CARBON-DIOXIDE EMISSIONS FROM TRAVEL AND FREIGHT IN IEA COUNTRIES: THE RECENT PAST AND THE LONG-TERM FUTURE

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This paper summarizes recent work at the International Energy Agency to quantify the underlying trends in emissions, as part of a study of the Transport/CO_2 strategies of six IEA Countries (Denmark, Germany, the Netherlands, Sweden, the United Kingdom and the U.S.). Where relevant, our analysis here refers to other IEA countries as well. Preliminary considerations were presented in "Transport, Energy, And Climate Changes" (IEA 1997b), which we refer to as Book One.

A new framework is presented, "ASIF," for decomposing emissions into activity, modal share, energy intensity, and carbon content of fuels. The savings in energy and CO_2 made before 1990 and trends since 1990 are compared to assess energy or CO_2 policies. Passenger and freight transports are differentiated in our analysis. For freight, key parameters are not so much the efficiency of trucks as the mix of trucks by size and capacity, the way their capacity is utilized, and actual traffic conditions. We then reintroduce schematic forms to suggest where to look for energy and CO_2 savings. This schematic will then serve for the case studies now in progress. We report somewhat pessimistically that while some countries appear to be attacking all components of CO_2 emissions, none have any clear and large dramatic savings in sight. However, new automobile technologies, spurred perhaps by voluntary agreements in Brussels, Tokyo, and Washington, could provide large, longer-term restraint as these new technologies penetrate the fleet.

Concern has been expressed in many governments and private studies over the costs of externalities from transportation, which include safety, air, water, and noise pollution, competition for urban space, balance of payments problems and risks associated with importing oil as the main transport fuels (Kaageson, 1993; COWI, 1993; OECD, 1995; CEC, 1995a; COWI, 1995a, 1995b; Dept. of Transport, 1996; Pearce et al., 1996; Det Oekonomiske Raad, 1996, Deluchi, 1997). No one doubts that transportation returns a huge surplus to every economy, but there are clearly significant parts of the driving cycle where real social costs are greater than the benefits accruing to drivers or shippers. Hence there is reason to believe that internalisation of costs through both direct charging and some regulations could have a significant impact on the system in the long run. This was emphasised in a review organised by the European Conference of Ministers of Transport (ECMT, 1998). That group concluded, "Significant welfare gains could be realized through an adjustment of charges and taxes to provide incentives for reducing the external costs of transport." They estimated that current welfare losses amount to "several points of GDP." Thus the transport system is out of economic adjustment.

One of these problems, though arguably of less impact in monetary terms, is the emission of greenhouse gases (GHG), such as CO_2 (IPCC, 1990; UM, 1991,3; Houghton, 1994; CEC, 1995b; UM, 1991; UM, 1993; VROM, 1996a, 1996b;

KOMKOM, 1997; NRC, 1997; Trafik Ministerium, 1997). CO_2 emissions from travel (and freight) have increased in most industrialized countries faster than population, and in many cases as rapidly or more than gross domestic product (GDP) (Schipper, 1996; IEA, 1997a). Indeed, in virtually all regions of the world, CO_2 emissions from transport are rising relative to total emissions. Policy makers have discovered this, and are asking why? This paper reviews some of the factors driving that increase. We acknowledge the importance of other sources of air pollution, as well as the other wide range externalities, but we focus only on CO_2 in this review.

Whatever the "real" external costs of each mode, all studies suggest that the values attached to the externality for carbon emissions alone tend to be low compared to those associated with other problems. Hence this suggests that CO_2 by itself may not be "felt" as a strong stimulus for change, but that changes to deal with the other problems may affect traffic, and therefore CO_2 emissions perhaps even profoundly. While the other externalities in transportation may be more serious than CO_2, they also threaten us today and in that way lead to feedbacks, by which technologies and policies could be brought to bear to reduce the problems. But CO_2 emissions present no obvious problem for the present generations. Were CO_2 emissions not increasing, authorities could wait for more information on possible damages before taking action. However the increases are internal and may be hard to reign in, hence the interest in a better understanding of the factors underlying the increases. Moreover policy makers are under pressure from other constituencies (domestic energy consumers, the power generation sector and industry) to 'hit' transportation's rising share of CO_2 emissions. As a result, policy makers are asking why emissions are rising in the transport sector?

This paper summarizes recent work at the IEA to quantify the underlying trends in emissions, as part of a study of the Transport/CO_2 strategies of six IEA Countries (Denmark, Germany, the Netherlands, Sweden, the United Kingdom and the U.S.). Preliminary considerations were presented at the 1997 Asilomar meeting, 1998 TRB meeting and in "Transport, Energy, And Climate Changes" (IEA 1997b), which we refer to as Book One. Where relevant, our analysis here refers to other IEA countries as well. Our presentation will include trends updated to 1995 or 1996.

TRENDS IN TRANSPORTATION ACTIVITY

Book One emphasised the importance of understanding the components of emissions in transportation, and the elements that together determine emissions. In this section we review the key transportation demands that are in turn derived for demands for personal access to people and services as well as manufacturing and trade in goods, travel and freight respectively. After we review these demands and the energy uses associated with them, we will study how they interact. In this review we include examples from countries not studied in depth where they illustrate important extremes of one or another parameter, or contrast with a similar country that we have studied in more detail.

Underlying Factors Affecting CO_2 Emissions For Travel And Freight: A Decomposition Approach

Schipper (1995) explains many of the steps used in obtaining and analysing bottom-up data on transport, particularly for understanding differences among countries (see also Schipper, Figueroa, Price, and Espey, 1993; Schipper, Steiner, Figueroa, and Dolan, 1993). As a next step, Lawrence Berkeley National Laboratory carried out an index decomposition of the factors underlying changes in CO_2 emissions from both freight and travel, as well as from other sectors (Schipper, Steiner, Duerr, An, and Stroem, 1992; Schipper et al., 1996; Scholl, Schipper and Kiang, 1996; Schipper, Scholl and Price, 1997).

All of these methods start from a basic formula (Schipper and Lilliu 1998). Consider that

$$\mathbf{G} = \mathbf{A} * \mathbf{S}_i * \mathbf{I}_i * \mathbf{F}_{i,j} \qquad (1)$$

where **G** is the carbon emissions (or other greenhouse gas), **A** is total travel, **S** is a vector of the modal shares *i*, and **I** is the modal energy intensity of each mode *i*. The last term $\mathbf{F}_{i,j}$ represents the sum of each of the fuels *j* in mode *i*, using standard IPCC coefficients to convert fuel (or electricity) used back to carbon emissions. More detailed analysis could explore the full fuel-cycle emissions from obtaining and refining the fuels, but the present analysis is limited to combustion.

The modal energy intensity term itself is composed of several components:

$$\mathbf{I}_j = \mathbf{E}_i * \mathbf{VC}_i * \mathbf{CU}_I \qquad (2)$$

where **E** is technical efficiency, **VC** vehicle characteristics, and **CU** capacity utilization for each mode *i*. Taking only **E** and **VC** yields what we call vehicle intensity, or fuel/kilometer.

Technical efficiency is the energy required to propel a vehicle of a given set of characteristics a given distance, and is affected by the motor, drive train, frictional terms (including drag), etc. For cars, characteristics could be represented by car power, and technical efficiency by energy use/km/unit of power. Capacity utilisation would be measured by people/vehicle. All three of these components share in determining how much energy is used to transport a person one kilometre by each mode. Fuel choice affects efficiency because some fuels, particularly diesel, are combusted more efficiently in their respective engines than others. Thus some terms in this decomposition that are nominally "technical"—energy intensities—actually have important behavioural components. Total travel and modal choice are obviously "behavioural" factors, too. The same is true for changes in power, or changes in traffic and driver behaviour, all of which affect how technology turns energy into mobility.

This relation illustrated by Equations 1 and 2 can be used to study changes in energy use or emissions over time, and the results expressed as indices marking the changes in each component. Many indices serve this purpose, but LBNL initially chose Laspeyres methodology for simplicity of calculation and because Laspeyres indices show the impact of one factor alone on overall change. However, the Laspeyres indices often leave large residuals. Since many factors change simultaneously, often in countervailing directions, more complex formulations such as Divisia or Adaptive Weighted Divisia (AWD) that capture the interactions of these terms (and hence reduce the unallocated residuals) are important tools (Greening, Davis, Schipper and Khrushch, 1997). The carbon emissions from electricity generation are apportioned to each mode in proportion to the share of final electricity used in that mode (for rail, metro, and tramways).

Feedbacks between these components are important, but not *major* in the countries we have studied. Unquestionably lower driving costs per km, whether brought on by lower fuel prices or lower fuel intensities, encourage more driving. But the elasticities are only modest: 10 percent lower costs leads to somewhat more than 1 percent more driving in the U.S. to perhaps 3 percent more in Europe, with the average around 0.2-0.25 (Johansson and Schipper 1997). Lower costs of using cars discourage use of other modes, as can be seen by comparing relative fuel and transit costs and relative ridership in different cities in Europe. As fuel costs rise, transit ridership rises slightly, and vice versa. In large countries with high freight volumes relative to GDP, the share of energy-intensive trucking tends to be small (under 40 percent) with the less energy intensive modes dominant. More subtle in nature is the impact of lower costs on technology, as suggested by Figure 11: technology is boosting power at roughly constant fuel economy, rather than reducing fuel use at roughly constant power. These are all important feedbacks, but they do not invalidate our main conclusions about historical trends. As we shall see subsequently, however, policies that only aim at lowering fuel use and fuel costs will usually lead to less CO_2 restraint than policies that include elements that counter this trend by either raising fuel prices or raising other variable costs of transportation.

This approach is very useful for the policy analysis that will follow. For one thing, many policy elements focus on one of the components in Equations 1 or 2. Many packages address most or all of them. Indeed, one powerful lesson we will draw from our work is that packages addressing all of the components in a concerted and coherent, self-consistent manner usually have a greater effect than the sum of the effects of policies addressing the elements separately. This is both because synergies among the policies can be more powerful than individual policies alone, and because the feedbacks noted above may act to offset hoped-for policy effects when key components are left out. In a historical perspective, analysis of past behaviour reveals which components have changed the most, perhaps (but not always) in response to policies, which are more rigid. For example, changing fuel prices, fuel economy regulations, and new technologies have had important impacts on fuel economy of cars, but little impact on the overall growth in car use with income. Judging from history which components of rising emissions may yield to different stimuli is an important part of the policy analysis that each country we have studied must undergo. Therefore we will use this framework in many circumstances to remind the reader how components of emissions have changed or are likely to change in the future.

Travel

Travel, or personal transportation, typically accounts for 60 to 70 percent of energy use and emissions from transportation. Travel activity **A** is measured in passenger kilometres over each mode **Si**. The key component is automobile travel, and that is driven by automobile ownership (Figure 1). Ownership has risen with income or GDP per capita, although it is showing some saturation in the most motorised countries, as the figure clearly suggests. Distance travelled per vehicle (vehicle-km, or v-km) is rising slowly with income too. However, distance travelled per capita (Figure 3) is rising more rapidly, principally because of increasing car ownership rather than the slow rise in distance travelled per vehicle.

