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Trends in truck freight energy use and carbon emissions in selected OECD countries from 1973 to 2005

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ABSTRACT

Trends in truck freight energy use and carbon emissions: In the age of global supply chains and "just in time" logistics, fast and efficient goods movement is often seen as an economic imperative. Growth in global goods movement not only translates into growth in commercial trucking activity but also into growth in the share of trucking compared to other modes of in-country freight transportation. These trends have a significant impact on the energy intensity of freight transport. Using a bottom-up approach relying on national data, this study compares the energy intensity of truck freight in Australia, France, Japan, the United Kingdom and the United States from 1973 to the present. The analysis builds on previous work by Schipper et al. (1997) and Schipper and Marie-Lilliu (1999) decomposing energy use for freight. Intensity is expressed in terms of vehicle intensity (megajoules/vehicle-kilometer), modal energy intensity (megajoules/tonne-kilometer), and carbon intensity (grams/tonne-km). The cross-country comparison highlights in part the influence of geography, transportation infrastructure, and truck utilization patterns on energy and carbon intensity from this sector. While improving fuel economy of individual vehicles is very important, large reductions in trucking energy use and emissions will also come from better logistics and driving, higher load factors, and better matching of truck capacity to load.

1. Introduction

Over a quarter of the energy consumed in the world in 2004 was used in the transportation sector (IEA, 2006). About a third of the share of world transportation energy is dedicated to the movement of freight within and between countries by trucks, ships, and rail (WBCSD, 2004). In many countries, trucking is supplanting rail and water transport as a means to deliver goods "just in time" to customers. The growth in global trade is not only changing how goods are moved but also the type of goods moved and how far or frequently they are transported. These changes have important impacts on the energy and carbon intensity of the trucking sector.

The conventional wisdom in the truck transport sector is that the operator's sensitivity to fuel costs drives the adoption of best available technologies and practices to reduce fuel use. However, prior cross-country evaluation of the sector's energy and carbon intensity shows that the trucking sector's energy intensity spans a large range. Indeed, the sector's energy and carbon intensity is a result of the combined effects of vehicle technology, fuel mix, vehicle loading, traffic, and relative modal share.

This paper looks at the trends in energy and carbon intensity of truck freight transportation in Australia, France, Japan, United Kingdom and United States. These countries were selected because they are thought to represent the range of energy and carbon intensities among member states of the Organization for Economic Co-operation and Development (OECD). The results are reported for the period between 1973 and 2005. The analysis builds on the methodology developed by Schipper et al. (1997) and Schipper and Marie-Lilliu (1999) and applies decomposition to identify the effects of activity, structure, relative modal share and intensity on the results obtained (Schipper and Marie-Lilliu, 1999). The paper finally includes a discussion of considerations for policymakers seeking to reduce energy use in the truck freight sector.

2. Methodology

A detailed description of the bottom-up methodology used to estimate energy and carbon intensity and perform the decomposition can be found in publications by Schipper et al. (1997) and Schipper and Marie-Lilliu (1999). To summarize, national data sources are used to separate road diesel used by trucking from

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that for buses, cars, and specialized vehicles like fire engines. Gasoline and alternative fuels consumed by smaller trucks involved in freight transportation are also included. Vehicle utilization data (vehicle-kilometer) come from national vehicle use surveys, while vehicle freight loading (tonne-kilometer) data come from national freight and/or trucking surveys. Both "own account" and "for hire" (trucking fleets and owner-operators) are included. Where unavailable, we estimated tonne-km for light trucks or trucks in the 3–6 tonne range at 0.25 tones/truck from known vehicle-kilometer data. These trucks only have a small impact on the total tonne-km, which is dominated by long-haul trucking; inserting them keeps the formulation in terms of tonne-kilometer.

2.1. *Scope*

The paper focuses primarily on road freight transportation by light and heavy-duty trucks. Both own account and common carriers are included. Activity and energy use of vehicles passing through a country where they are not registered were not included. Freight rail and water transport (inland and coastal) were evaluated and compared to truck freight transport. The analysis does not include air freight or pipeline transport due to the limited availability and high uncertainty of data for these modes.

2.2. *Data sources*

The data sources relied upon for this analysis are primarily statistical digest prepared by each country's ministries or agencies charged with compiling transportation activity and energy use data (OECD, 2006, 2007; ABS, 2004a, 2004b; ACG, 2007; MEDAD, 2005; MLIT, 2007a, b; ITPS, 2006; ECC, 2007; DFT, 2006; BEA, 2006; Davis and Diegel, 2006; BTS, 2006). Data on fuel use come from transport and/or energy statistics that are based both on surveys (or reported consumption by railroads) and on estimates that partition road or rail energy use according to practices discussed in Schipper et al. (1997) and Schipper and Marie-Lilliu (1999).

OECD publications provided the majority of economic and demographic data such as gross domestic product (GDP) and currency exchange rates based on purchasing power parity (PPP) (OECD, 2006, 2007). Carbon emissions were estimated using emission factors developed by the Intergovernmental Panel on Climate Change (IPCC, 1996).

