increase in road networks, at the national and city level?²⁷ Unlike motor vehicles, roads are not usually privately provided, and road provision may not be strongly conditioned by economic considerations. Nonetheless, knowledge about the recent trends in road provision and its relation to income, population, and settlement patterns is a useful guide to future road provision and an important input to transport policy making. Although the impact of economic development on roadway networks has long been a subject of descriptive studies for several countries, cross-country empirical studies are recent.²⁸

5.1 National road networks

The few available studies of road provision across countries are based on data that provide information on road length but not on road width or numbers of lanes. Data available for paved roads and total roads are reported by the countries and generally include urban roads, but country-level definitions sometimes vary with respect to coverage and technical classification. Data on paved roads are more comparable across countries

²⁵ Two of the previous estimates (or assumptions) were provided by Tanner, "Forecasts of Future Number of Vehicles;" and Mogridge, "The Prediction of Car Ownership." Tanner predicted a saturation level of 450 cars, and Mogridge, 660, per thousand persons for the UK.

²⁶ Ingram and Liu, "Vehicles, Roads, and Road Use."

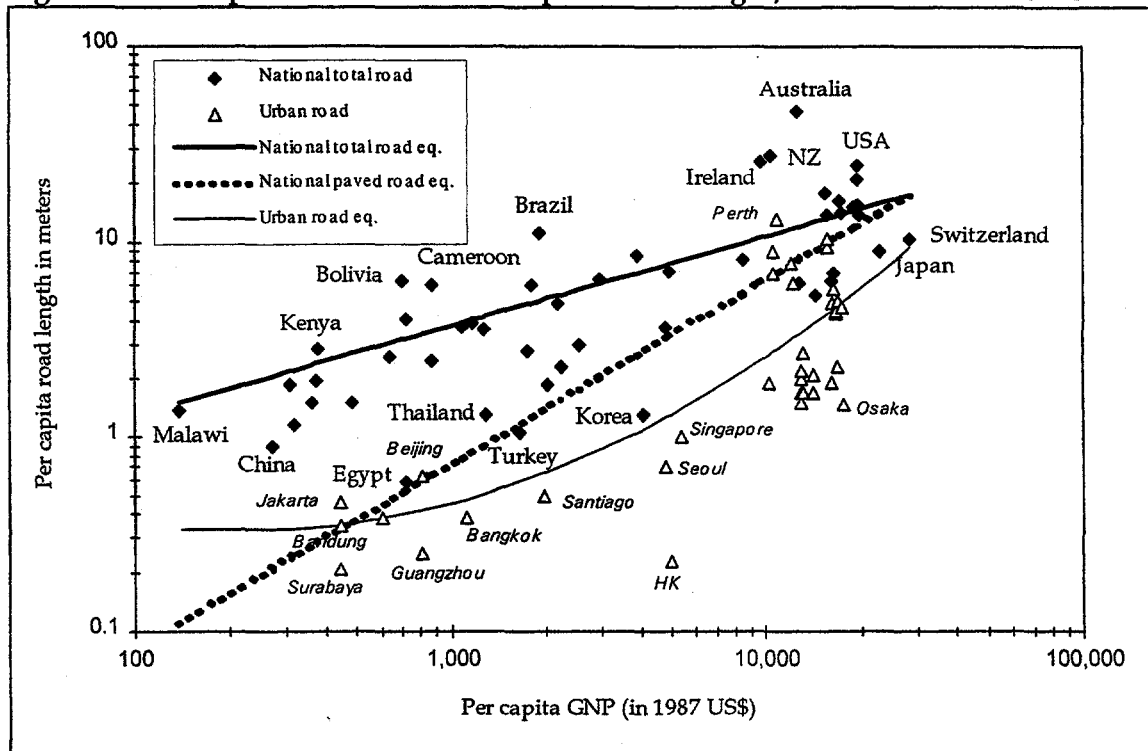
²⁷ This section draws heavily from Ingram and Liu, "Motorization and the Provision of Roads," and "Vehicles, Roads, and Road Use."