Figure 1: Car Ownership and Per Capita Income
1970-1995

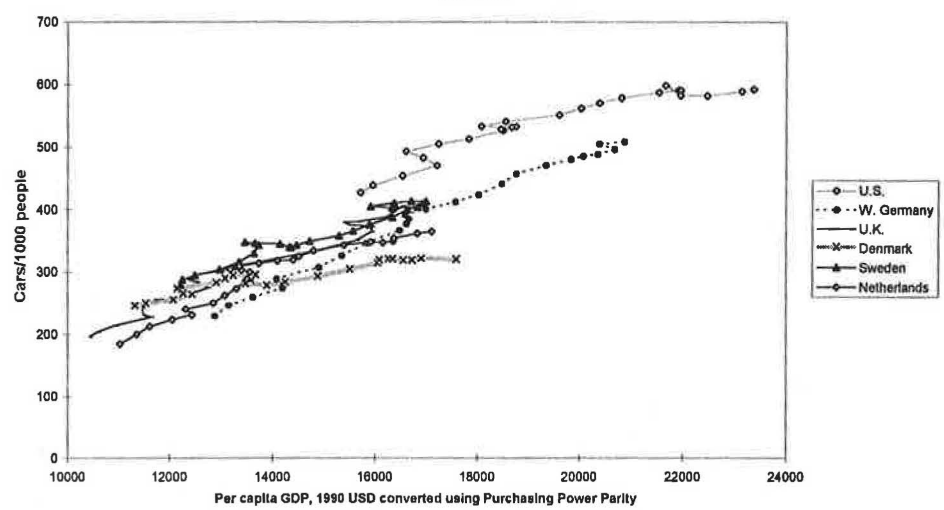
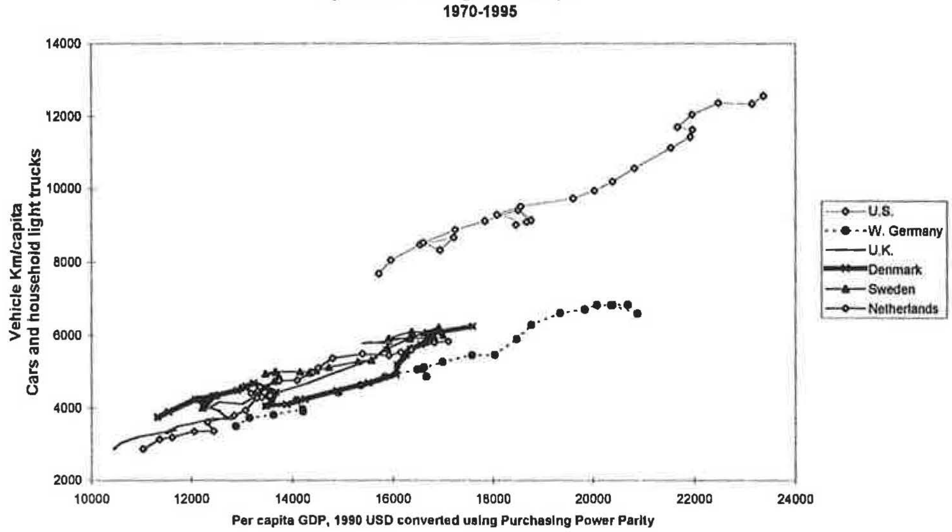


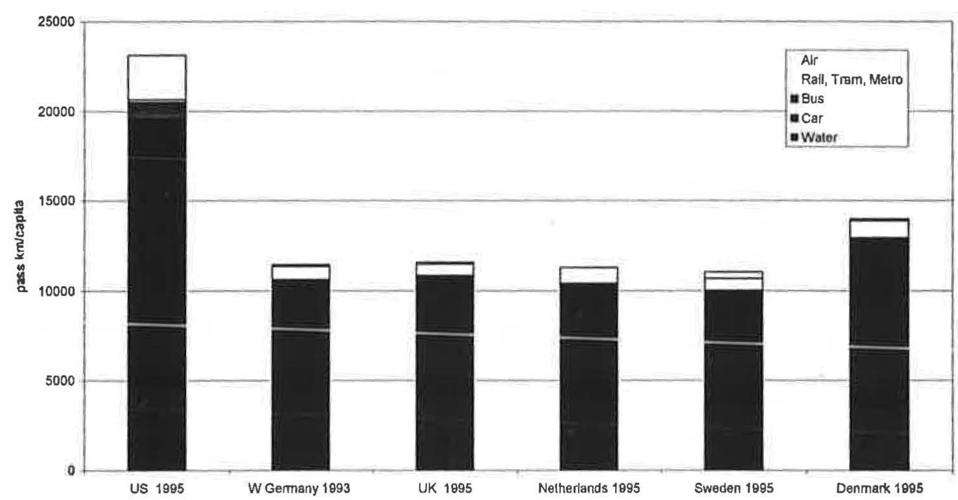
Figure 2: Car Driving and Per Capita Income
1970-1995



Comparison of Figures 1 and 2 shows that while Denmark has lower car ownership than most countries (at a given GDP/capita), it has about average driving for the European countries studied. That is, Danes have fewer cars but drive them significantly more than drivers in the other European countries. This is why distance driven per capita is so much more important than distance driven per car to determining total fuel use and CO2 emissions.

Figure 3 compares per capita motorised travel in the study countries in 1995 (1994 for West Germany), showing the dominance of the car. Total travel, as expressed by the distance travelled on all modes in passenger kilometres, is "driven" principally by car use. This indicator is rising at a less rapid rate than car use itself because the number of people in a car (load factor) is falling: the number of passenger-km in cars grows less rapidly than the number of vehicle-km covered.

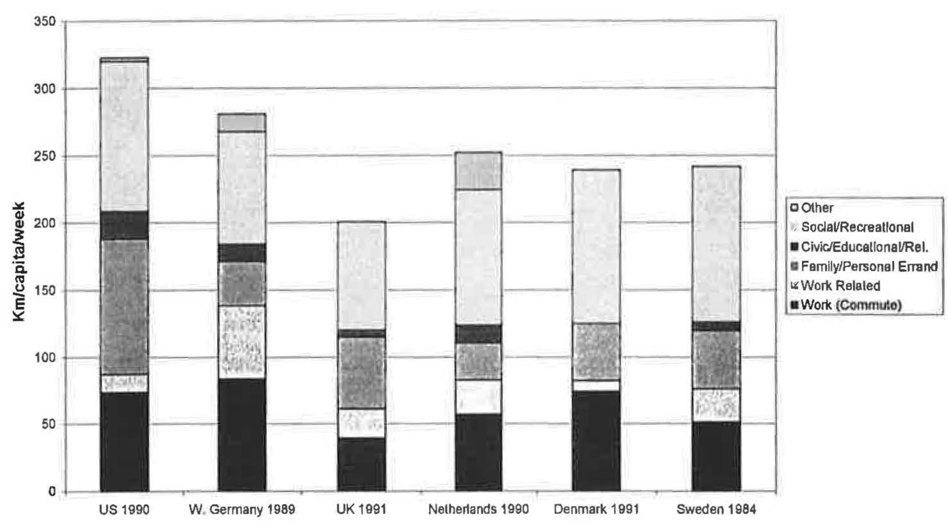
Chart 3: Per Capita Motorised Passenger Travel



More detailed comparisons reveal characteristics of aggregate travel that are important for emissions. Overall travel per capita is far higher in the United States than in the other countries shown, even for a given level of GDP per capita. The United States, Australia, and to some extent Canada (not shown) have roughly similar high levels of total travel, and the same high shares of car and air travel. This suggests that geographical factors play some role in determining total travel. By contrast, the United Kingdom, West Germany and the Netherlands are the most densely populated countries we studied, and have lower levels of travel and car dependence. Japan (not shown) is even more dense (when one considers that most people live on a fraction of the total land area there), and has even lower total travel than the European countries. Economic factors are certainly important, too, as we will note later. While there are important differences among European countries, it is nevertheless interesting how the overall pattern of travel tends to reveal these three groupings as determined by geography.

Travel patterns are an important element of the picture. The structure of travel by trip purpose, mode, and distance per trip affects fuel use and emissions because of congestion, motor performance, etc. Schipper, Figueroa and Gorham (1995) compared travel surveys from the United States and a number of European countries. Some results are shown in Figure 4. Work travel (mostly commuting, but some trips within work) accounting for 20-30 percent of travel, services, civic, educational, and family business for about 25 percent (except in the United States, where the share was higher) and leisure including culture, sports, outdoors, etc.) for the rest. The car dominates the latter two categories, but outside of the United States, the car accounts for only 40-60 percent of work trips, since these are more easily taken on collective modes. Including walking and cycling has little impact on total travel, but an important impact on total trips, since these can account for as much as 1/3 of trips. Nonwork trips seem to be leading growth of car use in the U.S., probably the result of much greater saturation of trips to work by car since the 1970s (over 85 percent of trips, of which only 1 in 10 as a passenger). In Europe, by contrast, there is still a slow increase in the share of work trips taken in cars. People are not only moving more, but the structure of mobility, in terms of mode and purpose, is changing slowly.

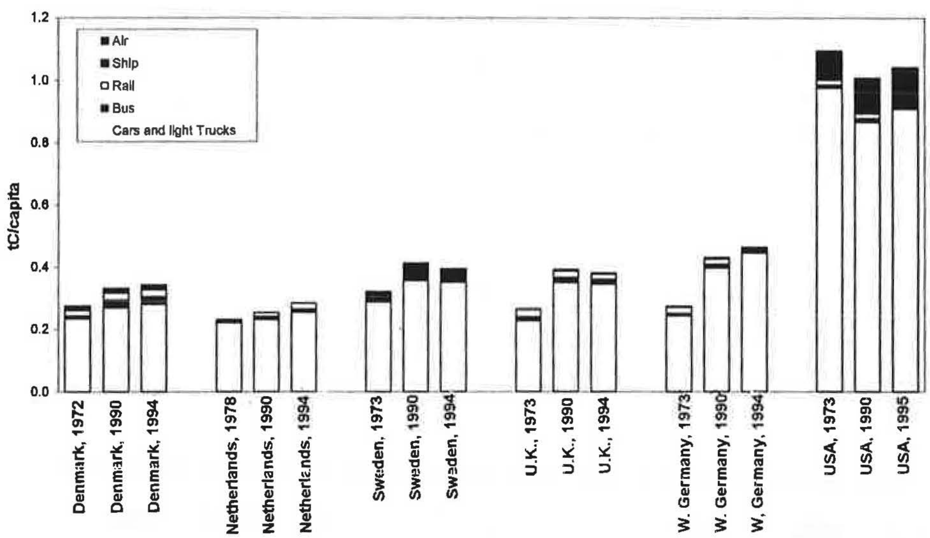
Figure 4: Passenger Travel by Purpose



Interestingly, the average trip length in a car remains around 13-15 km for the United States and all the European countries studied. Roughly 80 percent of all trips are less than 20 km and 60 percent are less than 10 km, which implies that the car is used mostly when its engine is cold. This raises fuel use and air polluting emissions. Ironically, cars are increasingly built for higher speeds and longer trips, but they are still used predominantly for local transportation. This also means that our conclusion about the importance of country size and geography might be challenged if car trips are roughly the same length in the United States as they are in the Netherlands. But the longer distances in the United States are balanced by many shorter car trips that are taken on collective modes, walked/biked, or not taken at all in Europe.

Since car (and air) travel has propelled most of the growth in travel, and since these modes require more energy and emit more carbon per passenger-kilometre than bus or rail modes, energy use and CO_2 emissions have risen faster than total travel per capita. Knowing the energy use for each mode we can tabulate emissions of CO_2 in a straightforward way. Figure 5 shows these patterns (in tonnes of carbon per capita) for travel (Schipper, 1995; Scholl, Schipper and Kiang, 1996). The U.S. has the highest emissions because it has both the highest level of travel (with the highest share in cars or air travel) and the highest emissions per unit of travel in cars. Japan (not shown) has low emissions principally because it has the lowest per capita travel and the largest share in rail and bus. European countries tend to cluster between these extremes, albeit more closely to Japan. We will explore details of the energy-use patterns later, but turn first to review key trends in freight transport.

Figure 5: Per Capita Emissions from Passenger Travel by Mode



Freight Transport

The other part of transportation we consider is goods movement, or freight carried on the territory of each country by truck, rail, or ship and barge. Activity in freight transport is usually measured in tonne-km, the number of kilometres each tonne moves. Figure 6 shows how the level of freight activity (within a country, including the domestic portion of foreign trade but excluding goods carried on trucks of a third country) itself is coupled to industrial GDP. Conspicuous is the wider spread among countries and the different rates of change of freight with changes in GDP. Figure 7 shows the same data by mode for 1995 (1994 for West Germany). These characteristics of freight are important for emissions.