2.3. *Decomposition*

The Laspeyres decomposition is performed on the results for the three main freight transport modes: truck, rail, and water transport. The resulting indexes indicate the effect of the level of activity, the relative modal share, and energy intensity of each mode. As described in Schipper et al. (1997) "the index calculates the percentage change in energy consumption relative to a base year that would have resulted if only one factor had changed". Although these factors are not independent from each other, the decomposition provides some insight on their potential relative impact on freight energy use.

The indexes are calculated using the following equations, where E represents energy use in petajoules in year i and mode j, A the activity in t-km in year i and mode j and S the modal share in percent in year i and mode j. E_o is the total energy use in the base year and A_{oj} is the activity in the base year for mode j. Eq. (1) portrays actual energy use by year, Eq. (2) the impact of changes in modal intensities (at base year modal mix), Eq. (3) the impact of modal structure shift, and Eq. (4) the impact of changing overall freight activity.

$$(\%\Delta E_{\text{actual}})_{o,i} = \frac{\sum_{j=1}^{n} E_{i,j}}{E_o} \times 100 \tag{1}$$

$$(\%\Delta E_{\text{intensity}})_{o,i} = \frac{\sum_{j=1}^{n} (E_{ij}/A_{ij}) A_{oj}}{\sum_{j=1}^{n} E_{ij}} \times 100 \tag{2}$$

$$(\%\Delta E_{\text{structure}})_{o,i} = \left(\frac{\sum_{j=1}^{n} (S_{ij}\,(E_{oj}/A_{oj})) \sum_{j=1}^{n} A_{oj}}{\sum_{j=1}^{n} E_{oj}} \right) \times 100 \tag{3}$$

$$(\%\Delta E_{\text{activity}})_{o,i} = \frac{\sum_{j=1}^{n} A_{ij}}{\sum_{j=1}^{n} A_{oj}} \times 100 \tag{4}$$

The Laspeyres index answers the question "how much did the dependent variable (energy or CO_2 emissions) change because a certain factor changed, all else being equal?" In the real world all factors change yielding residuals, which the simple Laspeyres index method does not include. More complex Divisia based indices that use logarithms of changes give smaller residuals (or none). However these indices are more complex to calculate and more appropriate when many sectors are being considered at once and fuels have wide CO_2 content (Murtishaw and Schipper, 2001). For purposes of this calculation the authors deemed the Laspeyres approach satisfactory. It is possible to include fuel specific terms, however the dominant fuels are diesel and gasoline, whose CO_2 emissions are similar. While electric traction in the rail sector is not insignificant in the European countries, its overall role in the CO_2 balance is small (even with sources ranging from nuclear and hydroelectric to coal) that it can be ignored in this decomposition.

2.4. *Limitations*

In each country, the scope, methodology, timing and frequency of data collection efforts differ widely. For example, from the mid 1980s to 2001, data for Australia were only available every third year. Also, vehicle classifications vary between countries and may not exactly match. These differences result in some uncertainty in directly comparing results across countries. The analysis used the broadest definition of freight truck in order to include all vehicle types involved in moving cargo in domestic traffic. Documentation for each country's statistics explicitly describe excluding transit traffic. If a cargo trip begins in one country and continues beyond its borders, only the portion of the trip within the country the trip began in is included in the statistics. National data sources try to exclude the fuel bought by transit trucking in any given country. There are however uncertainties associated with these adjustments, which are expected to be greater in smaller, non-insular countries such as France compared to large countries such as the United States or island nations such as Australia, Japan, and the United Kingdom.

There is also some uncertainty associated with determining the use of light duty trucks in freight transportation versus personal transportation for some data sets. When needed conservative assumptions were made to determine the vehicle-kilometer and loading of light duty trucks used for freight transport.

The paper's most notable limitation is the exclusion of pipeline transport. Indeed tonne-kilometer data for natural gas transportation by pipeline are very difficult to find and in some cases never collected and published. This exclusion is unfortunate, because pipelines carrying natural gas and oil have in many cases substituted rail, truck or barge transport. Thus the results underestimate the total domestic freight haulage, which is particularly important for the largest energy-producing countries in this sample, the United States and Australia, as well as the United Kingdom, where offshore gas is sent by pipeline to the mainland. Perhaps more importantly, the growth in freight is underestimated, since much of the natural gas used today substituted for coal or oil sent by the modes that are counted in the results for past years.

We noted that the countries covered in the paper represent a wide range of national circumstances. As shown in earlier work, however, other OECD countries present interesting features including high levels of transit traffic (Netherlands), very large load limits and trailer lengths (Sweden), few wide open flat roads for hauling (Norway), and very little true domestic long haulage (Denmark) (Schipper et al., 1997; Schipper and Marie-Lilliu, 1999). The freight activity, energy and carbon intensity for these countries will be included in future work as they represent valuable views on the extremes of various effects that can influence the evolution of energy use and emissions for freight in any country.

3. Results

In the process of this work, we updated and revised time series presented in previous work of truck activity, tonne-kilometer by mode, and energy use by fuel and mode from 1973 to 2005 (Schipper et al., 1997; Schipper and Marie-Lilliu, 1999). These numbers are used for graphs and time series of indicators presented herein, as well as the snapshots given that represent key years. The results will be published in full in future work.