²⁸ Esra Bennathan, Julia Fraser, and Louis Thompson, "What Determines Demand for Freight Transport?" Policy Research Working Paper 998 (Washington, D.C.: World Bank, 1992); David Canning, "A Database of World Infrastructure Stocks 1950-1995" Policy Research Working Paper 1929 (Washington, D.C.: World Bank, 1998); and Ingram and Liu, "Motorization and the Provision of Roads," and "Vehicles, Roads, and Road Use." Bennathan and others used data from 36 countries to analyze the relation of domestic rail and road freight transport demand (in ton-kilometers) to country income and land area variables. Canning analyzed several infrastructure stocks--including roads, telephones, and electric generating capacity--using a panel data set containing from 95 to 145 countries. Ingram and Liu analyzed the regularities of provision of roadway length using data from 50 countries and 35 to 37 cities spanning a wide range of income levels; their findings are summarized in this section.

than data on total roads because there is less ambiguity about what constitutes a paved road than what constitutes an unpaved road versus a track or trail.²⁹

The size of the national road network is associated with the size of the economy, geographical area, population, income per capita, and population density. Income per capita is a major determinant of road length at the national level. Both paved and total road length increase at a constant rate with per capita income, as can be seen in figure 2.³⁰ Estimates at the national level (using the techniques employed for vehicle ownership) find no saturation level for road density with respect to per capita income.

Figure 2. Per Capita Income and Per Capita Road Length, 50 Countries and 35 Cities



Note: Data points for paved roads are not shown for the sake of clarity.

Source: Ingram and Liu, "Vehicles, Roads, and Road Use."

Paved road length has an elasticity of 1 with respect to income (when income increases by 1 percent, paved road length increases by 1 percent), while overall road length increases only about half as fast as income (table 4). Population is a significant determinant of national total and paved road length, whereas population density affects only total road length. The national level of urbanization, the length of the rail

²⁹ Data are available from a number of sources, including *World Road Statistics* published annually by the International Road Federation. The problems with road definitions are discussed in Canning, "A Database of World Infrastructure Stocks 1950-1995."

³⁰ Nonlinear specifications produced R^2 no higher than those of the simpler linear specification.

Table 4. Estimated Effects of Population, Per Capita Income, and Population Density on Road Length

Dependent variable	Functional specification	Coefficient estimates ^a		
		Population	Per capita income	Population density
<i>At the national level</i>				
Length of total road	Cross section	1.0 *	0.5 *	-0.3 *
	20-year first differences	0.4	0.5	n.a.
Length of paved road	Cross section	1.0 *	1.0 *	0.0
	20-year first differences	1.3 *	0.8 *	n.a.
<i>At the urban level</i>				
Length of road	Cross section	0.8 *	varies ^b	-1.0 *
	First differences	0.5 *	0.1 *	-0.4 *

* Statistically significant at the 0.05 level.

a. All variables are in natural logarithm, and elasticities are jointly estimated.

b. The income elasticity increases with income level.

Source: estimated in Ingram and Liu (1997, 1998).

network,³¹ and gasoline prices have little influence on the length of either paved or unpaved roads at the national level. These estimates were based mainly on the cross-sectional variation in panel data, but estimates based on first differences over time in the same panel data produced generally similar results (except for the relation of total road length with population), as shown in table 4.

The major implication of these findings is that at the national level paved road length increases with per capita income at roughly the same rate as vehicle ownership. As a result, congestion does not appear to be a growing problem for the national road network in most countries.

Paved road density (length of paved road per unit of area) has an elasticity of 1 with respect to both population density and income density (income per unit of area), whereas total road density has an elasticity of about 0.7 with the same two variables. Paving roads is an efficient way to increase the quality of the national road network and costs less than constructing new roads because existing rights of way are used. The percentage of roads paved increases with per capita income and population density, and in the fifty countries studied it had an elasticity of approximately 1 with respect to both variables from 1970 to 1990. Paving occurs most intensively in low- to middle-income countries. Developing countries with average population densities (100 persons per square kilometer) and average per capita incomes (\$550 a year in 1987 prices) have about a third of their roads paved, a share that rises to more than three quarters when annual per capita incomes reach \$1000.

