Regularities in Travel Demand: An International Perspective

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ABSTRACT

This paper compares major mobility variables from about 30 travel surveys in more than 10 countries. The analysis of cross-sectional and longitudinal data broadly confirms earlier findings of regularities in time and money expenditure shares for passenger travel (travel budgets). Despite the rather rough stability, travel demand characteristics, influenced by the two travel budgets, show strong regularities across space and time for all countries examined.

INTRODUCTION

Although travel demand characteristics have been analyzed at all aggregation levels (individual, urban, regional, national, world-regional, and global), surprisingly little research has been dedicated to quantifying and comparing travel characteristics across national boundaries. Such cross-country comparison is important since it can reveal general trends and differences in the evolution of travel demand, possibly leading to a better understanding of underlying forces. Perhaps the most comprehensive work in this regard was performed jointly by the Organization for Economic Cooperation and Development (OECD), the Euro-

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pean Conference of the Ministers of Transport, and the Europe an Economic Community more than two decades ago (OECD 1977). This detailed, multiyear analysis, however, examined the integration of transportation infrastructures of Western European countries and thus inherently focused on long distance travel, defined there as a one-way trip of at least 80 kilometers. More recently, two studies compared the demand characteristics of primarily short distance travel between countries (Orfeuil and Salomon 1993; Schipper et al. 1995). Although these latter two studies offer useful analyses, both concentrated on *summarizing* travel patterns resulting from surveys and aggregate national data, such as reporting the number of trips per capita by purpose and mode, annual distance traveled, and other indicators of the transportation system; only little attempt was made to examine relationships between these mobility variables or across countries. Instead of comparing separate, aggregate indicators, the present comparison of mobility variables takes into account their interdependence. Following that more systematic approach, this study shows that travel patterns are very similar across all countries.

Central to such similarity is that fundamental travel behavior is stable across space and time. In the 1960s, Tanner (1961) first suggested that people dedicate the same generalized expenditures, the aggregate of money and monetarized time, for daily travel, on average, regardless of whether they reside in an urban or a rural area. However, the quality of Tanner's underlying travel time data was questionable since they completely excluded nonmotorized modes of transport and were derived from a combination of traffic volume data and only rough speed estimates for motorized modes. In the 1970s, Zahavi, basing his conclusion mainly on cross-sectional survey data from cities within and outside the United States, proposed that urban *travelers*, residents who make at least one motorized trip a day, spend a constant amount of time on their daily travel: about 1.1 hours per day (1981). In addition to maintaining a constant "travel time budget," urban travelers spend three to five percent of their income on travel if their associated household relies entirely on public transport. This fraction rises to 10 to 15% of income when the household owns at least 1 automobile. Working with these two fundamental constraints, Zahavi formulated an urban travel demand model simulating travel distances, modal splits, trip speeds, and other characteristics of the transportation system. Other analysts have examined the two "Zahavi budgets," generalizing them to the average *person*, rather than traveler. Among those, Goodwin (1976), basing his conclusion on 1975/1976 United Kingdom travel survey data, showed that the per person daily travel time, including walking, is stable over population density but varies with age, income, and motorization. Numerous subsequent researchers particularly examined the stability of the travel time budget for individual countries and cities. Some studies examined country averages, such as Hupkes (1982), while others differentiated according to city size, such as Katiyar and Ohta (1993). Since the travel budgets are broadly stable on aggregate levels but vary with several variables on a lower level of aggregation, there is an ongoing dispute regarding travel budgets' validity. While some researchers try to identify stability at high aggregation levels, others seek to understand variability at disaggregated levels (Kirby 1981).

The present paper reexamines the evidence of the per person travel time budget and travel money budget based on cross-sectional and longitudinal, mainly national, travel survey data from around the world and explores some budget implications on travel demand. A rough analysis of these data suggests that the travel budgets are only broadly stable on national aggregation levels; nevertheless, their implications on travel patterns are crucial. This analysis is divided into five main sections. The following section briefly describes the differences in the travel surveys employed. Thereafter the "big picture" of travel demand is presented, based on its main variables: two travel budgets and two travel components, trip rate and distance. In the subsequent section, the two travel budgets are considered in greater depth. Before the summary, the paper examines the budget implications for mode choice, land use, and human spatial interaction. The appendix presents the data used in this paper and estimates the daily distance traveled in Singapore.

COMPARABILITY OF UNDERLYING TRAVEL SURVEYS

Twenty-six national travel surveys from 11 industrialized countries, 5 city surveys from the developing world, and 3 surveys from African villages (table 1) form the basis of this analysis. All of these surveys describe travel behavior, including trip rate, trip distance, travel time, mode choice, and trip purpose. However, the data must be interpreted cautiously for a number of reasons.

Perhaps most importantly, survey methods differ across space and time. The attempt to improve the reporting of travel behavior through more sophisticated survey methods has at the same time weakened the basis for consistent comparison. While earlier surveys often relied on questionnaires that asked respondents to recall travel activities on a given day, today's more sophisticated surveys employ a travel diary in which a respondent records each place visited during the course of a day, along with the transportation mode used, time of day, and trip distance. Pretests of the 1995 U.S. travel survey showed that employing the diary method alone added 0.5 trip per capita per day, on average, to the number of daily trips per capita obtained using recall methods (PlanTrans 1997). Ideally, the travel diary is combined with a computer-assisted telephone interview (CATI) that allows real-time editing and internal consistency checks of respondents' indications.[1] Utilization of CATI in conjunction with the travel diary captures still more travel activities. For example, the Swiss 1994 survey, employing both diary and CATI, showed a 7% increase (from 82.4% in 1989 to

[1] In the 1995 Great Britain survey, a computer-assisted personal interview (CAPI) method was used.

TABLE 1 Travel Surveys Used

	Survey year	Reference
Countries		
Australia	1985/86	Adena and Montesin (1988)
Austria	1995	Herry et al. (1998)
France	1982, 1994	Madre and Maffre (1997)
Great Britain	1975/76, 1985/86, 1989/91, 1994/96	Department of Transport (1979, 1988, 1993), Department of the Environment, Transport and the Regions (1997)
Japan (urban areas)	1987, 1992	Ministry of Infrastructure (n.d.)
Netherlands	1985, 1990, 1995	Konen (1999)
Norway	1985, 1992	Vibe (1993)
Singapore	1991	Olszewski et al. (1994)
Switzerland	1984, 1989, 1994	Stab für Gesamtverkehrsfragen (1986) Dienst für Gesamtverkehrsfragen (1991) Bundesamt für Statistik (1996)
United States	1977, 1983, 1990, 1995	U.S. Department of Transportation (1983, 1986, 1991, 1994), Research Triangle Institute (1997)
West Germany	1976, 1982, 1989	Kloas et al. (1993)
Others		
Rural areas in Ghana, Tanzania, Zambia	late 1980s 1986	Riverson and Carapetis (1991) Immers et al. (1988)
Katmandu	1984	Pendakur and Guarnaschelli (1991)
4 Delhi suburbs	1981, 1982	Maunder (1982, 1983)

88.3% in 1994) in the mobile population compared with the mobile population in 1989, as ascertained by the travel diary method alone (Bundesamt für Statistik 1996). While all surveys except the 1977, 1983, and 1990 U.S. surveys employed the travel diary method, only the Dutch (all surveys), Norwegian (1992), Swiss (1994), and U.S. (1995) surveys combined the diary method with CATI (see table 2).

Another factor limiting the comparability of travel surveys is inherent bias. Although all sampling units are typically identified by multi-stage random sampling procedures ensuring an approximately balanced representation of the population, sampling errors remain. For example, households without a telephone connection obviously cannot be interviewed by the CATI technique described above. In the United States, about six percent of all households do not have a telephone connection, predominantly those in the South and those consisting of a single person (USDOC 1999). Travel patterns of these groups are underreported. Sampling-related biases can also result from the included age classes in a sample population. For example, excluding the very young population typically results in a higher average mobility. Survey length can also result in bias: a short survey, for example may not properly take into account seasonal influences on travel. Table 2 shows how most surveys' fieldwork spans at least a year in order to minimize such seasonal bias. Since all of these biases can be corrected only to some extent through appropriate weighting procedures, misrepresentations remain, and survey comparability is limited.

An increasingly important bias results from nonresponse. Societal groups difficult to engage include comparatively mobile persons (since they are harder to reach), people with visual disabilities, and male teenagers (DOT 1993). Their exclusion from surveys results in underreported travel activities. For example, the 1989 German survey underestimates travel probably because highly mobile people were not reached (Kloas, Kunert, and Kuhfeld 1993). An indirect measure of how well hard-to-reach groups are included in a survey is the response rate: the ratio of fully cooperating households to eligible households. Compared to the 1976 and 1982 German surveys, the underreported 1989 German travel survey has, in fact, the lowest response rate. However, since response rates are inherently lower for travel diary-plus-CATI surveys (due to the multiple interview steps involved), care must be taken when employing response rate as an indicator for survey bias.

Other survey inconsistencies result from different survey designs, objectives, and definitions. Some surveys examined did not focus on reporting a balanced, complete picture of mobility. For example, travel times indicated in the 1975/1976 Great Britain survey are unreliable in part because they were collected for only the seventh day of the week (DOETR 1995). Also, several surveys did not examine trip distances, such as the Japanese 1987 and 1992 surveys and the Singapore 1991 survey. In the latter case, trip distances could be estimated based on independent data (Appendix B). Other surveys provide a detailed picture only for weekdays; among those, neither the 1982 nor 1994 French survey reports walking trips on the weekend, and the 1995 Austrian travel survey does not consider weekend travel at all. These surveys could be taken into account only to a very limited extent. Likewise, other surveys that have employed different trip definitions, such as the Swedish surveys (Statistics Sweden 1987), could not be taken into account. Finally, since most of the examined surveys concentrate on the "typical daily travel," they underreport longer distance travel and thus travel time. Exceptions are the surveys from the Netherlands, Norway, and the United States.

In this initial step of a larger project, the pure survey results are compared without making adjustments for the inconsistencies described above. Instead, this paper considers inconsistencies by discussing their possible effects on the survey results. The next step of this project will be a more formal statistical analysis based on a larger number of surveys, which will then be corrected for their major inconsistencies.

BASIC TRAVEL TRENDS

As economies expand, travel increases, working hours gradually decline, and new opportunities for time use arise. While time dedicated to sleep and especially leisure activities rises with declining work time (at a 95% confidence level), time expen-

TABLE 2 Major Characteristics of All Travel Surveys Used in This Paper

	Fieldwork period	Age group	Sample size (# HH interviews)		Response rate	Degree of travel reporting: survey-to-total travel	Major survey characteristics
	month/year	years	#HH	percent population	percent	percent PKMT (all modes)	
Australia	N/A	≥ 9	18,000	0.12	N/A	76.0	Self-completion, mail questionnaire. No further information available.
Austria	10–12/96	≥ 6	12,564	0.56	73.4	N/A	Self-completion, mail questionnaire; tel. interview if missing written responses; proxy interviews; confirming zero trips; trips only collected for workdays; travel diary.
France	3/81–2/82	≥ 6	6,619	0.03	87.0	59.0	Travel diary and car diary (odometer reading after each trip); no walk trips reported on weekends; reported trip distance up to 80 km; con firming zero trips.
	5/93–4/94	≥ 6	14,213	0.06	70.9	58.3	Personal interview with one household member; car travel diary; no walk trips reported on weekends; reported trip distance up to 80 km; confirming zero trips.
Great Britain	7/75–6/76	≥ 3	9,589	0.05	65.4	83.4	Initial interview-self-completion questionnaire-second interview; travel diary.
	7/85–6/86	≥ 0	10,266	0.05	75.6	78.2	Initial interview-self-completion questionnaire-second interview; travel diary.
	1/89–12/91	≥ 0	10,752	0.05	79.8	61.2	Initial interview-self-completion questionnaire-second interview; travel diary.
	7/94–6/97	≥ 0	9,960	0.04	73.4	72.2	CAPI; travel diary; proxy interviews; confirming zero trips.
Japan	N/A	N/A	N/A	N/A	N/A	N/A	Survey limited to urban areas; trip distance only reported for automobile travel.
	N/A	N/A	N/A	N/A	N/A	N/A	Survey limited to urban areas; trip distance only reported for automobile travel.
Netherlands	1–12/85	> 12	9,287	0.17	61.1	109.6	CATI; travel diary; proxy interviews; confirming zero trips.
	1–12/90	> 12	10,139	0.17	55.2	101.9	CATI; travel diary; proxy interviews; confirming zero trips.
	1–12/95	≥ 0	68,433	1.05	53.7	95.8	CATI; travel diary; proxy interviews; confirming zero trips.
Norway	9/84–9/85	≥ 13	4,320 [a]	0.10	77.1	101.8	Personal interview; travel diary; confirming zero trips.
	9/91–9/92	≥ 13	5,992 [a]	0.14	67.5	103.7	CATI; travel diary; confirming zero trips.
Singapore	N/A	≥ 4	2,665	0.34	34.8	N/A	No trip distance reported; travel diary; only includes walk trips greater than 100 meters.
Switzerland	5–6/84	≥ 14	3,513	0.13	58.2 [b]	69.8	Self-completion, mail questionnaire; travel diary; confirming zero trips.
	5–6/89	≥ 14	20,472	0.73	63.0 [b]	87.7	Self-completion, mail questionnaire; travel diary; confirming zero trips.
	1–12/94	≥ 6	16,570	0.55	74.8	74.2	CATI; travel diary; proxy interviews; confirming zero trips.
United States	N/A	≥ 5	17,949	0.02	85.3	70.0	In-home interviews; no travel diary; no proxy interviews.
	2/83–1/84	≥ 5	6,438	0.01	93.3	74.1	In-home interviews; no travel diary; no proxy interviews.
	3/90–2/91	≥ 5	21,869	0.02	83.6	72.7	In-home interviews; no travel diary; no proxy interviews.
	5/95–6/96	≥ 5	42,015	0.04	50.8	94.7	CATI; travel diary; proxy interviews; confirming zero trips. Only travel day file considered here.