3.1. Freight activity

Freight activity is typically measured in tonne-kilometers (t-km), which is the product of the mass of freight and the distance it is carried. The total mass of freight carried in a country depends largely on the types of goods carried. In countries where economic activity is primarily focused in agriculture and resource extraction, freight mass transported tends to be higher than in countries where manufacturing activities dominate. The total distance traveled can reflect the geographic extent of a country. Nevertheless, the t-km metric does not provide information on some very important characteristics of freight activity such as the distance a specific product and each of its components are transported or the value of the freight transported.

There was a significant growth in truck freight activity over the last three decades in all the five countries. Table 1 provides GDP, and population in 1973 and 2005 as well as their growth rate during that period for each of the countries. Table 2 provides truck, rail and water freight transport activity and energy use in 1973 and 2005 and the growth rate between those years. The highest truck activity growth rate is in Australia where truck freight activity was more than six times larger in 2005 than in 1973. In Australia, Japan and the United States, the growth in truck freight activity was greater than the growth in GDP. This was not the case in France and in the United Kingdom, which also registered the smallest growth in truck freight activity.

Figs. 1 and 2 further illustrate the data in Tables 1 and 2. Fig. 1 shows the relationship between total t-km hauled and total GDP in each country. The countries can be divided in two distinct groups reflecting differences in their geography and the importance of production and transport of raw materials from agriculture and resource extraction. The United States and Australia have the highest freight haulage per capita or per unit of GDP, as might be expected for large countries. They also exhibit the largest combined shares of rail and water freight transport, representing the shipping of raw materials and grains over long distances in large quantities (Table 2). Consistent with earlier results, domestic freight haulage continues to grow with GDP. The results in Fig. 1 exhibit no signs of a decoupling between truck freight activity and GDP growth. Furthermore the countries that experienced the largest growths in truck freight activity are those to also have the largest growth in GDP over the period analyzed.

It is interesting to note that the rate of growth relative to GDP (or GDP elasticity) in the United States and Australia is significantly higher than that of the European countries. This may be a result of more open borders in Europe, which means more European trade is excluded from the data as it is in transit, while increased US and Australian imports (and exports) still have to move long distances within each country. Since a large fraction of GDP in European countries has been tied up in foreign trade, it is suspected that the exclusion of "overseas" truck bound freight is one reason for the slower growth in freight haulage shown in European countries.

Fig. 2 presents the modal energy intensity of each mode for each country in 1973 and 2005. Fig. 2 not only shows the difference across mode and countries, it also presents the changes over time. Truck transport requires the most energy per t-km in all countries both in 1973 and 2005. The following section presents more detailed results pertaining to truck modal energy. Modal energy comparison is further explored in the subsequent section.

Table 1
GDP and population for selected OECD countries, 1973 and 2005.

Country	GDP (billion 2000 PPP US $)			Population (million)		
	1973	2005	Growth (%)	1973	2005	Growth (%)
Australia	230	620	270	14	20	150
France	810	1660	210	53	63	120
Japan	1500	3460	220	110	130	120
United Kingdom	850	1700	200	56	60	110
United States	4300	11,000	250	210	300	140

Table 2
Truck, rail and shipping freight activity in billion tonne-kilometers and energy in PJ for selected OECD countries, 1973 and 2005.

Country	Truck freight activity (billion t-km)		Truck freight energy (PJ)		Rail freight activity (billion t-km)		Rail freight energy (PJ)		Water freight activity (billion t-km)		Water freight energy (PJ)	
	1973	2005	1973	2005	1973	2005	1973	2005	1973	2005	1973	2005
Australia	30	194	102	328	47	186	11	31	90	114	51	19
France	110	214	288	658	70	41	21	11	14	8	6	3
Japan	141	335	695	1034	58	23	15	4	208	212	210	103
United Kingdom	90	163	273	654	23	22	20	11	25	61	46	57
United States	956	2514	2891	6136	1244	2477	608	603	854	863	356	321

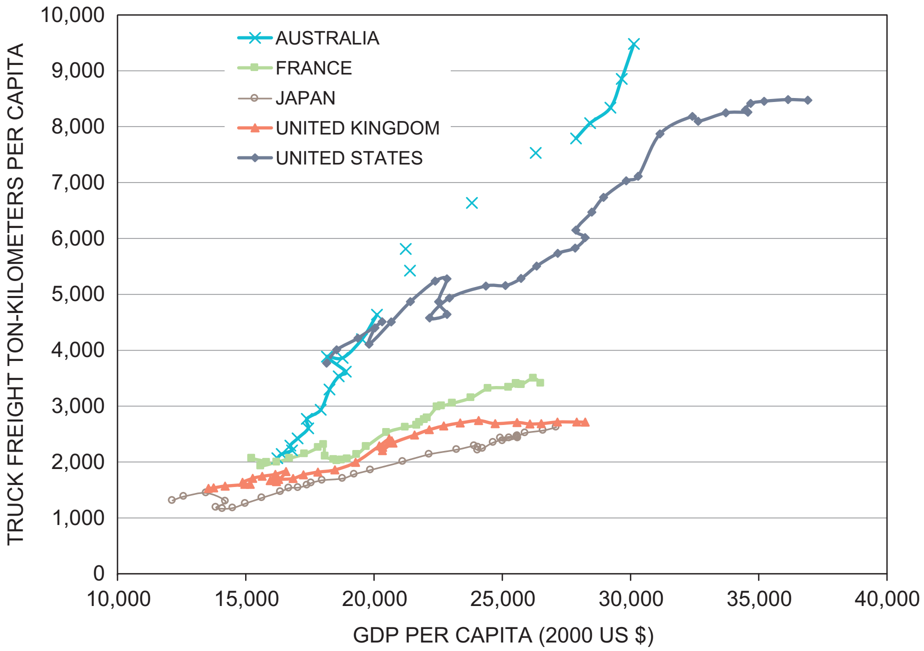

Fig. 1. Truck freight and GDP in selected OECD countries from 1973 to 2005.