Figure 6: Freight Transport and Industrial GDP

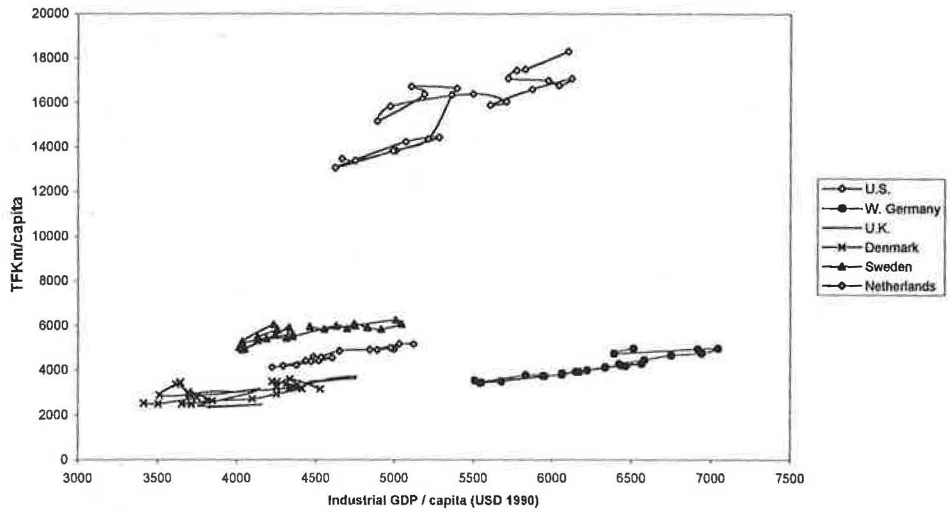
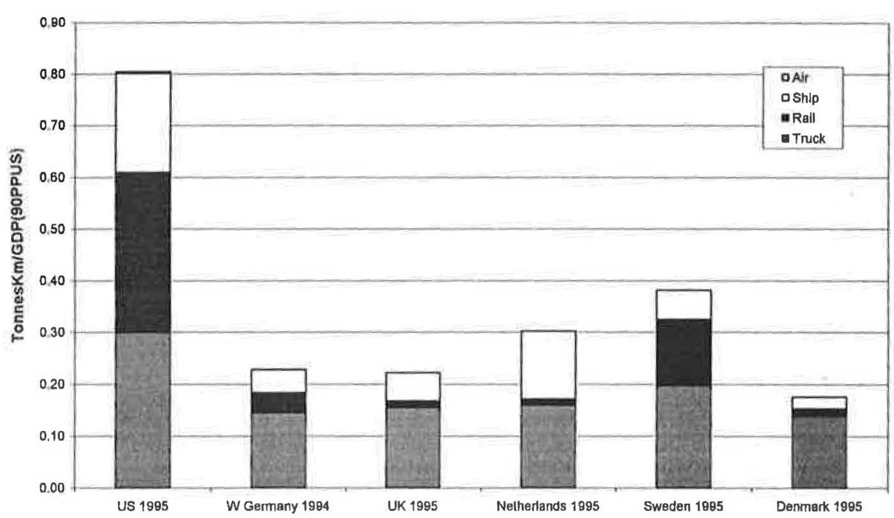
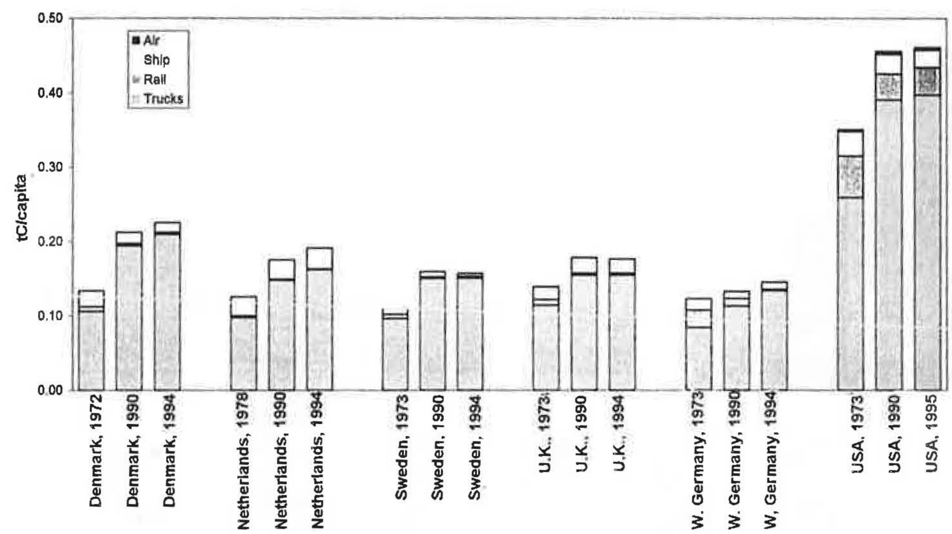


Figure 7: Freight Activity and Total GDP



Here two factors appear key to the level of freight relative to GDP. One is geography: Canada, Australia (not shown), and the United States have the highest levels of domestic freight for a given GDP. This high level is dominated by rail and shipping (barge or boat), two modes that have very low modal energy intensities. By contrast, Denmark, Germany, and the United Kingdom are dominated by trucking. Geography appears to work in the other direction here compared with its effect on travel: in small or dense countries, trucks more easily handle the relatively short distances freight travels. (Included in these data are freight movements by domestic haulers to borders, but not [except for Holland] freight movements of foreign-owned truckers within each country.) Another factor is the nature of freight hauled. In the large countries (as well as Sweden and Norway –not shown-), raw materials dominate freight and swell the totals because of both their bulk and the distances from point of origin (mines, forests, farms) to manufacturing and shipping points. Because of these factors, the ratio of energy use for freight to GDP for the big countries is not that much higher than that of the smaller countries. As Figure 8 shows, the CO_2 emissions patterns for freight relative to GDP are dominated by trucks. But there is greater variation in the ratio of emissions to GDP among countries than there is for travel, because both intensities and modal mix as well as the total level of freight, relative to GDP, vary so much among countries (Schipper, Scholl and Price, 1997). Germany has low emissions per unit of GDP because of low freight and low emissions per tonne-km for dominant trucks. The United States has low emissions per unit of freight but very high level of freight and consequently much higher emissions than Germany has. Denmark has low freight hauled per unit of GDP but a very high truck share and the highest ratio of emissions to tonne-km hauled, hence high emissions. Policies must consider each of these components to find where CO_2 restraint might occur.

Figure 8: Per Capita Carbon Emissions from Freight Transport by mode



Schipper, Scholl and Price (1997) review some of the components of freight activity. They found that some goods (bulk goods, raw materials) go mostly by rail and barge wherever possible, while smaller/lighter goods and goods with a higher value go most often by truck. This mix, as well as the intrinsic distances different kinds of goods travel, and the convenience of modes, appears far more important than energy alone in determining modal shift; conversely, little modal shift is motivated just to save energy.

ENERGY USE AND CARBON EMISSIONS: A CLOSER LOOK

Emissions per capita for both travel and freight rose fairly steadily in every country between 1973 and 1995. The major exceptions were the United States and Canada, where 1973 levels were only surpassed in the early 1990s. Moreover, the share of transportation energy use and carbon emissions in total energy use or emissions increased in every country studied. What drove these changes? Why was the United

States different until recently? Answering those questions may provide some important keys to future carbon restraint.

Closer examination of trends in vehicle fuel use link activity to emissions. We defined the vehicle energy intensity as energy use/vehicle kilometre, and the modal energy intensity as energy use per tonne-km or passenger-km (c.f. Equations 1 and 2). Vehicle intensity (for a given size and power) is related to the efficiency of the vehicle, while modal intensity depends also on the number of passengers or amount of freight carried. Since cars, trucks, and air travel account for most of the energy use, we will focus on trends in the intensities of these key modes.

Figure 9 shows the average automobile fuel intensity, or fuel use per 100 km, for car fleets (personal light trucks are taken into account in the United States, as they account for nearly 30 percent of household vehicles). This measure fell dramatically in the United States (and Canada, not shown), but barely changed in Japan (not shown) and in most European countries. Note that the figures for the early 1990s reflect car fleets that have been almost completely renewed since the early 1970s. Test figures for new automobiles fuel economy are shown in Figure 10 (personal light trucks are taken into account in the United States). These reflect a slow decline in intensities among fleets in Europe, but a reversal in the United States as the share in new "cars" of more fuel-intensive light trucks and sport-utility vehicles continues to increase.

Figure 9: On-road Fuel intensity and Carbon Intensity of Automobiles

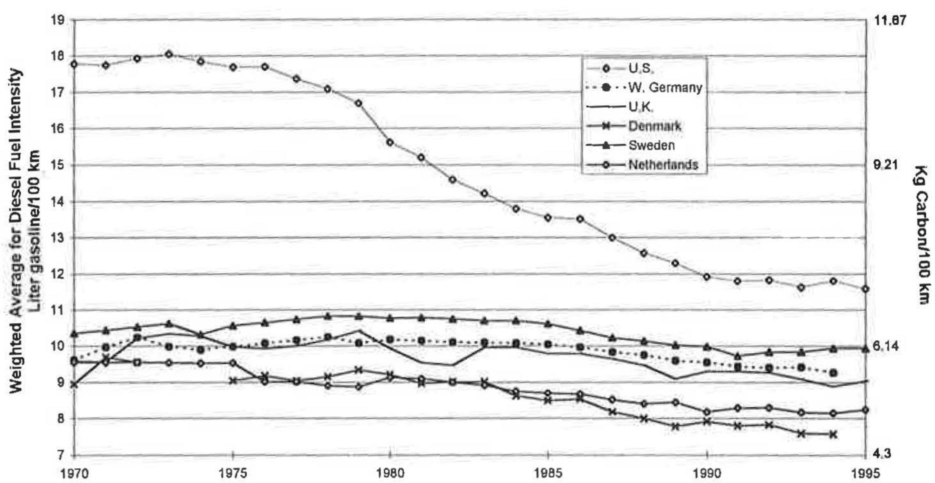
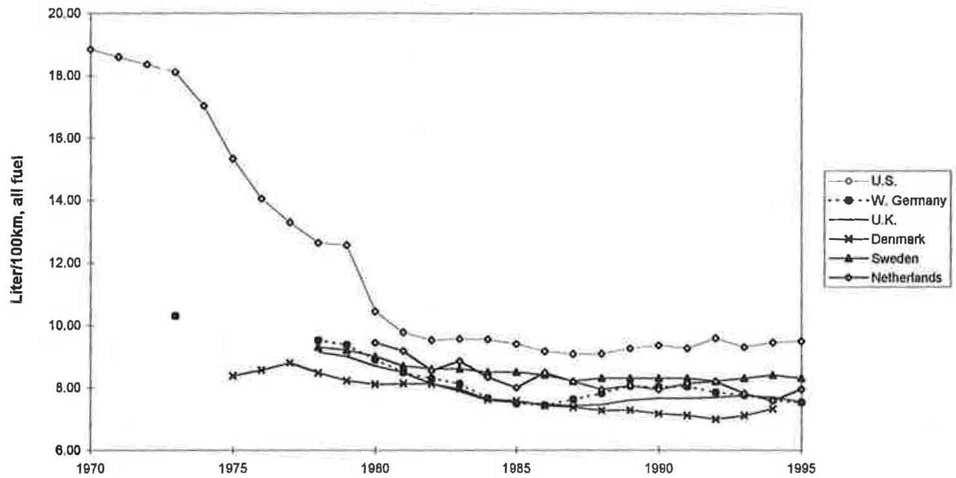


Figure 10: New Automobile Fuel Economy (tests) 1970-1995



The lack of dramatic change in the vehicle intensities in many countries may be a surprise to many but has a clear explanation. Vehicle performance and weight changes have absorbed some of the savings that advances in fuel consumption technology offer. Figure 11 shows that indeed fuel use per km per unit of new car power, averaged over each year's new cars is falling steadily and uniformly in every country, and in fact differs little from country to country. But Figure 12 shows that power is growing steadily, propelled mainly by higher incomes. Weight is also growing, both because cars are getting larger and because extra equipment and safety measures add weight as well. Thus new technology has made cars (and most other vehicles) more efficient, but only some of the results reduced fuel intensity. Ironically, the most powerful or heaviest fleets use the least fuel per unit of power or weight, a result of economics of scale. This means that fuel intensity need not grow as fast as power or weight. But there are no signs of a serious decline in fuel intensity through 1998.