TABLE 2 Major Characteristics of All Travel Surveys Used in This Paper *(continued)*

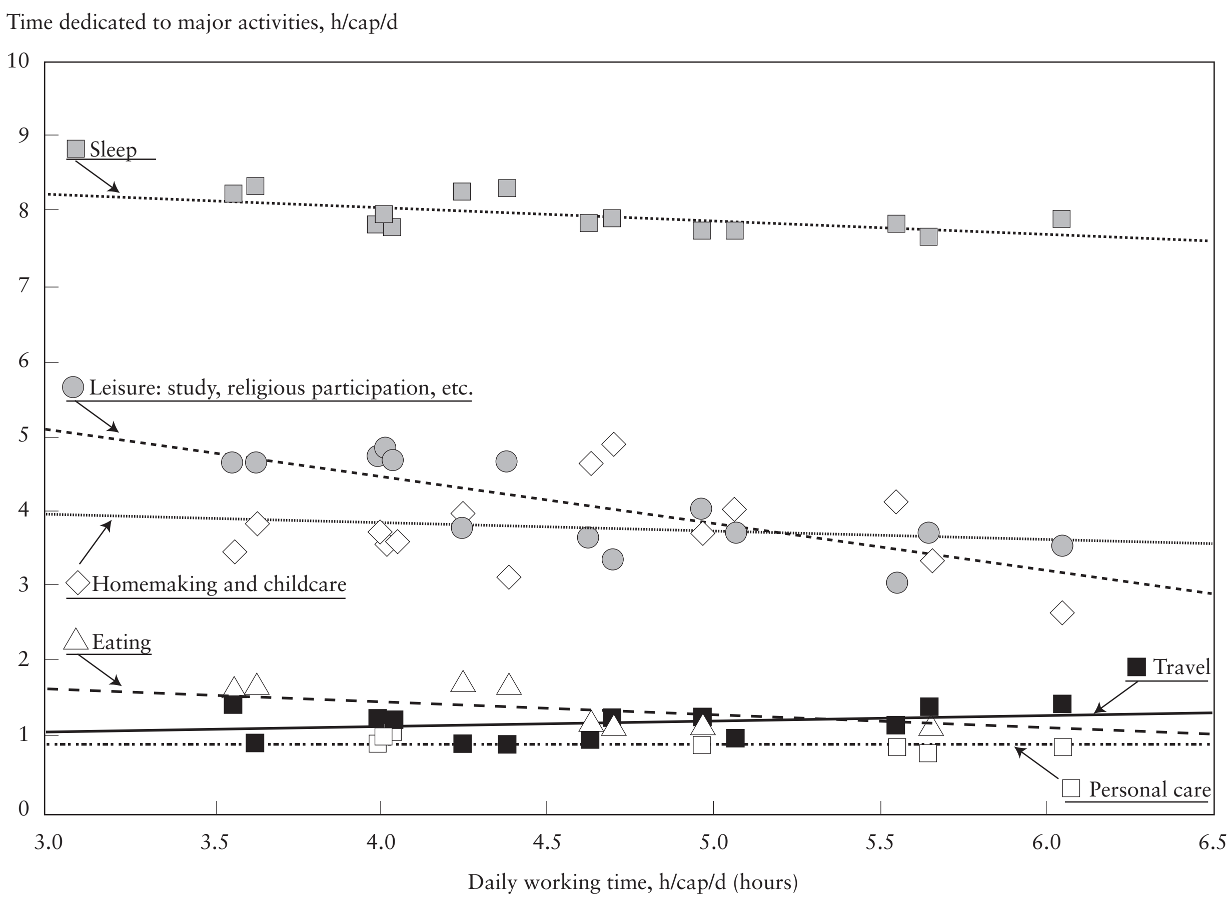
	Fieldwork period	Age group	Sample size (# HH Interviews)		Response rate	Degree of travel reporting: survey-to-total travel	Major survey characteristics
	month/year	years	#HH	percent population	percent	percent PKMT (all modes)	
West Germany	6/75–5/77	≥ 10	19,906	0.02	71.9	106.7	Self-completion, mail questionnaire; travel diary; proxy interviews; confirming zero trips.
	1–12/82	≥ 10	15,582	0.01	65.7	110.3	Self-completion, mail questionnaire; travel diary; proxy interviews; confirming zero trips.
	2/89–1/90	≥ 10[c]	24,849	0.02	64.0	83.8	Forms distributed and collected in person; travel diary; in-home interview if required; telephone interview if missing written responses; proxy interviews; confirming zero trips.
Delhi Suburbs	N/A		705–977	1.5–2.3		N/A	Personal interviews with whole household (prime income-earning member).

[a] Persons instead of households
[b] Basis includes non-eligible households
[c] Originally ≥ 6 years, however, better comparability of the 3 surveys requires neglecting the age group 6 through 9 years.
Note: For survey references, see table 1. Sources for national traffic volume: ICAO statistics for scheduled and charter air travel. All other modes from national statistics: Australia: Australian Bureau of Statistics (various years); Austria: not applicable since survey excludes travel on weekends; France: INSEE (1986, 1995); Japan: not applicable since survey includes trip length only for automobiles; Netherlands: Statistics Netherlands (1998); Norway: Statistics Norway (various years); Singapore: independent statistics not available; Switzerland: Bundesamt für Statistik (1997); Great Britain: Department of Transport (various years), United States: U.S. Department of Transportation (several years), Davis (1998); West Germany: Deutsches Institut für Wirtschaftsforschung (1987, 1996).
HH: household, PKMT: passenger-kilometers traveled. The response rate is defined as the number of complete household interviews to the number of eligible households

ditures for other purposes do not undergo such a systematic change. Among the latter is time dedicated to transportation. Figure 1 reports trends in time allocation to major activities as a function of work time in 14 agglomerations for 1965/1966. The cross-sectional data suggest that travel time averaged 1.22 hours per capita per day (h/cap/d), with a standard deviation 16% of the mean value. Because it is cross-sectional *and* longitudinal, the view of four fundamental mobility variables, including travel time expenditures, shown in figure 2 is more comprehensive. Figure 2a suggests that residents in very low income, latter-1980s African villages (data points 22, 23); high income, high population-density, 1970s–1990s Europe (data points 2 to 16); and very high income, low population-density United States in 1995 (data point 21) all spent roughly one hour traveling each day, despite differences in daily distance traveled of up to one order of magnitude.

Despite the observed overall stability, travel time expenditures vary across individual country data points (mean value 1.09 h/cap/d, standard deviation 0.16 h/cap/d). Cross-sectional and, to a lesser extent, longitudinal, data for Western European countries (data points 2 to 16) suggest that travel time has increased slightly with daily distance traveled. One could argue that this increase may in part indicate behavioral change since all these country surveys were conducted with travel diaries and thus are broadly consistent (see table 2). More importantly, however, the observed increase in travel time results from differences in survey techniques (all building on the

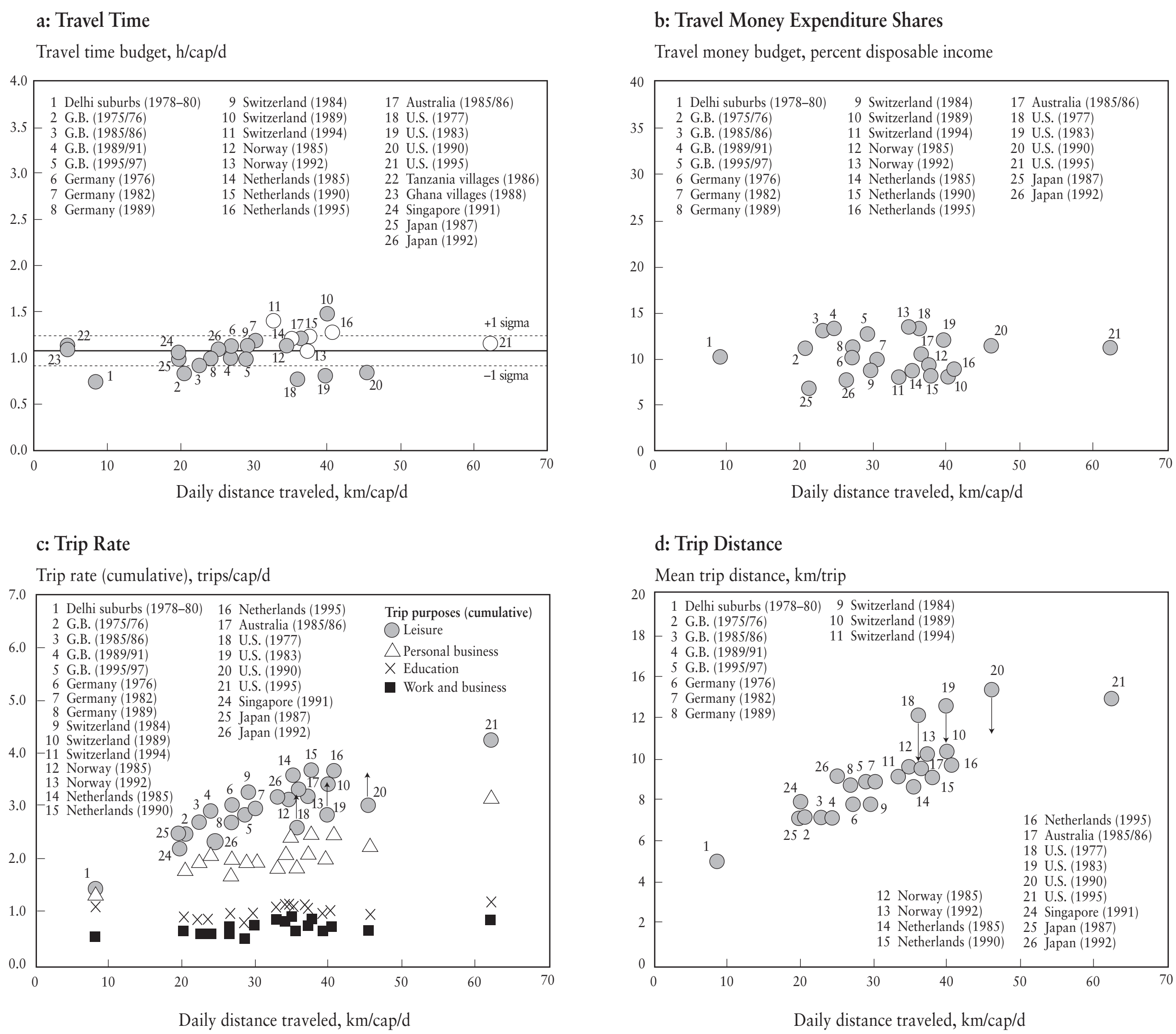
FIGURE 1 Time Expenditure for Major Activities as a Function of Work Time: 1965/1966



Notes: Data are taken from 14 different locations: Belgium, Kazanlik (Bulgaria), Olomouc (Czechoslovakia), 6 cities (France), Osnabrück (West Germany), Hoyerswerde (East Germany), Gyoer (Hungary), Lima-Callao (Peru), Torun (Poland), 44 cities (United States), Jackson (United States), Pskov (former Soviet Union), Kraguijevac (Yugoslavia), and Maribor (Yugoslavia). All data include the population between 18 and 65 years old. Changes in time dedicated to sleep and leisure are statistically significant at the 95% confidence level, as opposed to all other categories.

Source: Szalai et al. (1972)

FIGURE 2 Basic Variables of Human Mobility as Functions of Daily Distance Traveled



Empty circles in 2a = travel diary plus CATI
Dashed lines in 2a = ± 1 standard deviation

Note: The daily distances traveled in African villages were estimated by multiplying the travel time budget by a mean walking speed of four kilometers per hour. Those in Japan were derived from Japan's Statistic Bureau (1995) and multiplied by 0.86, the ratio of the survey-based automobile travel distance to that reported by official transit statistics. The data points in 2b slightly overestimate travel money expenditure shares since the survey-based daily travel distances often underestimate long distance travel (see table 2), whereas the economic statistics-based travel money budget figures account for all travel.

Sources: Table 1 for travel time and components, OECD (various years), and U.S. Department of Commerce (various years)

travel diary), included age groups, and degree of travel reporting.

Based on a rough estimate, table 3 reveals that these factors account for most of the differences in travel time expenditures between Great Britain in 1985/1986 (data point 3) and the Netherlands in 1985 (data point 14). Travel time data by age group from Great Britain 1985/1986, 1989/1991, and 1994/1996 travel surveys show that the exclusion of the age group of 0 to 11 years raises the per person travel time by nearly 6% (Williams 2000). In addition, complete travel reporting from originally 78% (see table 2) to 100% should result in an increase in per person travel time by roughly 9%. The factor 1.09 was estimated by extending the survey coverage to total passenger-kilometers (1/0.78), assuming a three-fold mean speed of long distance travel, 1+(1/0.78 – 1)/3, compared to the reported daily travel. Finally, the CATI method is reported to have increased the number of trips by seven percent in Switzerland (see above). We assume the same increase in per person travel time

TABLE 3 Daily per Person Travel Time Expeditures in Great Britain (1985/86) and the Netherlands (1985)

Per person travel time in Great Britain, 1985/86	0.92
Excluding age group of 0 to 11 years (• 1.06)	0.98
Complete travel reporting (• 1.09)	1.07
CATI method (• 1.07)	1.15
Per person travel time in the Netherlands, 1985	1.21

Note: Rough adjustments to the Great Britain survey for the age group not reported in the Netherlands survey, degree of travel reporting, and computer-assisted telephone interview (CATI) technique lead to a travel time budget similar to that of the Netherlands.

since although these "forgotten" trips plausibly occur over shorter distances, they are likely to be made by significantly slower, non-motorized modes. For comparison, Great Britain 1994/1996 National Travel Survey suggests that per person daily travel time declines by 14% from 0.98 to 0.84 h/cap/d if we exclude all walk trips below a distance of 1 mile. The resulting compounded estimate of 1.15 hours per day only differs by 5% from the 1985 per person travel time of 1.21 hours per day.