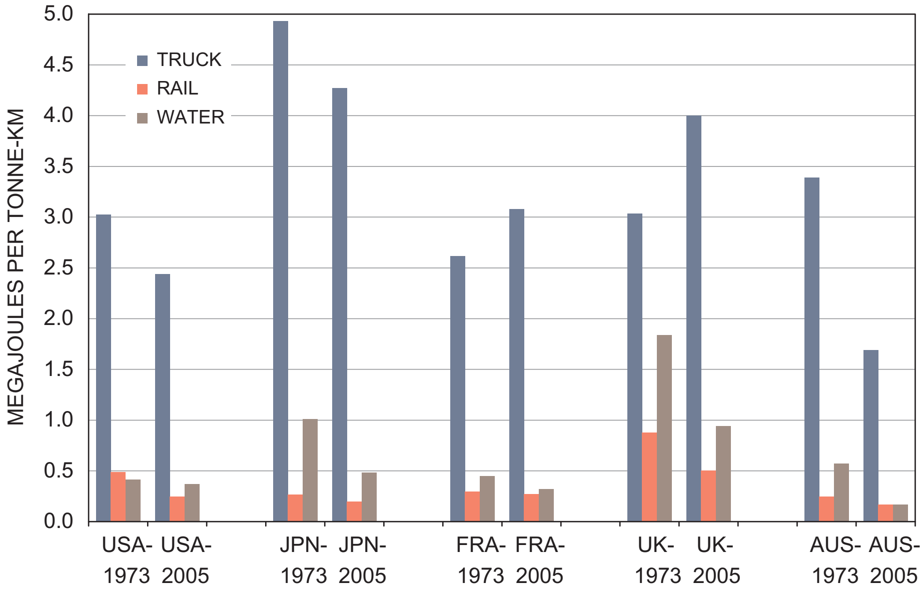

Fig. 2. Energy intensity by mode in selected OECD countries from 1973 to 2005.

3.2. *Truck modal energy and carbon intensity*

The truck modal energy intensity, expressed in MJ/t-km, depends on the energy used to move each truck and how these trucks are used to move goods, which is the truck capacity utilization. The energy used to move each vehicle is a result of the types of vehicles in the fleet (light or heavy trucks), the vehicles fuel intensity, the fleet fuel mix (diesel, gasoline, or alternative fuels) as well as the types of trips (length, terrain) and driving conditions (urban, rural, congestion). The truck capacity utilization depends also on the types of vehicles in the fleet and how they are loaded.

Table 3
Truck freight modal intensity in selected OECD countries, 1973 and 2005.

Country	Truck freight intensity (MJ/t-km)		
	1973	2005	% Growth (%)
Australia	3.4	1.7	−50
France	2.6	3.1	18
Japan	4.9	4.3	−13
United Kingdom	3.0	4.0	32
United States	3.0	2.5	−16

Truck modal energy intensity decreased in Australia, Japan, and the United States and increased in France and United Kingdom between 1973 and 2005 as shown in Table 3. The largest drop was in Australia with a reduction of 50%. The greatest increase was in the United Kingdom where modal energy intensity increased by 32%.

There remains however a wide range of intensities among the five countries as illustrated in Fig. 3, which presents the changes in freight truck modal energy intensity from 1973 to 2005 based on the time series derived from each country's fuel use and tonne-km for trucking. Japan truck freight sector remains the most energy intensive despite some improvement during parts of the thirty-year period. Australia and the United States have both supplanted France and have currently the top two least energy intensive sectors among the five countries. Australia's truck freight transport is by far the least intensive using about a quarter less energy per t-km than truck freight transport in the United States. This is in part a consequence of a high share of three-unit trucks that transport goods across the country's mostly desert interior.

The next two figures explore the trends in two key factors that impact the freight trucking sector's energy intensity. The first factor is the average truck fuel intensity, which is presented in MJ/km in Fig. 4. As with modal intensity, the countries' results