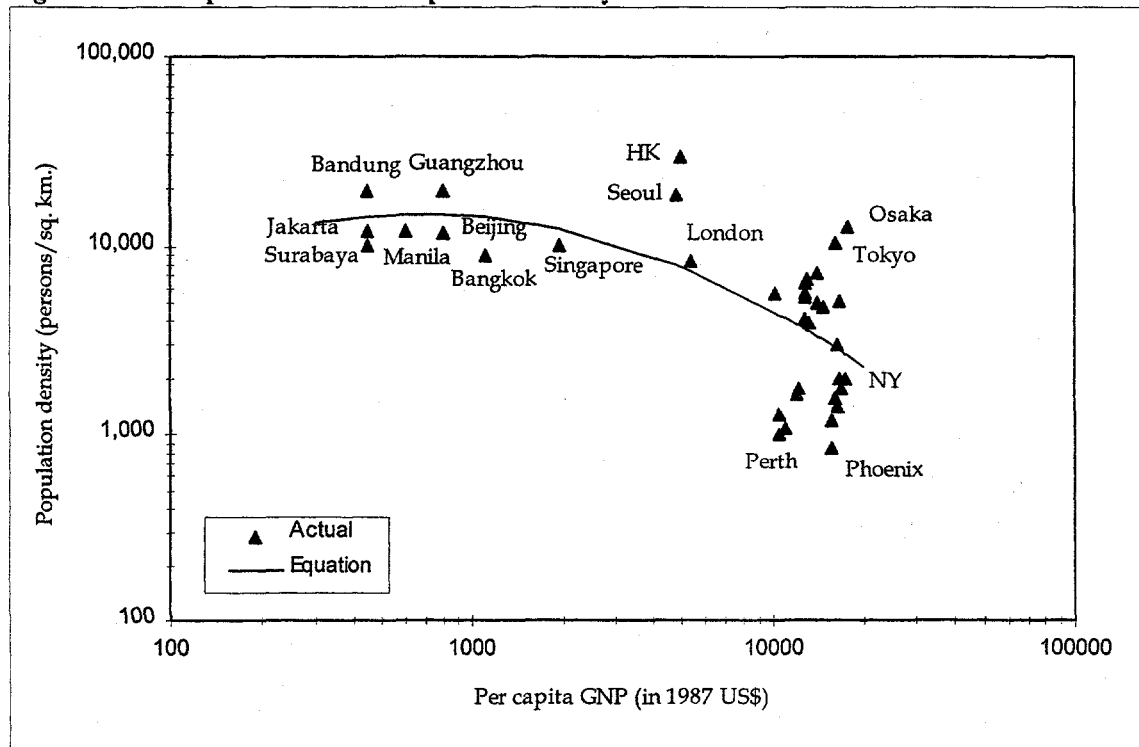
³¹ Ingram and Liu, "Motorization and the Provision of Roads," find that the length of the rail network is strongly related to per capita income (elasticity of 0.5) and population density (elasticity of -0.4), results similar to those for total roads.

5.2 Urban road networks

Road provision at the urban level differs greatly from that at the national level. Holding income and density unchanged, urban road length increases less rapidly than population; its elasticity with population is 0.8 (see table 4). The elasticity of urban road length with per capita income is not constant, as it is at the national level, but increases with income (see figure 2), and the elasticity of road length with population density is much stronger at the urban (-1.0) than the national level (elasticity of 0.0 to -0.3).³²

Urban population densities are often low when per capita income is high, but population densities vary widely in high-income cities (figure 3). This wide variation reflects the impact of historical paths of development on urban form. Cities that have experienced much of their population growth when auto ownership levels have been high have lower densities than other cities. In addition, high relative land prices are likely to raise population densities. The nonlinearity between urban population density and income shown in figure 3 contributes strongly to the nonlinearity between per capita roads and per capita income at the urban level in figure 2.

Figure 3. Per Capita Income and Population Density in 35 World Cities



Source: Ingram and Liu, "Vehicles, Roads, and Road Use."

³² These results are based on panel data from 35 cities in developing and industrial countries, and the elasticities take into account the strong negative relation between per capita income and population density at the urban level.

Comparisons of city data over time indicate that average population densities are falling in virtually all high income cities as both employment and residences decentralize. Overall urban population growth occurs through expansion of the urban perimeter by annexation of surrounding municipalities with lower densities than the core city.

When city effects are controlled for in first difference estimates, many of the relations differ from the cross-city panel estimates (unlike at the national level, where the panel and first difference results are broadly similar). In particular, the first difference estimates suggest that urban road length barely increases with per capita income over time; the income elasticity of urban road length is around 0.1 (table 4). Using the techniques pioneered for vehicle ownership, it is possible to estimate the saturation level of urban road provision, which is 23 kilometers of road length per square kilometer, a level very close to the 24.9 kilometers observed in Tokyo in 1960.

These results indicate that urban road length is increasing much more slowly over time than urban vehicle ownership. A 1 percent increase in income produces a 1 percent increase in the number of urban vehicles and a 0.1 percent increase in urban road length. Relatively little new road length is being constructed in urban areas, presumably because the cost of new rights of way is high in both economic and political terms. Most increases in urban road length come from annexation of areas contiguous to the city which are the sites of new urban growth and have lower land costs, more open space, and less congested roads. Hence, most new road capacity in urban areas comes from spreading development over space and not by increasing the density of roads in existing built up areas.