Improvements in survey methods, notably the transition from recall to the travel diary, along with the increase in travel reporting (by 35% between 1970 and 1995) have also strongly contributed to the increase in travel time in the United States (data points 18 to 21; see also table 2). Hence, if we compare only survey data points based on the most accurate method, travel diary plus CATI, with a travel coverage of close to 100% (see empty circles in figure 2a), the pattern of a cross-sectional increase in travel time with rising daily distance traveled becomes less evident, and mean travel time increases to 1.23 h/cap/d, with a standard deviation of 0.17 hours. According to table 2, the included age groups still differ between these countries. These numbers compare very well with those from time-use surveys designed to precisely capture time allocations, as displayed in figure 1, suggesting that 1.1 hours per capita per day, as often found in the literature, may underestimate average daily travel time.

From a longitudinal viewpoint that eliminates the effect of some exogenous forces on mobility patterns, such as from cross-country differences in land use, prices, and so forth, travel time expenditures follow no unique trend across countries. For example, Dutch travel diary plus CATI-based surveys suggest that travel time continuously increased from 1.21 h/cap/d in 1985 to 1.25 hours in 1990, to 1.30 hours in 1995. The 4% increase between 1990 and 1995 occurred despite an extension of the survey age group from people at least 12 years old to the entire population (see table 2). By contrast, travel time in Norway declined between 1985 and 1992, despite the transition from travel diary and personal interview to the more accurate, combined method of travel diary plus CATI.

Figure 2b reports travel money expenditure shares and deserves two explanations. First, as travel surveys typically do not investigate consumer expenditure behavior, we must use independent statistical data to analyze the relationship between money expenditure patterns and travel demand. For that purpose, we employ OECD National and Income Accounts (OECD various years) and National Accounts of the European Community (Eurostat various years). Second, the relationship between daily distance traveled and the travel money budget in figure 2b is not reflected precisely since the travel money budget measures the expenditure share for total travel including long-distance, while travel surveys typically underestimate long distance travel (see table 2). Thus, the travel money budget is slightly overestimated.

The spread of travel money expenditures is large compared to that of travel time expenditures (mean value 10.73, standard deviation 3.28, or a 31% deviation from the mean). It results from different price levels in the countries' respective economies. It also results to some extent from limited access to transportation systems. For example, due to a limited supply of parking spaces, automobile ownership in Japan is constrained. Travel money expenditure shares also depend on the underlying methods of estimation and the range of consumer groups included. Differences in these factors contribute to significantly different travel money expenditure shares, accounting for 11 to

13% of disposable income, if based on the personal consumption expenditures component of the National Income and Products Account (shown here), and for roughly 18% of disposable income if based on the consumer expenditure survey conducted by the United States Department of Labor (1997).

In contrast to the roughly horizontal development of the two travel budgets, both travel components increase uniformly with daily distance traveled. At low levels of daily distance traveled, people seem to undertake one to two trips per day, such as in Delhi suburbs in the late 1970s;[2] the associated mean trip distance is somewhat higher than five kilometers. Daily trip rate and distance (figures 2c and 2d, respectively) rise with increasing daily distance traveled to more than 4 trips and almost 15 kilometers, respectively (United States in 1995), exhibiting strong regularities. At low mobility levels, one trip in a day is dedicated to a combination of work (short term survival) and education (longer term well-being), and about half a trip on average is dedicated largely to personal business (essentially, shopping at local markets). The absolute number of trips per person in Delhi suburbs and the trips' distribution by purpose are consistent with the number found by many other surveys from developing countries not considered here since they don't report distance traveled. Examples included Jakarta (Badan Pengkajian dan Penerapan Teknologi and Forschungszentrum 1991), Sao Paulo (Metrõ 1989), and Santiago de Chile (Comisión de Planificación de Inversiones en Infraestructura de Transporte 1992). Daily distance traveled grows together with additional trips for personal business, such as for shopping, health care, religious services, and leisure, including holidays. At high income levels comparable to those of OECD countries, people make more than three trips per day, devoting approximately one trip to work or education, one to two trips for personal business, and one trip for leisure. The highest trip rate can be observed for the United States (1995), where the largest daily per person distance is traveled. Here, personal business trips account for nearly half of all trips made.

The development in trip rate by purpose is broadly stable, but here also differences exist. Variations result in part from inconsistent survey methods. Compared with work and education trips, best remembered by survey respondents and stable across all examined societies, occasional trips for personal business and leisure typically go underreported more often. Thus, the observed increase with rising daily distance traveled of these trips may at least in part result from improved survey methods. This is most evident for the 1977, 1983, and 1990 U.S. surveys, due mainly to the absence of a travel diary. Adding 0.5 trip to the per capita trip rates of the corresponding data points (18 to 20) to correct for the missing travel diary would lead to a cross-sectional trajectory in trip rate more consistent with all other surveys (see arrows in figure 2c). In all other cases, the increase in trip rate with rising daily distance traveled is essentially cross-sectional and remains approximately level within countries with rising daily distance traveled.

The evolution of trip rate is also influenced by differences in land-use: a lower population density tends to reduce trip rate and increase trip distance.[3] Comparing only those country data points based on a travel diary in combination with CATI yields land-use related differences in trip rate at a given daily travel distance. For example, it is lower in low population density Norway and higher in the high density Netherlands. Obviously, the variation in trip distance results directly from the variation in trip rate. Mean trip distance can be expressed by the ratio of daily distance traveled to trip rate and,

[2] The basic unit for measuring transportation activities is a trip, generally defined as a one-way move from an origin to a destination, motivated by a main purpose, and involving a public infrastructure. This definition is not always consistent across countries and surveys. Surveys with clearly inconsistent trip definitions were adjusted when possible and when not, were not taken into account. Another source of inconsistency is the fact that people are increasingly involved in more than one activity at a time, making phone calls during their daily commute; doing work, or enjoying leisure activities, while on an airplane; and so forth. Simultaneous activities cannot be taken into account here, as we must simplify human travel behavior in order to understand its fundamental characteristics.

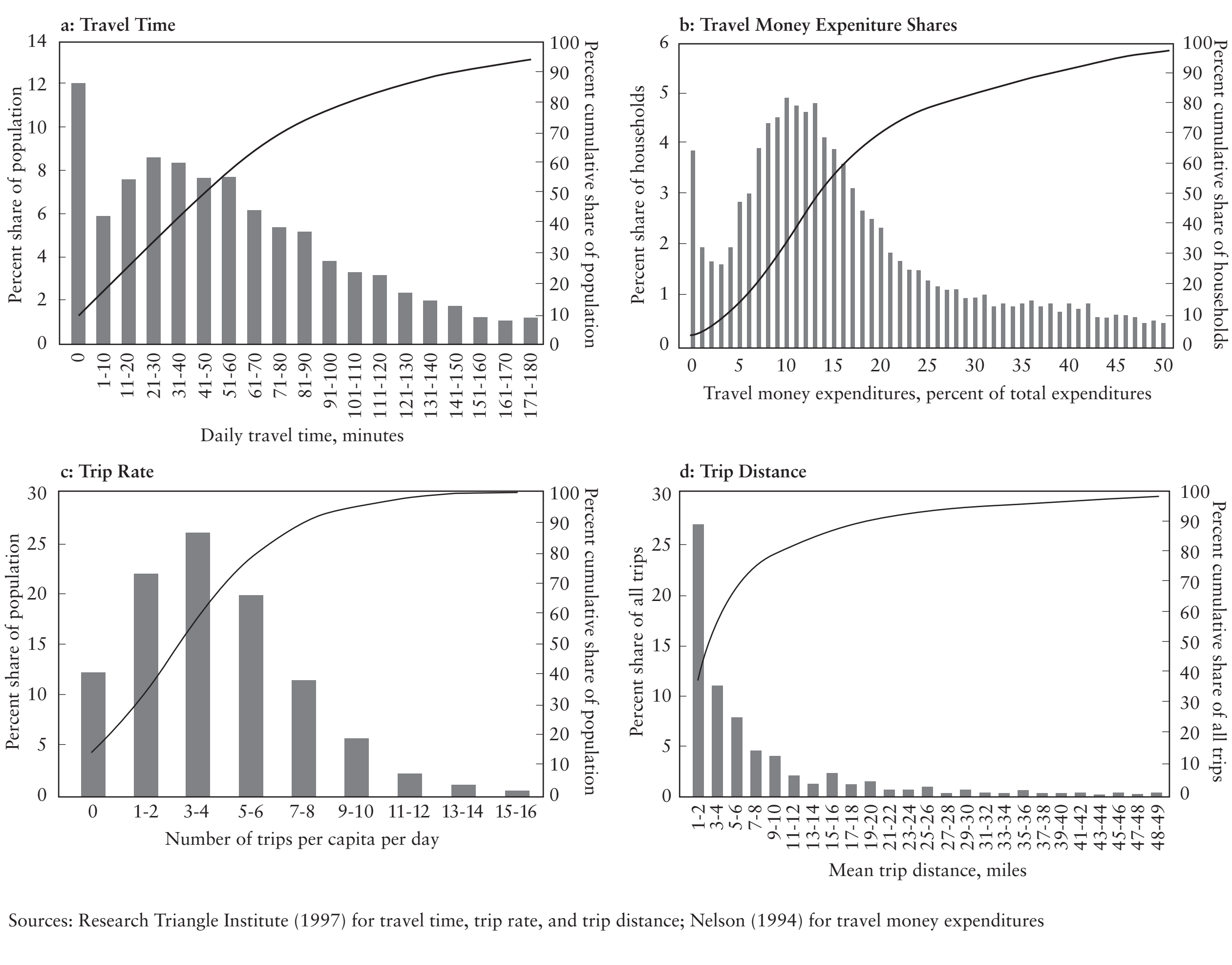
[3] Differences in trip rate also result from cultural and regional factors. For example, residents in hot areas such as Southern Europe and especially Africa are likely to have more work-related trips since many return home for lunch to escape the high heat for several hours (not shown here).

thus, from the different degrees of trip reporting within and between countries, over time. The arrows in figure 2d for the 1977, 1983, and 1990 U.S. travel surveys reflect the decline in mean trip distance resulting from correcting the trip rate.

TRAVEL BUDGETS

Analogous to figure 2, figure 3 illustrates the density and cumulative distribution functions of the four fundamental travel variables for the U.S. population in 1995. Only the travel money expenditure distribution is shown for 1989, the last year for which household consumer expenditures can be easily extracted from data tapes. The asymmetric shape of the density functions, reflecting a wide range of preferences by and constraints to individuals, causes the respective mean and median to differ strongly. For example, the average per capita travel time is 1.18 hours a day, while the typical U.S. resident travels only 50 minutes, 0.83 hours a day; approximately seven percent of the U.S. population travels longer than three hours per day. Similarly, figure 3b suggests that mean household transportation expenditures account for 19.3% of total expenditures, while the typical U.S. household dedicates only 13% of total expenditures to transportation. Still, three percent of U.S. households devote more than half of their expenditures to transportation. Finally, figures 3c and 3d show the well-known gamma functions and the corresponding cumulative distributions for trip rate and distance. Since all four travel variables in figure 3 are characterized by skewed distributions, the question of why travel time and money expenditure shares should remain constant, while trip rate and distance increase, arises. We will pursue this question in more detail in the following subsections.

FIGURE 3 Distributions of Basic Mobility Variables in the United States



Sources: Research Triangle Institute (1997) for travel time, trip rate, and trip distance; Nelson (1994) for travel money expenditures

Travel Time Budget

Since we cannot analyze the stability of the travel time distribution in figure 3 more carefully due to the lack of long-term, historical, cross-sectional raw data, we examine the available averages on a more disaggregate level. Figure 4 reports average travel time associated with different trip purposes. The overall development over daily distance traveled is illustrated in figure 4a. At first glance, travel time associated with work, including work-related business, and education seems to remain roughly constant at 0.21 and 0.09 h/cap/d, respectively, in industrialized countries, while travel time associated with personal business and leisure travel increases slightly. To better understand to what extent these trends may be influenced by changes in travel behavior and survey methods, we decompose per capita daily travel time into two factors, trips per capita per day (figure 2c) and mean travel time per trip for each trip purpose (figures 4b through 4f).

We begin with commuting, typically remembered best by survey respondents and thus least affected by inconsistent survey methods. Figure 2c shows that the number of trips associated with commuting is roughly stable over the entire range of daily travel distances. In addition, figure 4b demonstrates that the increasing mean distance to work has led to a slight cross-sectional and longitudinal rise in travel time in nearly all countries. Apparently, commuters have been unable to completely compensate for the longer commute to work with higher speed. Together, both trends suggest that mean daily commuting time per capita is slightly rising.[4] Essentially, the same relationship applies to work-related business trips (figure 4d). The slight increase, however, is not unique for all countries. In Norway, both travel time and trip rate for work and related business travel have essentially remained constant. The distinct trajectories in both figures of U.S. travel and other, mostly Western European travel, reflect differences in mean speed and, in turn, land-use.