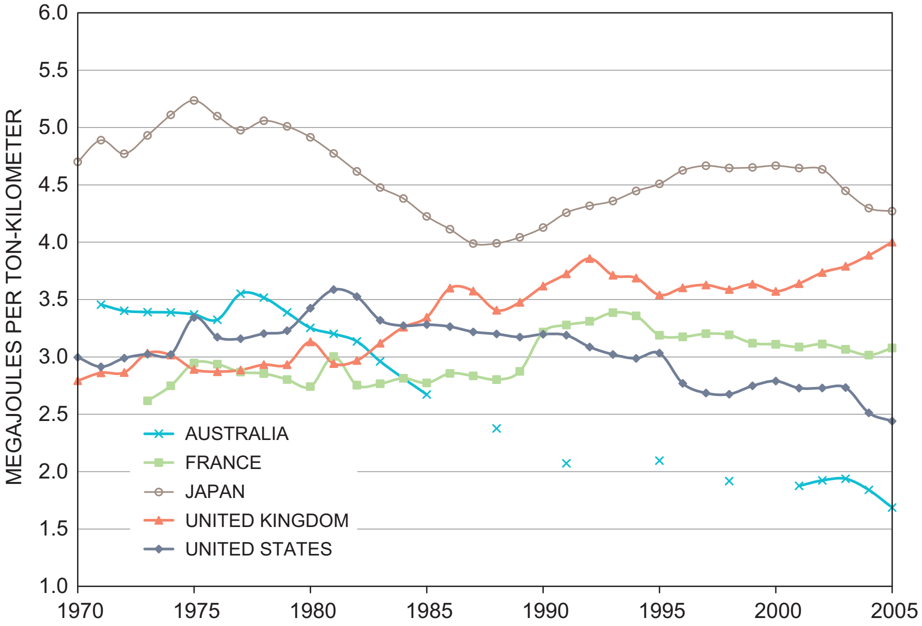

Fig. 3. Truck freight modal energy intensity in selected OECD countries from 1973 to 2005.

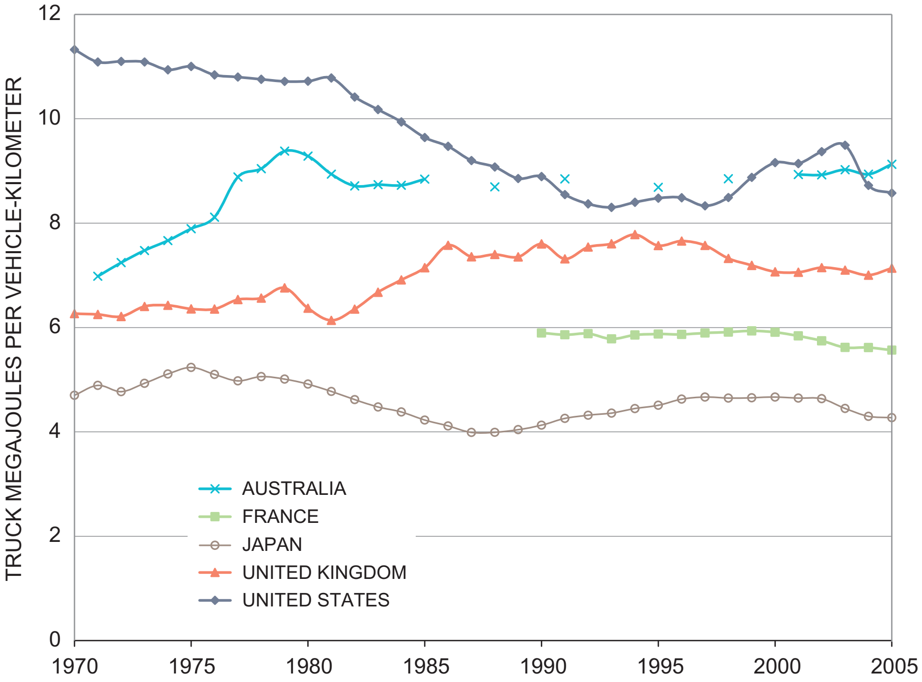

Fig. 4. Truck fuel intensity in selected OECD countries from 1973 to 2005.

span a wide range. Growths or reductions in intensity over the analysis period were less dramatic than the changes estimated for modal intensity. Vehicle fuel intensity fell in the United States and Japan by about 10% and decreased in the United Kingdom by 11% and by Australia by about 22%, the largest change among the five countries. Data for France for this metric was only available from 1990 to 2005 and showed an improvement of 6% over that period.

The differences in average truck fuel intensity reflect differences in fleet mix. For example, in Japan, smaller and in general more efficient vehicles account for a significant portion of vehicle-kilometers traveled. The small and mini category freight trucks account for the majority of the vehicle-kilometers in Japan, 58% in 2005 (MLIT). Small trucks in Japan have 4 or more wheels and dimensions equal to or smaller than $4.7\times1.7\times2.0\,\mathrm{m}^3$ (length × width × height), with engine displacement greater than 660 and up to 2000 cubic centimeters (cc). Mini trucks have 3 or more wheels and dimensions equal to or smaller than $3.3\times1.4\times2.0\,\mathrm{m}^3$, with engine displacement of 660 cc or smaller. These vehicle categories do not play a significant role in the transport of goods in the United States or Australia and are not separated out in the data sets. Rather heavier and less efficient vans, pick-up trucks and heavy-duty vehicles account the majority of vehicle-kilometers traveled transporting freight. European countries are in an intermediate situation.

The second factor is the average load per vehicle calculated by dividing the t-km by vehicle-kilometers (v-km) and presented in Fig. 5. This is both a function of average truck capacity and capacity utilization, particularly how often a truck runs empty. In Australia, the average load per truck increased dramatically over the 30-year period. In 2005, Australian trucks were carrying on average more than twice the average load carried in 1973. Average load also increased in Japan albeit more modestly with a 24% increase. There was no significant change in average load in France (from 1990) while the United Kingdom's average load decreased by about 15%. In the United States there was a very small increase in average load (8%). After a period of steady decline for most of the 1970s, 1980s and part of the 1990s, average truck load in the United States began to increase towards its mid-1970's value by 2005. The decline and rise are caused in part by the rapid rise then gradual decline of the share of commercial light trucks delivering freight.