Figure 11: New Car Fuel Intensity
(Normalized to Engine Power)

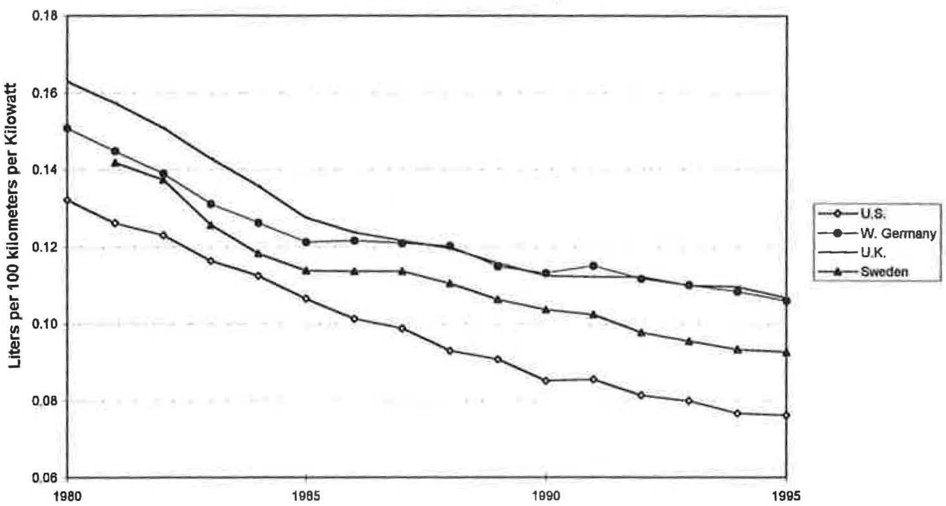
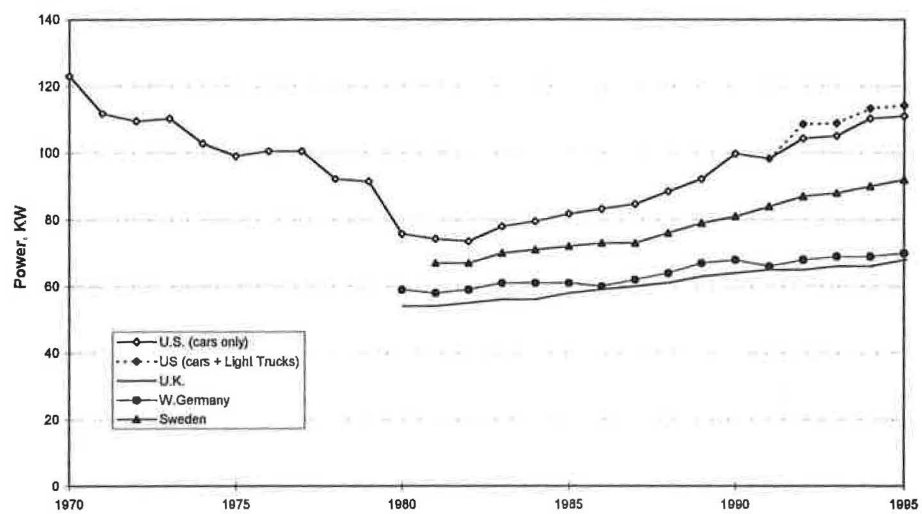


Figure 12: Average Power of New Cars Sold (kW)

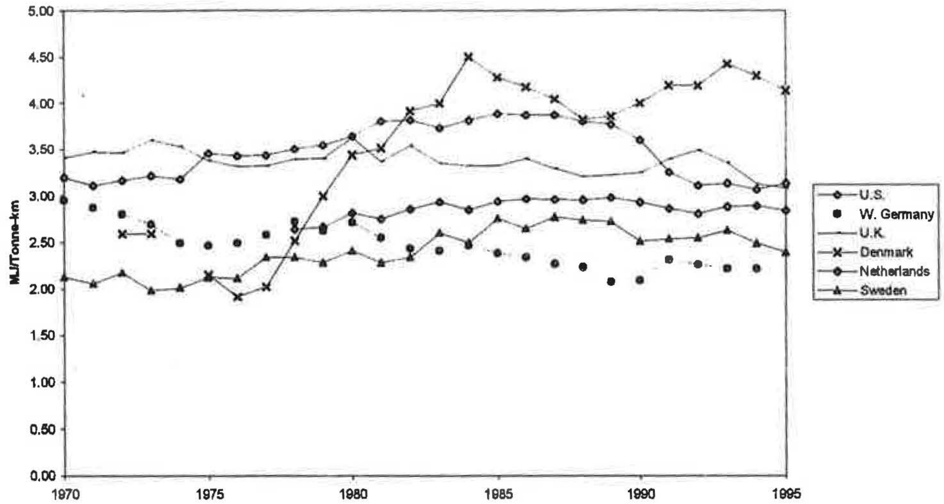


As noted previously, each year there have been fewer people per car in every IEA country. Reasons include continued drop in household size and an increase in single-person households, but also increased use of cars for commuting to and from work, particularly for women (or men as second wage-earners in families.). Since walking or biking and collective modes do have a large share of these trips in the densest areas of cities, it is not surprising if those who do drive to work are likely to do so alone, with load factors for these trips ranging from 1.1 in the United States to 1.3 in the Netherlands. Changes in the overall car load factor in European countries were great enough to offset the changes in vehicle intensity: it takes more energy to transport an average European or Japanese by car today than in 1973. But in North America, the vehicle intensities fell so much that the net fuel use per passenger km in cars fell by around 20 percent. In fact, in the U.S. today the average car and average city bus require about the same fuel per passenger-km, and emit about the same amount of CO_2 as well.

For air travel, the modal intensities have dropped dramatically. While new aircraft consume roughly 30-40 percent less fuel per seat-kilometre than those that made up the fleets in the early 1970s, the percentage of seats occupied (load factor) has also risen from around 50 percent to over 60 percent for domestic routes in most IEA countries. These changes led to a drop of 50 percent or more in the modal intensity of air travel, to where it lies close to the value for automobiles. The United States, with the largest average distances between domestic cities (approximately 1000 km per stage length, with similar figures for both Australia and Canada), has lower intensities then crowded Europe, where congestion on the ground and in the air pushes up intensities.

Freight is a different story. In every country, the vehicle intensity of trucks of a given size fell. This was a result of increased penetration of diesels as well as improvements in a given type of diesel or gasoline truck. But the ratio of fuel use to freight hauled did not fall in all countries, and continues to vary considerably among countries, as Figure 13 shows. Since the trucks are produced by large, international firms, difference between the figures shown cannot be very much attributed to actual differences in the energy efficiency of trucks. Instead the differences arise largely because of differences in fleet mix (between large, medium, and light trucks), differences in traffic, and above all differences in the capacity utilisation of each kind of truck (Schipper, Scholl, and Price 1997). Heavy trucks, when fully loaded (say with 40 tonnes) use about one-eighth the fuel per tonne-km as a light delivery truck carrying 200 kg. In Germany, regulations limit empty hauling, while in Denmark or the Netherlands more than 40 percent of all truck km are empty. And traffic on the open roads of the United States or Sweden is much more favourable to good fuel economy than that in Germany, the Netherlands, or Japan, where intensities are second only to those in Denmark. Danish intensities were high until taxation rules were revised, starting in 1992, ending the refund truckers got for most fuel taxation. Again, it is changes in the loading and utilisation of trucks that affect the overall evolution of each country's freight modal intensity the most. These changes have explanations in the need for just-in-time deliveries, the rising value (as opposed to tonnage) of freight, and above all the importance of other costs besides those of fuel in determining the optimal use of trucks.

Figure 13: Trucking Activity Energy Intensities



We can aggregate these results to two figures of merit: the aggregate emissions intensity of travel, and that of freight, i.e., ratio of emissions to passenger- or tonne-km. Figures 14 and 15 show the results, which follow energy intensity trends closely. Understanding these results improves if we use decomposition and indexing techniques for this purpose.

Figure 14: Aggregate Carbon Emissions Intensity of Travel

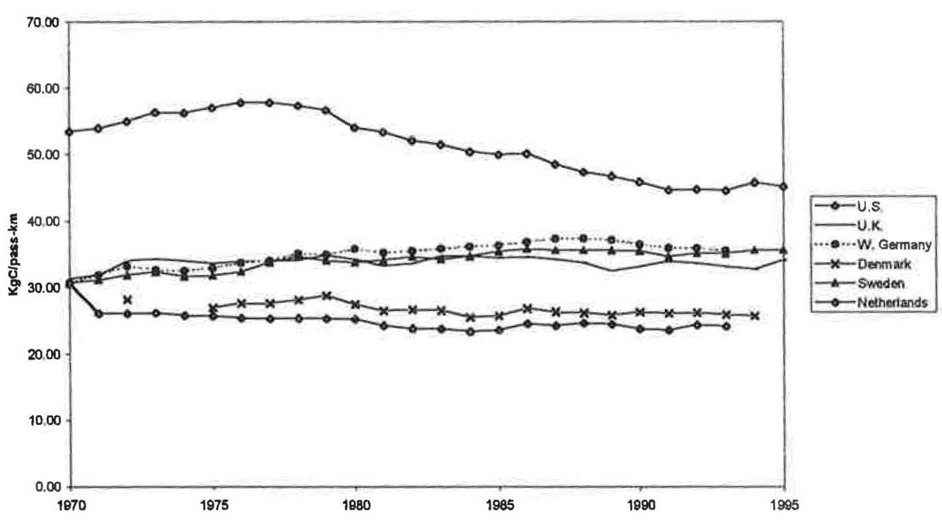
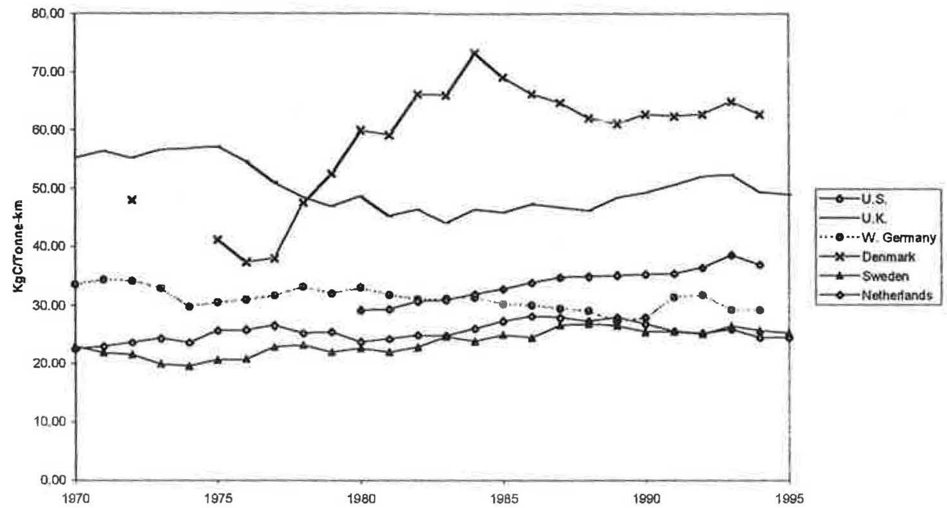


Figure 15: Aggregate Carbon Emissions Intensity of Freight Transport



DECOMPOSING EMISSIONS

In this section we provide a brief decomposition of emissions in 12 countries, including the six in our in-depth study. We use 1990 as the base year because of its importance to the Kyoto talks. Comparison of trends before and after 1990 offer insights into what policy-makers face in trying to hold down emissions from these sectors.

