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TRENDS IN TRANSPORTATION ENERGY USE, 1970-1988: AN INTERNATIONAL PERSPECTIVE*

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1. INTRODUCTION

Personal mobility and timely movement of goods have become increasingly important around the world, and energy use for transportation has grown rapidly as a consequence. Energy is used in transportation for two rather different activities: moving people, which we refer to as passenger travel, and moving freight. While freight transport is closely connected to economic activity, much of travel is conducted for personal reasons. In the OECD countries, travel accounts for around 70% of total transportation energy use. In contrast, freight transport accounts for the larger share in the Former East Bloc and the developing countries (LDCs).[1]

In our analysis, we focus on three elements that shape transportation energy use: activity, which we measure in passenger-km (p-km) or tonne-km (t-km), modal structure (the share of total activity accounted for by various modes), and modal energy intensities (energy use per p-km or t-km). The modal structure of travel and freight transport is important because there are often considerable differences in energy intensity among modes. Figure 1 illustrates the average 1988 average energy use per p-km of different travel modes in the United States (U.S.), West Germany, and Japan. With the exception of rail in the U.S., bus and rail travel had much lower intensity than automobile and air travel.[2] What is perhaps surprising is that the intensity of air travel is only slightly higher than that of automobile travel. This reflects the much higher utilization of vehicle capacity in air travel and the large share of automobile travel that takes place in urban traffic (automobile energy intensity in long-distance driving is much lower than the average over all types of driving).

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[1] The Former East Bloc includes the former East Germany. The LDCs include all countries outside the OECD and Former East Bloc.

[2] The high level of rail energy intensity in the U.S. is discussed in a later section.

The aggregate energy intensity of travel or freight transport is shaped by the relative importance of different modes and modal energy intensities, which are determined by vehicle fuel intensity (energy per km) and the utilization of vehicle capacity. An increase in the latter leads to a decline in modal energy intensity. Average vehicle energy intensity is shaped by the characteristics of old and new vehicles, the rate at which new vehicles replace old ones, and by factors that affect in-use energy intensity. These include vehicle maintenance, driving habits, and the operating environment. Traffic congestion increases idling time and the amount of distance covered at very low speed, both of which increase fuel consumption per km. Congestion is also a factor for airplanes, as crowded conditions at airports increase time spent circling.

The quality of the transport infrastructure affects both mode choice and energy intensity. Quality factors that affect mode choice include the amount of time required for a trip and the level of amenity. Poor road quality, which is common in the LDCs, leads to higher energy intensity for the vehicles that use them. Where roads are in bad condition, truck operators often choose heavy vehicles that can stand the punishment to which they are subjected.

This chapter is divided into separate sections on passenger travel and freight transport. Within each of these, we present discussions for the OECD countries, the LDCs, and the Former East Bloc. Around 64% of total world transportation energy use in 1988 was accounted for by the OECD countries, which reflects the high level of automobile ownership and use. The shares of the LDCs and the Former East Bloc were only 22% and 14%, respectively. Since 1970, however, growth has been much faster in the LDCs (5.1% per year) than in the OECD countries (2.4%) and the Former East Bloc (2.0%) (Figure 2).

For eight OECD countries and the Soviet Union, we have divided energy use as it appears in most statistics (disaggregated into road, rail, air, water) into passenger travel and freight transport components. This was accomplished by careful bottom-up analyses of data from each country. Data on p-km and t-km by mode were assembled from national transportation statistics. The data sources for the OECD countries are given in Schipper and Meyers (1992). The sources for the Soviet Union are given in Schipper and Cooper (1991). Unless noted otherwise, the source of the data in all tables and figures is the above (ongoing) research projects.

We have not assembled a comparable data base for the LDCs. The analysis presented here relies on previous research (see Meyers 1988) and reports from various countries, as noted in the text. Because our research has looked more closely at the OECD countries, and because the available data are more detailed and reliable for these countries, the bulk of the discussion concerns them.

Unless noted otherwise, we refer to *domestic* transportation only (i.e., within national boundaries). We briefly cover international air travel, but have not covered maritime freight transport. The statistics reported here refer to transport via motorized modes only. Walking and human- and animal-powered vehicles account for a significant amount of travel and freight transport in LDCs, and even a few percent of total p-km in Europe. Except where noted, energy use is measured in terms of final energy.[3]

2. PASSENGER TRAVEL

People travel for a variety of reasons, including work commutes, on-the-job trips, shopping, social visits, and recreation. The number of trips people make in a given period is conditioned by their particular life situation and preferences, their income, the cost of travel, the amount of time available for travel, and the

[3] We primarily present energy use in Joules. 1 exajoule (EJ, 10^{18} Joules) = 0.948 quads = 23.9 Mtoe. 1 megajoule (MJ, 10^6 Joules) = 948 kBtu.

amount of time needed to accomplish various trips. The distance of various trips is affected by the spatial relationship between origin-destination pairs, such as home-work or home-shopping. The choice of mode for a given trip is shaped by many factors, including the purpose and distance of the trip, availability and cost of modes, speed of modes, the quality of the travel experience, personal income, and preference. Some modes compete for certain types of travel, but not for others.

2.1. OECD Countries

The eight OECD countries ("OECD-8") for which we assembled data on travel activity and energy use by mode together account for over three-fourths of total OECD travel energy use.[4] Among these eight, the U.S. accounted for 70% of total travel energy use in 1988 (Table 1). In our discussion, we focus on three entities: the U.S., Japan, and a European six-country aggregate (Europe-6). The data include domestic travel only. In Western Europe, air travel among countries is about 60% greater than total domestic air travel (Boeing 1991). Domestic air travel in Europe has grown faster than intra-Europe international travel, however, as travelers increasingly fly on routes for which rail or car were more common in the past.

Table 1. Travel Energy Use and Activity in the OECD-8 in 1988

	Energy Use		Activity	
	(exajoules)	%	(bn p-km)	%
United States	14.50	71	5733	60
Japan	1.59	8	1081	11
Europe-6	4.44	22	2682	28
West Germany	1.36	7	659	7
United Kingdom	1.09	5	604	6
France	0.91	4	678	7
Italy	0.80	4	590	6
Sweden	0.19	1	103	1
Norway	0.09	0.4	48	0.5
OECD-8	20.53	100	9495	100

2.1.1. Energy use and activity

Between 1973 and 1988, total energy use for travel grew by 13% in the U.S., 55% in Europe-6, and 76% in Japan (Table 2). For all countries, growth in p-km has been substantial (30-40%). In the U.S., a significant decrease in aggregate energy intensity dampened growth in energy use. In Japan, increased energy intensities contributed significantly to growth in energy use, while in Europe-6 intensity increased only slightly.

[4] See Schipper et al. (1991) for further discussion of energy use in passenger travel in these countries.

Table 2. Growth in Travel Energy Use, Activity, and Aggregate Energy Intensity, 1973-1988 (total % change)

	Energy use	P-km	Aggregate intensity
United States	13	38	-18
Japan	76	40	25
Europe-6	55	44	7
West Germany	56	33	17
France	50	46	3
United Kingdom	42	41	0
Italy	85	61	15
Sweden	37	39	-2
Norway	80	56	15
OECD-8	23	40	-13

In the U.S., the ratio of p-km to GDP declined between the early 1970s and the early 1980s, but has remained about the same since 1982 (Figure 3). In Japan, domestic travel has grown more slowly than GDP since the early 1970s, while in Europe the two have increased at about the same rate. Travel increased in part because population grew. There was a decline in per capita travel after the 1973 oil embargo in the U.S. and Europe-6 (slightly), but not in Japan (Figure 4). It fell again in the U.S. during and after the 1979-80 oil price rise, but not in Europe and Japan, where the increase in retail gasoline prices was proportionately smaller than in the United States. Between 1981 and 1988, however, per capita travel in the U.S. grew considerably. In all countries, leisure and vacation-related travel has been a major source of growth.

Per capita travel is about twice as high in the U.S. as in Europe and Japan. While one might think that the average trip covers a longer distance in the U.S., given its geography, surveys suggest that this is not the case for automobile trips, which account for most travel. Rather, the number of trips per capita is higher in the U.S. than elsewhere.

Travel is affected by changes in disposable income, since people may take or curtail trips, or take longer or shorter trips, depending on their financial situation. The decline in per capita travel in the U.S. in the 1979-81 period was due to effects of the recession on disposable income and business travel as well as the influence of higher fuel prices. The change in highway vehicle-km per adult in the U.S. between 1960 and 1987 closely paralleled real disposable income per capita, corrected by a moderate fuel price elasticity of -0.1 (Ross 1989).

2.1.2. Change in mode shares

Between 1973 and 1988, the fraction of travel p-km accounted for by automobiles declined from 91% to 86% in the U.S., but increased from 43% to 53% in Japan, and from 79% to 82% in Europe-6 (Figures 5 through 7).[5] There was considerable growth in air travel in the U.S. An increase in the share of air travel

[5] We use the term "automobiles" to include "personal" light trucks (which includes vans and jeeps). Light trucks and similar vehicles are only included in the U.S. data, since such vehicles are not commonly used as passenger vehicles in Europe and Japan. For the U.S., survey data indicate that the fraction of total light trucks that are used for personal business is 65-75%.

has also occurred in Japan and, to a lesser extent, Europe. (Again, much air travel within Europe is between countries and is not counted in the statistics we report here.) Air travel still accounts for a very small fraction of total travel, but growth in its share has major implications for energy use because it is more energy-intensive than other modes.[6] The volume of travel by rail and bus remained roughly constant in the U.S., Japan, and Europe, but their shares of total travel declined considerably. They are still important modes in Japan, but are relatively insignificant in the United States.

Growth in the number of cars in use has been considerable in Japan (from 15 to 31 million between 1973 and 1988) and Europe-6 (from 61 to 98 million). Even in the U.S., where per capita ownership was already at the 1988 European level in 1970, the number of automobiles grew by 50% between 1973 and 1988. Increased car ownership has led to reduced use of bus and rail and higher overall travel as well (Webster et al. 1986).

Demographic and social factors have boosted car ownership. In the U.S., the coming of age of the "baby boomers" caused a large growth in the driving age population. The percentage of eligible drivers with a driver's license also grew, in large part because of the movement of women into the labor force. In 1969, 39% of adult women were employed, and 74% of them had licenses. By 1983, 50% were employed, and 91% of them had licenses (Ross 1989).

Annual distance traveled per car has fluctuated in the U.S., but was about the same in 1988 as in 1970 (Figure 8). In Europe-6, there was a decline between 1970 and 1974, but a slight increase since then (mainly due to growth in the United Kingdom).[7] The average distance declined in Japan through 1981 because private cars, which are driven less distance than company cars and taxis, gradually accounted for a larger share of the total vehicle fleet; but it has increased since then as private cars came to be driven more frequently and farther. Distance per car might have increased more had there not been growth in household ownership of second or even third vehicles, which tend to be used less than the primary car. In the U.S., kilometers (km) per licensed driver increased more than did km per automobile.

2.1.3. Energy intensities

The structural change described in the preceding section had only a modest net effect on aggregate travel energy intensity in the U.S. and Europe-6, but contributed significantly to an increase in intensity in Japan (Table 3).[8] In West Germany, which also had a sizable increase in aggregate energy intensity, most of the growth was due to an increase in modal energy intensities rather than the structural change away from rail and buses.

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[6] One reason why air travel accounts for a much higher fraction of total travel volume in the U.S. than in Japan and Europe is because destination points in the U.S. are so much farther apart (especially with major cities concentrated on the Atlantic and Pacific coasts).

[7] The increase in the U.K. can be largely explained by the rise in the use of company-provided cars and taxation policies that favor use of company cars (Ferguson and Holman 1990).

[8] The method used to decompose change in aggregate energy intensity is rooted in the use of fixed-weight or Laspeyres indices. For further details see Schipper et al. (1991).