Taken together the information in Figs. 4 and 5 provide additional details that can be helpful in understanding the trends in Fig. 2. Higher average loads, longer distances and lower congestion permit less energy intensive trucking in Australia and the United States. In Japan, freight is moved by a large fleet of smaller vehicles carrying smaller load for short distances on congested roads, yielding higher truck modal energy intensity. As a result trucking in Japan is a more carbon intensive freight transport mode than trucking in Australia as shown in Fig. 6.

3.3. *Freight modal comparison*

Clearly changes in total freight fuel use and carbon emissions are driven more by the level of freight and the modal intensities than by modest changes in fuel intensities. To gauge the overall picture of changes in freight activity, Fig. 7 provides the activity in t-km divided by GDP for all major freight transportation modes: rail, water, and road. Water transportation includes both inland waterways and coastal water transportation. In all the countries analyzed except Australia the ratio of activity to GDP decreased from 1973 to 2005. A decrease in the ratio is typical as a country's economy produces higher value goods but there are no significant changes in transportation distances.

An increase in the ratio indicates growth in tonnes or km more rapid than GDP. While most OECD economies are producing or trading fewer tonnes of goods, the goods they do produce may pass through more intermediate stages, or they may send more goods to export, both of which raise tonnes or km or both. This appears to have happened in Australia.

The share of trucking compared to other modes grew in all countries between 1973 and 2005, as shown in Table 4. As cargo type is one of the main drivers of modal share, this trend typically represent a shift from mainly transporting raw materials to mainly transporting manufactured goods and high value shipments that move more rapidly by truck than by rail or ship. The greatest growth in trucking share occurred in Japan, France and Australia. Rail lost the largest share in France and Japan whereas water transportation lost the largest share in Australia and the United States.

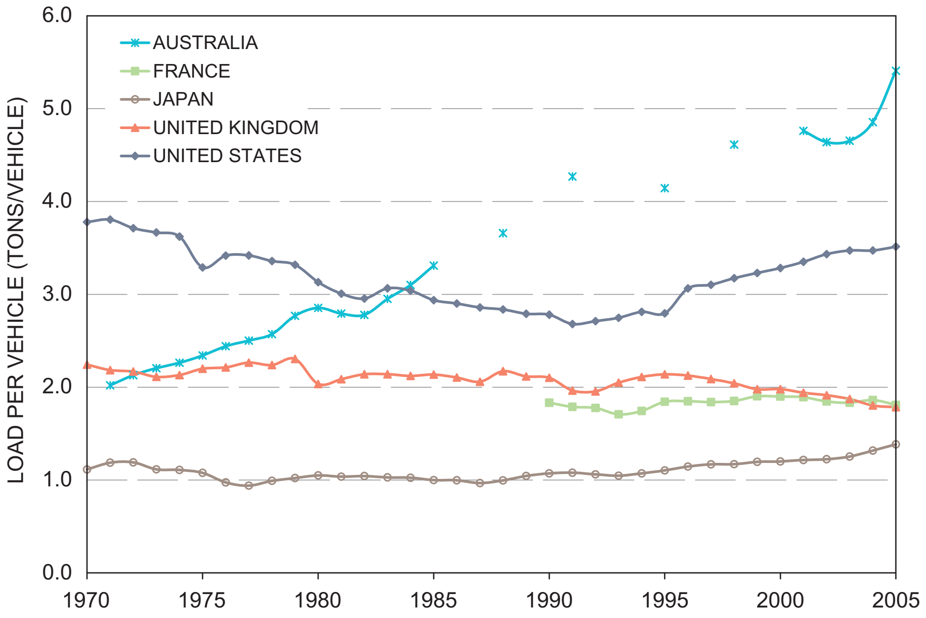

Fig. 5. Average truck loading in selected OECD countries from 1973 to 2005.