Decomposition of Emissions from Travel

For travel, higher per capita travel (total activity) increased emissions in every country, as Table 1, based on Laspeyres indices, shows for the group of aggregates. Modal shifts (structure) towards more energy-intensive modes (cars, air) increases emissions by as much as 25 percent (in Japan, shown for reference), but in most countries by up to 1-3 percent using the 1990 modal structure as reference. This growth in activity is clearly income-driven (Johansson and Schipper 1997). Since car ownership is also income driven, and car ownership growth lies at the root of the modal shifts, we can say that modal shifts as well are income driven. And since modal shift itself moves people to more rapid modes and those that move them considerably longer distances (air, for example), we can say that higher incomes are associated with greater and more rapid travel.

Falling energy intensities of vehicles themselves reduced emissions in more than half of the countries, but falling load factors in cars (and bus and rail in many countries) offset this restraint, leading to a net increase in energy use (and CO_2 emissions) per passenger-km in cars. Indeed, only in North America were the emissions savings from lower modal intensities greater than 20 percent. Changes in Europe and Japan were small because power and weight increases offset most of the impacts of technical improvements. And in all countries, falling load factors in cars, as well as in many countries on busses and rail, also increased emissions. These factors combine to give the changes in energy intensities shown. Shifts in fuel mix and utility mix (not shown separately) had almost no impact, for two reasons. First, the emissions per unit of energy released from diesel and gasoline are very close, although diesel is slightly higher. Second, the role of electricity for travel (rail, trams) is so small that even the almost complete transition away from fossil fuels in some countries (Sweden, France) had only a very small impact on emissions from this sector. Combing the energy intensities and fuel factors yields carbon intensities. Thus by 1994/1995, incomes and behavioural factors had clearly increased CO_2 emissions, even after over a decade of relatively high road fuel prices.

TABLE 1 Average Annual Percentage Changes in Carbon Emissions from Travel, 1973-1990, 1990-1994, Laspeyres Decomposition, 1990 Modal Structure

	EFFECTS 1973-1990							***EFFECTS 1990-1994***						
	Actual	Activity	Structure	Carbon Int.	Energy Int	Fuel Mix	GDP	Actual	Activity	Structure	Carbon Int.	**Energy Int.**	Fuel Mix	GDP
Denmark	1.1	1.2	-0.2	0.0	-0.1	0.1	1.8	0.9	1.1	0.0	-0.1	-0.2	0.0	1.6
Norway	3.3	2.9	-0.1	0.4	0.5	-0.1	3.3	0.1	0.4	-0.4	0.1	0.1	0.0	3.0
Sweden	1.8	1.3	-0.1	0.4	0.5	0.0	1.9	-0.1	-0.2	0.1	0.0	0.0	0.0	-0.6
Finland	3.6	2.8	0.2	0.4	0.1	0.3	2.9	-1.5	-1.0	0.1	-0.5	-0.4	-0.1	-5.3
Netherlands	-0.5	2.4	0.2	-0.5	-0.7	0.2	2.5	3.6	2.4	-0.1	1.3	0.0	1.2	2.1
France	2.5	2.5	0.1	-0.2	-0.1	-0.1	2.4	1.6	2.1	0.4	-0.9	-0.9	0.1	0.9
W.Germany	2.8	2.2	0.2	0.4	-0.1	0.5	2.2	-0.8	-0.1	0.0	-0.6	-0.9	0.3	1.8
Italy	3.5	3.8	0.0	-0.3	-0.5	0.2	2.8	3.7	3.5	0.4	-0.6	-0.5	-0.2	0.7
UK	2.4	2.7	0.2	-0.5	-0.6	0.0	2.0	-0.3	0.0	0.1	-0.4	-0.2	-0.1	0.9
USA	0.5	1.7	0.0	-1.4	-1.4	0.0	2.7	2.1	1.9	0.0	0.2	0.2	0.0	2.3
Japan	3.7	2.9	1.0	-0.5	-0.4	0.0	3.7	4.9	2.3	0.9	1.7	1.6	0.0	1.4
Australia	2.8	3.3	-0.3	-0.2	-0.3	0.0	3.0	2.1	2.2	1.3	-0.7	-0.8	0.0	3.3

Note. The Netherlands from 1978, Australia from 1974, Denmark from 1972.

We noted that fuel mix has almost no effect on our results. This is in part because the mix of fuels varies so little in CO_2 content. To be sure, increased use of diesel cars should reduce intensities. Some of this has occurred in Germany and the Netherlands (as well as Italy and France, not examined in detail in this study.). In all these countries, however, diesel is priced lower than gasoline. This advantage is utilized by those with greater than average yearly driving distances. And to some extent (Hivert 1996), those switching from gasoline to diesel increase their driving, consistent with the lower diesel price. Finally, marketing data show that for any given car model, a diesel version tends to have 10-15 percent more power than its gasoline counterpart, to make up for the generally lower acceleration of a diesel engine. Thus only part of the potential economy of a diesel engine is actually realised as lower fuel use and CO_2 emissions in the countries where diesel cars are popular. This digression reminds us that ultimately we have to consider terms other than **I** alone in causing changes in emissions.

Since 1990, the picture of emissions is somewhat different. Since 1990, carbon intensity fell slightly in a few countries (Finland, France, West Germany, Italy, and Australia). Most important, the decline from intensity changes in the United States has ceased. In all but two countries, the rate of growth in emissions, relative to GDP, after 1990 is higher than it was before 1990. And with recovery from recession, higher economic growth in many countries has stimulated both greater activity and slightly more rapid shift to cars and air travel. Thus since 1990, trends in emissions point away from their path before 1990.

Decomposition of Emissions from Freight

Table 2 decomposes CO_2 emissions for freight in the same way as for travel. In all of the countries studied, *actual* emissions increased, and in nearly half of the countries studied, this increase was greater than that of GDP, which is shown in the last row. In a majority of countries, modal shifts (towards trucking), or *structure*, increased emissions, often by more than was the case for travel. In contrast with travel, the modal *energy intensities* of freight (energy/tonne-km) reduced emissions in more than half the countries. The impacts of changes in fuel mix (including fuels used to generate electricity) were again small, except where railroads underwent significant electrification and electricity was generated by low-CO_2 sources. Unlike travel, (electric) rail plays a more prominent role in carrying freight. Still, as Figure 8 shows, emissions from freight are dominated by those from trucks, so it is this mode, like cars, whose evolution is the most important for that of the sector's emissions.

Interpreting the differences in changes before and after 1990 is difficult. This is because 1990-92 was a period of recession for many countries, with drop in freight activity that often left truck fleets carrying fewer tonnes per kilometre, i.e., lower load factors. After 1990, emissions rose faster than GDP in seven of twelve countries, while before 1990 the reverse was true. What is striking is that carbon intensity fell or increased by less than 0.1 percent/year in seven countries in both periods. At the same time the structural shifts towards trucking and thus greater carbon intensity were in general stronger than the same shifts to cars and air travel. We surmised that for freight, fuel prices played a less important role in the overall evolution of energy use and emissions than they did for travel. The lack of a strong difference in emissions paths between the period of higher prices (which can justifiably include the years 1986-1990 when effects of new equipment were still being felt strongly through stock-turnover) and period of lower prices is thus not surprising.

TABLE 2 Average Annual Percentage Changes in Carbon Emissions from Freight, 1973-1994, Laspeyres Decomposition, 1990 Modal Structure

	EFFECTS 1973-1990							EFFECTS 1990-1994						
	Actual	Activity	Structure	Carbon Int.	Energy Int.	Fuel Mix	GDP	Actual	Activity	Structure	Carbon Int.	Energy Int.	Fuel Mix	GDP
Denmark	2.8	1.6	0.7	0.7	0.6	0.0	1.8	2.5	-1.3	-0.2	4.2	4.2	0.0	1.6
Norway	2.1	2.0	0.9	-0.7	-1.2	0.4	3.3	1.3	0.9	-0.2	0.5	0.7	-0.2	3.0
Sweden	2.5	1.0	0.5	1.0	1.2	-0.1	1.9	0.3	0.1	0.8	-0.6	-0.7	0.0	-0.6
Finland	2.2	1.7	0.5	0.0	0.0	0.0	2.9	-1.2	0.4	-0.9	-0.6	-0.3	-0.3	-5.3
Netherlands	4.5	2.3	1.5	1.1	0.6	0.0	2.5	3.0	1.8	1.3	-0.1	0.2	0.0	2.1
France	2.0	0.5	1.3	0.4	0.6	-0.1	2.4	2.0	0.6	0.9	0.5	0.6	0.0	0.9
W.Germany	0.6	1.8	1.2	-1.9	-1.9	0.0	2.2	4.5	1.9	1.2	1.4	1.7	-0.3	1.8
Italy	4.9	4.3	-0.1	0.7	0.6	0.1	2.8	0.7	1.0	0.2	-0.5	-1.5	1.0	0.7
UK	1.6	2.4	0.1	-1.0	-1.1	0.1	2.0	0.1	0.1	0.8	-0.7	-0.8	0.1	0.9
USA	2.5	1.9	0.8	0.1	0.1	0.0	2.7	0.6	2.9	1.7	-3.6	-3.5	0.0	2.3
Japan	2.0	1.7	1.7	-1.2	-1.3	0.1	3.7	2.4	-0.1	0.6	1.9	1.9	0.0	1.4
Australia	3.3	2.2	2.9	-1.8	-2.0	0.2	3.0	0.8	2.8	0.3	-2.3	-2.2	0.2	3.3

Note. The Netherlands from 1978, Australia from 1974, Denmark from 1972.

Summary: More Motion, More Rapidly, Raised Emissions

Changes in the amount people (and goods) travel have been the dominant cause of rising emissions. Technical factors, as the vehicle and modal energy intensities represent, led to some restraint of emissions in a few cases for cars and trucks but only gave a net reduction in per capita emissions (for travel) in one country. Behaviour and system optimisation factors (i.e., modal choices and utilisation, speed), clearly boosted emissions as well. As of 1998, there was little sign that these factors alone were abating, although their coupling to ever-rising GDP may be weakening. Policies aimed at restraining CO_2 emissions from travel and freight should focus on the underlying factors driving emissions up since 1990, as these are likely the forces policies must circumvent. We turn to some of those forces next.

THE CHALLENGES FACED: TRADITIONAL DRIVING FACTORS OF RISING INCOMES AND FUEL PRICES

The foregoing reminds us that GDP is an important factor driving both passenger travel (cf. figures 1-2) and freight (Figure 6). Figures 16 and 17 make this connection for travel and freight-related carbon emissions. Only in the United States does there appear to be some relenting or decoupling, both during the periods of the oil shocks (the bumps in emissions per capita at 18,000 $1990 US and 21,000$ per capita GDP) and a slowing of growth after that period. This trend of slowing growth (versus GDP) can be discerned in all countries, but it is not very marked at all. For freight, there is less of a clear trend in any country, in part because the ratio of carbon to freight hauled fell in more countries than it did for travel, in part because the coupling between freight hauled and GDP varies more over time and among countries. Nevertheless, our earlier suggestions that income has been the key driving factor, are validated by these figures, and confirmed by many statistical investigations (Johansson and Schipper 1997; Bennathan, Fraser and Thompson, 1992).