Table 3. Decomposition of the Change in Aggregate Travel Energy Intensity, 1973-1988 (total % change)

	Change in aggregate intensity	Decomposition		
		Structure	Intensity	Interaction[a]
United States	-18	3	-15	-6
Japan	25	20	5	0
Europe-6	7	4	4	-1
West Germany	17	5	12	0
Sweden	-2	4	-2	-4
Norway	15	14	7	-6
France	3	2	2	-1
United Kingdom	0	5	-3	-2
Italy	15	4	12	-1
OECD-8	-13	4	-14	3

[a] Because the structural and intensity variables interact in a nonlinear fashion, the two effects do not sum to the total change in aggregate intensity.

Automobiles. Automobile energy use per p-km declined by 18% in the U.S.; increased in Japan, West Germany, Italy, and Norway; and remained about the same in the rest of Europe between 1973 and 1988. A decline in the number of passengers per trip (partly due to a decrease in family size and increased numbers of cars per household) contributed to growth in energy intensity. In the U.S., the average load declined from 2.2 persons per car in 1970 to 1.7 in 1983 and 1.5 in 1990. A decline also occurred in Japan (2.2 to 1.8), West Germany (1.7 to 1.5), Italy (2.0 to 1.7), and elsewhere in Europe.

Average fuel use per km fell more than did use per p-km. In the U.S. it declined by 29% between 1973 and 1988 (Figure 9). The fuel intensity of cars fell by 33% (to 12 liters/100 km, or 20 mpg), but this was balanced somewhat by an increase in the use of light trucks as passenger vehicles. The share of personal light trucks in total automobile vehicle-km increased from 9% to 18%. The fuel intensity of light trucks fell by 19% (to 18 liters/100 km, or 13 mpg), but remained well above that of cars.[9]

In Europe and Japan, there was little change in automobile fleet fuel intensity. While there were technical improvements in new cars that contributed to higher efficiency, this was counterbalanced by an increase in the size and power of automobiles and deterioration in operating conditions (more traffic congestion). In West Germany, for example, the fraction of all automobiles that had engine displacement of 1500 cm^3 and above increased from 40% in 1973 to 60% in 1987, and the average horsepower rose from 59 to 77 (DIW 1991). By 1990, more than 80% of all cars sold in West Germany could reach 150 km/hr or greater, and 30% of them could surpass 180 km/hr. The average weight of an Audi 80 increased from 855 to 1050 kg between 1970 and 1991, while that of an Opel Kadett grew from 685 kg in 1963 to 865 kg in 1991. The average size of engines in the United Kingdom (U.K.) and France also rose. In the U.K., growth in use of company cars has contributed to an increase in car size (Potter 1991). As Figure 10 illustrates for the U.K., the trend in Europe toward larger cars had begun in the 1960s.

[9] Some of the improvement for light trucks reflects a shift within the light trucks category to smaller vans and pickup trucks.

The turnover of the fleet had a different effect in the U.S. than in Europe and Japan. In the U.S., the sales-weighted average fuel intensity of new automobiles (including all light trucks) declined by nearly 50% between 1973 and 1982 (Figure 11), so turnover of the stock strongly depressed fleet average fuel intensity. In Europe and Japan, the fuel intensity of new cars improved much less than in the U.S., in part because it was already much lower in 1973, and in part because growth in vehicle size and power offset technical efficiency gains.[10] Test data show some decline in new car fuel intensity since 1975 in several countries, but intensity has increased since 1982 in Japan and since 1985 in West Germany as average size and power has risen. The continued decline in France and Italy is partly due to growing penetration of diesel-fueled cars, which have lower fuel intensity than comparable gasoline-fueled cars.[11]

In the U.S., a shift to smaller cars contributed only slightly to the decline in new car fuel intensity after 1975. Average interior volume hardly changed between 1978 and 1988. (Since 1980, compacts have gained share at the expense of sub-compacts, but mid-size cars have also lost share.) Most of the change came from a decrease in fuel intensity within each size class. The average power of new cars fell by 25% between 1975 and 1980, contributing to a decline in intensity, but has increased since 1982, pushing intensity upward (Heavenrich and Murrell 1990).

Fuel economy improvements have come from three main sources: propulsion-system engineering, other elements of vehicle design, and performance trade-offs. In the U.S., engineering improvements are exemplified by the remarkable 36% increase in power per unit of engine size between 1978 and 1987. The ratio of vehicle weight to interior volume was reduced by 16% in this period, and reductions in air drag and rolling resistance (through introduction of radial tires) have also contributed to fuel economy improvement. Acceleration performance decreased in the 1980-82 period, which contributed to a decline in fuel intensity, but it has progressively improved since then.

The above discussion refers to passenger cars, but a significant factor in the U.S. has been an increase in the popularity of light trucks for personal use. The share of light trucks (of which 65-75% are for personal use) in total sales of light-duty vehicles rose from 19% in 1975 to 30% in 1988. Since light trucks have higher average weight and power than cars, this shift has somewhat balanced the decline in fuel intensity of new cars.

Worsening traffic congestion has pushed upward on the actual fuel intensity of the automobile fleet in most OECD countries. In the early 1980s, the U.S. Environmental Protection Agency (EPA) determined that vehicles in use achieved 15% lower fuel economy than the nominal vehicle rating based on the driving cycle test (Westbrook and Patterson 1989). Some observers believe that the discrepancy has grown to as much as 25% as a result of increasing urban congestion, increasing share of urban driving (the EPA rating assumes 55% of vehicle-km are urban), higher speeds on open highways, and higher levels of acceleration in actual use than in the test. It may also be the case that the average length of urban trips has decreased, and shorter trips use more fuel per km than longer ones (because the engine is cold for much of the trip).

In the 1970s, the reduction of highway speed limits in the U.S. dampened fleet fuel intensity. In West Germany, conversely, the lack of speed limits on expressways has contributed to demand for high-powered cars and high driving speeds. While there are speed limits on motorways in the rest of Western Europe, relatively few drivers keep to these limits. Even when limits are observed, the fact that

[10] Because of the difference in testing procedures, and differences in calculating averages, we caution against comparing new car fuel economy too exactly among countries. The trends over time within a country, however, give a valid picture for test performance, if not actual performance on the road.

[11] The diesel share of total automobiles (not only new ones) in France and Italy rose from 1% or less in 1970 to 12% and 14% respectively in 1988.

increasing numbers of cars are built to attain speeds in excess of 150 km/hr reduces the fuel economy of these cars at "ordinary" speeds (60-80 km/hr) (Dolan 1991).

Air travel. Energy use per p-km in domestic air travel declined considerably in the U.S., Western Europe, and Japan between 1973 and 1988 (Figure 12). The U.S. decline—a remarkable 50%—exceeded that of Europe and Japan.[12] An increase in load factor (passengers per available seats) contributed to the drop in energy intensity. In the U.S., load factor rose from 54% of available seats in 1973 to 63% in 1988. Load factors also increased in Western Europe and Japan. (For example, Air France reports that its system load factor rose from 53% in 1973 to 62% in the late 1980s.)

Decline in energy use per seat-km was the major factor. New planes with significantly lower fuel intensity entered the fleets in large numbers. They were on average larger than those they replaced, and larger planes tend to use less energy per seat-km than smaller planes with comparable technology.[13] There was also considerable decline in fuel intensity in planes of a given size (Gately 1988). Technological changes included more fuel efficient engines, improvement in aircraft structural efficiency (lighter airframes), and improved lift/drag performance. Airlines also retrofitted old planes with new engines (often for noise abatement reasons), and added seats. Lastly, airlines and airports instituted various operational improvements. As a result of these factors, energy use per seat-mile of U.S. jet aircraft declined by one-third between 1973 and 1988.

Bus and rail travel. Bus and rail travel combines urban transit and intercity service, with the former being much more energy-intensive than the latter. Bus energy use per p-km increased in Western Europe and the U.S., and changed little in Japan. In the U.S., energy use per vehicle-km increased by nearly one-third for transit buses between 1973 and 1988, reflecting operation in increasingly congested conditions.[14] Energy use per p-km increased even more due to a decline in average load factor. In Western Europe, congestion and declining ridership due to rising acquisition and use of cars increased the intensities of bus travel. In the U.K., there has been a shift to smaller buses (which use more energy per seat-km) since deregulation in 1986.

The energy intensity of rail travel declined slightly in Western Europe in the early 1970s, but has changed little since then. Rail energy intensity in Japan, which is much lower than elsewhere due to high levels of ridership, has remained about the same since 1970. The intensity declined somewhat in the U.S. between 1976 and 1981, but has risen since then. The increase is due to the growth in urban rail as a share of total rail p-km as new fixed rail systems have gone into service in several large metropolitan areas. Rail energy intensity is several times higher in the U.S. than in Europe and Japan (see Figure 2) due in part to the relatively large share of urban and commuter rail in total rail travel. These types of rail systems are more energy-intensive than intercity rail because there are more trains running more frequently at a lower average speed and with lower load factors (especially during non-peak hours).

2.1.4. The effect of fuel prices on intensity trends

Although we have not performed a formal analysis of the impact of fuel price changes, some observations may be made. As shown in Figure 13, the increase in real gasoline prices in the 1970s was fairly modest in most countries.[15] Prices increased more in 1979-1981, but declined thereafter. In Western Europe and

[12] Data supplied by several European airlines confirmed that this trend is also seen in international travel. Indeed, the long-range aircraft used by European and Japanese airlines for intercontinental travel have significantly lower energy use per p-km than do smaller planes flown on domestic routes.

[13] For U.S. aircraft, available seats per plane increased from 111 in 1970 to 148 in 1980 and 161 in 1987.

[14] School buses, which have low energy intensity due to their high load factor, constitute a significant portion of bus travel in the United States. The U.S. energy intensity would be higher if they were excluded.

[15] Prices from 1980 onward are taken from the International Energy Agency's quarterly publications, *En-*

Japan, car buyers sought larger and more powerful cars, but the rise in prices and pressure from governments concerned about oil imports caused manufacturers to incorporate technical improvements that kept new car fuel intensity from rising, and in fact caused it to decline. The fall in real price after 1981-82 had an impact, however, especially in Japan, where new car fuel intensity began to rise. In the U.S., the impact of rising prices is difficult to judge, since the government's fuel economy standards were an influential intervention in the market (Greene 1990). The steady decline in real price since 1981 certainly contributed to lessened interest in fuel economy on the part of buyers. What is striking is that the real price of gasoline in 1988 in most countries was close to its 1970-1973 level.

2.1.5. Comparing travel energy intensity among countries

Although aggregate travel energy intensity in the U.S. declined considerably between 1973 and 1988, at 2.5 MJ/p-km it remained much higher than in the other OECD countries. The 1988 energy intensity of other countries can be divided into three tiers. "Low intensity" (1.3-1.4 MJ/p-km) countries include Japan, Italy, and France. "Medium intensity" (around 1.8) countries include Norway, Sweden, and the U.K.; West Germany was "medium high" at 2.1.

Differences in aggregate travel energy intensity are due to variation in the modal structure of travel as well as in modal energy intensities. Figure 14 shows the actual 1988 travel energy intensity in each country and what it would have been if each country had a modal structure equal to the OECD-8 average. In this hypothetical case, the U.S. intensity declines, intensities in Western Europe increase slightly, while intensity in Japan increases considerably. The remaining difference among the countries is due to variation in the energy intensity of each mode, especially automobiles.

If each country had a modal structure similar to that of Japan, but with their own modal energy intensities, total OECD-8 energy use for travel in 1988 would have been 11% lower than it actually was. If the U.S. modal mix were imposed on all eight countries, total energy use for travel would have been 7% higher than it actually was. (Japan and the U.S. have the lowest and highest shares of energy-intensive automobile and air travel of total travel.) The same experiments carried out in 1970 would have yielded 25% lower and 8% higher energy use respectively, indicating that the differences in modal mix have decreased over time.

Per capita energy use in automobiles is around three times as high in the U.S. as the Europe-6 average. If U.S. automobiles in 1988 had averaged the same fuel intensity as European ones, the U.S. per capita value would have been about twice that of Europe-6 (Figure 15). If U.S. automobiles had been driven the same distance per year as European ones, U.S. energy use would have been about two and one-half times that of Europe. If both of the above had been the case, the U.S. value would have been only about 50% greater than that of Europe. The remaining difference is due to the higher level of automobile ownership per capita in the United States. While the U.S. remains above Western Europe in terms of automobile fuel intensity, average distance, and ownership, the differences have narrowed. Whereas in 1973 automobile energy use per km was twice as high in the U.S. as in Europe-6, by 1988 it was only about 50% higher (refer back to Figure 9); and part of the difference is due to the popularity of light trucks in the U.S.