Completely different settings with respect to mean travel speed and land-use can significantly widen the relatively close range between commuting distance and time. The two data points representing time expenditures above 0.7 hours illustrate the difficulty of keeping commuting time down in low income countries (Delhi suburbs between 1978 and 1980, data point 24) and high population density cities (Singapore in 1991, data point 25), where residents are constrained in selection of an appropriate residential location and transport mode. Due to the limited travel time budget, travel time associated with purposes less important than work, which ensure short-term survival, is therefore significantly reduced.[5]

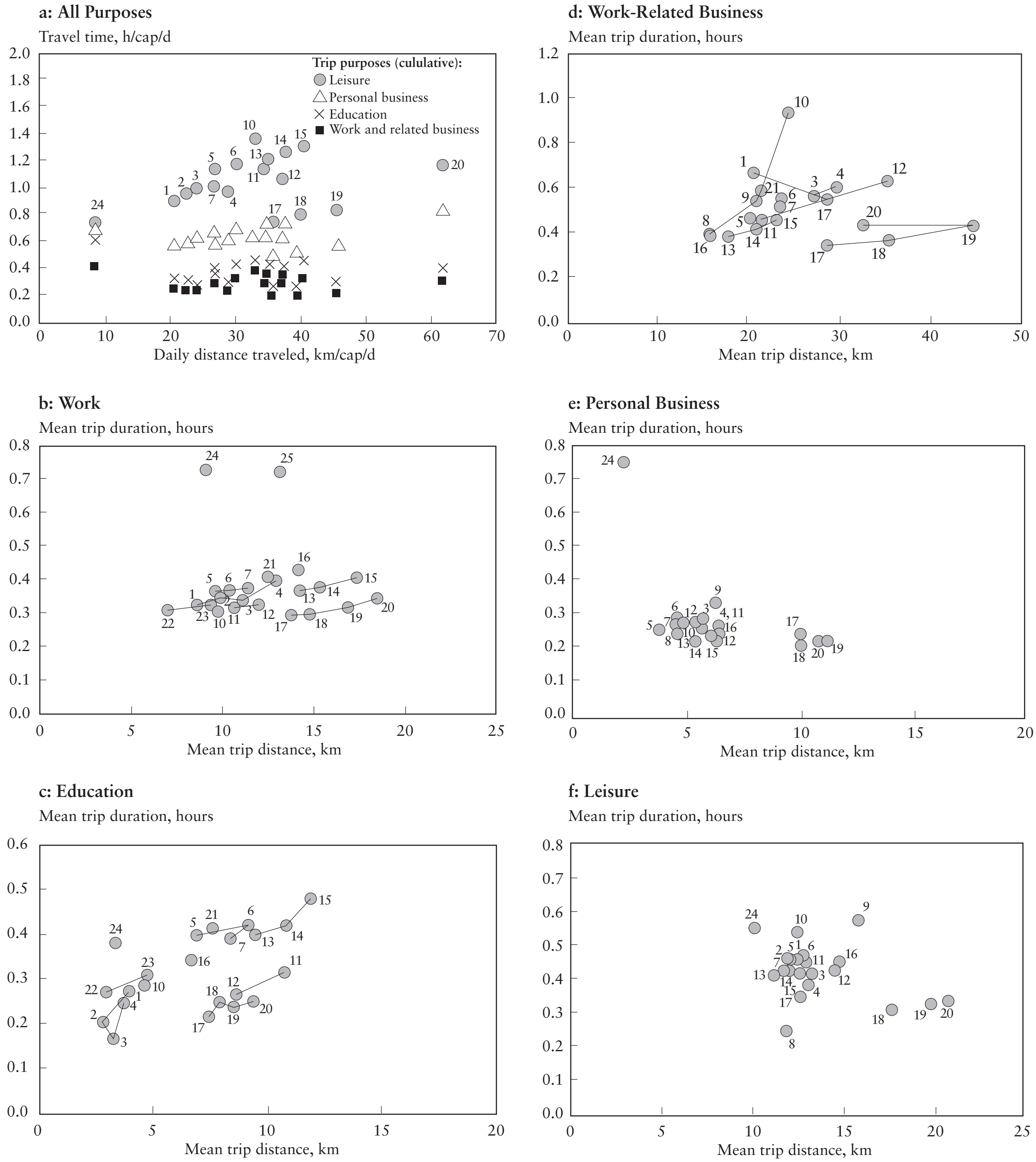
The increase in travel time over trip distance for education-related trips is stronger compared to work and work-related business trips since students are typically more constrained in their choice of transportation modes (figure 4c). The mainly cross-sectional increase in travel time results from a comparable speed, distance per trip (abscissa) divided by time per trip (ordinate), of the average mode of transport in different environments (for example, location and accessibility of schools). Land-use differences, as well as different modal constraints, are responsible for altering mean speeds, i.e., higher in the United States and Norway (low population density) and lower in Western Europe (higher population density). Combined with a roughly stable trip rate, per capita travel time for education trips has remained roughly constant within most of and across the examined countries.

Travel time expenditures for personal business and leisure trips (figures 4e and 4f) do not rise with trip distance and thus roughly follow a budget-like development, an independent and thus horizontal trajectory over mean trip distance, exempting the comparatively high travel time associated with especially personal business but also leisure trips in

[4] This increase in work-related travel time rejects conventional wisdom, which suggests that commuting time would remain generally constant over time and the increased distance would be completely absorbed by land-use changes. See, for example, Levinson and Lumar (1994) and the discussion on journey-to-work trip times in Kenworthy and Laube (1999).

[5] Similarly high average commuting times can be observed in Russian cities in the early Twentieth century (Zuzanek 1980) and for high population density Japan in 1996 (Statistics Bureau 1998). High average commuting times are also observed in Western high density cities. For example, according to the 1992–1994 United Kingdom travel survey, Londoners have spent an average 0.83 hours getting to work in central London, twice the national average (DOETR 1995).

FIGURE 4 Allocation of Travel Time



Legend

1 G.B. (1975/76)
2 G.B. (1985/86)
3 G.B. (1989/91)
4 G.B. (1995/97)
5 Germany (1976)
6 Germany (1982)
7 Germany (1989)
8 Switzerland (1984)
9 Switzerland (1989)
10 Switzerland (1994)
11 Norway (1985)
12 Norway (1992)
13 Netherlands (1985)
14 Netherlands (1990)
15 Netherlands (1995)
16 Australia (1985/86)
17 U.S. (1977)
18 U.S. (1983)
19 U.S. (1990)
20 U.S. (1995)
21 Austria (1995)
22 France (1982)
23 France (1994)
24 Delhi suburbs (1978-80)
25 Singapore (1991)

Sources: Tables A-1 and A-2

Delhi suburbs (data point 24). In general, people seem to be willing to spend only 0.22 to 0.34 hours for personal business trips (figure 4e), on average, independent of the distance. Similarly, the trip duration of leisure trips (figure 4f) has remained constant in the United States, while trip distance has increased by almost 50%. If we exclude the three Swiss survey data points with implausibly large variation (data points 8 to 10) in the same chart, leisure trips in Western Europe show a less diffuse pattern and can be considered roughly constant. The total effect of the two factors, the mainly cross-sectional increase in trip rate and the roughly constant travel time per trip, is an essentially cross-sectional increase in travel time per capita and day associated with personal business and leisure trips. Only in the Netherlands and the United States, where trip rates have increased slightly with rising daily distance traveled, we conclude a gradual longitudinal increase in per capita travel time associated with these two trip purposes.

Overall, without any compensation mechanism, the slight longitudinal increase in travel time associated with work and related business trips, observed for nearly all countries, leads to a gradual increase in total per capita daily travel time. This increase may be amplified by a rise in travel time associated with other trip purposes; however, since such a rise was mainly observed across countries, it can also reflect exogenous factors rather than revealing a longer term longitudinal trend. A compensation mechanism leading to lower trip rates with rising travel time per trip can only be observed in extreme cases, such as between the industrialized world and the developing countries or very high population density areas. In these settings, people are forced to perform drastically less since they spend significantly more time on trips. Since none of the trends in rising travel time described above is uniform across all countries, these trends are likely to be much smaller on a higher, world-regional and global aggregation level. Thus, it occurs that the per person travel time budget can most appropriately be considered as roughly constant on such high aggregation levels.

Travel Money Budget

After housing and food, transportation expenses typically represent the third major household expenditure item, accounting for 3 to 5% for zero-car households and stabilizing at 10 to 15% of disposable income for households with at least one automobile, as suggested by Zahavi (1981). Figure 5 confirms these shares in total consumer expenditures for six countries, France, Italy, the Netherlands, the United Kingdom, the United States, and West Germany. While food expenditure shares, including restaurant visits, have strongly declined during the past decades, those associated with housing and especially with transportation have shown much less variation.[6] In most countries, travel money expenditure shares have remained especially stable above motorization rates of 0.30 cars per capita or about 0.85 cars per household since beyond this threshold nearly all households own and operate an automobile on average (see gray arrows in figure 5). Only in West Germany have transportation expenditure shares continued to rise. Perhaps most interesting, travel money expenditure shares have remained stable even during the two oil shocks in 1973/1974 and in 1978/1979. Data from the United States suggest that travelers have adjusted by buying more fuel-efficient cars and temporarily reducing automobile travel (see Schafer and Victor 2000).

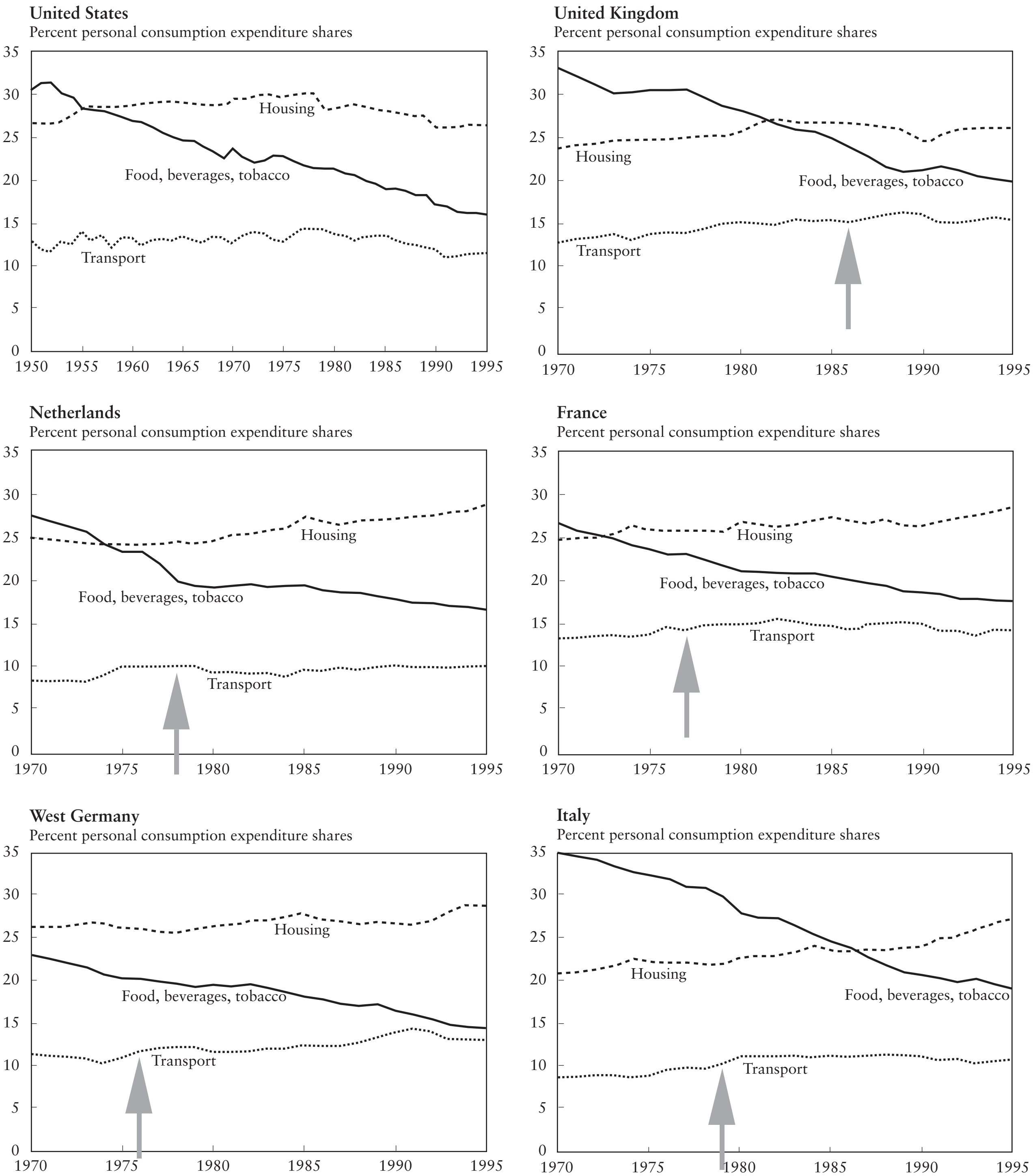
As with the travel time expenditures, the slightly different development of the travel money expenditure shares (approximately constant above 0.30 cars per capita in the United States, the United Kingdom, the Netherlands, France, and Italy while continuously rising in West Germany above that threshold) implies that higher confidence of a stable travel money budget exists at a higher aggregation level than the country data shown here.

Travel Budget Substitutability

A tight stability of both travel time and money expenditures implies that both travel budgets are independent and thus not substitutable on aggregate levels. However, even after correcting for the survey

[6] On a net basis, the declining food expenditure shares were compensated by services, ranging from medical expenses to recreation and education.

FIGURE 5 Personal Consumption Expenditures as a Fraction of Total Personal Consumption Expenditures



Note: Arrows indicate a motorization rate of 0.30 cars per capita (about 0.85 cars per household), at which nearly all households own and operate an automobile on average.