6. Producing motor vehicle transport services

Thus far the analysis has focused on vehicles and roads, but what consumers and firms actually seek or demand are transport services—that is, the movement of goods and passengers from one point to another. How do we relate our information about vehicles and roads to these transport services that are the object of demand? Motor vehicle transport services are produced by combining vehicles with roads (and other factors), much as labor and land are combined to produce agricultural products or as labor and machinery are combined to produce manufacturing goods. Economics has long used production functions to relate inputs to outputs, and this approach is used here to analyze how economies combine vehicles and roads to produce transport services.³³

In the context of a typical production function, the cost-minimizing solution is for the ratio of inputs to depend on their relative prices and on technological factors that may differ across countries. The question is whether assumptions of competitive behavior and efficiency are relevant in motor vehicle transport service production. What really matters in this framework is government provision of roadways. Vehicle owners have an incentive

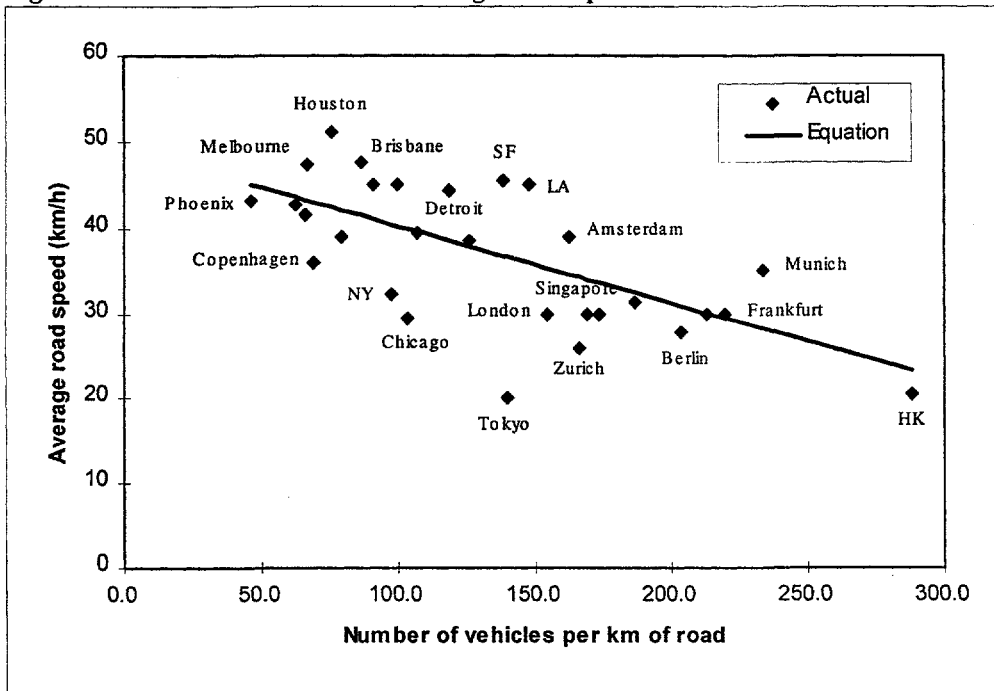
³³ This section draws heavily on Ingram and Liu, “Motorization and the Provision of Roads,” and “Vehicles, Roads, and Road Use.”

to be efficient, but do government road departments? To the extent that governments invest in roads based on economic approaches (such as cost-benefit analysis) or in response to economic pressures, road provision may be reasonably efficient in economic terms. As shown earlier, road provision has strong relations with economic variables.

A direct measure of the ratio of inputs for a production function approach would be actual traffic volumes (vehicle kilometers traveled) per kilometer of road network. There is surprisingly little information on aggregate traffic volumes at the national or urban level, however, and such data are often based on intermediate variables such as fuel consumption. Most traffic volume data are measured on specific streets or roads because the information is needed to analyze network use. Motor vehicles per kilometer of road has been used as an indirect measure of the ratio of inputs in the work reported here and is a proxy for the more desirable volume measure.

How good a proxy is the indirect measure (motor vehicles per kilometer of road) for the desired traffic volume measure? There is a strong relation between speed (or congestion) and traffic volume that is typically summarized in a speed-volume diagram that shows that speed falls (and congestion rises) as traffic volumes increase. At the urban level, the ratio of vehicles per kilometer of road has a relation with average speed similar to that speed-volume curves for segments of streets or roads (figure 4).