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ergy Prices and Taxes. For the years before 1980, we used a compilation of prices carried out by Ms. Pat Baade of the U.S. DOE Energy Information Administration. While these data were never officially published, they are well explained and referenced, and map almost perfectly into the IEA series, which begin in 1978. Prices were converted to real local (1980) currency and then converted to U.S. dollars using 1980 purchasing power parities, as given by the OECD.

2.2. Developing Countries

Lack of reliable data limits our ability to analyze change in travel energy use in the LDCs. On the activity side, complete data on p-km are either not available or of questionable accuracy. On the energy side, time-series disaggregation of transport energy use between travel and freight transport is rare, and is more difficult than in the OECD countries because it is not uncommon for freight trucks to use gasoline. In addition, significant numbers of cars and trucks are used for both passenger travel and freight, often simultaneously.

Despite the lack of data, it is evident that per capita travel has increased considerably in the LDCs. Chinese data show growth in p-km per capita averaging nearly 11% per year between 1975 and 1988, but the 1988 level of 570 was still quite low even by LDC standards (ERI 1989).[16] In much wealthier South Korea, the data show a three-fold increase from 970 to 3,200 p-km/capita between 1970 and 1987 (KEEI 1989). In Brazil, per capita road travel, which accounts for over 90% of estimated total travel, increased from 1,600 p-km in 1973 to 3,700 p-km in 1985 (Geller and Zylbersztajn 1991).

Buses and, in a few countries, rail, still account for a large majority of motorized travel in most LDCs. In South Korea, for example, the data show a decline in the shares of buses and rail between 1972 and 1987, but they still accounted for 60% and 24% of total travel in 1987, respectively, while cars (including taxis) accounted for only 14%. In China, rail still dominates travel, but its share of total p-km declined from 70% to 53% between 1970 and 1988, while the highway share increased from 23% to 41%. (The available data do not distinguish between buses and automobiles, but it is clear that buses account for a large share of total highway p-km, as ownership of private vehicles is very low.) In India, the share of road modes in total travel (78%) is larger than in China, and has grown since the 1970s. In most countries, there has also been considerable growth in the number of cars (Figure 16).[17] In much of Asia, there has been rapid growth in mopeds and motorcycles. Lastly, domestic air travel has increased considerably in large countries in the past decade, in part because of lack of good highway or rail networks. In China, for example, the share of air in total travel grew from only 0.2% in 1970 to 3.4% in 1988.

The structure of travel in most LDCs shows a highly skewed pattern, with most people relying on bus, rail, or non-motorized modes, while the wealthier use cars. Conventional and collective taxis (jitneys) are also important in most cities. Historically higher income and urbanization levels in Latin America and the Middle East have led to greater penetration of cars than in Asia and Africa. Business, government, and taxi operators own a considerable share of total automobiles in many LDCs.

Change in the energy intensity of travel modes in LDCs is difficult to assess. It is likely that the nominal energy intensity of new cars has declined in most LDCs in keeping with international trends in vehicle technology (Meyers 1988).[18] In Brazil, for example, the transition from gasoline- to ethanol-fueled cars has reduced average fuel intensity, since ethanol permits the use of engines with higher compression ratio. In addition, there has been reduction in the fuel intensity of both new gasoline- and ethanol-fueled cars. Test data from manufacturers show a 10% reduction between 1983 and 1987 in the fuel intensity of new alcohol-fueled cars, which accounted for the majority of new cars sold in the mid-1980s. There has also been considerable improvement in automobile energy efficiency in India, where the protected industry historically produced very fuel-inefficient cars. The opening of the automotive

[16] China's statistics on travel probably reflect the actual situation fairly well, since the number of cars is very low.

[17] The data are based on official vehicle registration statistics, as given in national sources. These overstate the actual number of cars in use in some cases.

[18] Compared with Western standards, cars in LDCs are smaller, less powerful, and less likely to have energy-intensive features such as automatic transmission and air-conditioning.

industry to foreign collaboration played a major role in this change.

It is probable that in many if not most LDCs, the trend toward higher efficiency of new cars has been countered by a gradual worsening of urban traffic conditions and, in some cases, a shift to larger, more powerful cars. Increasing congestion has probably had a similar effect on the energy intensity of buses.

2.3. Former East Bloc

Despite the huge size of the former Soviet Union, the level of per capita travel (about 6,000 p-km in 1988) was half that of Japan, and one-third that of Western Europe. Growth in travel averaged 4.5%/year between 1973 and 1988, slower than the 7.5%/year between 1960 and 1973. Rail and bus dominate passenger travel (with 32% and 28% of total p-km in 1988, respectively), but automobile and air travel have grown twice as rapidly as total travel, and thus increased their shares to 21% and 12% by 1987 (Figure 17).

The growing shares of automobile and air travel have contributed to an increase in aggregate travel energy intensity. Since the early 1970s, however, the intensity of automobile travel has declined as more small cars entered the fleet. If used under Western conditions, we estimate that the energy intensity of the Soviet car fleet would be around 9 liters/100 km, or 26 mpg, which is not far above that of Western Europe.[19] But Soviet cars have considerably less power than Western ones. The actual on-the-road energy intensity of Soviet cars appears to be 11-12 liters/100 km (20-22 mpg) due to the poor quality of fuel, vehicle maintenance, roads, and parts.

The energy intensity of Soviet air travel declined by about 10% since the early 1970s due mainly to an increase in aircraft size. Load factors have remained constant at nearly 100%. For this reason, the energy use per p-km of Soviet air travel is low compared with OECD countries, even though energy use per seat-km is about 50% higher than that of aircraft fleets in the West.

For Poland, the total level of travel appears to be around 6,000 p-km/capita, which is about where Western Europe was in 1970 (Leach and Nowak 1990). Domestic air travel is far less important in Poland than it was in the Soviet Union, but automobile travel is higher. The number of cars grew by nearly 13% per year between 1970 and 1987. At 110 cars/1000 people, ownership was twice that of the Soviet Union.

2.4. International Air Travel

International air travel throughout the world increased nearly six-fold between 1970 and 1990—twice as much as world domestic air travel.[20] The share of international travel in total air travel rose from 30% in 1970 to 44% in 1990. The largest absolute growth in international air travel has been in trans-Atlantic travel, but the relative increase has been much larger for trans-Pacific and Europe-Asia travel (Figure 18). International travel within Asia (especially connections with Japan) has also grown significantly.

Most international travel markets are more competitive than domestic markets, so air carriers tend to use the newest, most efficient equipment on these routes. The longer distances of most international routes also favor use of more modern, larger aircraft. As a result, these routes tend to be less energy-intensive than domestic ones. In addition, longer flights are less energy-intensive than short ones because the fuel used in take-off and ascent is a smaller share of overall fuel use.

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[19] Large official cars account for a considerable share of the Soviet fleet. If they were removed, the average fleet intensity would be lower.

[20] Data in this section are from Boeing (1991).

3. FREIGHT TRANSPORT

The usual indicator of freight transport activity is tonne-km (t-km), which measures the weight of freight and the distance it is moved. (It does not consider the characteristics and value of the freight, however.) The distance of trips is shaped by the physical geography of a country, as well as by the geographic patterns of economic production and consumption. The total tonnage of freight shipped in a country depends on the magnitude and nature of agricultural, mining, and manufacturing output. As an economy evolves from economic output centered on agricultural and mining products to one in which manufactured goods predominate, the ratio of tonnage to GDP declines because manufactured goods have a higher value per tonne. Shipment of fuels for domestic use and export comprises a significant share of total freight t-km in many countries, so change in the mix of primary energy sources can affect freight transport.

The mode choice for freight shipments is strongly shaped by the type of freight to be moved. Mining and agricultural products, which have low value per tonne, are often transported via rail or water, both of which are much less energy-intensitive than trucks. As economies develop, intermediate and final goods take on a greater share of freight. Since trucks offer greater flexibility for such shipments, they tend to assume an increasing role in freight transport over time. Other factors affecting mode choice include the nature of the transport network (roads, rail, waterways), cost factors, the distance of trip, and time requirements.

The data reported in this section refer to domestic freight shipments. Fuel purchased by ships engaged in international commerce is counted as "marine bunkers" and is not included in national energy consumption.

3.1. OECD Countries

We organized data on freight transport energy use and activity by mode in the 1970-1988 period for eight OECD countries.[21] Among these eight, the U.S. accounted for 62% of total energy use in 1988 (Table 4). Europe-6 accounted for 24%, Japan for 14%.

[21] We have not included t-km shipped and energy used by oil and gas pipelines due to lack of time-series data for most countries. In the U.S., the amount of natural gas shipped in pipelines in 1985 was estimated to be equal to around 7% of total freight t-km (Ross 1989).

Table 4. Freight Transport Energy Use and Activity in the OECD-8 in 1988

	Energy Use (exajoules)	%	Activity (bn t-km)	%
United States	5.58	62	4100	74
Japan	1.21	14	483	9
Europe-6	2.14	24	947	17
West Germany	.42	5	265	5
United Kingdom	.51	6	209	4
France	.53	6	171	3
Italy	.54	6	229	4
Sweden	.07	1	52	1
Norway	.06	1	23	4
OECD-8	8.93	100	5530	100

3.1.1. Energy use and activity

Energy use for domestic freight transport increased by 40%, 33%, and 48% between 1973 and 1988 in the U.S., Japan, and Europe-6, respectively (Table 5). Growth in total freight t-km was less than this, so aggregate intensity rose somewhat. Aggregate intensity rose considerably in Italy, Sweden, and France, where there was no change in activity and a large increase in intensity due to a substantial decline in the share of rail. The strong shift in the French primary energy mix away from oil contributed to both of these phenomena.

Table 5. Growth in Freight Transport Energy Use, Activity, and Aggregate Intensity, 1973-88 (total % change)

	Growth in energy use	Tonne-km	Aggregate intensity
United States	40	34	4
Japan	33	18	12
Europe-6	48	32	12
West Germany	17	24	-6
France	44	-2	46
United Kingdom	29	51	-14
Italy	134	77	32
Norway	43	34	7
Sweden	46	12	31
OECD-8	41	32	6

The ratio of freight activity to GDP has declined since the early 1970s in Japan, and since 1980 in the U.S. (Figure 19). There has been essentially no change in Europe-6. Despite the decrease in the ratio in the U.S., it remains around three times as high as in Western Europe or Japan. The sheer size of the U.S. is partly responsible for this high level. There is also considerable shipment of bulk materials

(including grain and coal for export) over long distances. Another reason—also related to size—is that various types of freight activity that are international (and therefore not counted in domestic activity) for Europe and Japan take place domestically within the United States.

The ratio of total freight tonnage to GDP is probably falling in most countries, given the change in materials utilization that has taken place. West German data show a decline over time in the average number of tonnes per trip (DIW 1991). But there are more frequent small shipments in many cases, so total freight km has likely grown faster than GDP.

3.1.2. Modal structure

There has been a slight shift of freight t-km from rail to trucks and ships in the U.S. (Figure 20). In Japan and Europe, there was a major shift from rail to trucks. The share of freight activity in trucks increased from 35% to 51% in Japan and from 54% to 63% in Europe-6 (Figure 21). The share of rail declined from 14% to 5% and 28% to 18%, respectively. A large drop in the share of rail in France contributed strongly to the Europe-6 trend.

The increase in the role of trucks reflects change in the composition of freight toward products for which trucks have inherent advantages over competing modes. In addition, the growing use of "just-in-time" delivery in manufacturing has favored trucks.

Ships and barges are an important freight transport mode in the U.S., where agricultural and mining products rely heavily on them, and in Japan, which has considerable inter-island shipping. Ships are relatively less important in Europe, though there is considerable freight moved by ship between countries.