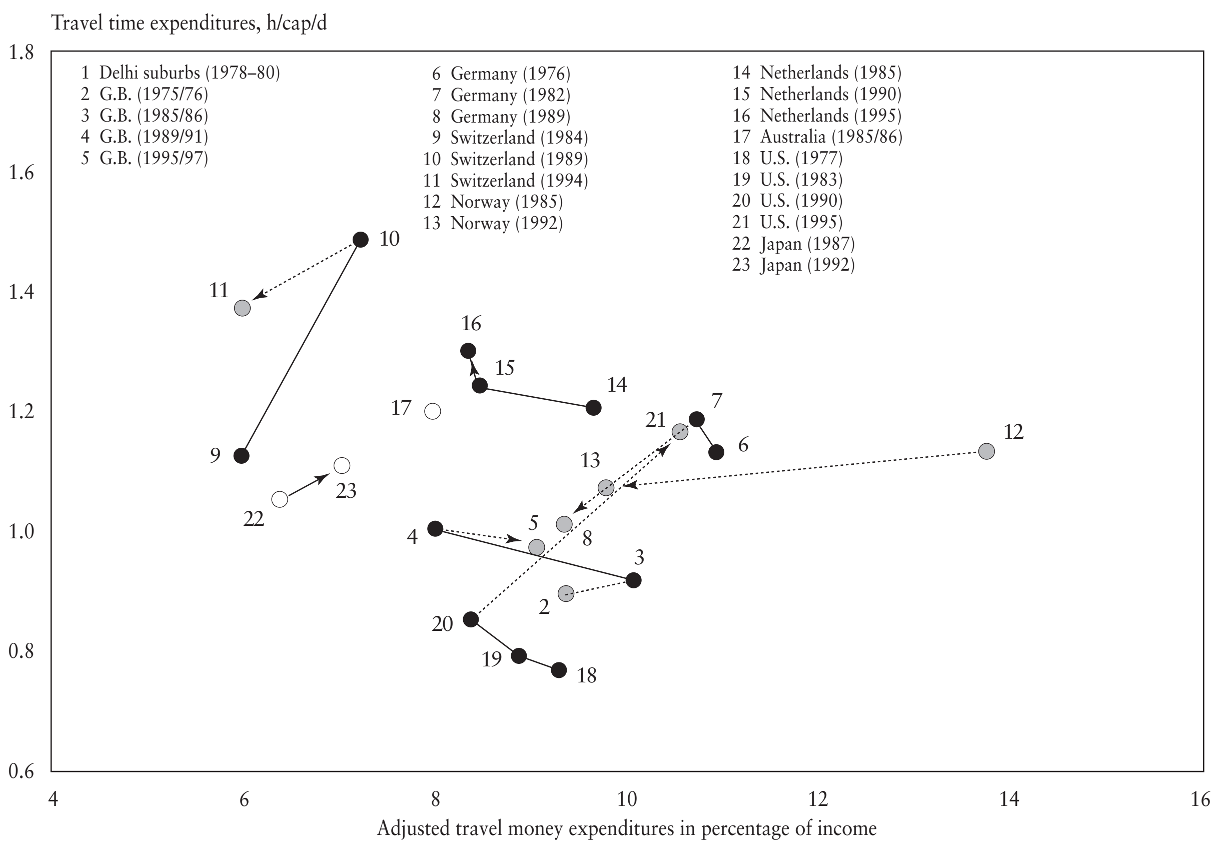
Sources: U.S. Department of Commerce (various years) and Eurostat (various years) inconsistencies, some variations of both budgets in figures 2a and 2b remain, raising the question of whether they are systematic, and thus reflecting the substitution occurring on a national level, or just "noise" due to survey methods' inconsistencies.

Answering this question requires travel time and money expenditure data be measured consistently. This, however, is not the case. While travel money expenditures are derived from independent national economic accounts that cover total travel, including long-distance (air) travel, travel time expenditures are based on the travel surveys listed in table 1, which, in most cases, only capture typical daily travel. We roughly adjust the travel money budget by simply multiplying it by the ratio of travel survey-reported daily travel distance to independent transport statistics daily travel distance from table 2.[7] In addition, travel time expenditures are underestimated in some surveys, since, for example, short trips, typically made on foot and requiring a comparatively long time per distance, are underreported (see the three early U.S. surveys, represented by data points 18 to 20). Although we cannot directly correct for this second source of inconsistency, we can largely eliminate it by focussing only on such series of surveys that were conducted using similar methods.

Figure 6 reports a simple test of budget substitutability. Most of the country data points, based on surveys with consistent methods and without any obvious bias (black circles), suggest that budget substitution has in fact occurred. Among those are the 1976 and 1982 Germany surveys (the 1989 survey underreported travel behavior of the highly mobile population), the 1985/1986 and 1989/1991

[7] This adjustment is based on the assumption that costs per passenger-kilometer are equal for long and short distance travel. However, in 1995 costs for air travel were 8 cents per passenger-kilometer (pkm) in the United States, while automobile and public transport costs were about 20 and 17 cents per pkm, respectively (APTA 1998; Davis 1998; USDOC 1998). Therefore, this correction may slightly overestimate the "adjusted travel money expenditures."

FIGURE 6 Substitution of Travel Time and Money Expenditures



Note: Surveys with consistent methods and without obvious bias are represented with black data points. White dots indicate unknown survey methods or when only one survey was available.

Sources: Table 1 for travel time budgets; OECD (various years) and U.S. Department of Commerce (various years) for money expeditures.

Great Britain surveys, the three surveys from the Netherlands, and the three early U.S. surveys. In contrast, the Swiss 1984 and 1989 surveys do not follow such a trend. Neither do the two Norwegian surveys, where the shift from travel diary to travel diary plus CATI has even resulted in a decline in travel time.

In summary, figure 6 suggests that substitution between travel budgets occurs on a national level; however, exceptions exist. This confirms the conclusion that both budgets can most appropriately be considered as roughly constant on higher than national aggregation levels.

INTERPRETATIONS OF TRAVEL BUDGET STABILITY

Transportation analysts have formulated different hypotheses to explain the roughly stable travel budgets. For the most thorough and critical discussion, see Goodwin (1981). Kirby (1981) classifies these hypotheses into three fundamental ways of interpreting travel budgets.

One interpretation regards the budgets as purely empirical laws of travel behavior for groups of individuals. Marchetti (1994), for example, considers the travel time budget as an instinct-driven, anthropogenic invariant. He suggests that people are "cave animals" who control their exposure time to risk, their time traveling in the unprotected environment, to about one hour per capita per day.

A different way to consider the travel budgets is to treat them as byproducts of allocations of time and money. The time constraints of primary activities naturally limits travel. Figure 1, for example, shows that people spend approximately 8 hours per day sleeping, almost 4 hours on homemaking and childcare, and 8 to 9 hours on the aggregate of work and leisure. With the addition of about two hours for eating and personal care, only somewhat more than one hour per day is left for travel. (Such a direct limitation does not exist for the travel components.) The money consumed by primary activities also limits travel, and a similar analysis can be made on the basis of travel money expenditures (see figure 5).

Another interpretation considers the budgets as input for decisionmaking, such as how to maximize utility. Hupkes (1982), for example, suggests decomposing the utility of travel time into a derived utility and an intrinsic utility. The derived utility, a measure of the need for travel to pursue a primary activity, increases with travel time, saturates, and subsequently declines as less time becomes available to pursue additional activities. The intrinsic utility, the satisfaction of travel as an end in itself, follows the same pattern, albeit at a much lower utility level. The total utility of travel time is then the sum of the derived and the intrinsic utility. Hupkes acknowledges that the resulting total utility curves not only differ by person but also change over a person's lifetime.

None of these hypotheses alone provides a sufficiently rigorous explanation, despite the observed rough stability of the travel budgets. In fact, some of them can be ruled out as independent hypotheses. For example, if the travel time budget were exclusively a fundamental human constant, its distribution over a population should be normal with a small spread. However, that is clearly not the case, as shown in figure 3a. Also, the travel time budget is certainly not a pure residual since time allocations to work differ greatly across nations. In figure 1, work time varies from 3.6 to 5.7 h/cap/d; nevertheless, the change in travel time is statistically insignificant across all data points. While each of the above interpretations fails to explain the stability of the travel budgets individually, it appears that they do, to some extent, complement one another. Travel time and money expenditures are byproducts of spatially separated primary activities and simultaneously represent enabling factors for or constraints to performing additional activities, depending on their utility.

It should also be noted that neither budget is unique. For example, the stability of personal care time expenditures in figure 1 is reflected by a mean of 0.92 h/cap/d, with a standard deviation of 18% of the mean value. Thus, analogous to the "travel time budget," a "personal care time budget" can be defined. Similarly, the money expenditure shares to housing in figure 5 are relatively stable, except perhaps in Italy. This phenomenon may also allow for the definition of a "housing money budget," accounting for 20 to 30% of total household expenditures.

TRAVEL BUDGET IMPLICATIONS FOR MOBILITY

Despite their rough stability, the two travel budgets have important implications on travel patterns. We begin with mode choice and then turn our attention to land-use changes. An examination of the daily range of human interaction closes the section.

Mode Choice

The travel money budget represents the fraction of disposable income devoted to travel. Thus, a fixed travel money budget establishes a direct relationship between disposable income and daily distance traveled, provided average user costs of transport remain constant (see Schafer and Victor 2000).[8] While the constant travel money budget leads to rising travel demand, the roughly constant travel time budget requires travel at a higher speed and thus shifts toward faster modes. In the subsequent subsections, we explore the modal shifts in short distance and long distance travel.

Short Distance Travel

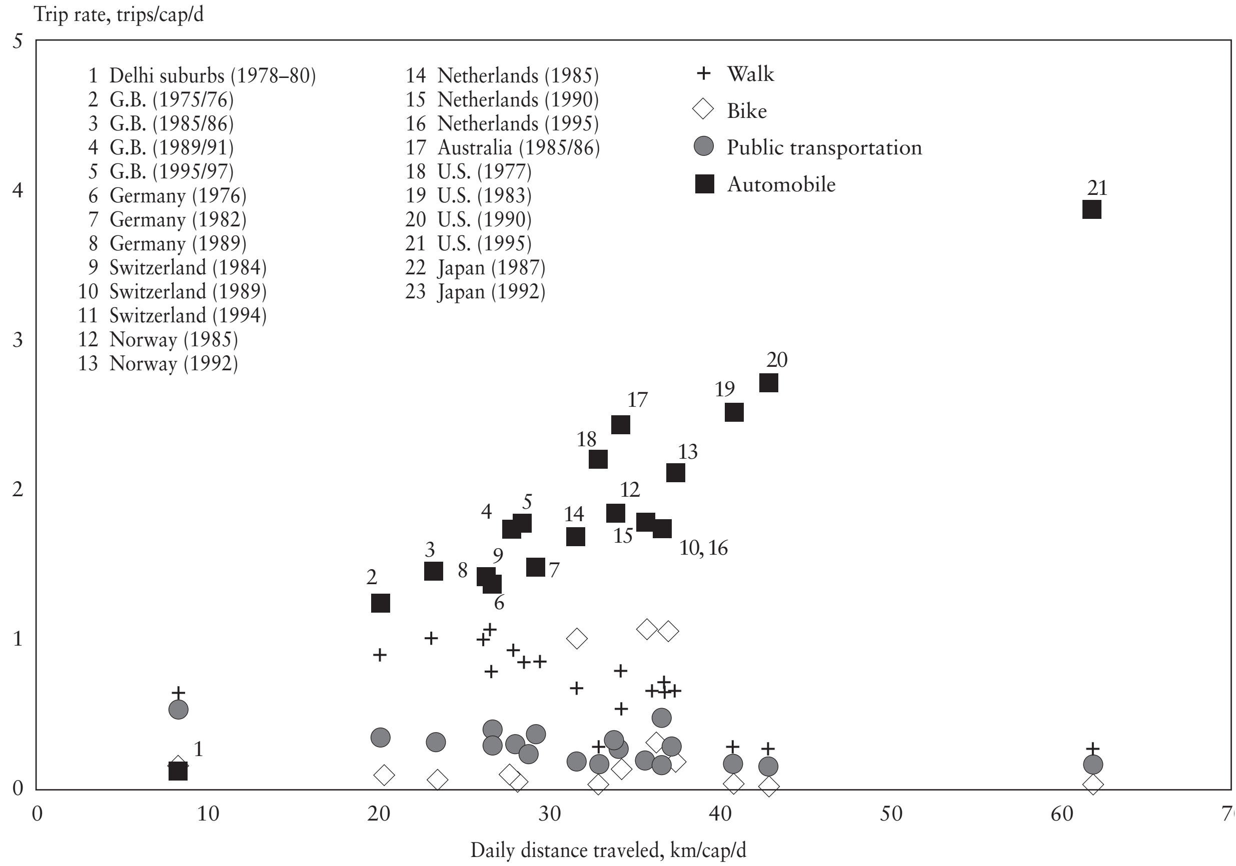
To stay within the travel time budget, traveling longer distances requires a higher mean speed. As the automobile offers the highest mean door-to-door speed of all modes in short distance transport, it therefore provides a continuously increasing number of trips as the daily distance traveled increases. At the same time, the use of low speed public transport and nonmotorized means has to decline. Figure 7 reports the trends of the continuous, nearly linear growth in automobile trips and the declining trip rate of nonmotorized and public transport modes above a daily distance traveled of 25 kilometers. The following points are noteworthy.

In contrast to the broadly consistent automobile trajectory in figure 7, the trips by nonmotorized and public modes of transport are underestimated in the 1977, 1983, and 1990 U.S. surveys, as can be seen by comparing their data points' locations with corresponding data points of other countries at similar daily distances traveled. For example, at a daily travel distance of about 34 kilometers, Americans only walk 0.25 trips per day, according to the 1977 U.S. survey (data point 18), whereas Australians (data point 17) perform more than twice as many walking trips. The same applies to trips by public transport modes. This suggests that the lower trip rate of mainly personal business trips of the 1977, 1983, and 1990 U.S. surveys in figure 2c largely results from the underreported trips by nonmotorized and public transport modes. The latter roughly add 0.5 trips per capita, reflecting the average difference in trip rate between the diary method and the recall methods in pretests of the 1995 U.S. travel survey.