Figure 16: Per Capita GDP and Per Capita Carbon Emissions from Travel Sector

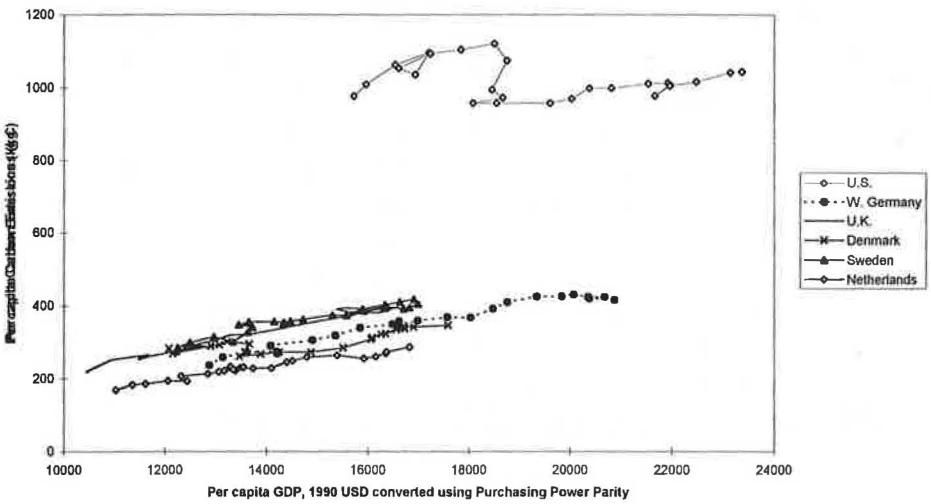


Figure 17: Per Capita GDP and Per Capita Carbon Emissions from Freight Sector

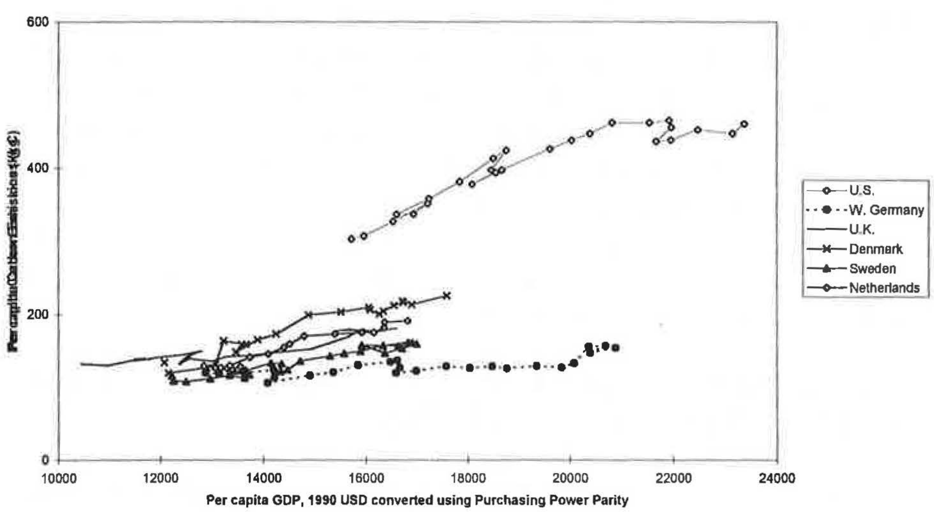


Figure 18 shows the development of average fuel prices in the countries we have studied. Diesel and LPG prices are included, weighted by their shares of total energy use for car travel in their respective countries using net heating value. Figure 19 shows fuel costs, defined as fuel prices in each country multiplied by the average on-road fuel intensity for each country's fleets. What is surprising is that fuel prices in any country were higher for such a short time, and how little changed prices were in the mid 1990s from their real 1973 values. This is more dramatic in Figure 19, which includes the effects of improved real fuel economy on costs. Fuel costs of driving one km. in the U.S. in 1995 are a full 30 percent below what they were in 1973 and nearly 70 percent below their peak level of 1981.

Figure 18: Automobile Fuel Prices

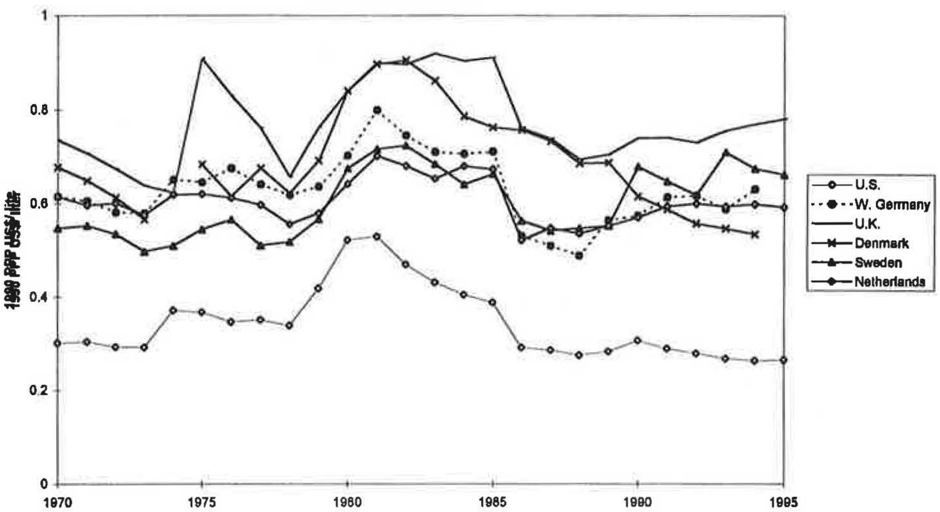
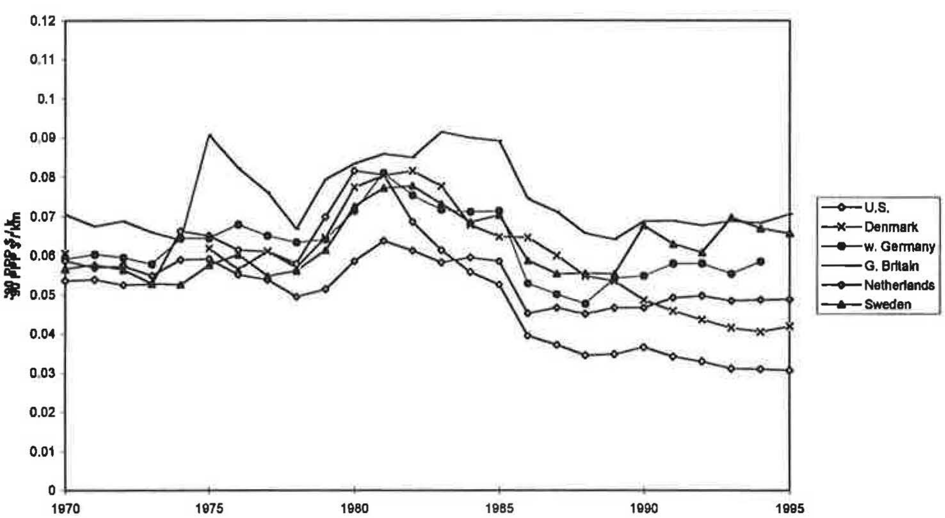


Figure 19: Car Fuel cost per Kilometre



Note too that in Figure 19 there is approximately a 2-1/2 to 1 spread in real prices as measured using purchasing power parity. In 1981 this spread was compressed to 2:1, but got larger as U.S. prices fell in real terms with almost no new taxes making up even for the impact of inflation on taxes. The movements in Sweden, Germany, and the Netherlands from the late 1980s were principally do to higher taxes, while those in Denmark result from a purposeful lowering of taxes. Now matter which perspective is taken, it is clear that few drivers in the countries studied saw real, steady price increases that left them in the mid 1990s paying more to use fuel than they did in the early 1970s.

Did higher fuel prices not affect fuel use or emissions? It is often forgotten that for most countries, real fuel prices were higher than average only for two brief periods, 1974-7 and 1979-1985, periods too short to expect radical changes in both vehicle technology and use and modal choice to occur, let alone major rearrangement of the housing and mercantile infrastructure affecting the origin and destinations of travel and freight respectively. Still, emissions per unit of GDP did fall somewhat in these periods, and emissions unit of activity fell as well. This was most dramatic in the United States where travel-related emissions in 1985 were at their 1973 level despite 13 percent more travel. Both prices and the Corporate Average Fuel Economy standards pushed new car fuel intensity downward, as Figure 10 showed. Even there, however, emissions began to rise after fuel prices dropped and new car fuel economy stagnated in the late 1980s.

Some of the decline in car fuel intensity continued after oil prices crashed, because of the technological gains that were started in the high-price years, gains still working their way into the fleet through vehicle turnover. Yet prices seem to play a pivotal role in fuel economy or fuel use over the long run. One way to see this is to view all the countries in cross section. Figure 20, however, shows that there is a significant relationship between car fuel intensity (or per capita car fuel use) and real fuel price (with diesel included at its share of car fuel in each country). This is even more striking if we plot fuel use per capita versus the weighted price (Figure 21). If fuel use for cars in Figure 21 were normalised by GDP instead of population, the U.S. point would fall somewhat closer into the line. Interestingly, both Canada and Australia, which are included in these plots, fit nicely between the United States and Europe. This suggests that the United States is not a freak or outlier. While we do not suggest that geography or other factors are unimportant to fuel use, the role of prices and incomes are clearly very strong.

Figure 20: Car Fuel Intensity and Fuel Prices, 1995

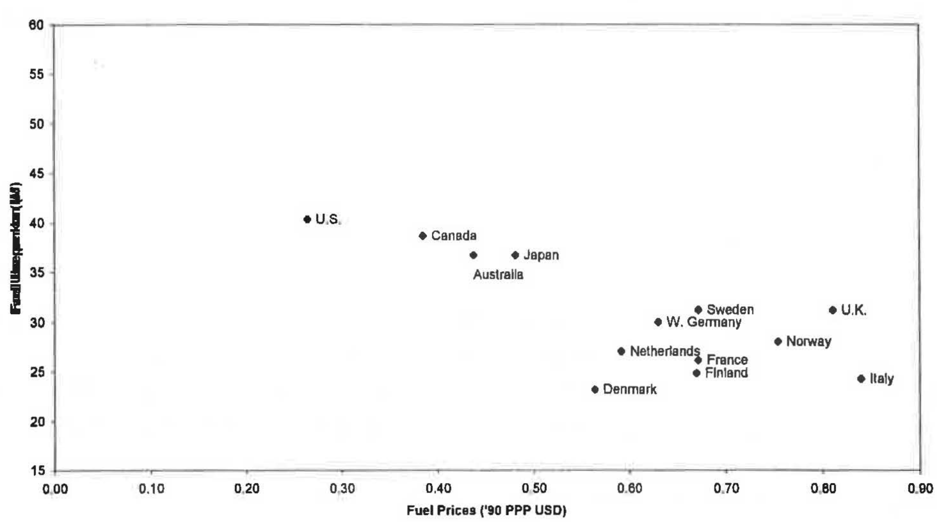
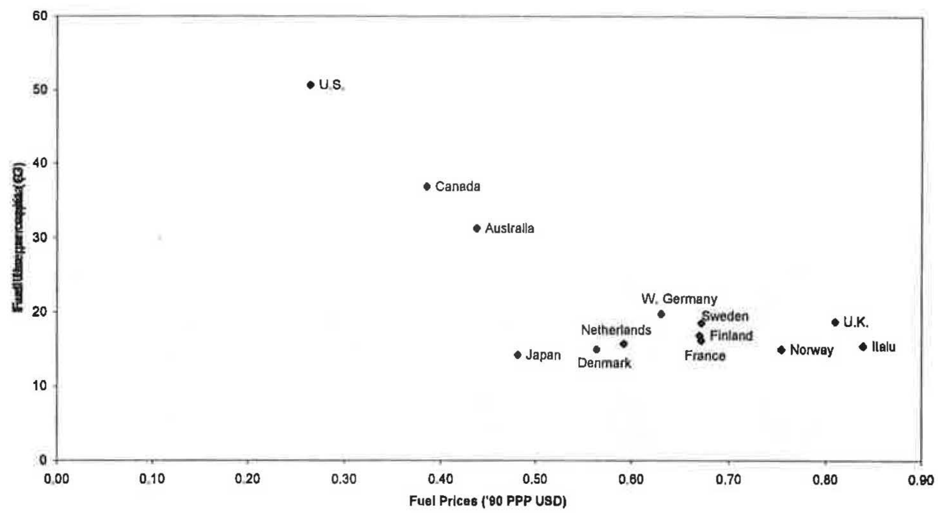
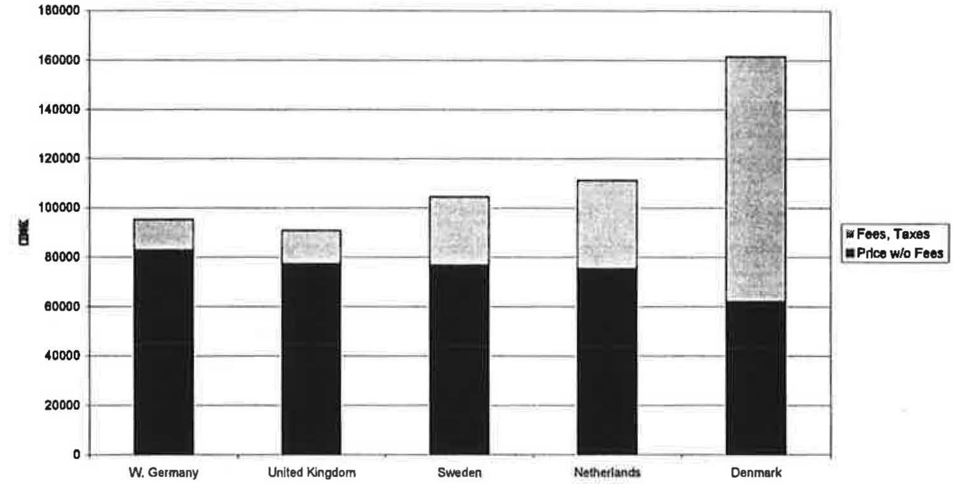