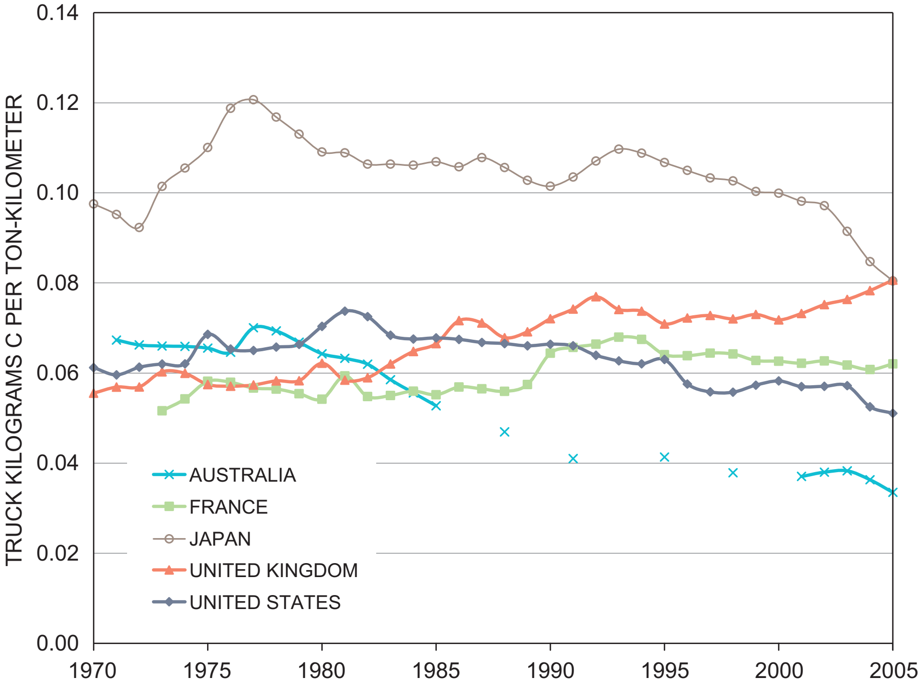

Fig. 6. Truck freight modal carbon intensity in selected OECD countries from 1973 to 2005.

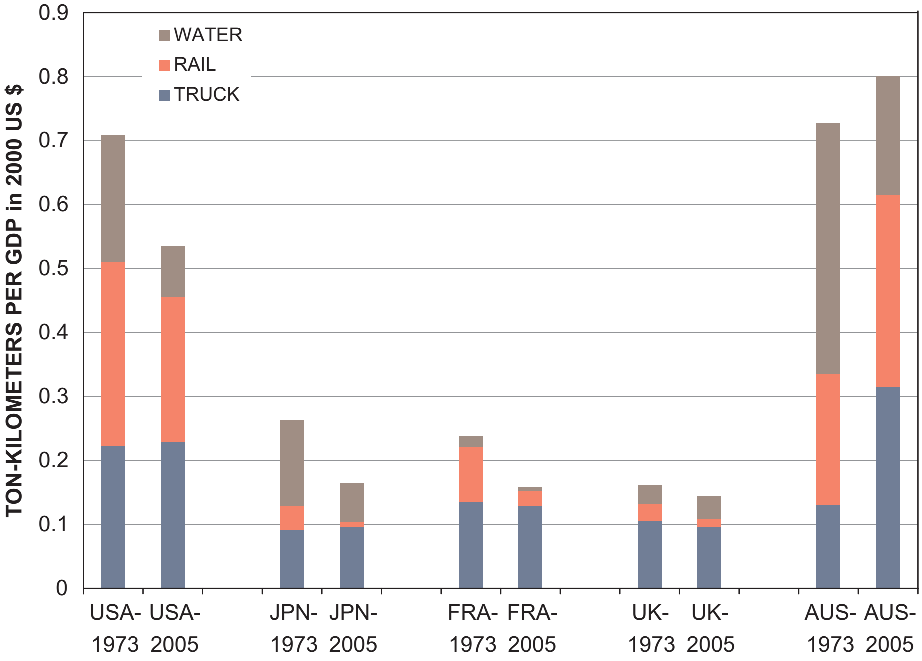

Fig. 7. Activity normalized by GDP in selected OECD countries, 1973 and 2005.

Table 4
Freight activity by modal share, 1973 and 2005 (% of t-km).

Mode	Australia		France		Japan		United Kingdom		United States	
	1973 (%)	2005 (%)	1973 (%)	2005 (%)	1973 (%)	2005 (%)	1973 (%)	2005 (%)	1973 (%)	2005 (%)
Truck	19	39	57	81	35	59	65	66	31	43
Rail	28	38	36	16	14	4	17	9	41	43
Water	53	23	7	3	51	37	18	25	28	15

Table 5
Laspeyres decomposition of freight energy use, 1973 and 2005 (2000 = 100).

Country	1973				2005			
	Actual energy	Intensity effect	Structure effect	Activity effect	Actual energy	Intensity effect	Structure effect	Activity effect
Australia	51	189	58	42	117	92	102	125
France	49	85	78	72	104	99	107	98
Japan	58	113	69	71	97	92	107	99
United Kingdom	55	101	99	56	117	115	101	100
United States	52	114	79	56	96	89	100	108

In general, the share of trucking activity compared to other modes is largest in the smaller countries. In Japan, France and the United Kingdom, trucking accounted for 60–80% of the freight t-km for 2005. This share is significantly smaller in the two resource and materials intensive countries, the United States and Australia. In previous work results showed that Canada resembled the United States or Australia, while Norway, Sweden, and Finland were found to be intermediate to these two groups (Schipper et al., 1997; Schipper and Marie-Lilliu, 1999).

A decomposition analysis was completed to better understand the interaction between intensity, structure and activity on freight energy use. A percentage change in energy use was calculated to represent change if only one of the three factors had changed relative to the results in the year 2000. The results of the decomposition analysis are shown in Table 5.

The result of the analysis for 2005 shows that in France and Japan the changes in structure, primarily the growing share of trucking compared to other modes, would have driven an increase in energy use, consistent with earlier findings. In the United States and Australia, activity would have led to increase in energy consumed in the freight transportation sector. Intensity would have slightly decreased energy use in France, Japan, Australia and the United States but would have been the main driver of increase in energy use in the United Kingdom.