3.1.3. Energy intensities

Trucks. The energy intensity of freight trucking (energy per t-km) increased by about 13% in the U.S. between 1973 and 1988 (Figure 22). It declined by 16% in Japan, and increased slightly in Europe-6. In Japan, intensity rose through 1976, but fell sharply in the 1977-80 period.

In the U.S., the data show that average fuel use per km was the same in 1988 as in 1973 for both medium and heavy (tractor-trailer) trucks. Improvement in technical efficiency was apparently offset by increase in operating speeds on intercity highways and increasing traffic congestion in urban areas. The overall increase in energy per tonne-km was probably due to factors related to the operation of trucking fleets and the nature of freight carried. Despite deregulation of the trucking industry, there is evidence that there was an increase in empty backhauls, resulting in reduced tonnage per distance traveled (Mintz 1991). In addition, it appears that the weight carried per volume of truck capacity declined. One reason for this is increased packaging for many goods (packaging is light-weight but takes up truck capacity).

Rail. Between 1973 and 1988, the final energy intensity of rail freight transport declined by 34% in the U.S., by 26% in Europe-6, and by 58% in Japan, where rail activity fell considerably (Figure 23). Electrification accounts for part of the decline in Japan and Europe. (The efficiency of a diesel locomotive is 20-25%, that of electric traction 90%; so replacement of diesel by electricity causes a significant decline in final energy intensity.) Other factors were the use of stronger locomotives and the trend to cutting unprofitable lines, which presumably supported smaller trains with less than full loads. The large decline in Japan in the 1987-88 period is apparently due to a radical restructuring of the rail industry that took place (Kibune 1991).

3.1.4. Decomposing change in freight energy intensity

Between 1973 and 1988, aggregate freight transport energy intensity increased by 4% in the U.S. and by 12% in Japan and Europe-6. Structural change toward trucks contributed strongly to the increase in Japan, more than offsetting decline in energy intensities (Table 6). It accounted for all of the aggregate intensity increase in Europe-6.

Japan, West Germany and the U.K. had a net decline in modal energy intensities. The U.S. showed little change, as the increase in intensity for trucks was offset by decreases in other modes. In Europe-6, the countries averaged out to almost no change. France, Italy, and Sweden had increases in the modal intensity of trucks, which more than offset decreases in the intensity of other modes.

Table 6. Decomposition of Change in Aggregate Freight Transport Energy Intensity, 1973-1988 (total % change)

	Change aggregate intensity	Decomposition		
		Structure	Intensities	Interaction
United States	4	3	1	0
Japan	12	30	-13	-5
Europe-6	12	13	-2	1
West Germany	-6	15	-20	-1
Sweden	31	4	27	0
Norway	7	15	-5	-3
France	46	22	18	6
United Kingdom	-14	1	-12	-3
Italy	32	15	14	3
OECD-8	6	8	-2	0

3.2. Developing Countries[22]

Energy use for freight transport has risen significantly in the LDCs. In China, the ratio of freight tonne-km to GDP declined slightly between 1978 and 1988, perhaps reflecting some lightening of economic output. Data for South Korea show little change in the ratio between 1970 and 1987. Brazilian data, on the other hand, show a significant increase between 1973 and 1985; greater transport of agricultural and mineral products from the Amazon region may have played a role.

The modal structure of freight transport in LDCs varies across countries and over time depending on the composition of economic output and national geography. China and India have extensive (but out-moded and overburdened) rail networks. Both countries have considerable shipment of grains, coal, and other mineral products for domestic consumption. Rail has historically dominated freight transport in both, though the share of trucks has increased since the 1970s. Chinese data show the share of road transport in total tonne-km rising from 6% in 1978 to 13% in 1988. Ships have also become more important in China, and accounted for the same share (42%) as rail in 1988.

[22] The data sources for China, South Korea, and Brazil are the same as those given in the section on passenger travel.

Except for China and India, most LDCs have not built extensive rail networks.[23] Much of the freight is moved by truck or, in some countries, via ships. Where the manufacturing sector has grown rapidly, the share of trucks in freight transport has risen also. In South Korea, for example, the share of trucks increased from only 11% in 1970 to 48% in 1987, while rail declined considerably in share.

Growth in the share of trucks leads to an increase in the aggregate energy intensity of freight transport. Data from South Korea show a 13% increase in this indicator even for the short period from 1983 to 1987. In Brazil, on the other hand, the data show a decline in the share of trucks from 62% in 1973 to 54% in 1985, and an increase in the share of ships. Since the latter have much lower energy intensity than trucks, this shift contributed to a decline in aggregate freight transport energy intensity.

Lack of data makes it difficult to assess how the energy intensity of particular freight transport modes has changed in LDCs. However, for trucks, two factors have contributed to a decline in energy intensity. One is a shift from gasoline to diesel-fueled trucks. The other is an increase in the share of heavy trucks, which tend to use less energy per t-km than medium or light trucks. In Brazil, the fraction of diesel-fueled trucks increased from about 50% of the fleet in 1973 to over 85% by 1985, while the fraction of heavy and semi-heavy trucks rose from 15% to 28%. In India, the transition from gasoline to diesel-fueled trucks is nearly complete, while in China most trucks still use gasoline. Trucks in India are larger than those in China, but are often overloaded, which leads to high energy use per km. In both countries, technological improvement affecting the fuel efficiency of gasoline and diesel trucks has been minimal. Poor road conditions in these countries and others contribute to high fuel intensity.

The energy intensity of rail transport has declined in India due to increasing use of diesel and electric locomotives in place of inefficient steam locomotives using coal, but the efficiency of diesel and electric locomotives has not improved very much. In China, steam trains are still predominant, though a growing use of diesel locomotives has reduced energy intensity.

3.3. Former East Bloc

Relative to economic activity, the level of freight transport in the Soviet Union was very high because of the dominance of heavy raw materials and energy. Pipeline shipment of oil and gas (a substantial amount of which was destined for export) accounted for one-third of total tonne-km in 1988. (Even if we exclude pipeline transport for comparability with OECD countries, the Soviet level is still high.) In addition, the lack of real markets meant that materials and goods were often shipped long distances because of the way the "buying" and "selling" ministries exchanged.

Pipeline shipment of oil and gas accounted for most of the growth in total freight transport after 1974 (Figure 24). The increase in other transport modes averaged only 2%/year between 1973 and 1987, compared to 6%/year between 1965 and 1973. This reflects the slowing of the Soviet economy. Excluding gas pipelines, rail accounted for around two-thirds of freight tonne-km. Trucks accounted for only 7% due in part to the relative unimportance of consumer goods and the lack of deliveries of these goods to consumer outlets.

Because of the dominance of rail, the aggregate energy intensity of Soviet freight transport was low relative to Western European levels. The energy intensity of each mode is close to levels in the West; this is not due to high vehicle efficiency, however, but rather to the importance of large shipments of bulk materials. The intensity for trucks fell, mainly because of an increase in the share of diesel trucks. Rail energy intensity (final energy) has also decreased, first through replacement of coal traction by oil, then

[23] In part this reflects the colonial history and its ending during a period when highways were preferred over railways. The small size of internal markets also made construction of rail networks less attractive.

through electrification.

The pattern in Poland is quite different from that of the former Soviet Union. Total freight transport reached only 4,250 t-km/capita in 1987, far below the level of the Soviet Union but close to that of West Germany (Leach and Nowak 1990). Compared to West Germany, however, Poland has a high level of t-km per GDP, in part because coal shipments are very important. Three-quarters of domestic freight was hauled by rail, a share that has remained stable since the late 1970s. In part this reflects the importance of coal for domestic use and export. The fuel intensity of trucks is considerably higher than in Western Europe.

4. CONCLUSION

Per capita travel has increased throughout the world as personal mobility has grown and business links have expanded. In all regions, there has been a shift in modal structure toward automobiles and airplanes, though the shares of these modes are much lower in the Former East Bloc and the LDCs than in the OECD countries. This shift has caused growth in the aggregate energy intensity of travel. The energy intensity of automobile travel declined considerably in the U.S., but changed little in Western Europe and Japan, where growth in vehicle size and power offset technical efficiency gains. In the Former East Bloc and the LDCs, the extent of any decrease in automobile energy intensity is difficult to judge, but appears to have been modest. In contrast to automobiles, the energy intensity of air travel fell dramatically in all of the major OECD countries.

Freight transport per unit GDP declined somewhat in the U.S. and Japan, but changed little in Western Europe and (probably) the Former East Bloc. In the LDCs, trends in the ratio have differed among those countries for which we had historical data. As in travel, there has been a shift toward a more energy-intensive structure, in this case from rail to trucks, whose flexibility and convenience provide advantages for moving many manufactured products. In contrast to automobiles, there has not been much decline in truck energy intensity, at least in the OECD countries. In some LDCs, the shift from gasoline to diesel trucks has reduced energy intensity somewhat. There has been more decline in the energy intensity of rail freight transport, though some of this is also a result of fuel switching.

The combination of growth in activity, structural change toward more energy-intensive modes, and a relatively modest (in most cases) decline in modal energy intensities has led to a considerable growth in transportation energy use throughout the world. Since oil products account for almost all transport energy use, this growth has been the key factor pushing upward on world oil demand. It has also contributed to the rise in global CO_2 emissions.

Our intention in this paper has been to shed light on past trends. A discussion of the future outlook for transportation energy use is presented elsewhere.[24] An important difference between the period covered here and the next decade or two is that increase in world oil prices is expected to be modest. This means that there will be little incentive to improve efficiency to save money. On the other hand, environmental problems are more pressing than in the past at local and global levels, and the transportation system is approaching or already in crisis in many cities. Strategies that improve the energy efficiency of vehicles can reduce some of these problems, but making changes with respect to transport activity and modal structure will be required in order to move toward a system that is sustainable in the long run.

[24] See Chapters 8, 9, and 10 in Schipper and Meyers (1992).

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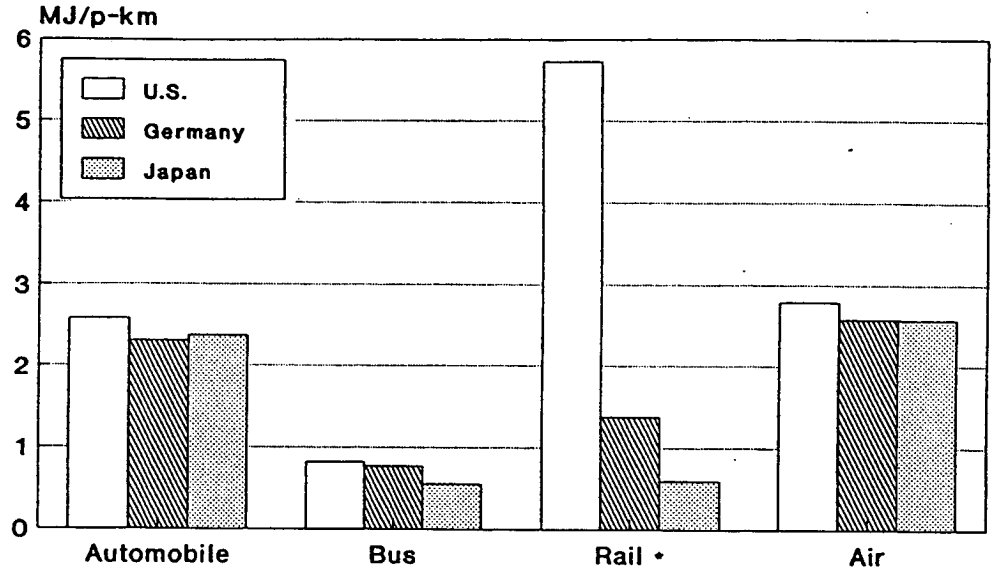
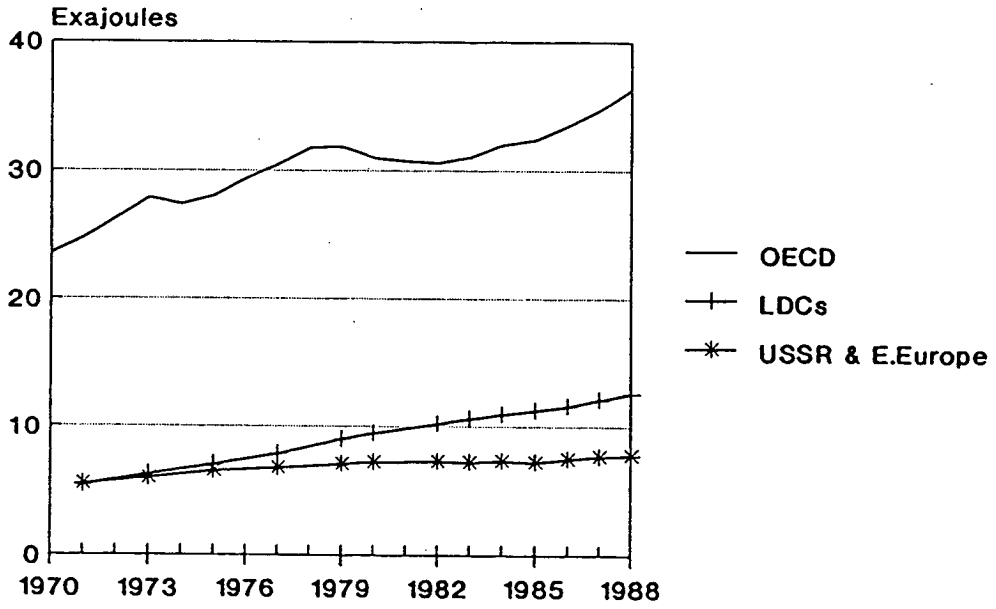
Energy Intensities by Mode of Travel In OECD Countries, 1988



* Electricity counted as primary energy.