Figure 4. Vehicle-Road Ratio and Average Road Speeds in Urban Areas



Source: Generated from data provided in Newman and Kenworthy, *Cities and Automobile Dependence*

The cost of roads varies systematically across countries, reflecting variation in the price of land and of the (mostly) nontraded inputs (for example, labor and most construction materials) used in road construction. The price of motor vehicles

should not vary across countries because they are traded goods (although countries obviously impose different taxes and fees on motor vehicles). The ratio of the prices of nontraded to traded goods typically increases with per capita income. If a network is congested, however, then increases in the number of motor vehicles per kilometer of road will reduce speeds and increase the cost of vehicle operation. Congestion costs will increase with the value of time (which increases with per capita income) and have the potential to offset the effect of rising road costs on the ratio of vehicles to roads.

In most countries the national road network is not congested, so the cost of roads relative to vehicles should rise with per capita income, and there will be no offsetting time saving from lowering congestion. As a result, the ratio of vehicles to roads should increase at the national level. At the urban level, the costs of congestion will increase with income, and the benefits of reducing congestion will tend to offset the increasing cost of roads relative to vehicles, making it difficult to predict, a priori, how the ratio of vehicles to roads will vary with per capita income. Other variables can be used in this production function approach, but the focus here will be on income and population density.

6.1 Motor vehicle services at the national level

As shown earlier, both motorization and the provision of roads are strongly associated with per capita income at the national level. Because the number of vehicles increases faster with income than does the total national road length, the number of vehicles per kilometer of total road increases with income; the income elasticity is around 0.4 (table 5 and figure 5). These increases are occurring at low ratios of vehicles to roads, however, confirming that congestion on national roads is not a common problem, even in high income countries. The relation between vehicles per kilometer of total roads and income is reasonably similar in cross section and first difference (time series) specifications using constant elasticities.

This result is consistent with the hypothesis that the cost of roads at the national level increases more rapidly than the cost of vehicles as incomes rise (because roads are nontraded and vehicles are traded goods). The number of vehicles per kilometer of total roads is independent of population but positively associated with population density (the elasticity is about 0.2).

The length of paved road at the national level increases with income at about the same rate as the number of vehicles (see tables 2 and 4), so with constant elasticities the number of vehicles per kilometer of paved road length varies little with per capita income (see figure 5 and table 5). There may be some increase in this ratio over time (the first difference elasticity with income is 0.2, but it is not statistically different from zero in table 5). Population density has a mildly negative effect on the number of vehicles per kilometer of paved road, with an elasticity of -0.1, suggesting that both paved roads and alternative modes may be associated with density.

Table 5. Estimated Effects of Population, Per Capita Income, and Population Density on the Vehicle-Road Ratio

Dependent variable	Functional specification	Coefficient estimates ^a		
		Population	Per capita income	Population density
<i>At the national level</i>				
Vehicles/total road km	Cross section	0.0	0.4 *	0.2 *
	20-year first differences	0.3	0.4	n.a.
Vehicles/paved road km	Cross section	0.0	0.0	-0.1 *
	20-year first differences	-0.9	0.2	n.a.
<i>At the urban level</i>				
Vehicles/road km	Cross section	0.1	varies ^b	0.6 *
	First differences	0.5	0.9	0.5