Although the number of trips by mode broadly follows the same trend, quantitative differences again exist. The most significant difference can be observed at a daily distance traveled of roughly 37 kilometers, when the number of trips by automobile ranges from 1.8 (the Netherlands in 1990) to 2.5 (Australia in 1986). This difference results mainly from different levels of travel reporting in these countries. While the reported daily travel distance in the 1990 Netherlands survey is very close to those indicated by independent statistics, the Australian survey underestimated daily distance traveled by 24% (see table 2). Thus, in a consistent comparison, the Australian trip rates should be closer to the automobile trajectory. In other words, data point 17 should be slightly higher, taking into account long distance automobile trips, and at a 32% (1/(1–0.24)) higher daily distance traveled. A second, albeit weaker, factor contributing to the differences in automobile trip rate between the countries is difference in land-use settings, culture, and transport policies. Australia has a high automobile trip rate and is a country with extremely low urban population densities while the Netherlands has a low automobile trip rate and is densely populated. Additionally, the Netherlands has a range of transportation systems management measures and the bicycle pro-

[8] Estimating average user costs from the ratio of transportation expenditures, disposable income times travel money budget, and daily travel distance, including long distance (air) travel, suggests that they have remained roughly constant over the survey years and are 10 cents (1995 U.S.$)/passenger-kilometer (c/pkm) in the United States, 11 to 12 c/pkm in the Netherlands, 11 to 14 c/pkm in Great Britain, 15 to 16 c/pkm in Switzerland, 15 to 17 c/pkm in Norway, 19 to 20 c/pkm in Germany, and 23 to 24 c/pkm in Japan (OECD various years; Eurostat various years; and references listed in table 2).

FIGURE 7 Number of Trips by Mode versus Daily Distance Traveled from Table 1



Note: Above a daily distance traveled of 25 kilometers, the automobile provides all additional trips and increasingly substitutes for trips originally taken with other, slower modes. See tables 1 and A-2.

vides an average of one trip per person per day.[9] Note, however, that bicycles do not only substitute for very short distance automobile trips but also for trips made by public transport or on foot (see the comparatively lower share of these trips in figure 7). A quantification of this substitution, however, requires harmonized travel surveys. This example illustrates that differences in land-use and transportation policy can alter the number of automobile trips within a limited range but are unable to change the fundamental relationships of the transportation system expressed by the two travel budgets.

Figure 7 also shows that aggregate, independent cross-country comparisons of trip rates by mode may give a distorted view of travel patterns. U.S. residents make nearly four automobile trips per person a day, compared to only two to three trips that Western European residents make, mainly because U.S. residents travel a much longer distance per day. Thus, an increase in daily distance traveled in Western Europe will also lead to a higher level of automobile trips and a corresponding decline in trips covered by public and nonmotorized modes. However, despite the consistent trajectory for automobile trip rates over the entire range of daily distance traveled, it is unlikely that the Japanese and Europeans will ever match the high U.S. level of automobile usage. Since automobiles operate at lower mean speeds in more densely populated Europe and, especially, Japan (see table A-2), travelers need to shift to high speed transport modes at a lower automobile trip level in order to increase their daily distance traveled if they do not accept higher travel times.

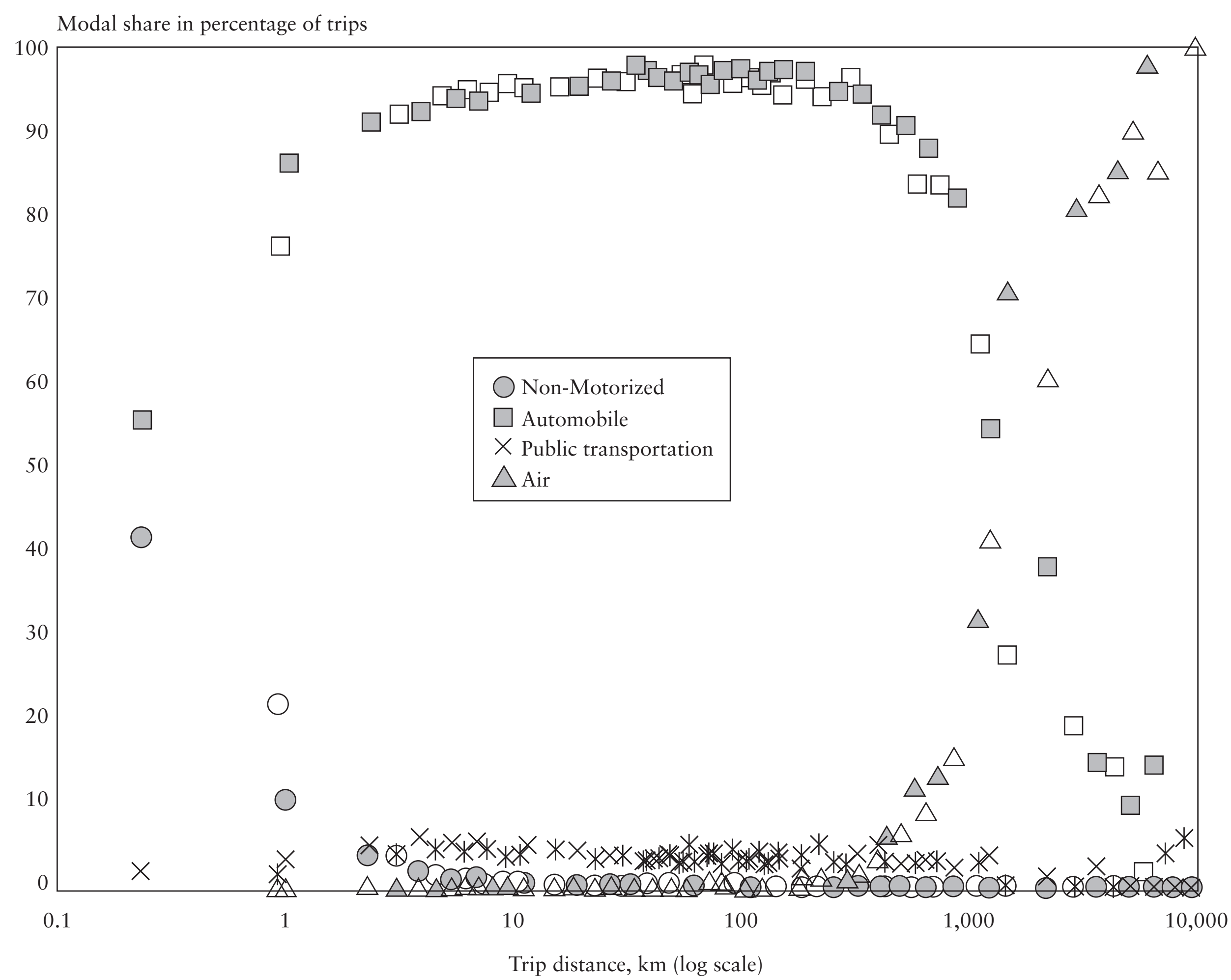
[9] Bicycle usage is high due to a number of extremely favorable conditions, such as active government policy supporting bicycle use; the country's geography, high population density and the associated constrained supply of parking spaces, plain surface area, and numerous small cities; and a relatively dry climate (Welleman et al. 1995).

Long Distance Travel

A continuous increase in daily distance traveled ultimately requires automobile usage over the entire range of trip distances when this mode offers a speed advantage over other travel modes. The dominant role of the automobile in passenger travel over a wide range of trip distances is shown in figure 8 for the United States in 1990 and 1995. The automobile already replaces walking for distances below 1 kilometer and dominates transportation supply over 3 orders of magnitude, that is, to trip distances of about 1,000 kilometers. This corresponds to one day trip by automobile (10 hours at 100 kilometers per hour (km/h). Longer distance trips are predominantly provided by higher speed aircraft. Other modes, such as bicycles and public short distance transport (mainly urban buses, commuter rail, and subways), operate in niche markets, such as in densely populated areas and for transport of children and the elderly, for example. Their maximum share is well below 10% of all trips. The share of these niche market modes can be significantly higher at short travel distances in other, Western European countries. In the Netherlands, for example, bicycles account for almost half of all trips at a distance of two kilometers.

Figure 8 roughly depicts the long term "equilibrium state" of short distance travel, as the potential for further increases in the transport system's mean speed seems nearly exhausted. Greater potential for

FIGURE 8 Modal Split (Trips) in the United States for Short and Long Distance Travel



Gray data points = 1990
White data points = 1995

Note: Trips consist of day trips and period trips (longer than one day).

Sources: U.S. Department of Transportation (1991) and Research Triangle Institute (1997) increased mean speed and thus daily distance traveled exists in long distance travel, for which aircraft can replace automobiles at distances below 1,000 kilometers. According to the 1995 Nationwide Personal Transportation Survey (Research Triangle Institute 1997), mean aircraft speed typically exceeds that of automobiles already at a distance of 400 kilometers.[10] While aircraft account for only 5% of all trips of that distance today, a continuous increase in daily distance traveled will require substitution of automobile travel by air travel at distances between 400 and 1,000 kilometers in the future, or about 15% of the 1995 total passenger traffic volume. In addition, high speed ground transportation and rapidly accessible short haul jet aircraft offer further potential for increasing mean speed at distances between 100 and 400 kilometers for intercity travel, corresponding to another 15% of the total passenger traffic volume in 1995. This trend is consistent with the projected increase in air travel at the expense of automobile travel, first in the industrialized countries and later worldwide (Schafer and Victor 2000).

Land-Use Changes

In the past, the gradual increase in mean travel speed has led to increasing trip distances in general and to significant changes in land use in particular. Using the trip distance between home and work as an aggregate indicator for land-use changes, figure 9 reports the associated increasing population spread versus daily travel distance. The upper extreme of the substantial vertical variation in mean distance to work mainly results from constrained choices of residence and transport mode (Delhi suburbs, data point 1 and Singapore, data point 24), whereas the lower extreme represents different commuting behavior of Swiss residents (data point 11).[11] While the growth relationship between daily travel distance and mean distance to work suggests that people do not chose their residence by minimizing their commuting distance, they, however, seem to experience an upper commuting boundary. Without the special cases of Delhi suburbs and Singapore, the data points for Great Britain (2 to 5) and the United States (especially 18, 20, and 21) represent the maximum average distance people are willing to commute at a given daily travel distance. This boundary seems to level off with rising daily travel distance; otherwise, commuting time would rise more sharply as observed in figure 4b. Only the introduction of a faster travel mode could provide a further significant increase in commuting distance.

The same figure may also help explain why land-use policies aiming at reducing (automobile) traffic are limited on an average, national scale. While figure 7 suggests that automobile trips can be limited by reducing daily distance traveled, figure 9 shows that the mean distance to work has increased in all countries, including the Netherlands, which has one of the highest population densities and best-practiced transportation systems management measures in the world. Perhaps most striking, the mean trip distance to work is almost 15 kilometers, higher than all other European countries examined here, including low population density Norway.

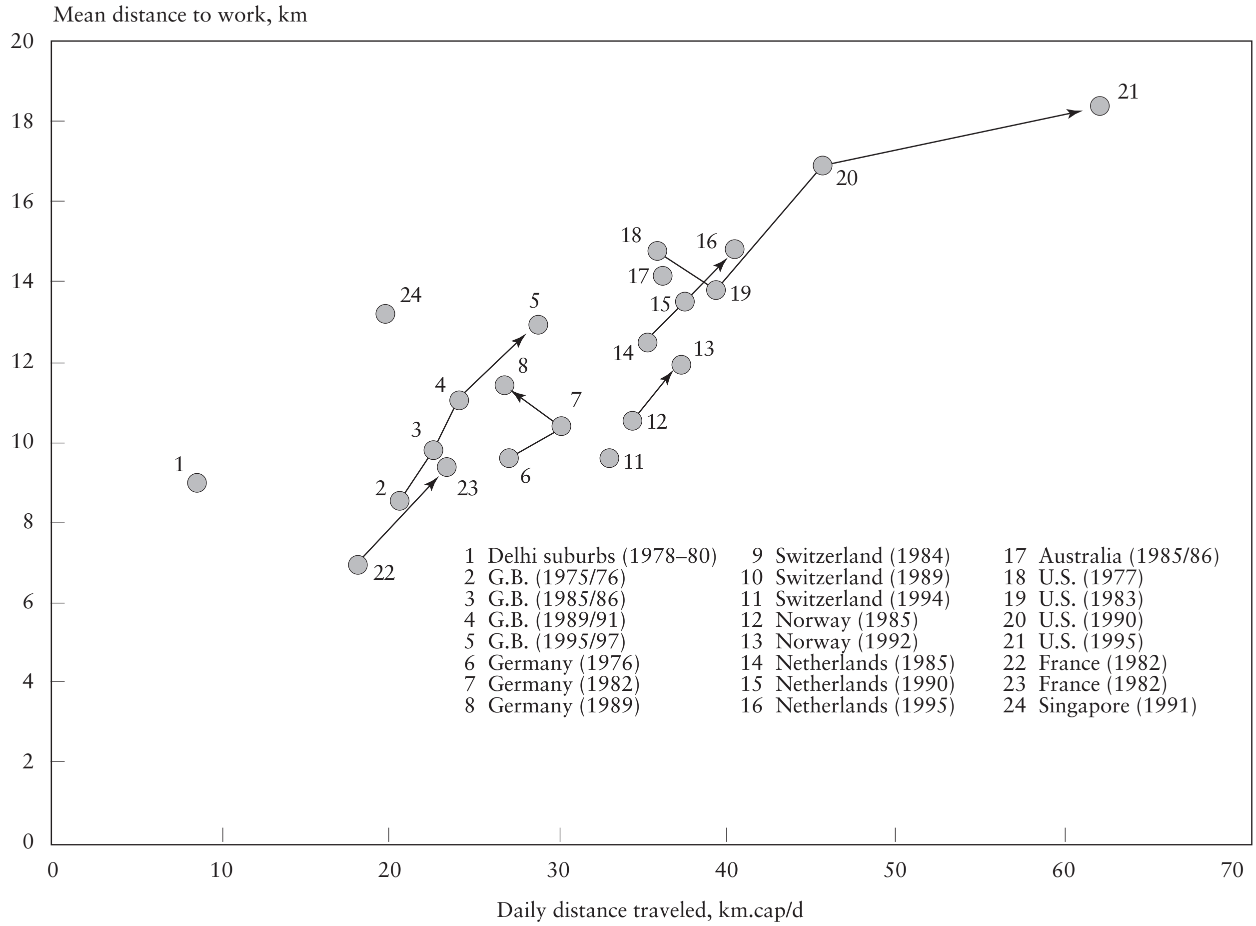
Daily Range of Human Interaction

A constant travel money budget translates rising income into rising traffic volume, especially trip distance. On an aggregate level, the relationship is determined by the mean speed of the dominant mode of transport and by the travel time budget. Figure 10 summarizes the resulting daily range of human interaction in terms of the cumulative share of trips versus travel distance. In low income rural Zambia in 1986, 90% of all trips associated with fundamental daily needs, such as fetching water or reaching work in the field, require less than 3 kilometers of travel, allowing one home-based, nonmotorized return trip within the daily travel time budget of 1.2 hours. Trip distances to collect firewood are somewhat longer and are longest for trips to rural health care centers and school. In

[10] This threshold can be also derived from a mean aircraft speed of 500 km/h and a return trip time of 3 hours from city center to airport and a mean automobile speed of 100 km/h in long distance travel.