Figure 21: Per Capita Car Fuel Use and Fuel prices, 1995



The fact car fleet fuel intensities appear to be almost linearly related to fuel prices, and that U.S. vehicle fuel intensity in 1994/5 appears consistent with the points from the other countries is striking. This suggests that automobile fuel intensity is indeed a function of fuel price in the long run. But automobile efficiency in a technical sense now varies little among countries (cf. Figure 11), since, as for trucks, vehicles are produced by international companies sharing largely the same technologies. Instead fleet-average automobile size or weight (cf. Figure 12), power, and features that differentiate the points for fuel intensity in Figure 21, with vehicle ownership and use taxation, including the impact of company car taxation, certainly explain some of the scatter, since these policies affect not only the ultimate cost of fuel to the user but the cost of using the vehicle as well, which is much more significant (Schipper and Erickson, 1995; Schol and Smokers, 1993; NEDC, 1991; Fergeson, 1990). It is not unreasonable to assert, without formal proof, that these characteristics depend on incomes (including car taxation) and fuel prices, but this formal dependence will have to be subject of future study. Nevertheless, governments do affect car prices through taxation and this has a clear affect on their characteristics and fuel use (Johansson and Schipper 1997). Figure 20 makes this point another way: Shown in Fig. 22 is the same car taxed in each of the study countries (except the United States, where the taxes would amount to a few percent only, according to Schipper and Eriksson 1993). The large levies in Denmark reduce car ownership (evident in Figure 1), but not necessarily car use (Figure 2). They clearly force Danes to buy considerably less fuel-intensive cars than their Swedish or German neighbours (Figure 9).

Figure 22: Cost of an Opel Astra 1.6 litre GL 3 door, 1994



Source: Vejtransporten i tal og tekst Danish auto importers Assn, 1993

Freight presents a somewhat different picture. In contrast with cars, the correlation between trucking fuel intensity and truck fuel price is very poor (Fig 23). The correlation between the ratio of trucking energy to GDP and trucking fuel price, shown in Figure 24, suggests that trucking energy depends somewhat on price, both through modal intensity and through total volume of truck freight shipped. Thus in a cross-national comparison, prices appear to affect both fuel intensity and fuel use in most cases, but the relationships are stronger for car use than for trucking. We do not have fuel prices for other modes, but since these fuels are untaxed and since other modes of freight consume one third to one tenth as much fuel per tonne-km as trucking, we expect fuel prices to be even less important for these modes than they are for trucking.

Figure 23: Fuel Intensity and Fuel Prices for Trucking, 1994

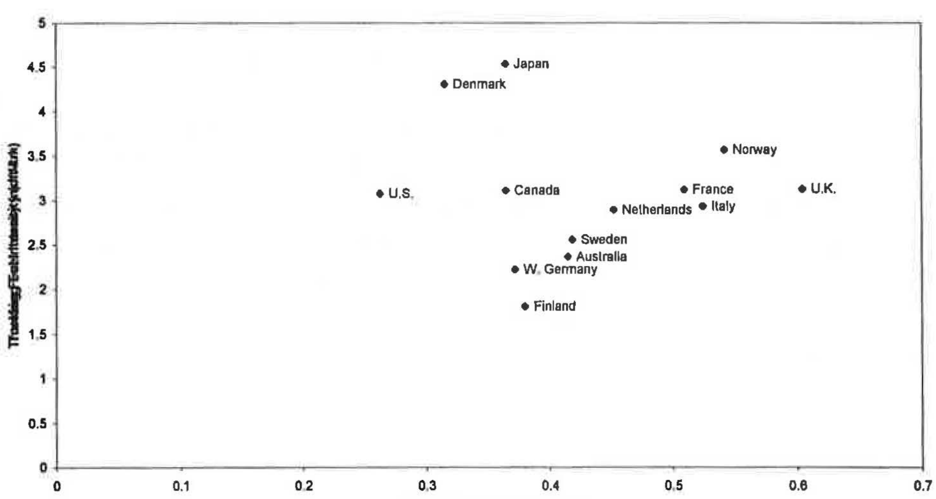
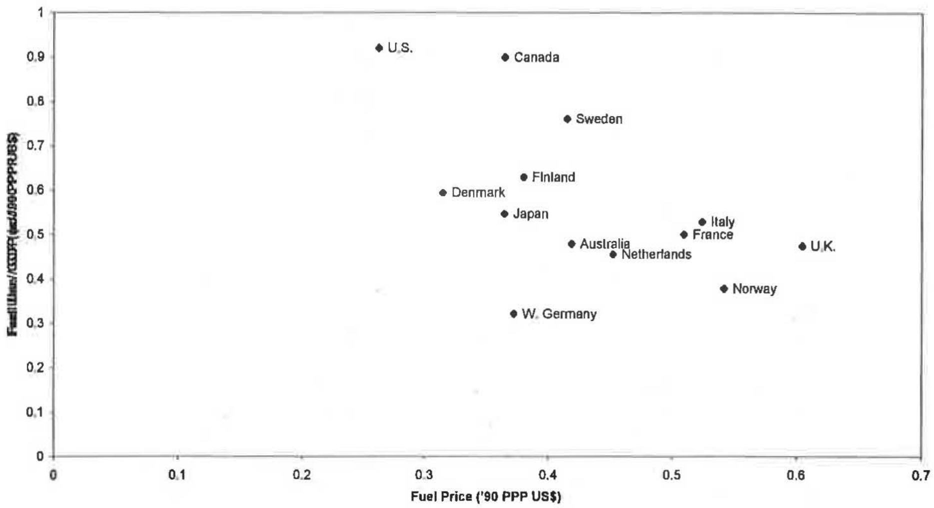


Figure 24: Fuel Use per Unit of GDP and Fuel Prices for Trucking, 1994



Thus factors causing changes in CO_2 emission are intimately related to the nature of transportation—comfort, convenience, speed. Thus driving activity—distance—as well as modal choice are related to individual and societal choices about housing, work and leisure location. The same is true for freight. But the cost of fuel is but a small fraction of the total cost of either travel or freight, even before the cost of the transport infrastructure is considered. And the choices noted here are deeply rooted in a transportation context. This means that these choices—today's slowly evolving transportation patterns—may be difficult to stop simply because of CO_2 concerns. To be sure, natural limits (saturation of distance or time of travel, potential saturation of the distance physical goods are sent around) or local constraints (congestion, parking problems, local pollution) may slow or reverse some of these trends. But most national transport plans still foresee increases in personal and goods transportation with GDP without policy intervention.

It is significant nevertheless that emissions from freight, in contrast to those from travel, show restraint from lower energy intensities in roughly half of the countries studied. We speculate that this may be because structural effects on freight demand are more intense and also because freight services unlike private mobility consumption responds to business needs. Although the importance of fuel costs to total freight costs, or to the total costs of products delivered is small, there is clearly always room for saving fuel at the margin, subject to the constraints imposed by costs for equipment, labour, and maintenance. The same is true for air travel, which showed uniform and deep reductions (50-60 percent) in fuel use or emissions per passenger-km in all countries from both improved technology and higher load factors. In this case, however, fuel accounted for as much as 20 percent of operating costs and even in 1997 remains a source of cost pressure to airlines. Thus the distinction between enterprises and private automobile use may be important for explaining differences in the evolution of fuel intensities and CO_2 emissions from these different branches of transportation.

The couplings between travel or freight and GDP illustrated by Figures 5 and 8 are daunting. While there is no denying fuel prices affect this coupling through both fuel intensity and to some extent distance travelled, few expect fuel prices to change radically because of oil market changes or even taxes designed to represent the CO_2 externality itself. To some extent there may be saturation in the level of travel or freight, but no one expects either level to decline if GDP keeps rising. With that rise, then CO_2 emissions are not expected to decline. Or are they? What could cause changes is a combination of transportation policy reforms in the near term, technological changes in the longer term, and consumer/shipper responses to both forces. We review these possibilities next.

WHAT IS BEING DONE? POLICIES AND TECHNOLOGIES AS DRIVING FACTORS

Several European countries appear to be making serious efforts to deal both with fundamental problems associated with transportation (congestion, air pollution, safety, noise, roadwear) and with CO_2. This section introduces us to a framework for analysing policies, which will then be enumerated country by country, a framework based on the decomposition analysis noted above.

The key motivation is that alluded to in the introduction: Experts and policy-makers alike (as well as some vehicle-users) find that there are times (and places) in the driving cycle where the real social costs of driving exceed by significant amounts the private costs paid for a marginal km of vehicle use. Furthermore, the carbon-dioxide component of that excess is probably small. Therefore, the key steps in transport policy may well focus on non-CO_2 externalities, but to the extent they reduce traffic, will reduce CO_2 as well. And to the extent that these measures raise the cost of driving, they will offset the downward impacts on costs of measures that reduce fuel consumption per kilometer.

To evaluate these efforts we can use a simplified version of Equations 1 and 2 as an analytical framework illustrated in Figure 25. Options to mitigate CO_2 emissions from transport are illustrated in Figure 26, which is based on the decomposition depicted in Equations 1 and 2 but further elaborated into sub-components. As Figure 25 suggests, there are these basic choices:

- Reduce, or restrain the growth in the movement of people and goods (the A term in Equation 1)—though this is considered a significant challenge economically and politically;

- Reduce the modal energy intensity of the various modes (cf. Equation 2) using less energy for the same mobility or getting more mobility from the same energy, by improving the technologies of vehicles (less fuel per kilometre), improving utilisation (less vehicle-km per passenger or tonne-km), or shifting some activity towards less fuel-intensive modes (the S term in Equation 1), reversing the trends illustrated in Figures 7 and 11; and

- Reducing the CO_2 content of fuels.

