

Long-Term Trends in Global Passenger Mobility

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INTRODUCTION

Anticipating the evolution of travel demand on high, aggregate levels is critical for industry to project the number of vehicles and amount of fuel use, and for governments to plan infrastructure extensions, to predict transport sector greenhouse gas emissions, and to evaluate mitigation policies. This paper shows that only few variables are needed to explain past and project internally consistent future levels of aggregate, world-regional travel demand and mode choice. It concludes with highlighting the enormous challenges that exist for reducing greenhouse gas emissions from especially passenger aircraft, the fastest growing mode.

DETERMINANTS OF AGGREGATE TRAVEL DEMAND AND MODE CHOICE

Growth in per capita income and population are the two single most important drivers of passenger mobility. During the past 50 years, global average per capita income has increased slightly more than three-fold and world population has more than doubled. Their combined growth by a factor of 7.4 has translated into a nearly proportional increase in passenger mobility. That nearly direct relationship can be explained by the so-called travel-budgets, observed roughly constant averages of expenditure shares of money and time.

Although highly variable on an individual level, large groups of people spend about 5% of their daily time traveling. The stability of the (aggregate) “travel time budget”, first hypothesized in similar form for urban travelers by the late Jacob Zahavi (Zahavi, 1981), is illustrated in Figure 1 for a wide range of income levels. On average, residents in African villages, the Palestinian Authorities, or suburbs of Lima spend about 1.2 hours per day traveling, as do those living in the automobile dependent societies of Japan, Western Europe, or the United States.

[Figure 1]

A similar transition from variability at disaggregate to stability at aggregate levels can be observed for travel money expenditure shares, i.e., the percentage of income dedicated to travel. Zahavi observed that households that exclusively rely on non-motorized modes and public transportation spend only about 3-5% of their income on travel, while those owning at least one motor vehicle dedicate 10-15% of their income to satisfy their transportation needs. Figure 2 shows that the aggregate “travel money budget”, here defined as total travel expenditures divided by the gross domestic product (GDP), follows

[†] The fundamental ideas underlying the model described in this paper were jointly developed with David G. Victor, Stanford University. See, Schafer and Victor (2000).

a similar pattern, i.e., rising from about 5% of GDP at motorization rates close to zero cars per 1000 capita (nearly all U.S. households without a car in 1909 or least developed countries today) to around 10% of GDP at about 300 cars per 1000 capita (industrialized countries today), an ownership level of about one car per household of three to four. In addition, travel demand and mode choice depend on the average speed the modes operate with and travel costs to the consumer. The drastic decline in air travel costs during the past decades contributed to the strongly rising share of that mode.

[Figure 2]

THE PAST FIVE DECADES IN WORLD TRAVEL DEMAND

To study the historical and project the future development of global travel demand, a unique dataset of passenger mobility was estimated for eleven world regions, covering passenger-km traveled (PKT) of four major modes of transport (light-duty vehicles, buses, railways, and aircraft), and spanning over five decades (1950-2000).¹ The overall relationship between GDP per capita and per capita PKT is shown in Figure 3. The saturating travel money budget, described above, helps explain that rising GDP translates into rising travel demand.

[Figure 3]

Over the past five decades, Earth inhabitants have increased their travel demand from an average of 1,400 to 5,500 km, using a combination of automobiles, buses, railways, and aircraft. Since the world population grew nearly 2.5-fold during the same period, world PKT increased by one order of magnitude, from nearly 3.6 to some 33 trillion. The highest growth in PKT by a factor of more than 20 has occurred in the developing world, where the combined growth in per capita GDP and population was largest. However, the “mobility gap” to the industrialized regions remains substantial. In 2000, residents in the industrialized world traveled 17,000 PKT per capita on average, five times as much compared to those living in the developing world. Despite its uniform growth, the average amount of travel per person can differ significantly at a given income level across regions, mainly because of different price levels of transportation and land.