n.a. not applicable

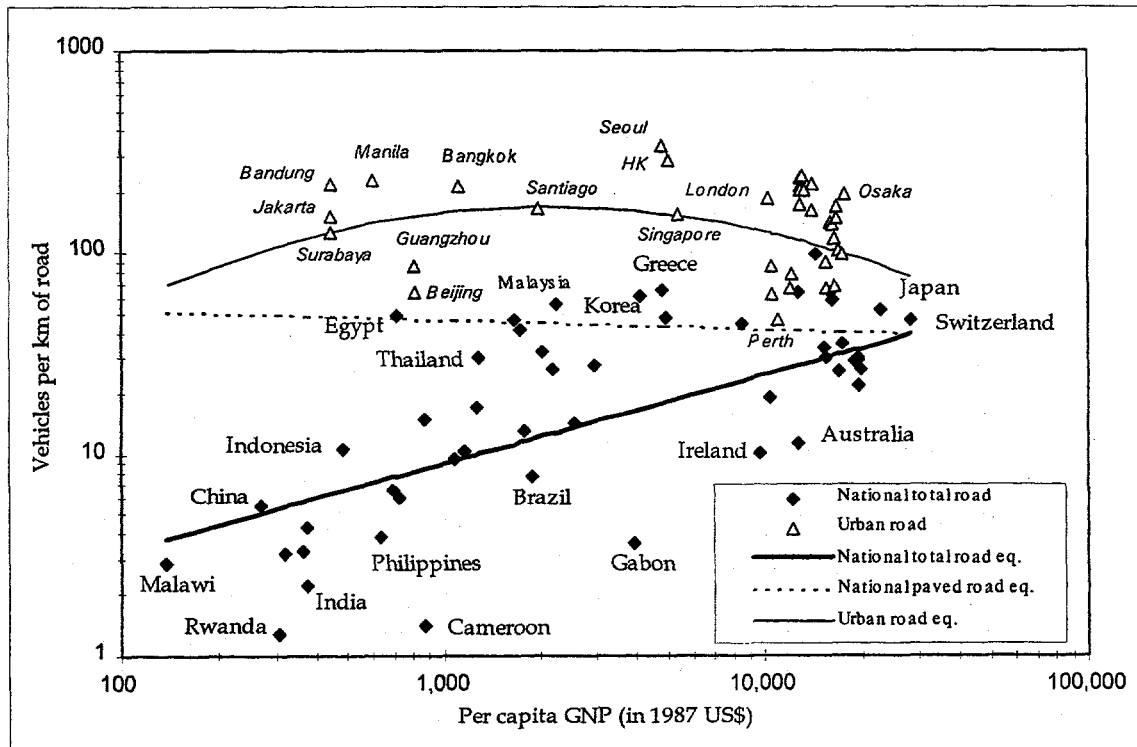
* Statistically significant at the 0.05 level.

a. All variables are in natural logarithm, and elasticities are jointly estimated.

b. The elasticity first rises and then falls with income.

Source: estimated in Ingram and Liu (1998).

Figure 5. Per Capita Income and Vehicle-to-Road Ratio in 50 countries and 35 Cities



Note: Data points for paved roads are not plotted for the sake of clarity.

Source: Ingram and Liu, "Vehicles, Roads, and Road Use."

Estimates of saturation levels for the vehicle-to-road ratio do not converge for either vehicles per kilometer of total road or vehicles per kilometer of paved road. This is consistent with the view that national roads are generally uncongested.

6.2 Motor vehicle services at the urban level

Urban vehicle ownership increases regularly with income, while urban road length increases very little with income initially, and then rapidly, in a nonlinear fashion. As a result, the ratio of motor vehicles to roads in cities rises with income when incomes are low and then declines with income when income are high (see figure 5). This result, based on comparisons across cities, indicates that the high costs of congestion in high income cities may stimulate road building. Time series results based on first differences indicate, however, that the ratio of motor vehicles to roads is rising over time in virtually all cities (table 5), reflecting the slower increase in urban road length than in urban vehicle ownership over time. The ratio of motor vehicles to roads in urban areas is positively related to population density, with an elasticity from 0.5 to 0.6 in both cross section and first difference estimates. Estimates of the saturation level for motor vehicles per kilometer of road in urban areas yield a value of 550 vehicles per kilometer. The maximum value observed in a sample of 35 cities is 425 (in Paris).

These results reflect the interaction of countervailing forces generated by congestion in urban areas. At the national level, where roads have little congestion, the ratio of vehicles to roads increases over time because roads become more expensive relative to vehicles as incomes rise. However, at the urban level rising congestion creates travel delays that become more costly as incomes rise. This makes it attractive eventually to increase the supply of roads in high income urban areas. The cheapest way to do this is by expanding the urban area—incorporating into it existing roads that are relatively uncongested—a solution which produces decentralized urban growth.

7. Prognosis

Analyses reviewed here indicate that income growth is the main determinant of increases in motor vehicle fleets at both the national and urban level and that the elasticity of vehicle ownership with income is constant or declining over the range of country incomes. Together, those findings suggest that there is no critical income level at which vehicle ownership suddenly begins to accelerate. Although elasticity estimates vary, a good point estimate for the elasticity of fleet growth is approximately 1 with respect to per capita income (measured across countries using market exchange rates) and population. These values mean that country motor vehicle fleets grow in proportion to total country incomes. With these values, simple projections of motor vehicle fleets can be made at global, regional, and country levels.

7.1 Global motor vehicle fleet growth

Table 6 shows the share of population, gross national product GNP, and motor vehicle fleet held in 1995 by 23 high-income countries and by 125 low- and middle-income countries; it also shows motor vehicle fleet projections for the same sets of countries.³⁴ In 1995, the low- and middle-income countries had a modest share of global GNP and motor vehicles, but a high share of population. The simple illustrative motor vehicle fleet projection in table 6 is based on the assumption that GNP grows at three percent in high-income countries (close to actual experience in 1980-1990) and five percent in low- and middle-income countries (an optimistic rate based on the highest rates experienced in each region over the past 15 years).