Figure 1

Transportation Energy Use 1970-1988



Source: IEA (1989,1990)

Figure 2

Domestic Travel Per Unit of GDP

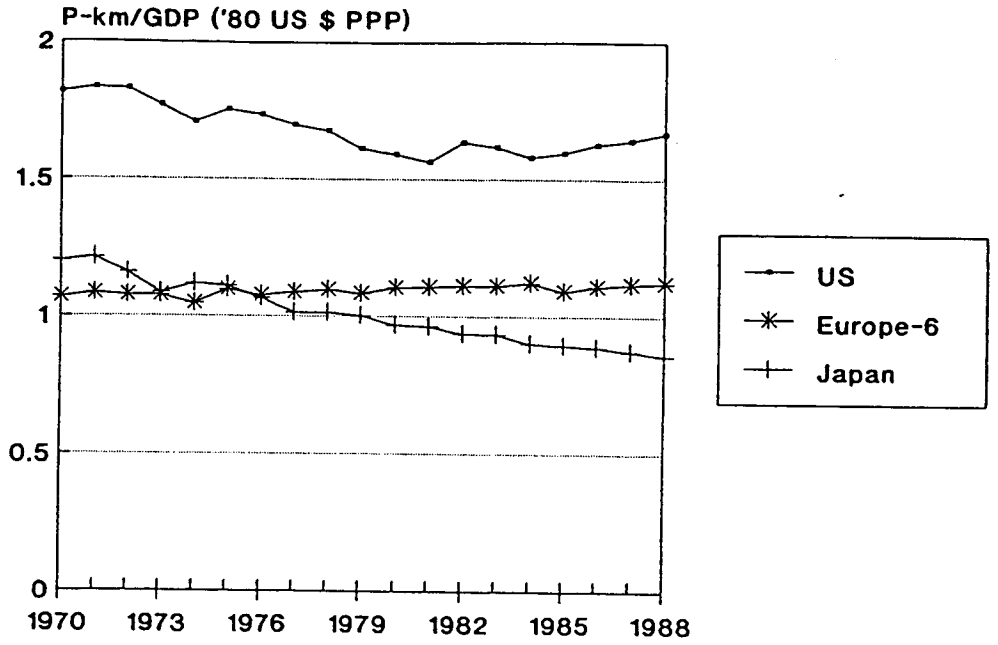


Figure 3

OECD Per Capita Travel 1970-1988

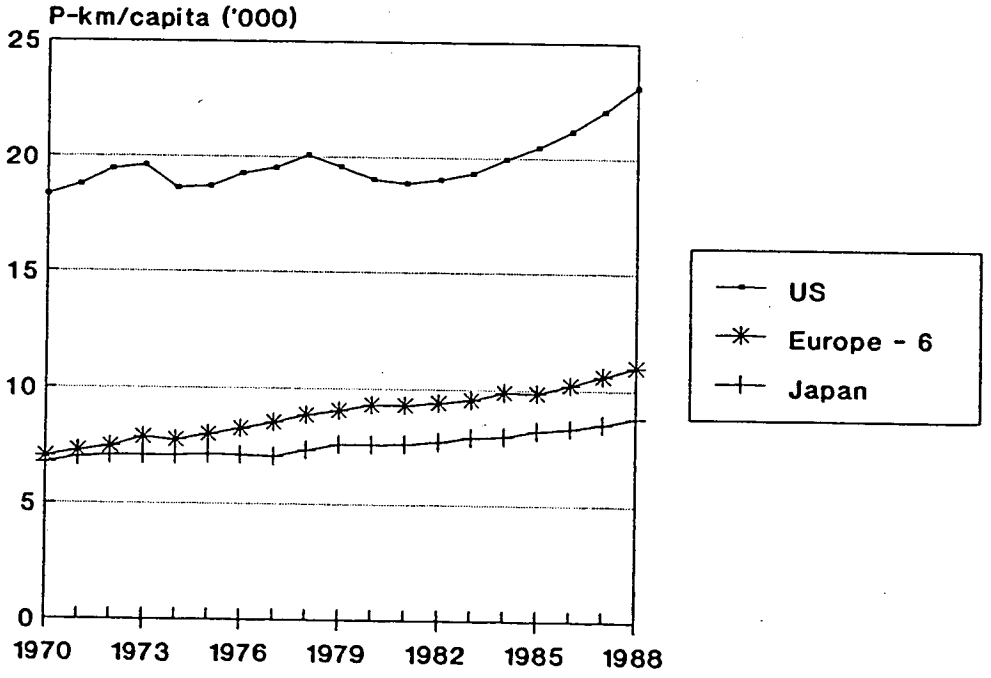


Figure 4

Domestic Travel by Mode
U.S., 1970-1988

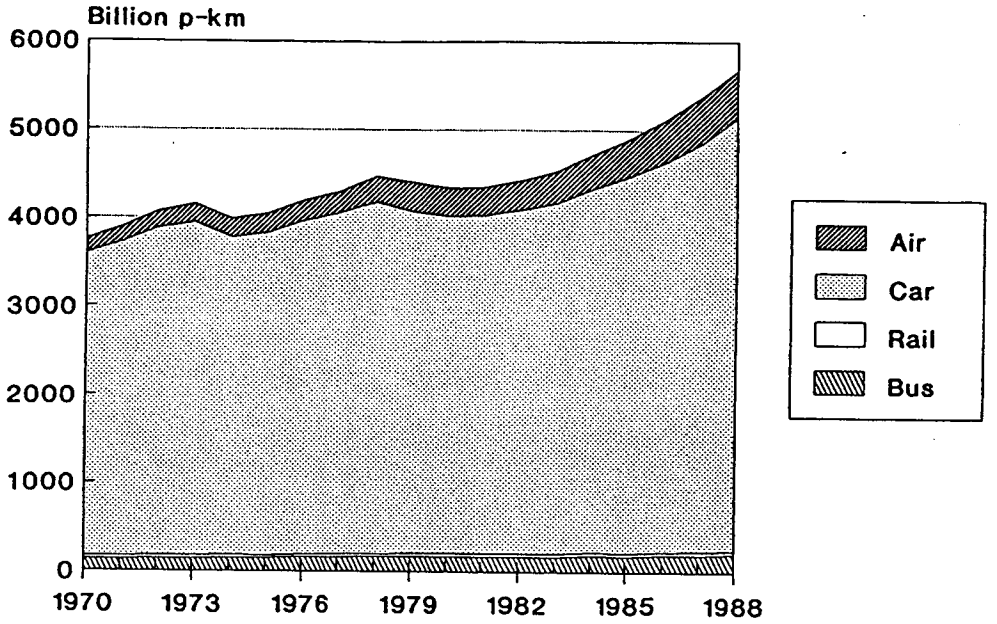


Figure 5

Domestic Travel by Mode
Japan 1970-1988

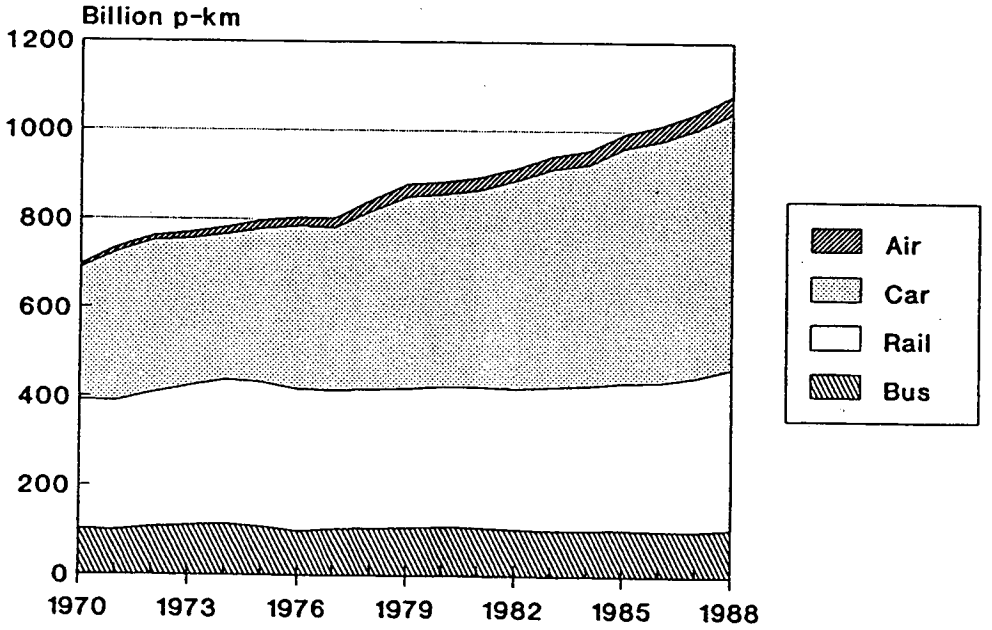
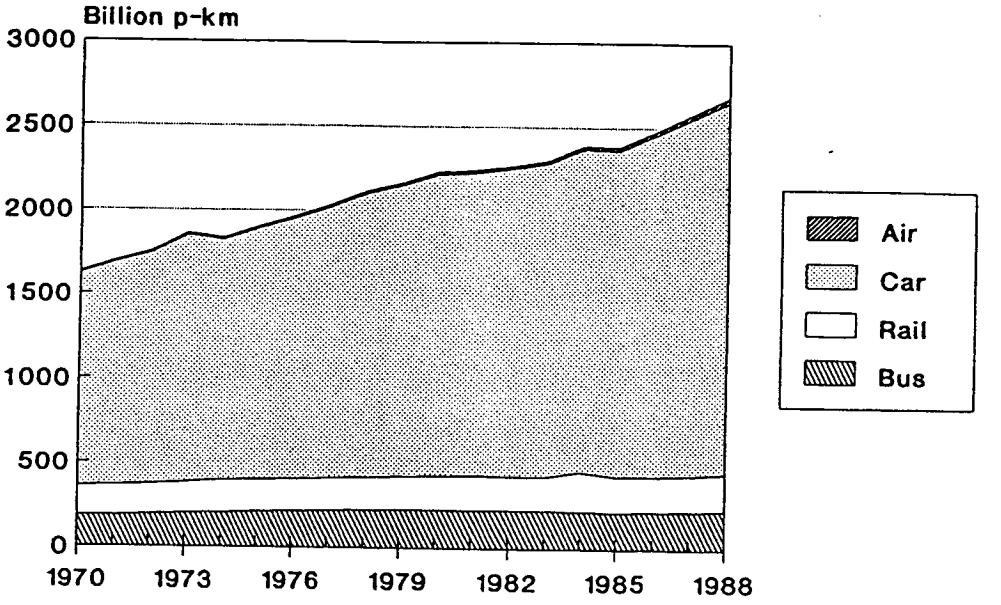