While the travel money budget translates rising per capita GDP into rising PKT per capita, the fixed travel time budget requires the increasing travel demand to be satisfied within the same amount of time. Since each transport mode only operates within a range of speeds, the increasing per person PKT can only be satisfied by shifting toward ever-faster transport systems. Figure 4 reports the continuous shifts toward faster modes from mass transportation, i.e., the aggregate of buses and low-speed railways, to light-duty vehicles, and to high-speed modes of transportation, i.e., aircraft and high-speed rail, again for a 51-year historical time horizon. Similar to the variability of total mobility, differences in travel costs and associated urban land-use characteristics lead to different levels in mode shares at a given level of PKT per capita.

[Figure 4]

¹ This dataset is an update of an older 1960-1990 dataset by the same author, see Schafer (1998).

THE NEXT FIVE DECADES IN WORLD TRAVEL DEMAND

If travel expenditure shares remain approximately stable, any future increase in per capita GDP continues to cause a rise in PKT. At the same time, the fixed travel time budget continues to push travelers toward faster modes of transport, as their travel demand rises. The highest level of travel demand would be achieved, if travelers used the fastest mode of transport over their entire daily travel time budget, 365 days a year. Assuming that aircraft would gradually increase their current average “door-to-door” speed of about 260 km/h, which includes the transfer to and from the airport, to 660 km/h, the current average airport-to-airport speed for flights within the US, a travel time budget of 1.2 h/d, over 365 d/y, the annual per person traffic volume would result in approximately 289,000 km. At that high mobility level, most travel would be international. Thus, prices would adjust, and so would income levels. Hence, regional differences in per capita traffic volume at a given GDP per capita, mainly resulting from differences in land-use and prices, would decline, and the eleven trajectories ultimately converge into one single point in the far future. Given the historical development, it is assumed that the GDP per capita value of that “target point” corresponds to US\$(2000) 289,000.

This imaginary world of high-speed transportation helps projecting future levels of PKT by approximating each of the eleven world-regional trajectories in Figure 3 by one and the same type of regression equation and by constraining one parameter of that equation such that the simulated trajectory needs to pass through the target point.² Future levels are then determined by the predicted levels of GDP/cap and population.³ The stable relationship between growth in GDP and traffic volume implies that world travel demand increases approximately in proportion to the projected level of income, from 33 trillion passenger-km in 2000 to 105 trillion in 2050. Due to their projected higher growth in income and population, developing regions will contribute a rising share, ultimately accounting for 60% of the world traffic volume in 2050, up from about 50% in 2000. (Obviously, higher GDP growth rates in developing regions will further increase their share in the world traffic volume).

Given the fixed travel time, future shares of low-speed public transportation modes, light-duty vehicles, and high-speed transportation systems need to lie largely within the shaded envelopes in Figure 4, unless a very significant increase in speed will emerge for any of

² The general form of the regression equation is $PKT/cap = \chi \cdot (GDP/cap)^\alpha \cdot (P_T)^\beta$, with parameters χ being a constant, α the income elasticity, and β the price elasticity which need to be estimated. However, since long-term historical data of P_T are only available for very few countries, the last factor is dropped. Thus, χ includes the averages of travel money budget and price of travel in a particular region. Imposing the target point condition leads to an estimate of χ .

³ The world-regional GDP per capita projections used here are derived from recent reference runs of the MIT Joint Program on the Science and Policy of Global Change Systems model, where growth rates of industrialized regions were slightly reduced to better match the mean values of past projections (Paltsev, personal communication). See, e.g., Nakicenovic et al. (2000). Overall, purchasing power parity adjusted gross world product per capita is projected to increase from US\$ 7,500 per capita in 2000 to US\$ 14,200 in 2050. Population projections are the medium variant of UN population projections, United Nations (2004).

these modes. The precise shift in mode shares, required to satisfy the projected travel demand through 2050, can be derived through a number of approaches, but perhaps most convincingly through estimating the parameters of the functional form of statistical consumer choice models. However, in this application, such models would require time series data (1950-2000) on mode speeds and travel costs per mode. Estimates of such data exist for the United States and to a limited extent for a few European countries and Japan, but are essentially unavailable for most countries of the (developing) world. Due to that lack of data, simplified projections were performed for all regions.⁴ These projections were retrospectively compared to estimates derived with more sophisticated statistical models for those regions for which more complete speed and cost data are available.⁵