Table 6. Share of Global Population, GNP, and Motor Vehicle Fleet in High-Income and Low- and Middle-Income Countries, and Motor Vehicle Fleet Projections

	Low and middle income countries	High income countries	All countries
<i>Initial global shares - 1995</i>			
Population	84%	16%	100%
GNP	19%	81%	100%
Motor vehicles	25%	75%	100%
<i>Projected motor vehicles by year (in millions)</i>			
1995	164	487	651
2000	209	565	774
2010	340	759	1,099
2020	555	1,020	1,575
2030	905	1,370	2,275
2040	1,470	1,840	3,310
2050	2,400	2,475	4,875

Data sources: World Bank, *1997 World Development Indicators* (Washington: World Bank, 1997); American Automobile Manufacturers Association, *World Motor Vehicle Data* (Washington: American Automobile Manufacturers Association, 1996).

Based on these growth rates, the projections indicate that more than half of the world's annual increase in motor vehicles will occur in high-income countries until 2025. The motor vehicle fleet in low- and middle-income countries is not projected to exceed that in high-income countries until after 2050. Because the GNP growth rates used for low- and middle-income countries are optimistic, the time taken to achieve equivalence of fleet increments is likely to be longer than suggested by these estimates. The growth rates of incomes and fleets in low- and middle-income countries are high, but are operating on a small base.

³⁴ High income countries are defined by the World Bank as those having a GNP per capita of \$9,386 or more in 1995. See World Bank, *1997 World Development Indicators* (Washington, D.C.: World Bank, 1997), p. xxii.

Barring a profound change in vehicle fuels and fuel efficiency, or alterations in land use patterns that would shorten average travel distances per vehicle, emissions of carbon dioxide are likely to increase at about the same rate as vehicle fleets. More than half of vehicular carbon dioxide emissions will come from high-income countries for the foreseeable future. The production of other emissions (hydrocarbons, nitrogen oxides, etc.) are likely to vary dramatically across countries because emission control technologies vary. The fleets in high-income countries typically have much lower emission rates than the essentially uncontrolled fleets in low- and middle-income countries. However, this is changing, as many low- and middle-income countries are requiring emission controls for vehicles and are beginning to control the production of heavily polluting technologies such as two-cycle gasoline engines. The adoption of emission controls by most low- and middle-income countries is overdue because many of their large cities have the worst urban air pollution in the world, and the costs of vehicular emission controls have fallen over time.

Simple projections of motor vehicle fleets ignore changes in prices that may affect demand. The available evidence suggests that vehicle users react to price changes in ways that moderate the effects of price changes on vehicle ownership and use. Increases in gasoline prices encourage the purchase of more fuel efficient vehicles and reduce vehicle use somewhat. Increases in the price of new vehicles (for example, by means of purchase taxes on new cars) also increase the price of second-hand vehicles and extend the life of vehicles. This reduces the annual depreciation rate (a major component of the annual user cost of a capital good) and helps to offset the effect of the price increase. Thus price increases can reduce the demand for vehicle ownership and use, but demand is fairly inelastic with respect to price, partly because of the possibilities for compensating behavior. Therefore, price increases that are significantly larger than income increases will be required to produce substantial effects on vehicle ownership.

The distributional impact of taxes is often a policy concern. In low- and middle-income countries taxes on automobile ownership and use are progressive with income because it is the high income households that own cars.³⁵ This is not true in high income countries, where the vast majority of households own a car.

7.2 *Vehicles and roads at the national level*

Road infrastructure has expanded with income at the national level across countries. Paved road length has been expanding at about the same rate as the number of motor vehicles, but total (paved and unpaved) national road length has expanded only about half as fast. High income countries now have less scope for expanding paved roads faster than

³⁵ Gordon Hughes, "the Incidence of Fuel Taxes: A Comparative Study of Three Countries," in D. Newbery and N. Stern, eds., *The Theory of Taxation in Developing Countries* (New York: Oxford University Press, 1987), pp. 533-559.

total roads because a large proportion of their roads are paved. Paving existing roads remains a cost effective way for low- and middle-income countries to improve the productivity of their road systems as motor vehicle fleets expand.