Figure 6

Domestic Travel by Mode
Europe-6 1970-1988



Does not include internat'l air travel

Figure 7

Distance Travelled per Automobile
OECD Countries 1970-1988

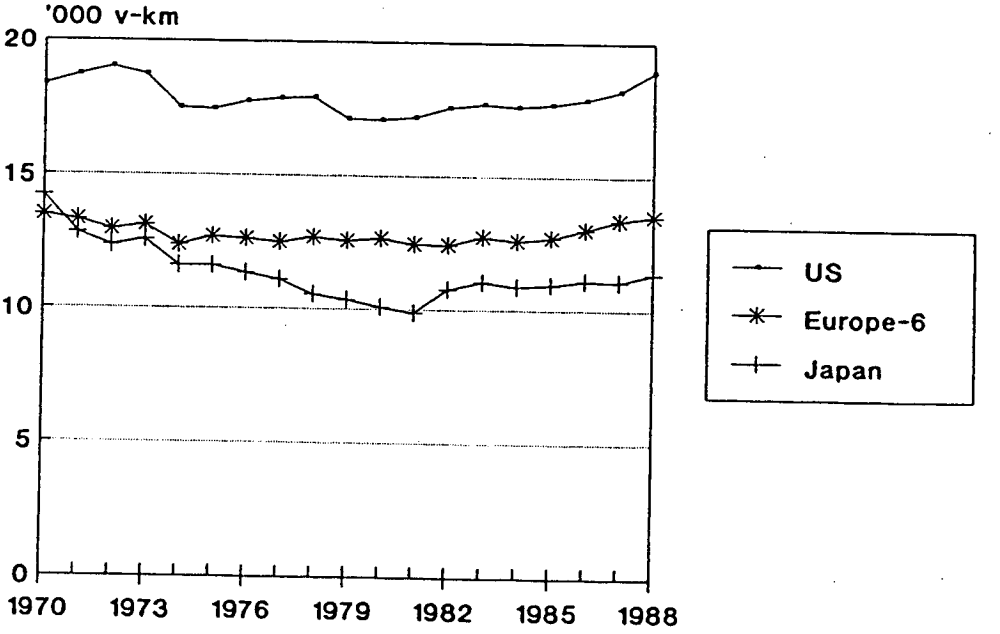


Figure 8

OECD Automobile Energy Intensities
1970-1988

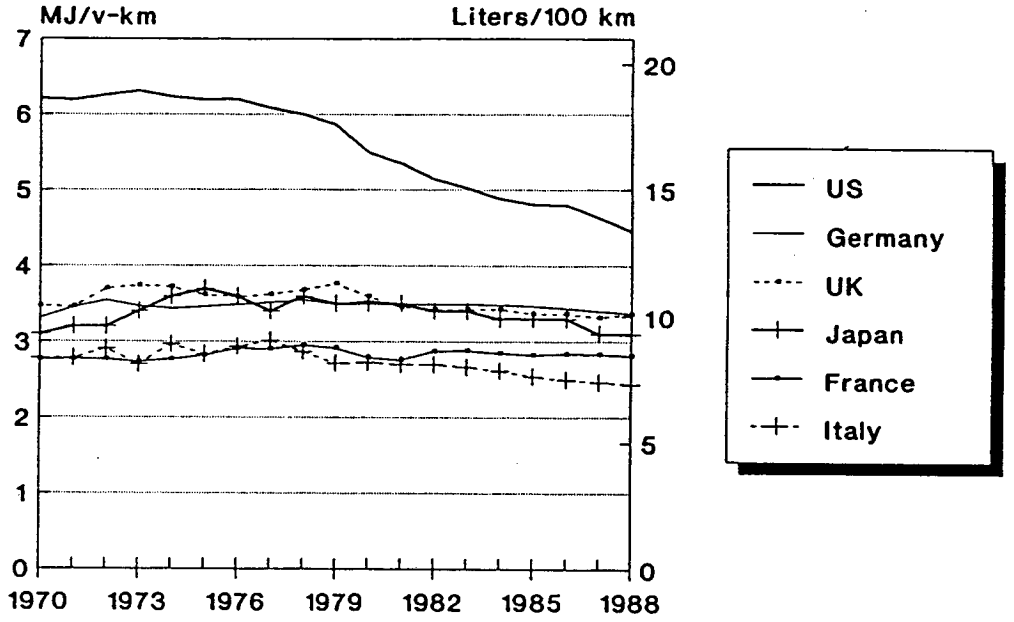


Figure 9

Automobiles by Engine Size
Great Britain 1965-1988

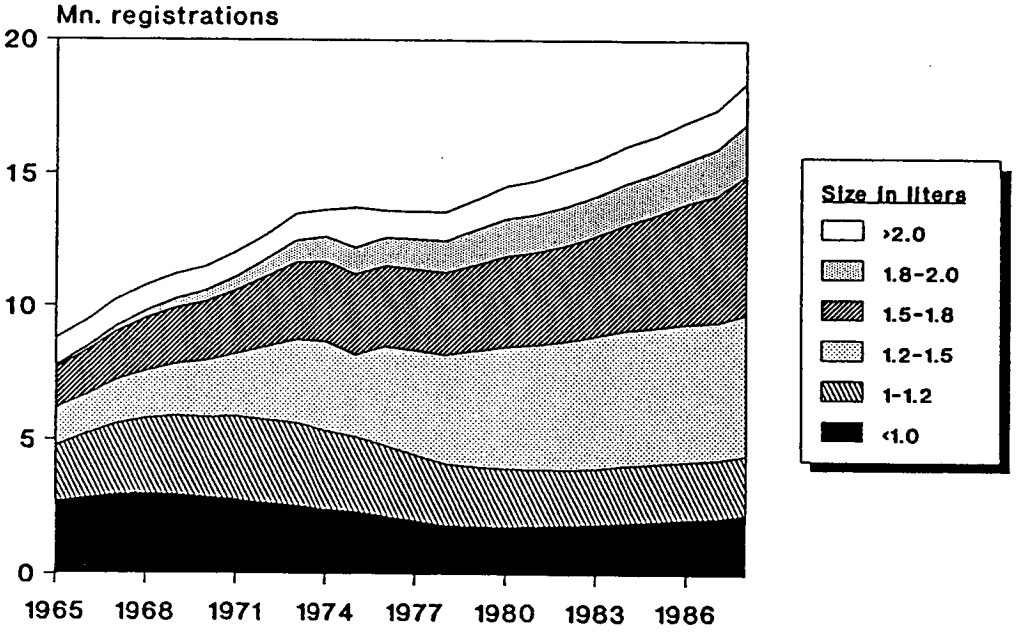
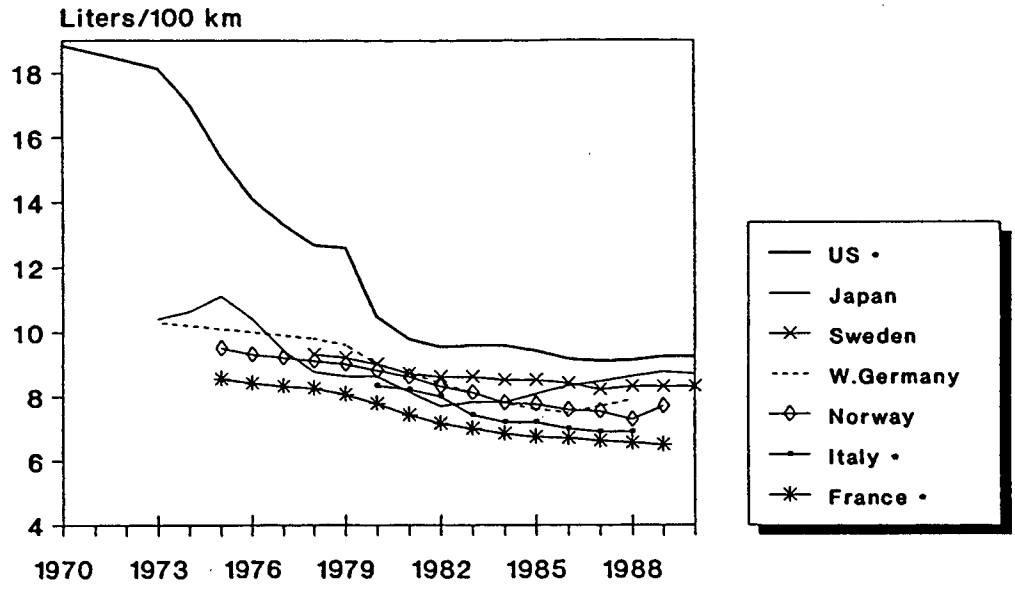