In the industrialized world, light-duty vehicles and high-speed transportation modes will account for roughly equal shares and for nearly the entire traffic volume in 2050. By contrast, in the reforming and developing economies, the automobile will supply most of the PKT, followed by low-speed public transportation. Globally, the traffic shares of public transport modes and automobiles will decline by about 6 and 12 percentage points below the 2000 level by 2050, respectively, while the relative importance of high-speed modes will rise from 10% to about 30%. Figure 5 summarizes the global development in PKT by major mode of transport for 1950, 2000, and the projection for 2050. [Figure 5]

This projection of future passenger mobility was performed in an unconstrained world. A separate analysis of potentially limiting factors, including the continuous supply of oil products, the need for higher aircraft speeds, the potential substitution of travel by telecommunication means, rising level of travel congestion, etc. suggest that none of these constraint is likely to become binding over the next five decades.

IMPLICATIONS FOR GREENHOUSE GAS EMISSIONS

To illustrate one implication of rising travel demand, we examine the growth of carbon dioxide emissions by high-speed transportation. (For simplicity, all high-speed transportation is now assumed to exclusively consist of air travel). In addition to the projected eight-fold increase in air travel demand, future levels of air travel released greenhouse gas emissions will depend upon technology choice and utilization, and the type of transportation fuel employed. Current assessments of the resource base of fossil fuels suggest that there will be a sufficient amount of (synthetic) oil to fuel transportation and other demands well beyond mid-century. Table 1 summarizes the major reduction opportunities of aircraft energy use for a given travel demand from recent studies. Even if successfully reducing aircraft energy use by 33-46%, the year 2000 level carbon dioxide emissions would still multiply by a factor of four to six. As this example shows,

⁴ In this simplified projection, we determine plausible shares within each modal envelope at the projected level of PKT, depending upon whether a particular region is an early adopter or a latecomer with regard to the diffusion of automobiles (see, e.g., Grübler, 1998). Latecomers achieve lower shares of light-duty vehicle travel as they already “leapfrog” into high-speed travel.

⁵ For example, the estimation of a detailed statistical choice model for North America yields a 2050 share of 55% for high-speed transportation, which compares to 56% using the simplified approach. The statistical model allowed performing a range of sensitivity tests.

controlling greenhouse gas emissions from transportation will remain a significant challenge for generations to come.

[Table 1]

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Further Reading:

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multiplied nearly 10 times through 2000 and is likely to multiply by a factor of 30 through 2050. For comparison, over the same time scales, GDP has grown by a factor of 7 and 20, respectively.