The income elasticity of road provision appears to be constant across country income levels. This constancy is so strong that saturation levels for roads at the national level cannot be estimated. Although the number of motor vehicles per unit of total national road length increases with country income levels, the national ratios are so low that few national roads are congested. Moreover, simple economic reasoning suggests that it is efficient for the ratio of vehicles to roads to increase with income as long as the roads are uncongested.

7.3 Vehicles and roads at the urban level

At the urban level vehicle ownership trends and determinants parallel those at the national level. Urban vehicle ownership is strongly determined by income and its elasticity with income is also approximately 1. This parallel does not extend to road provision. At the urban level roads expand very little with income at low income levels, and then more rapidly at high income levels, producing a ratio of vehicles to roads in urban areas that first rises with income and then declines. Another sharp distinction is that the ratio of vehicles to roads is much higher in urban areas than on national networks, and urban road systems are frequently congested.

To reduce congestion in urban areas, either vehicle ownership and use can be reduced or road space and the efficiency of road use can be increased. Reducing vehicle ownership and use can be done by increasing prices of cars and gasoline, but as noted above, very large price increases are required to have much of an effect. Because the levels of auto-related negative externalities are chiefly associated with vehicle use, public policies targeting vehicle use, rather than vehicle ownership, will be more effective in addressing those externalities. The first-best price for reducing congestion would be a congestion toll because it directly prices the negative externality. The limited experience with congestion tolls suggests that they can be effective at curbing auto use. In Singapore, which has the longest experience with congestion tolls, they appear to help reduce congestion.³⁶

During recent decades, urban areas have coped with congestion by spreading their activities over larger areas and adding road space by annexation. Decentralized urban development is most evident in high income countries, such as the United States and Australia, where land costs at the periphery of urban areas are relatively low. Yet over a 20-year period in the global sample of 35 cities analyzed here, average population densities declined in 25 cities and the urban area increased in 30, so urban area expansion and

³⁶ For an analysis of Singapore's experience, see Timothy D. Hau, "Congestion Charging Mechanisms for Roads: An Evaluation of Current Practice," Policy Research Working Paper 1071 (Washington, D.C.: World Bank, 1992). Several other cities, including Oslo and Trondheim, have more recently instituted area license schemes like that of Singapore. Chapter X in this volume addresses congestion tolls.

decentralization is a common pattern of urban growth. Cities with high densities typically face high relative land prices at their peripheries, and their expansion will occur at higher densities than in cities that face low peripheral land prices. As a result, urban areas will not converge to similar levels of population density and congestion. Instead, population densities and congestion in a particular city will depend on relative land prices at the urban periphery, urban income levels, and the city's historical endowment of structures and roads.

7.4 Unanswered questions

Other than its contribution to the production of global greenhouse gases, the most serious negative externalities from motorization—congestion and air pollution—are experienced primarily in urban areas. Further analysis of rapidly growing urban areas in developing countries is needed to evaluate policy options in transport and the effects of the detailed composition of motor vehicle fleets. For example, few studies of motorization include motorcycles (which are present in significant numbers in many countries), and little attention has been given to such components of the fleet as buses and trucks. In addition, the impact of transit availability on urban vehicle ownership and use has received little attention outside high income countries, where the effects appear to be small. Two other data weaknesses pervading studies of motorization and roads are that comparable data on prices and taxation across cities and countries and over time are elusive, and the most readily available data on roads measure only road length, whereas lane miles of road or better measures of road capacity would clearly be more appropriate.

Traffic congestion appears to have a strong impact on urban development patterns, as cities decentralize and spread their development into surrounding areas in order to increase the supply of urban roads and moderate congestion. This phenomenon deserves more attention and analysis. If firms and households move in ways that foster low-density development at the periphery of urban areas in order to reduce congestion, they may also do so in order to avoid congestion tolls. How urban development will react to congestion tolls is an open question.

The fact that road provision across countries behaves in accordance with predictions based on economic efficiency is surprising. The economic predictions are derived from behavior that is conditioned by economic discipline. But roads are not supplied by private firms functioning in market environments—they are typically planned and financed by governmental agencies, which often seem to be well insulated from market forces. Yet even though road agencies are not actors in a market, they do operate in a political environment that is affected by economic forces and may produce outcomes that are reasonably efficient in economic terms. Albert Hirschman has developed this point, arguing that public infrastructure is provided by the public sector in a framework of “induced decision making” that tracks economic growth in a process of overbuilding and

shortfalls, and produces outcomes that are responsive to economic needs.³⁷ The pattern of road provision across countries is consistent with Hirschman's argument.

³⁷ Albert O. Hirschman, *The Strategy of Economic Development* (New Haven: Yale University Press, 1958).

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