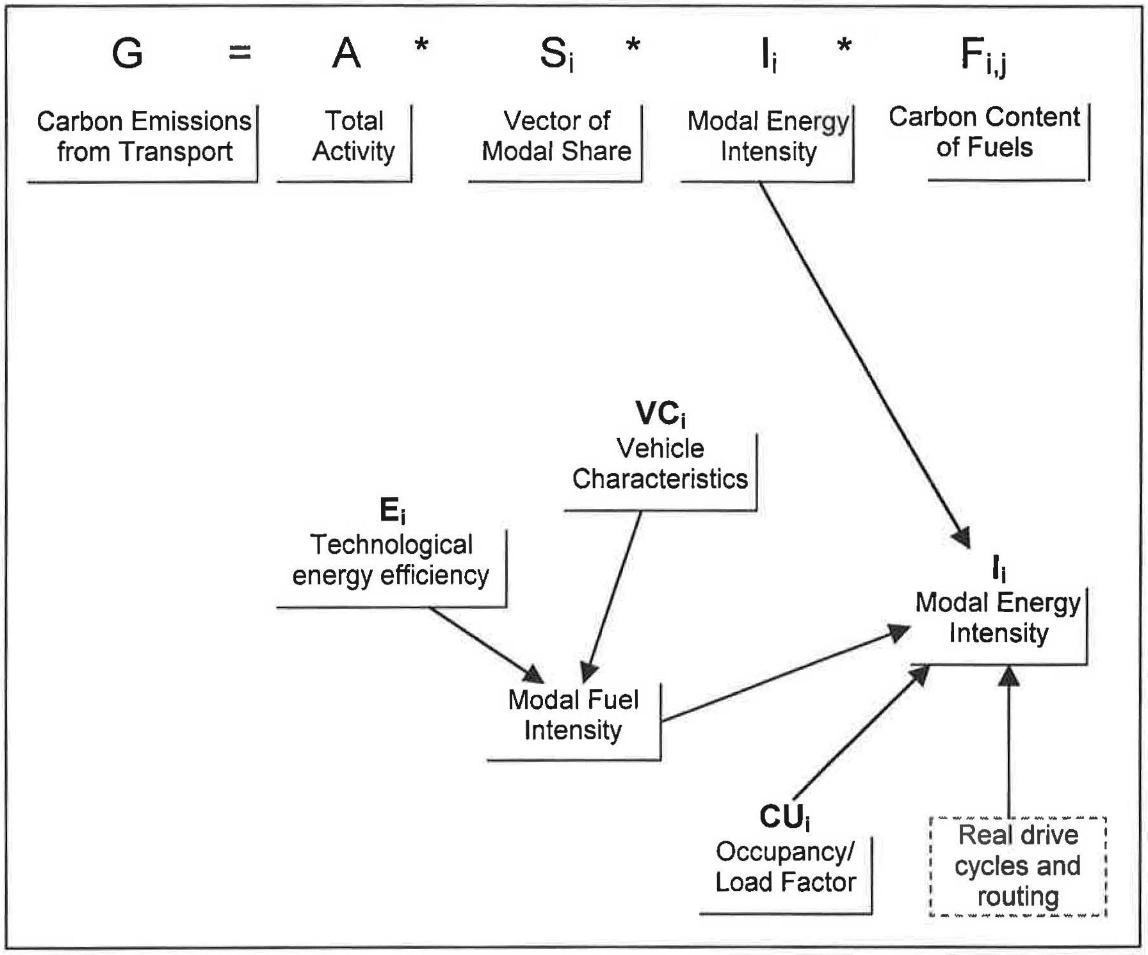


FIGURE 25 How transport CO_2 emissions are accounted for in terms of mobility, energy efficiency and carbon content of fuels.

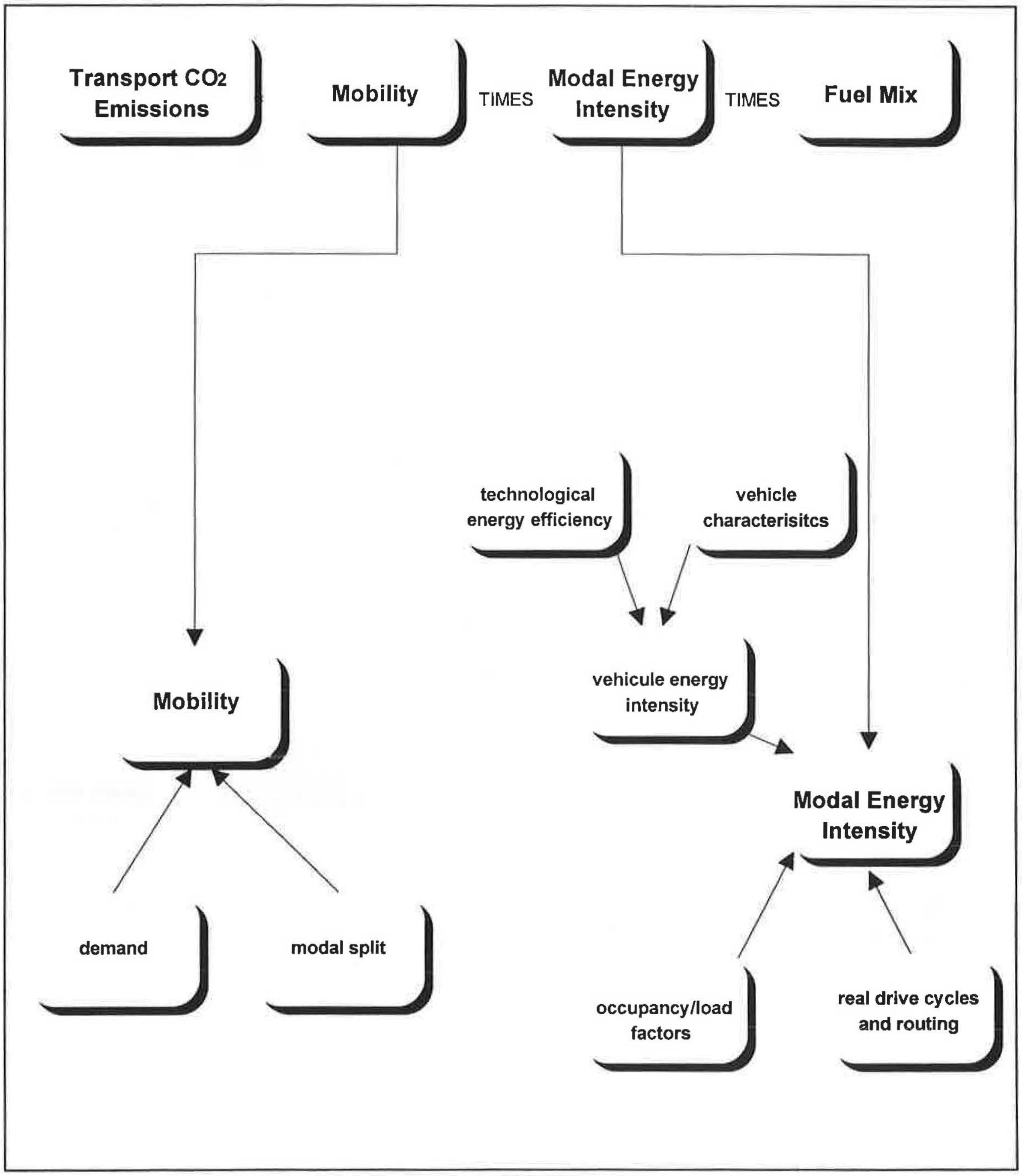


FIGURE 26 Actions in IEA countries to restrain transport CO_2 emissions.

In simple terms, relatively large reductions in transport CO_2 emission from a given baseline can be achieved by making relatively small changes in two or more factors noted above. A 10 percent reduction in total emissions could be achieved by a 3 percent reduction in each of the factors of mobility, intensity and fuel mix. However, the scale of the technological, economic and political challenges associated with simultaneous reductions cannot be overstated. Indeed the converse is also true: relatively large growth in emissions can result from relatively small increases in two or more of the factors. We cannot assume that it is equally easy to change each component by the same amount, or that changes in each component will be smooth over time. Experience shows that in the short term, mobility and modal mix may change, while in the longer term, technology is more likely to change unless strong pressures remain that limit mobility or raise its cost.

The interactive dependence of transport emissions on mobility, intensity and fuel mix suggests that packages of measures, which simultaneously address multiple options, have greater synergies and lead to greater mitigation. However, constraining mobility is a major boundary condition since it implies overcoming real political and economic challenges. On the other hand, the thrust of transport reform packages in a number of European countries will directly or indirectly raise the cost of personal and goods mobility in congested or otherwise sensitive areas, which may lead to less traffic and some changes of mode. These cost shifts are likely to be much larger than those associated only with fuel taxation, hence their overall impacts on total mobility, on utilisation, and on modal choice could be significant. Thus one could imagine an integrated transport/CO_2 strategy in which fuel prices and technological improvements affected primarily I and F, while reforms in the way transport is priced might have a significant impact on A and S (equation (1)). For now we will not identify which countries aim at which components of Figure 26, but this will become clear as we study each country in depth.

Figure 26 also spawns interest about the "potentials" for changes in each category. These can be posed in a static framework, e.g., move 5 percent of current traffic now on cars on to existing local bus and rail lines, in a dynamic framework, e.g., slow the growth in car traffic from its present rate (relative to GDP growth) by increasing the growth in use of these other modes; or in a policy framework, e.g. under what changes in prices and policies might either the static or dynamic change occur? A key question is time frame: how long would it take to change the entire truck fleet or move freight loading terminals to locations where less fuel would be wasted idling in traffic, etc? And perhaps the most obvious question is one of costs: how much would individuals and society pay for alternative technologies? How much more or less would trucking cost if changes in the system occurred that increased load factors? How much car power or weight would car buyers forego for each 10 percent increase in fuel prices or in the taxes on new cars?

Unfortunately, few of these questions are accurately answered with observations of past and present patterns. But some of the transport-policy or CO_2 policy-studies we reviewed did try to pose the dynamic and policy questions with models, identify key assumptions, note possible feedback between the terms, and calculate or approximate the outcomes in the future. To be sure, the potential for savings remains, particularly in the area of "vehicle fuel intensity" (i.e., technological energy efficiency and, although less likely, vehicle characteristics). Alternative fuels also show promise, but at higher cost than gasoline or diesel fuel. But no country seems to have figured out how to translate potential into reality without incorporating a great deal of patience stretched out over two or more decades, and strong political will. This does not mean there will not ultimately be low-cost ways of reducing carbon emissions from transportation, only that it will take many decades to restrain emissions at low cost. This may be the most important lesson of this study so far, and sobering for policy makers and analysts alike.

SUMMARY

We have reviewed key trends driving freight and passenger transportation in IEA countries since the early 1970s. In spite of two oil crises that affected fuel prices profoundly, the growth in underlying demand for travel and freight stayed closely coupled to economic activity, although some signs of saturation have appeared in the most motorised countries. Fuel intensity for cars or trucking fell significantly only in a few countries, and in no countries is either of these key indicators falling faster than underlying activity is rising. Consequently CO_2 emissions are rising, in most countries faster than the Kyoto targets imply.

This view should not be taken too pessimistically. As we note in IEA 1997b and IEA 1997c, most major automobile companies have announced dramatically new approaches to *marketing* vehicles with significantly lower CO_2 emissions, both through efficiency and through use of fuel cells or hybrid engines. Voluntary agreements between manufacturers or their associations and governments in Brussels and Tokyo appear to have spurred development and marketing of more efficient models, some of which have been announced or are being marketed already. Attacks on transport externalities promise to restrain growth in overall activity and even encourage a boost in the modal shares of less carbon-intensive modes. A carbon tax would give some encouragement towards both less carbon intensive fuels (natural gas in the short run) and perhaps spur serious development of low carbon biomass fuels in the longer term. Not surprisingly, all of these elements are present in the preliminary transport and environmental plans of each country we have studied, save the U.S., where the focus is on automotive technology. How each country's plan shapes up will be the subject of a subsequent presentation, but how emissions actually evolve will, of course, not be known for some time. This time element is the one most forgotten, but is the ultimate barrier to dramatic change, since vehicle stocks, driver habits, and freight patterns take decades to change (IEA 1998). Perhaps the most elusive element of all is patience, since we can only wait a long time to see how things turn out.

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