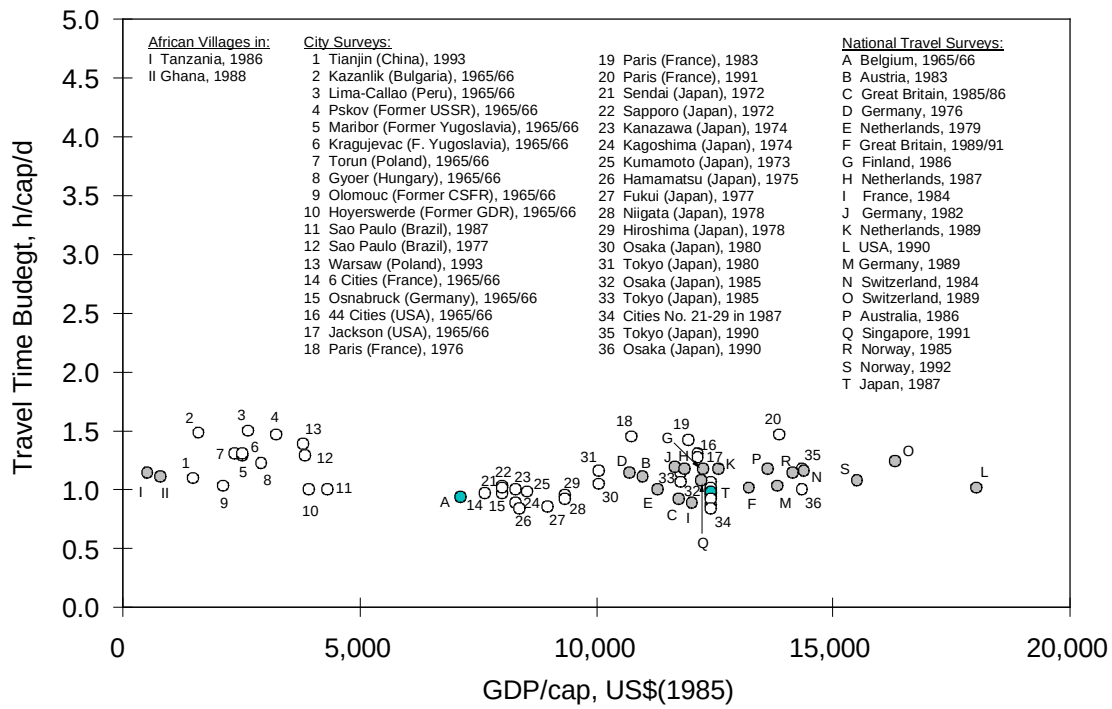


Figure 1

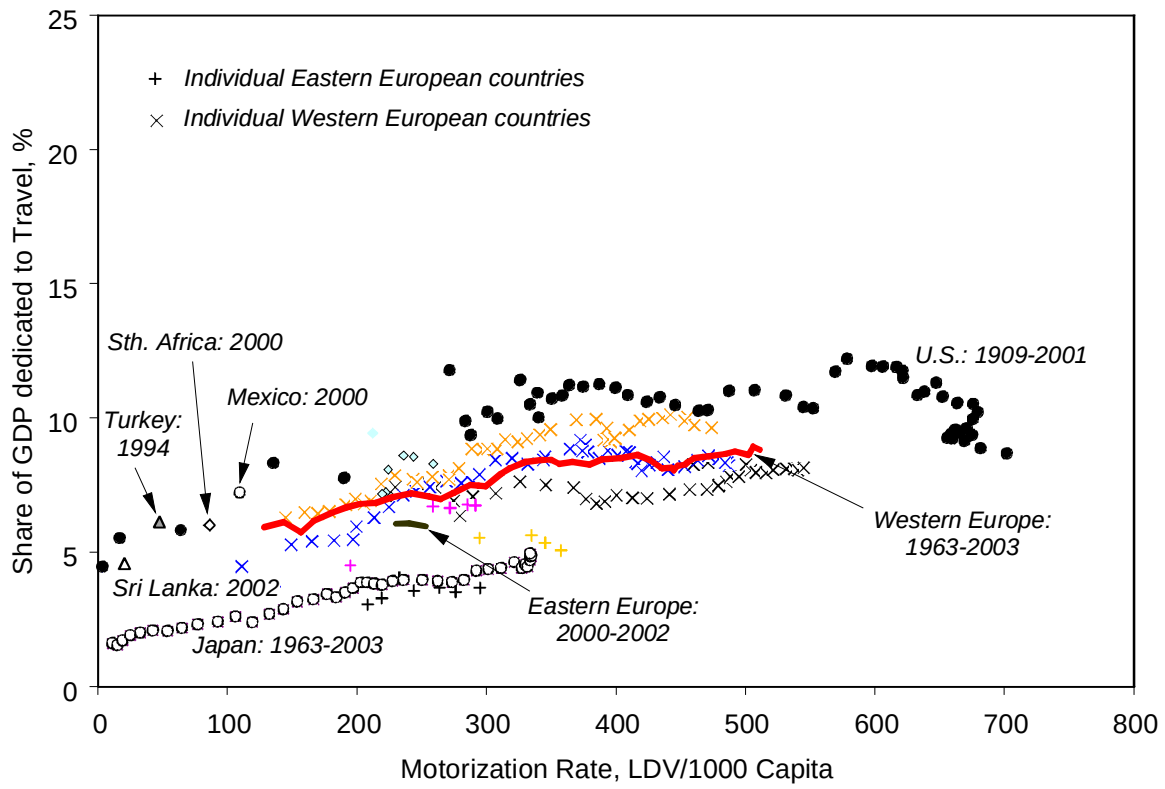


Figure 2

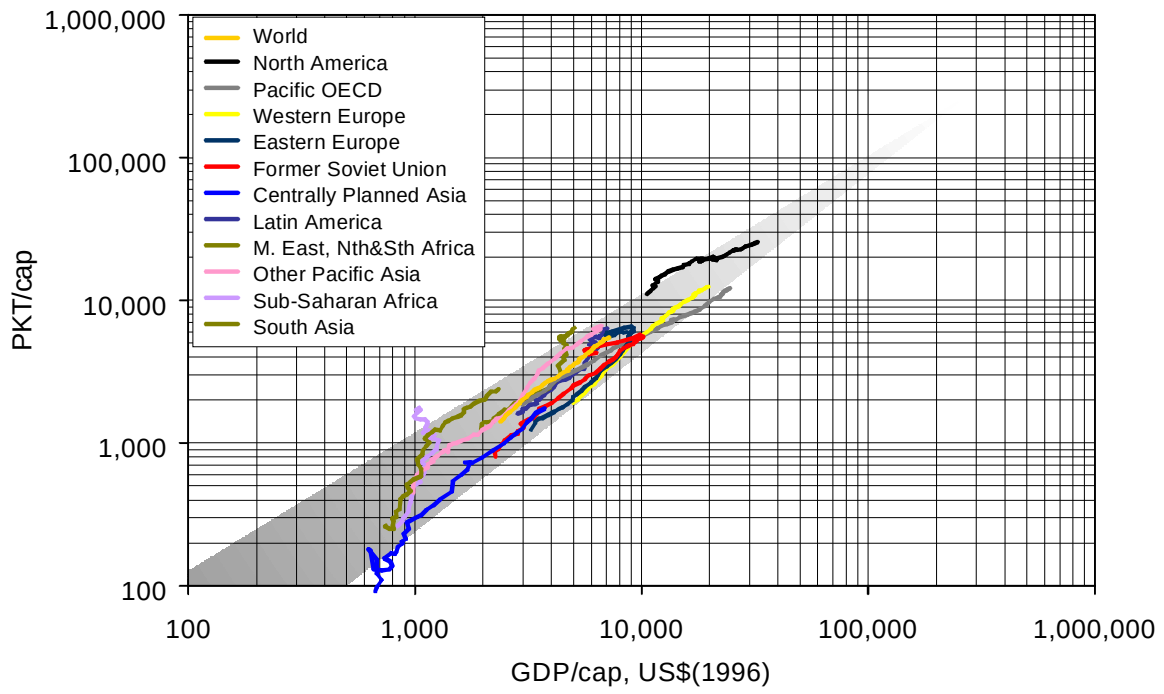


Figure 3

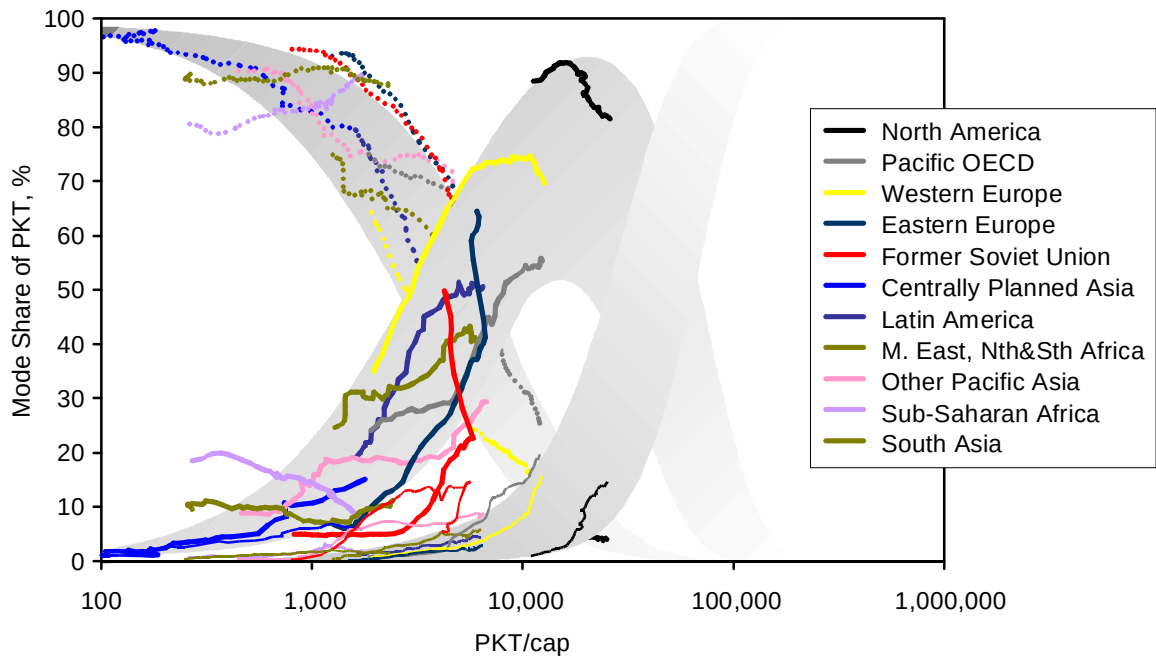


Figure 4