Looking at the changes in energy used in freight transportation in 1973 with respect to 2000, we see in retrospect that modal structure and activity effects drove up energy use between 1973 and 2000. In all countries except France, energy intensity changes reduced energy use to 2000.

4. Summary and conclusion

Overall freight activity and the share of trucking are still coupled to GDP growth. Drivers include the growth in international trade, "just in time" business practice, e-commerce, as well as the handling of intermediate products. Overall freight energy costs still remain a small part of overall manufacturing costs, as evidenced by the small share of freight energy in total energy (roughly 10–15%), which represents itself less than 10% of total GDP compared to manufacturing's share of GDP between 20% and 30% for most OECD countries (OECD, 2006, 2007). Only Australia showed an increase in the freight/GDP ratio, probably a consequence of Australia's increase in markets for energy intensive raw materials including energy.

Even in countries with relatively even modal shares (including natural gas pipelines), energy use for trucking dominates total use for freight. Trucking energy and carbon intensity has fallen in three of the five countries analyzed in part because of increased load per vehicles (especially in Australia) and improvement in average truck vehicle efficiency. However truck utilization is still not optimized. Future energy (and emissions) savings can arise both from better truck and engine technologies as well as better overall handling of truck freight, and improvements in traffic conditions.

Overall freight energy use including energy use for rail and water transportation has increased. This growth was driven by both modal shifts towards trucking, which is more energy intensive than other modes and by the growth in overall freight activity, particularly in Australia.

Earlier work noted that the types of cargo transported experiencing the greatest growth are high value goods that demand both flexibility and speed, which favor trucking as a transportation mode.

Concerns about both the future of oil supplies, carbon emissions and global climate change have not escaped the trucking sector. What are the prospects for at least reducing growth in fuel use and emissions, if not reversing it? There seems little opportunity for gains from changes in structure such a major shift from trucking to rail. Instead, it appears that the most obvious gains will come from logistics, the improved handling of goods and utilization of trucks as average loading is still well below average truck capacity. Related to this is better matching of truck size and capacity to cargo load and type. Improving logistics also includes optimizing the locations of where goods are produced and loaded/unloaded. It is likely that increases in traffic congestion might even cause some intermediate producers and handling facilities to locate more closely to main roads, rail terminals and other places that reduce the need for truck use.

Emerging consumer preferences for locally produced products may also impact the distance certain goods are moved. In addition, there is a growing interest among the public as well as retailers and service providers in understanding the life cycle energy use and carbon emissions of goods and services in order to inform purchasing decisions.

Traffic conditions could improve through measures such as road improvements, tolling, and truck routes that avoid major congested areas. Road pricing or fees that depend on truck capacity and t-km hauled could further stimulate more efficient cargo handling.

Improvements in vehicle technology are another option to restrain or reduce truck energy use. In 2005 Japan adopted heavy-duty truck fuel economy standards that require an average 12% improvement in fuel economy in 2015 compared to 2002 for new trucks. In the United States, United Kingdom and Canada government-sponsored voluntary programs educate fleet about best practices to reduce fuel use and facilitate the adoption of more efficient retrofit and new vehicle technologies. It is also possible that increased availability of lower carbon fuels also provide reductions in trucking carbon intensity in the future.

A number of important issues remain at the forefront for those concerned with the continued rise in CO_2 emissions from freight.

Primarily, the data do not indicate a "dematerialization" of economies that would suggest a weakened link between economic activity and freight hauled. As the previous papers suggested, goods may be transported more often in their transformation from raw materials to intermediate goods to final goods. While it is noted that the freight hauled/GDP ratio for all countries studied save Australia fell, this does not represent a strong decoupling, particularly as we have not included pipeline and air freight transport.

The modal shift towards increased trucking raised energy use and emissions. Inclusion of air freight transportation in this evaluation would only strengthen this finding. While there is some resurgence of rail in some countries, trucking seems to increase its share because of the flexibility and speed it offers. This is particularly important for high value goods such as computers. This development is consistent with the picture of valuable materials being lifted more throughout the supply chain while at the same time transport of bulk raw materials is declining. Exactly where rail or sea could compete with trucking (or air) for high-value, high priority goods would give clues as to what would restrain continued modal shifts towards more energy and carbon intensive modes. It is important to emphasize that trucking fuel costs are only part of the factors determining how goods are moved and hence should not be the sole focus of policies to reduce energy use and emissions from freight transportation.

Indeed, the role of fuel prices in determining trucking technology, loading, and other factors that affect energy intensity should be examined closely. Independent truck owner-operators may not be able to afford sophisticated trucking technologies that could save fuel. At the same time more complete loading of trucks, better traffic conditions, and other logistical factors could save truckers time, wear and tear, and fuel use as well. As with all measures that save energy by reducing freight costs, there might some rebound effect that encourages greater volumes to be transported.

Finally, this work not explicitly highlighted the contributions of alternatives to diesel and gasoline because the observed use in the compiled data is minimal. Whether significant gains in developing low-carbon trucking fuels can be achieved is beyond the scope of this article. This overview does show that trucking in particular and freight transportation in general is operated as a system and this appears to be the one of the most important factor in understanding energy intensity from trucking.

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