Figure 10

New Automobile Fuel Economy, Test Values
OECD Countries, 1970-1990



• Includes diesels
US includes light trucks

Figure 11

Domestic Air Travel Energy Intensities
OECD Countries, 1970-1988

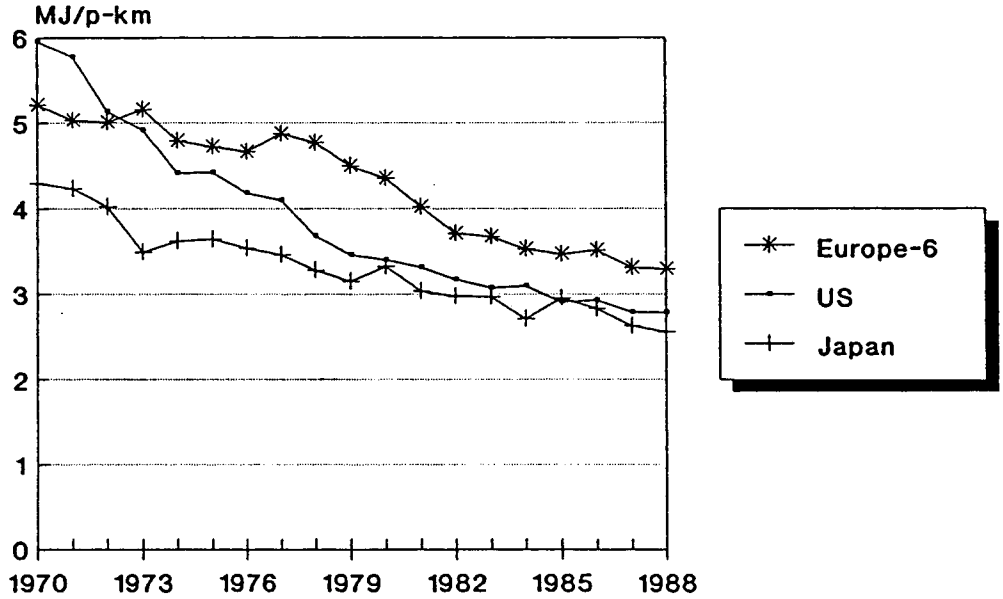


Figure 12

OECD Automobile Fuel Prices
Weighted Average of Gasoline and Diesel

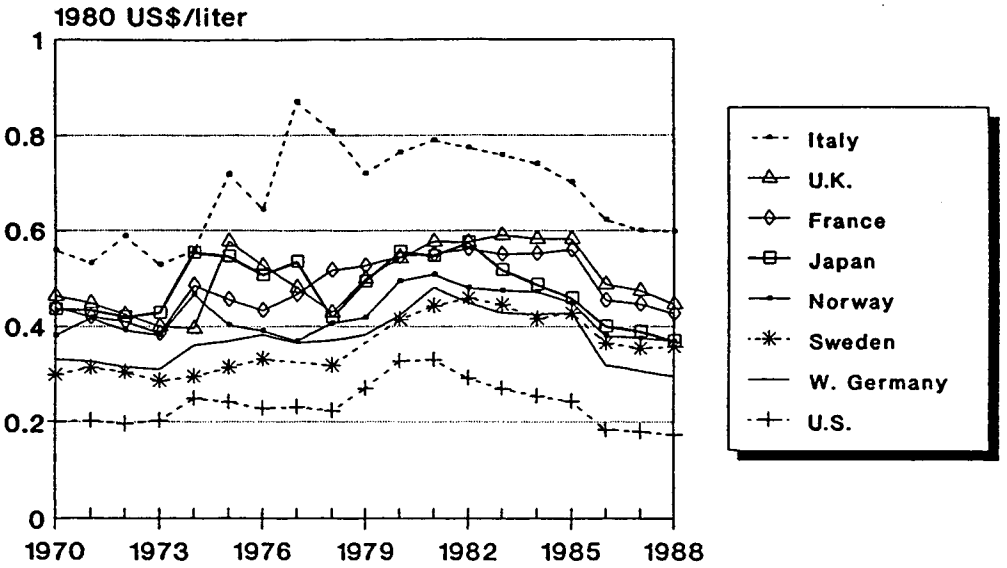
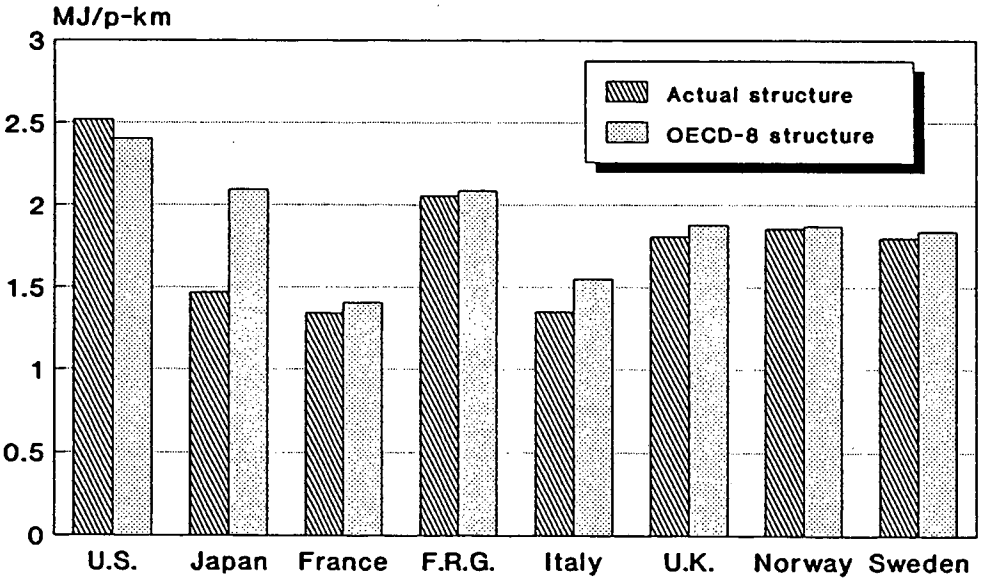


Figure 13

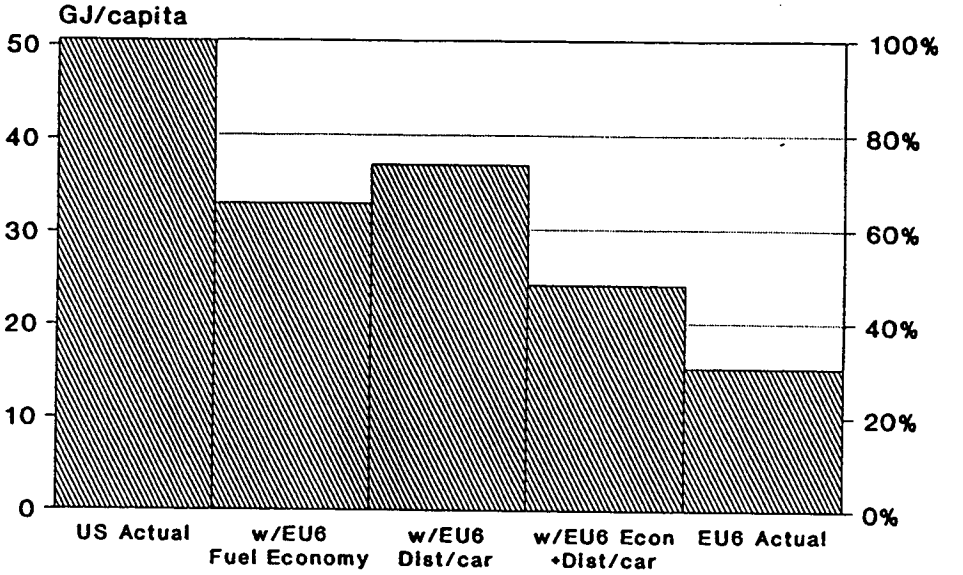
1988 Travel Energy Intensity *
Actual and OECD-8 Structure



* Using each country's own modal energy intensities

Figure 14

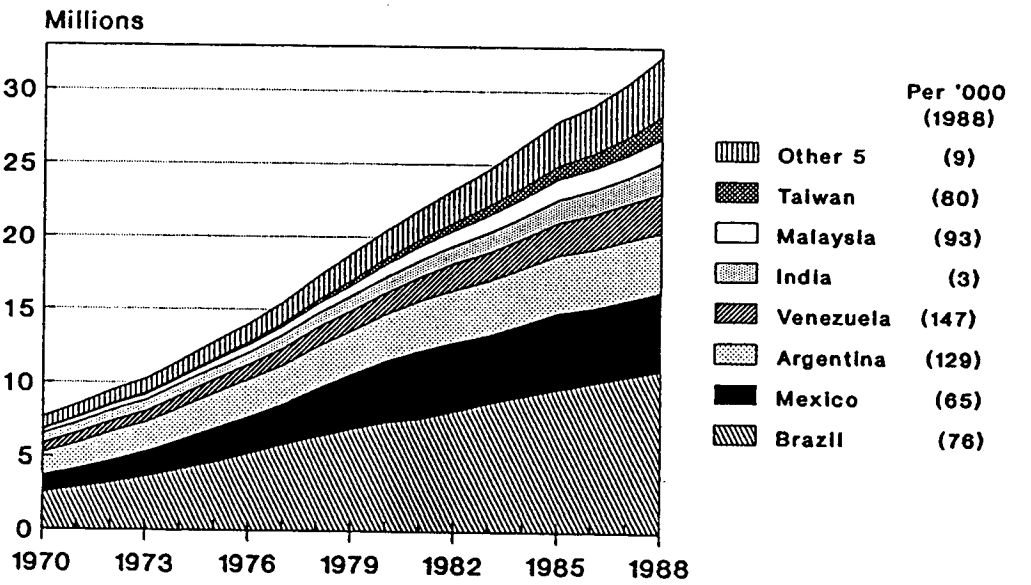
Per Capita Energy Use by Automobiles
Comparison of U.S. and W.Europe* in 1988



* W.Germany, France, Italy, UK, Norway, Sweden (EU6)

Figure 15

Automobiles in Selected LDCs
1970-1988



Other 5: Indonesia, S.Korea, Pakistan, Thailand, Philippines

Figure 16

Passenger Travel in the Soviet Union
By Mode 1970-1988

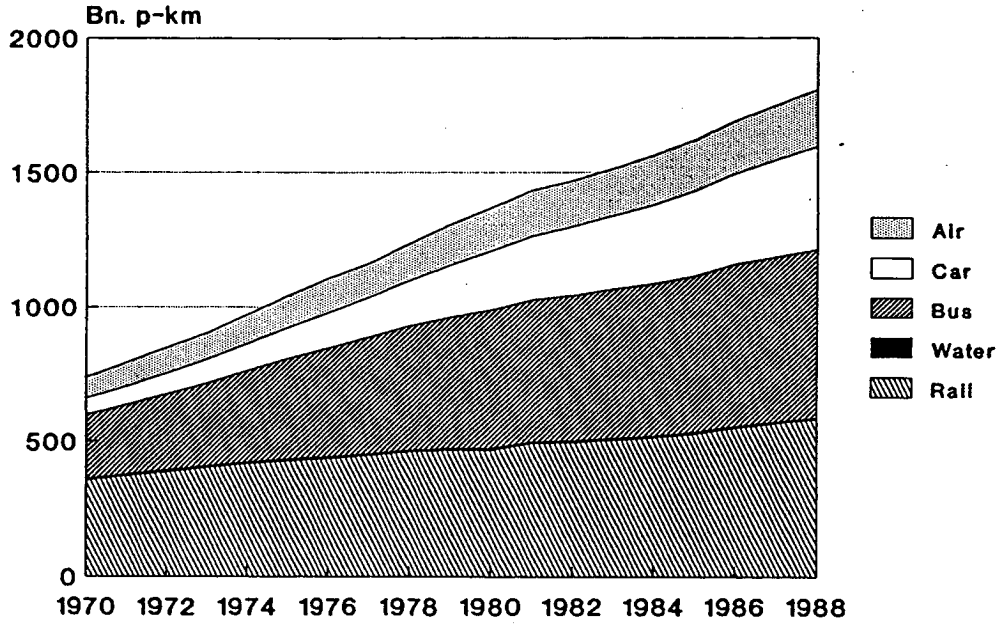
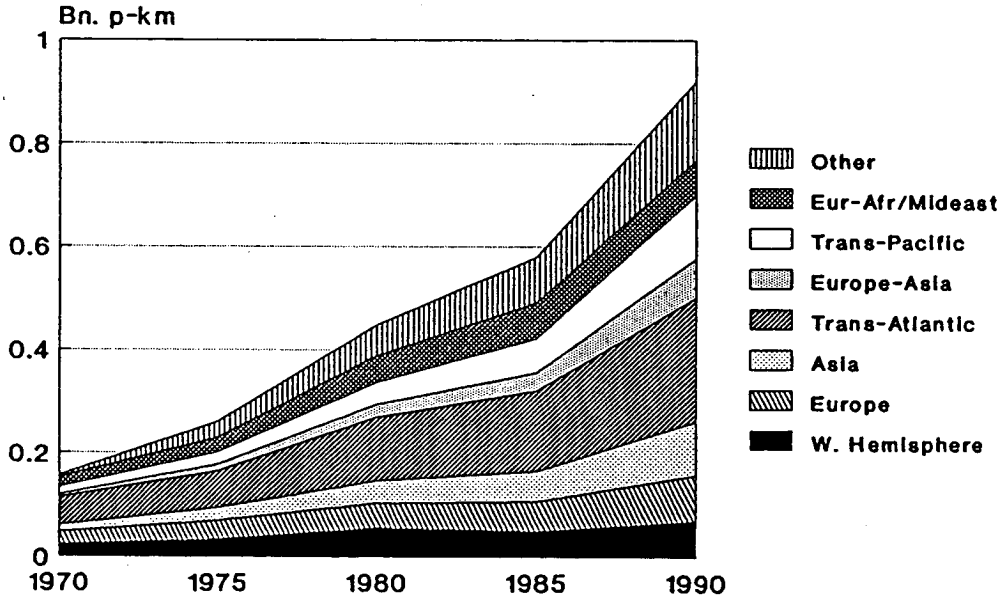