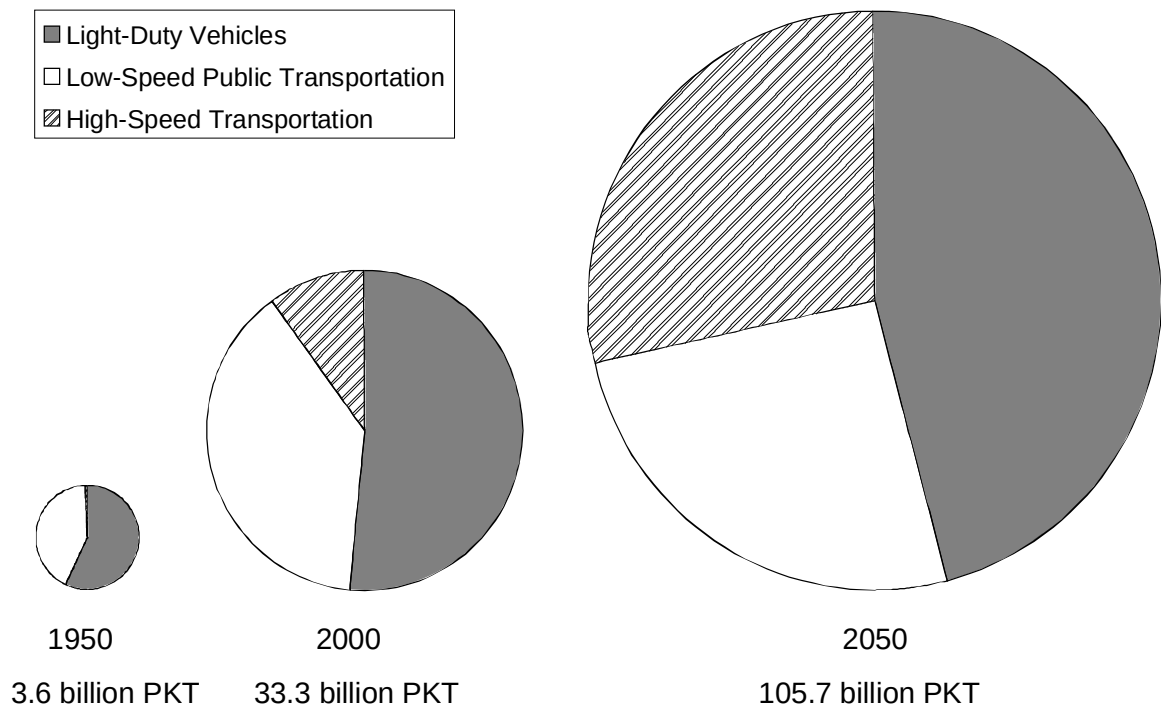


Figure 5

Table 1 Percent change in aircraft energy use by 2050 through various measures.
Source: Lee et al. (2001), Jamin et al. (2004).

	Low Estimate	High Estimate
Aircraft Technology	-25	-45
PAX Load Factor	-10	-10
Direct Flight Routings	0	-11
Shift to High-Speed Rail	-1	-1
Total	-33	-56

Note: High-speed rail estimates based upon 50% market share in 10 U.S. high-density corridors with a cumulative great circle distance of 16,700 km.