[11] Swiss residents travel comparatively short distances to work since a considerable fraction, 40% of commuters, make two additional trips to return home for lunch (Bundesamt für Statistik 1996).

FIGURE 9 Mean Trip Distance to Work



Source: Table B-1

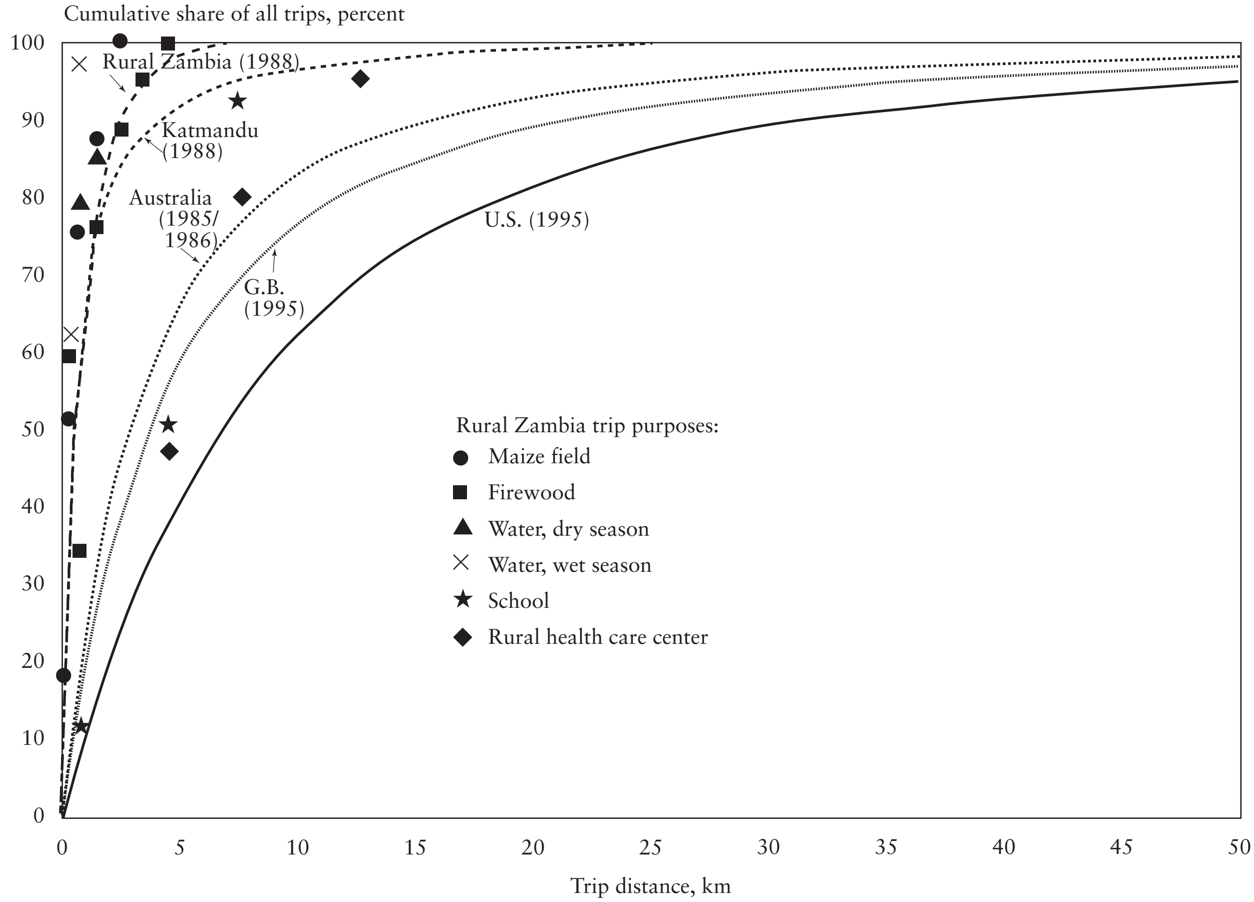
response to exogenously imposed requirements to travel long distances to school, people don't adjust: pupils reportedly do not to attend classes on a regular basis (Immers et al. 1988). Altogether, 95% of all trips are less than 5 kilometers, the mean distance a person can travel on foot within 1.2 hours.

Higher income results in longer travel distances since people can purchase faster transportation, thus enabling longer distances be covered within a given time. In the 200,000-inhabitant capital of Nepal, Katmandu, 95% of all trips evolved well below a distance of 10 kilometers in 1988. The almost two-fold mean travel speed as compared with rural Zambia results from the 25% trip share of buses and other forms of commercial public transport in Katmandu. With rising incomes and a fixed travel money budget, people increase their mean speed and daily travel distance by allocating more money to travel. In the high income, automobile-dominated United States, 95% of all trips are made within a distance of 50 kilometers, the distance that can be covered by automobile within the travel time budget. With even greater income and a continuous supply of high speed transport, 95% of all trips will be longer distance. Ultimately, in a transportation world dominated by high speed modes, the trip boundary may rise to 500 kilometers, corresponding to the distance aircraft and high speed ground transportation systems, such as magnetic levitation trains, can cover within a travel time of slightly more than one hour.

CONCLUSIONS

Aggregate travel behavior is determined largely by two budgets: the share of monetary expenditure and the amount of time that individuals allocate to transportation. However, neither budget is unique or completely stable. We have shown that time and

FIGURE 10 Cumulative Distribution of per Capita Trip Rate for All Modes by Trip Distance and Purpose



Note: The fitted curves are of the type $y = k\left[1/(-c)^b - 1/(x-c)^b\right]$
Source: See table 1.

money budgets dedicated to activities other than travel exist with at least the same statistical stability and that both travel budgets are variable, cross-sectionally and longitudinally. While probably most of these budgets' variation can be attributed to inconsistent survey methods, part of the variation may also be due to behavioral change. Given the fact that the two budgets vary differently across countries, it may be most suitable to consider them as approximately constant on only very high (world-regional, global) aggregation levels.

Both travel budgets are of very rough nature only. However, since they apply to virtually all people, independent of income, space, and time, strong regularities in aggregate travel patterns are observed when we compare cross-sectional and longitudinal data of all travel surveys, including those from the developing world. The travel money budget along with country-specific characteristics of the transportation system (land-use, prices, etc.) translates disposable income into daily distance traveled. All other patterns can be largely explained by the travel time budget. Using this approach, travel patterns of countries with very different characteristics at first glance evolve on nearly uniform trajectories. Thus, despite their only rough stability, the travel budgets offer a simple, elegant framework on the basis of which average travel behavior characteristics can be approximated on aggregate levels. Whether both budgets will remain roughly stable on highly aggregate levels over the long term depends on several factors, ranging from how society adjusts to new information and telecommunications technology to the effect of societal transformations with respect to changing age profiles and altered values. So far, however, such changes have not induced large alterations in either travel budget.

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APPENDIX

Mobility Indicators by Trip Purpose and by Major Mode of Transport for Seven Industrialized Countries

Tables A-1 and A-2 report averages for per capita trip rate, mean trip distance, and mean trip duration, as well as the resulting daily per person traffic volume and time, by trip purpose and transportation mode, from travel surveys in seven industrialized countries and four Delhi suburbs. Note that the two tables' totals for one and the same survey may differ slightly, due to their differing treatments of not-ascertained and non-responses. Also, due to rounding, numbers may not add up to totals displayed.

Since travel surveys are often based on different methods, the reader must be cautious when comparing indicators not only across countries but also across different years for the same country. This is especially true for comparisons of the 1990 and 1995 trip rates in the United States. The reported numbers give only a rough picture of people's mobility (see section on the comparability of the underlying travel surveys).

Estimate of Average Daily Travel Distances in Singapore

Because the Singapore survey did not report travel distances, these had to be estimated based on the travel time distribution and estimated mean speeds by mode. Table B-1 reports all data used for the estimation, including the estimates in detail. Also, the trip distance to work of 13.2 kilometers (figure 4b) was approximated based on a travel time of 43.2 minutes per trip and the mean speed as given in table B-1.

TABLE A-1 Indicators of Daily Mobility by Trip Purpose for Seven OECD Countries

	1975–1977					1982–1986					1989–1992					1994–1996				
	TR T/cap	TD km/T	TV km/cap	TL h/T	TT h/cap	TR T/cap	TD km/T	TV km/cap	TL h/T	TT h/cap	TR T/cap	TD km/T	TV km/cap	TL h/T	TT h/cap	TR T/cap	TD km/T	TV km/cap	TL h/T	TT h/cap
Australia																				
Work & education						0.69	12.4	8.5	0.41	0.28										
work						0.51	14.1	7.2	0.43	0.22										
business						0.02	15.1	0.3	0.39	0.01										
education						0.16	6.6	1.1	0.35	0.06										
Personal business						0.80	6.5	5.2	0.25	0.20										
Leisure						0.57	14.8	8.5	0.45	0.25										
Home						1.31	10.6	14.0	0.35	0.47										
All travel						3.37	10.7	36.2	0.36	1.21										
Great Britain																				
Work & education	0.99	8.2	8.1	0.34	0.34	0.88	9.3	8.2	0.32	0.28	0.93	10.6	9.9	0.32	0.30	0.86	11.5	9.9	0.37	0.32
work	0.56	8.5	4.8	0.33	0.19	0.51	9.8	5.0	0.35	0.18	0.53	11.1	5.9	0.34	0.18	0.44	12.9	5.6	0.40	0.17
business	0.10	20.3	2.1	0.67	0.07	0.08	28.4	2.3	0.63	0.05	0.11	27.5	3.0	0.55	0.06	0.10	29.6	3.1	0.61	0.06
education	0.32	3.9	1.2	0.27	0.08	0.29	2.8	0.8	0.21	0.06	0.29	3.2	0.9	0.17	0.05	0.32	3.7	1.2	0.25	0.08
Personal business	0.86	4.8	4.2	0.28	0.24	1.02	5.5	5.6	0.28	0.29	1.21	5.7	6.9	0.29	0.35	1.13	6.4	7.2	0.27	0.30
Leisure	0.69	12.6	8.7	0.47	0.32	0.77	11.9	9.2	0.46	0.35	0.85	13.3	11.3	0.42	0.36	0.90	13.1	11.8	0.40	0.36
All travel	2.54	8.3	21.0	0.36	0.90	2.67	8.6	23.0	0.34	0.92	2.99	9.4	28.1	0.34	1.01	2.90	10.0	28.9	0.34	0.98
Netherlands																				
Work & education						1.16	13.3	15.4	0.37	0.43	1.07	14.5	15.5	0.39	0.41	1.06	15.8	16.7	0.46	0.46
work						0.58	12.2	7.1	0.36	0.21	0.63	13.3	8.5	0.36	0.23	0.52	14.8	7.7	0.39	0.20
business						0.36	17.3	6.3	0.39	0.14	0.25	20.4	5.1	0.42	0.11	0.24	22.8	5.4	0.47	0.11
education						0.21	9.4	2.0	0.40	0.08	0.18	10.7	2.0	0.42	0.08	0.30	11.9	3.6	0.48	0.14
Personal business						1.35	5.4	7.3	0.23	0.31	1.47	5.4	7.9	0.22	0.32	1.48	6.2	9.2	0.24	0.35
Leisure						1.13	11.1	12.5	0.42	0.47	1.21	11.9	14.3	0.43	0.52	1.17	12.6	14.7	0.42	0.49
All travel						3.64	9.7	35.2	0.33	1.21	3.75	10.1	37.7	0.33	1.25	3.71	10.9	40.6	0.35	1.30
Norway																				
Work & education						1.19	12.2	14.5	0.34	0.40	1.16	13.0	15.1	0.34	0.39					
work						0.67	10.6	7.1	0.32	0.21	0.67	11.9	8.0	0.33	0.22					
business						0.18	21.1	3.8	0.46	0.08	0.11	34.9	3.8	0.64	0.07					
education						0.34	10.7	3.6	0.32	0.11	0.38	8.6	3.3	0.27	0.10					
Personal business						0.93	6.4	6.0	0.27	0.25	1.03	6.4	6.6	0.23	0.23					
Leisure						1.07	12.9	13.9	0.46	0.49	1.06	14.6	15.5	0.43	0.46					
All travel						3.19	10.8	34.4	0.36	1.14	3.25	11.4	37.2	0.33	1.08					