Figure 17

International Air Travel
1970 - 1990



Source: Boeing 1991

Figure 18

Freight Transport per Unit GDP
OECD Countries 1970-1988

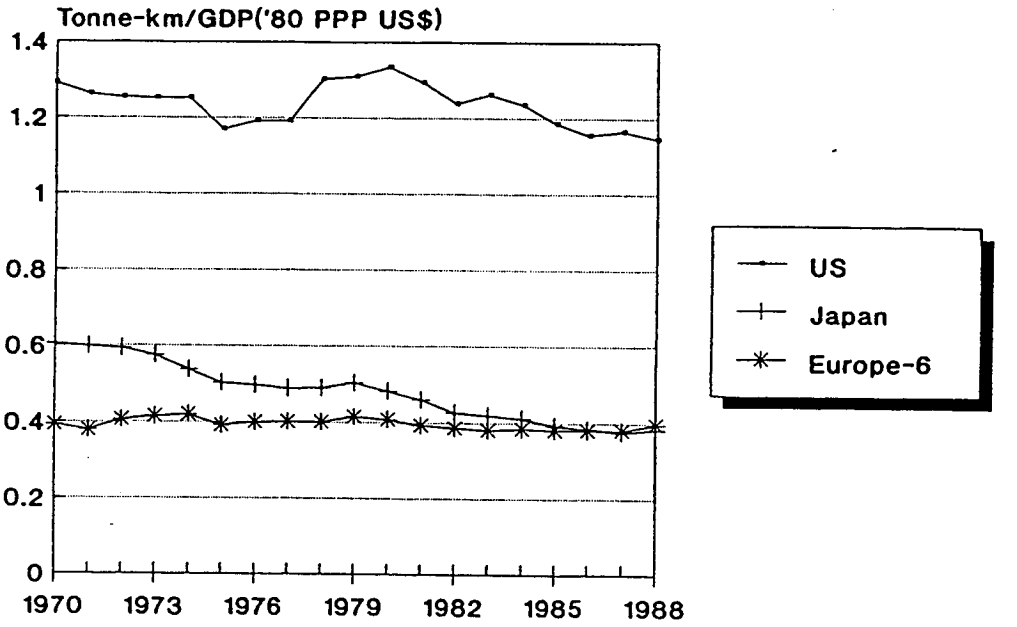


Figure 19

Freight Transport by Mode
U.S., 1970-1988

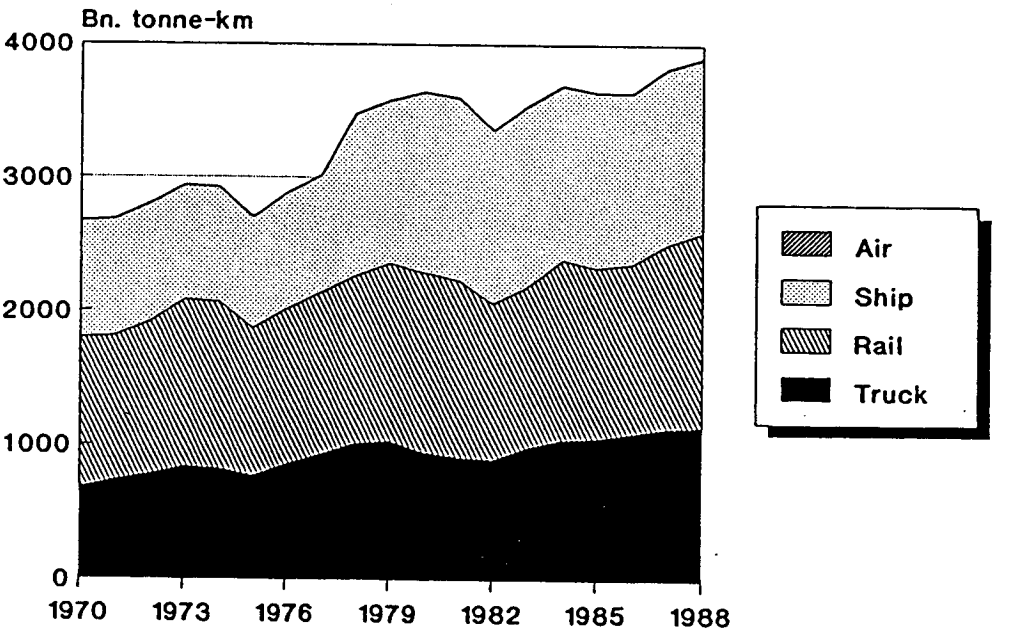


Figure 20

Freight Transport by Mode
Europe-6, 1970-1988

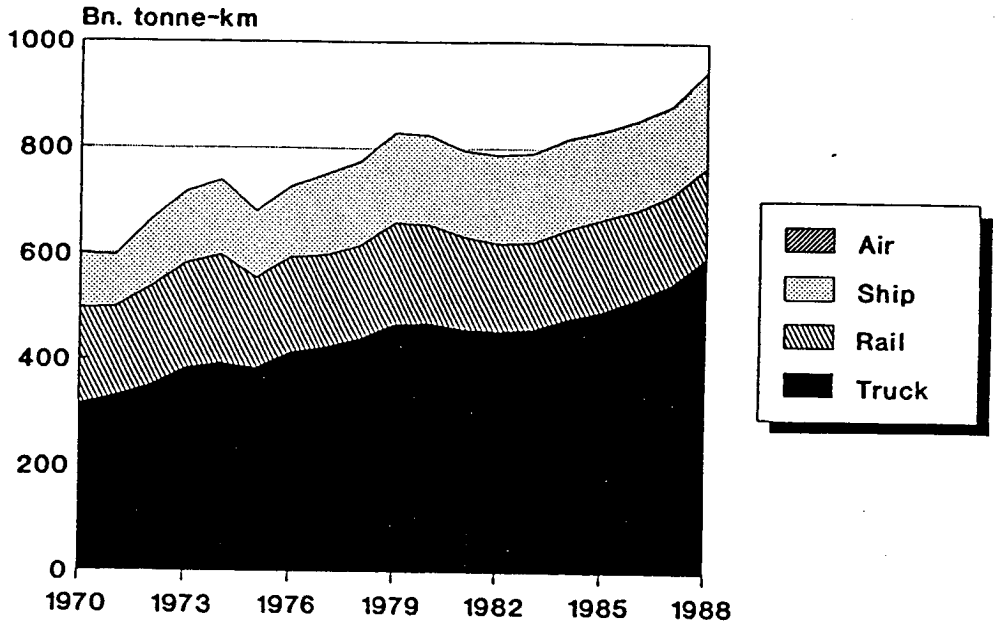


Figure 21

Truck Freight Energy Intensity
OECD Countries 1970-1988

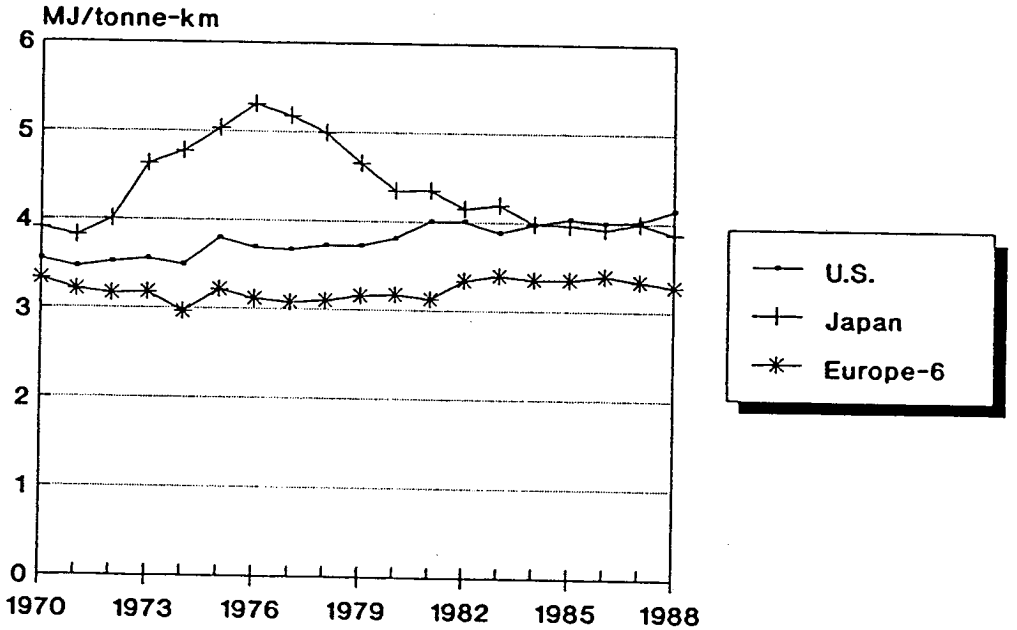
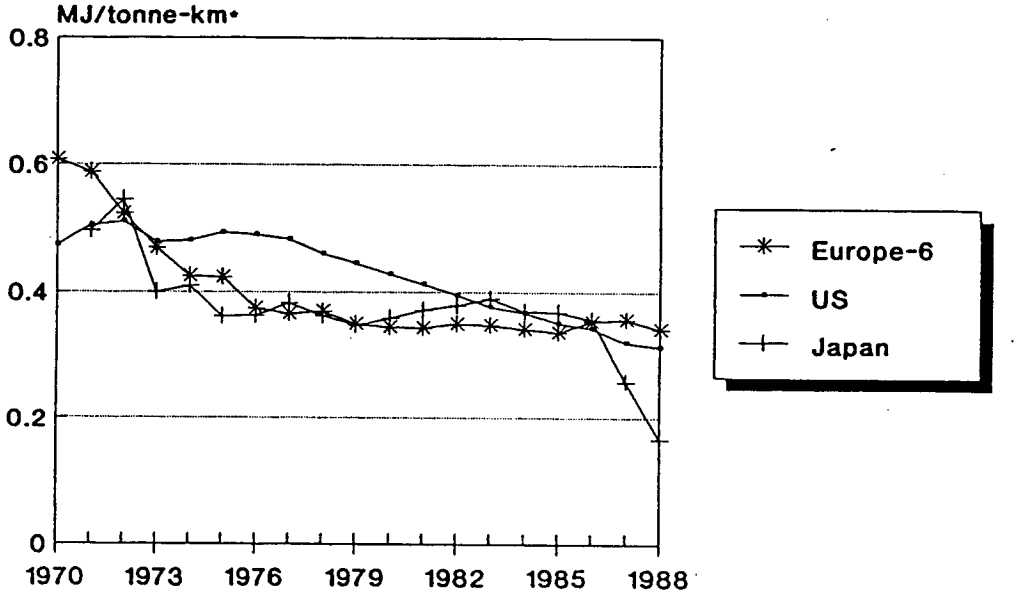


Figure 22

Rail Freight Energy Intensity
OECD Countries 1970-1988



* Delivered energy

Figure 23

Freight Transport in the Soviet Union
By Mode 1970-1988

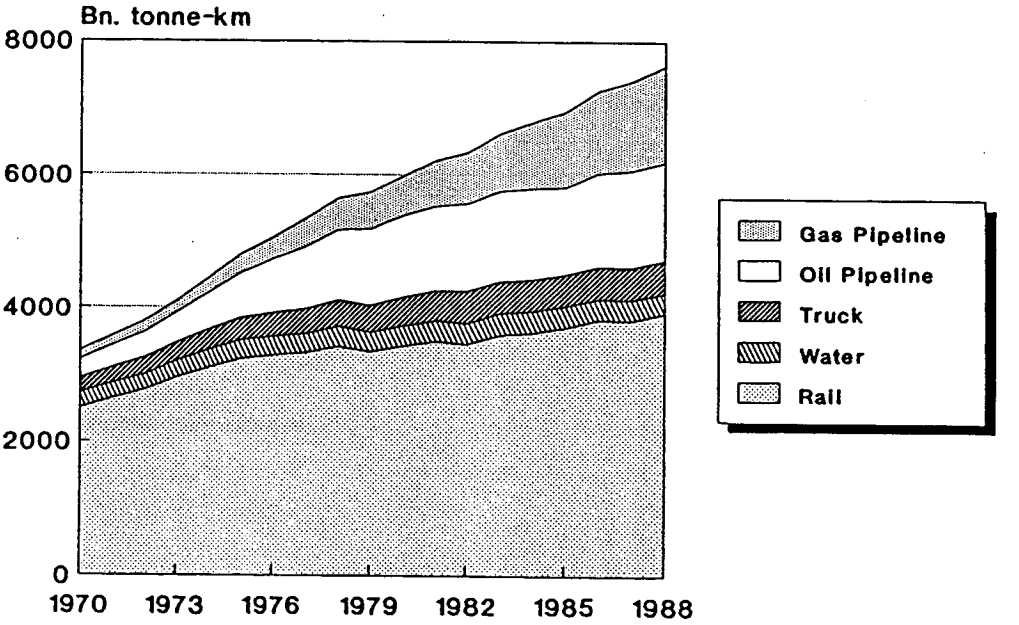


Figure 24

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