TABLE A-1 Indicators of Daily Mobility by Trip Purpose for Seven OECD Countries (*continued*)

	1975–1977					1982–1986					1989–1992					1994–1996				
	TR T/ cap	TD km/ T	TV km/ cap	TL h/ T	TT h/ cap	TR T/ cap	TD km/ T	TV km/ cap	TL h/ T	TT h/ cap	TR T/ cap	TD km/ T	TV km/ cap	TL h/ T	TT h/ cap	TR T/ cap	TD km/ T	TV km/ cap	TL h/ T	TT h/ cap
Switzerland																				
Work & education						1.33	8.9	13.7	0.31	0.47	1.52	8.1	16.0	0.40	0.60	1.16	10.6	12.3	0.40	0.46
work						N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.73	9.6	7.0	0.31	0.23
business						0.12	15.2	1.8	0.40	0.13	0.30	20.5	6.1	0.56	0.17	0.17	24.1	4.1	0.94	0.08
education						N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.26	4.6	1.2	0.29	0.16
Personal business						0.79	4.6	3.6	0.26	0.20	0.78	6.3	4.9	0.34	0.26	0.75	5.7	4.3	0.26	0.19
Leisure						1.00	11.9	11.9	0.33	0.38	1.14	15.8	18.0	0.58	0.66	1.34	12.4	16.6	0.54	0.72
All travel						3.35	8.8	29.2	0.30	1.04	3.45	11.5	39.8	0.45	1.54	3.25	10.2	33.2	0.42	1.38
United States																				
Work & education	1.03	13.6	13.9	0.29	0.29	1.02	13.2	13.5	0.29	0.30	1.01	15.1	15.3	0.30	0.31	1.25	16.9	21.1	0.33	0.41
work	0.57	14.7	8.4	0.31	0.18	0.60	13.7	8.3	0.30	0.18	0.62	16.8	10.4	0.33	0.20	0.76	18.4	14.0	0.35	0.27
business	0.11	28.3	3.0	0.35	0.04	0.07	35.1	2.4	0.38	0.03	0.04	44.4	1.9	0.44	0.02	0.11	32.3	3.6	0.44	0.05
education	0.35	7.4	2.6	0.22	0.08	0.35	7.9	2.7	0.25	0.09	0.35	8.5	3.0	0.24	0.09	0.38	9.4	3.6	0.25	0.10
Personal business	0.91	10.1	9.2	0.24	0.22	1.05	10.1	10.6	0.23	0.24	1.30	11.0	14.4	0.22	0.29	1.97	11.0	21.7	0.22	0.44
Leisure	0.71	12.6	12.6	0.35	0.25	0.82	19.8	16.2	0.31	0.26	0.76	20.8	15.9	0.34	0.26	1.08	17.8	19.2	0.31	0.33
All travel	2.65	13.5	35.8	0.30	0.80	2.89	14.0	40.3	0.28	0.80	3.08	14.8	45.6	0.28	0.86	4.30	14.4	61.9	0.27	1.18
West Germany																				
Work & education	1.07	10.4	11.1	0.39	0.42	1.06	12.1	12.8	0.41	0.43	0.93	12.2	11.3	0.40	0.37					
work	0.68	9.6	6.5	0.37	0.25	0.64	10.4	6.7	0.37	0.24	0.63	11.4	7.2	0.38	0.24					
business	0.15	20.0	3.0	0.47	0.07	0.17	22.9	3.9	0.54	0.09	0.11	22.9	2.5	0.52	0.06					
education	0.24	6.9	1.7	0.40	0.10	0.25	9.2	2.3	0.42	0.10	0.19	8.3	1.6	0.39	0.07					
Personal business	1.01	3.8	3.8	0.26	0.27	0.95	4.7	4.5	0.29	0.28	0.82	4.7	3.9	0.27	0.22					
Leisure	1.01	12.0	12.1	0.46	0.46	1.01	12.8	12.9	0.47	0.48	0.98	11.7	11.5	0.43	0.42					
All travel	3.09	8.7	26.9	0.37	1.14	3.02	10.0	30.2	0.39	1.19	2.73	9.8	26.8	0.37	1.02					
4 Delhi suburbs																				
Work & education						1.17	6.2	7.2	0.55	0.65										
work						0.58	9.0	5.2	0.73	0.42										
business						N/A	N/A	N/A	N/A	N/A										
education						0.59	3.3	2.0	0.38	0.23										
Personal business						0.25	2.2	0.6	0.24	0.06										
Leisure						0.07	10.1	0.7	0.56	0.04										
All travel						1.49	5.7	8.5	0.50	0.65										

T = trip; TR = mean trip rate; TD = mean trip distance; TV = mean daily per capita traffic volume; TL = mean trip length; TT = mean daily per capita travel time
For data source and exact survey years, see table 1

TABLE A-2 Indicators of Daily Mobility by Major Mode for Seven OECD Countries

	1975–1977						1982–1986						1989–1992						1994–1996					
	TR T/cap	TD km/T	TV km/cap	TL h/T	TT h/cap	V km/h	TR T/cap	TD km/T	TV km/cap	TL h/T	TT h/cap	V km/h	TR T/cap	TD km/T	TV km/cap	TL h/T	TT h/cap	V km/h	TR T/cap	TD km/T	TV km/cap	TL h/T	TT h/cap	V km/h
Australia																								
Walk							0.55	1.0	0.6	0.25	0.13	4.2												
Bike							0.13	2.5	0.3	0.25	0.03	9.9												
Public transport							0.27	11.7	3.1	0.49	0.13	23.8												
Automobiles							2.41	12.4	30.0	0.35	0.84	35.8												
All travel							3.38	10.1	34.3	0.34	1.14	30.0												
Great Britain																								
Walk	0.89	1.0	0.9	0.26	0.23	3.8	0.96	1.0	0.9	0.24	0.23	4.0	0.90	1.0	0.9	0.25	0.23	3.8	0.83	1.0	0.8	0.24	0.20	4.0
Bike	0.08	2.7	0.2	0.23	0.02	11.7	0.07	2.7	0.2	0.24	0.02	11.4	0.06	3.1	0.2	0.24	0.01	12.8	0.05	3.5	0.2	0.29	0.01	12.0
Public transport	0.35	10.5	3.6	0.56	0.19	18.6	0.30	12.0	3.6	0.59	0.18	20.4	0.28	13.8	3.9	0.62	0.18	22.4	0.25	13.8	3.5	0.61	0.16	22.6
Automobiles	1.22	12.8	15.6	0.37	0.45	34.5	1.45	12.8	18.6	0.34	0.49	37.9	1.73	13.4	23.1	0.34	0.59	39.3	1.75	13.8	24.1	0.34	0.60	40.0
All travel	2.53	8.0	20.3	0.35	0.89	22.7	2.78	8.4	23.3	0.33	0.92	25.5	2.97	9.5	28.1	0.34	1.01	27.9	2.88	9.9	28.6	0.34	0.98	29.3
Netherlands																								
Walk							0.71	1.2	0.8	0.28	0.20	4.3	0.65	1.2	0.7	0.27	0.17	4.3	0.69	1.3	0.9	0.27	0.18	4.7
Bike							0.99	3.2	3.1	0.25	0.25	12.5	1.07	3.1	3.3	0.26	0.27	12.2	1.04	3.2	3.3	0.25	0.26	12.6
Public transport							0.17	23.0	3.9	0.83	0.14	27.7	0.18	27.4	4.9	0.89	0.16	30.8	0.17	29.5	4.9	0.90	0.15	32.6
Automobiles							1.68	14.2	23.8	0.34	0.56	42.2	1.76	15.2	26.8	0.34	0.60	44.5	1.72	16.1	27.7	0.36	0.61	45.2
All travel							3.55	8.9	31.7	0.33	1.15	27.5	3.66	9.8	35.8	0.33	1.21	29.6	3.62	10.2	36.8	0.33	1.21	30.4
Norway																								
Walk							0.79	1.4	1.1	0.29	0.23	4.8	0.66	1.4	0.9	0.25	0.16	5.7						
Bike							0.20	2.1	0.4	0.21	0.04	10.1	0.20	2.6	0.5	0.21	0.04	12.7						
Public transport							0.31	32.4	10.0	0.85	0.26	38.0	0.26	27.0	7.0	0.83	0.21	32.7						
Automobiles							1.84	12.2	22.5	0.32	0.59	38.1	2.09	13.9	29.0	0.31	0.66	44.2						
All travel							3.14	10.8	34.1	0.36	1.13	30.2	3.21	11.7	37.5	0.3	1.07	34.9						
Switzerland																								
Walk							0.98	0.8	1.0	0.23	0.28	3.6	0.75	1.6	1.2	0.34	0.26	4.5						
Bike							0.35	2.0	0.8	0.18	0.08	11.0	0.33	2.9	1.0	0.30	0.10	9.6						
Public transport							0.38	12.3	5.5	0.53	0.24	23.2	0.46	17.1	7.9	0.80	0.37	21.4						
Automobiles							1.42	11.3	19.2	0.29	0.50	38.7	1.72	15.1	25.9	0.42	0.72	36.2						
All travel							1.71	13.0	26.6	0.29	0.59	45.1	3.41	10.8	36.9	0.44	1.49	24.8						

TABLE A-2 Indicators of Daily Mobility by Major Mode for Seven OECD Countries (*continued*)

	1975–1977						1982–1986						1989–1992						1994–1996					
	TR T/cap	TD km/T	TV km/cap	TL h/T	TT h/cap	V km/h	TR T/cap	TD km/T	TV km/cap	TL h/T	TT h/cap	V km/h	TR T/cap	TD km/T	TV km/cap	TL h/T	TT h/cap	V km/h	TR T/cap	TD km/T	TV km/cap	TL h/T	TT h/cap	V km/h
United States																								
Walk	0.25	0.4	0.1	0.16	0.04	2.7	0.26	0.6	0.1	0.17	0.04	3.5	0.22	1.0	0.2	0.17	0.04	6.2	0.24	0.8	0.2	0.17	0.04	4.7
Bike	0.02	5.8	0.1	0.22	0.00	26.5	0.02	3.3	0.1	0.26	0.01	13.0	0.02	3.2	0.1	0.22	0.00	14.5	0.04	2.1	0.1	0.19	0.01	11.4
Public transport	0.16	12.4	2.0	0.49	0.08	25.4	0.16	13.9	2.2	0.51	0.08	28.5	0.15	15.4	2.3	0.47	0.07	32.7	0.16	28.4	4.6	0.68	0.11	41.7
Automobiles	2.19	13.8	30.2	0.29	0.64	47.1	2.49	15.5	38.5	0.29	0.69	56.0	2.68	15.1	40.5	0.27	0.72	56.1	3.85	14.8	57.1	0.28	1.06	53.9
All travel	2.65	12.5	33.1	0.29	0.78	42.6	2.93	14.0	40.9	0.29	0.81	50.4	3.07	14.0	43.1	0.27	0.83	51.7	4.30	14.4	62.0	0.28	1.22	50.9
West Germany																								
Walk	1.05	1.1	1.2	0.30	0.31	3.8	0.84	1.2	1.0	0.32	0.27	3.7	0.77	1.5	1.1	0.30	0.23	4.9						
Bike	0.28	2.1	0.6	0.25	0.07	8.1	0.34	2.6	0.9	0.28	0.10	9.3	0.33	3.0	1.0	0.28	0.09	10.5						
Public transport	0.37	15.1	5.6	0.69	0.26	21.9	0.37	17.3	6.5	0.73	0.28	23.5	0.27	17.3	4.6	0.63	0.17	27.6						
Automobiles	1.39	14.0	19.5	0.36	0.51	38.3	1.47	14.3	21.0	0.37	0.55	38.4	1.37	14.6	20.0	0.38	0.53	38.0						
All travel	3.09	8.7	26.9	0.37	1.15	23.4	3.02	9.7	29.4	0.39	1.19	24.7	2.75	9.8	26.8	0.37	1.02	26.2						
4 Delhi suburbs																								
Walk							0.67	N/A	N/A	N/A	N/A	N/A												
Bike							0.15	N/A	N/A	N/A	N/A	N/A												
Public transport							0.53	N/A	N/A	N/A	N/A	N/A												
Automobiles							0.11	N/A	N/A	N/A	N/A	N/A												
All travel							1.45	5.7	8.5	0.50	0.65	13.1												

T = trip; TR = mean trip rate; TD = mean trip distance; TV = mean daily per capita traffic volume; TL = mean trip length; TT = mean daily per capita travel time; V = mean trip speed

For data source and exact survey years, see table 1.

TABLE B-1 Estimate of Average Daily Travel Distances in Singapore

Mode	Travel time min/cap/d	Mean speed km/h	Distance traveled km/cap/d	Reference/comments
Walk	8.9	4.4	0.65	Tanaboriboon (1986)
Bike	0.2	6.0	0.02	Relates to Indonesian cities (Tjahjati et al. 1991)
Motor Bike	1.6	32.3	0.86	Assumed to equal automobile speed
Automobile	11.5	32.3	6.19	Fwa et al. (1993)
Bus	34.5	17.0	9.78	Mean over different services and times, Ang (1993)
MRT	6.8	17.0	1.93	Assumed to equal bus speed
Others	1.2	17.0	0.34	Assumed to equal bus speed
Total	**64.7**	**18.3**	**19.77**	Resulting from above data

Sources: Travel times by mode are derived from Singapore survey (Olszewski et al. 1994, tables 7.7, 8.1, and 10.2). All mean speeds are taken from the indicated references or are estimates