The Potential of Economic Incentives to Reduce CO_2 Emissions from Goods Transport

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1. Introduction

At a global level, the movement of freight accounts for roughly a third of all the energy consumed by transport (IPCC, 2007). In 2004, transport accounted for 23% of total energy-related CO_2 emissions, suggesting that freight transport was responsible for around 8%. In a business-as-usual scenario, freight's share of these emissions is likely to rise. Transport as a whole, in contrast to most other sectors, is sharply increasing its output of CO_2. Within the transport sector, freight tonne-km are expected to grow at 2.5% per annum between 2000 and 2030 by comparison with a 1.6% annual increase in passenger-kms (World Business Council for Sustainable Development, 2004). This increase in freight traffic will be partly a function of the expansion of production and consumption, but also reinforced by an extension of the average distance that each unit of freight is moved. Globalisation is lengthening supply lines, thereby increasing the freight transport intensity of the world economy.

The amount of CO_2 emitted by each tonne-km of freight movement also appears to be rising as more carbon-intensive transport modes, particularly airfreight and trucking, capture a greater share of the freight market (IPCC, 2007). The diffusion of the just-in-time principle both geographically and across industry sectors may also be depressing vehicle load factors and further increasing CO_2 emissions per tonne-km, though this is difficult to confirm empirically on the basis of currently available data.

Given the strength and prevalence of these various freight transport trends, devising practical and cost-effective carbon mitigation strategies for this sector presents a major challenge. This paper examines the nature and scale of this challenge and identifies a series of economic measures that might be deployed to arrest and ultimately reverse the growth in freight-related CO_2 emissions. It begins by reviewing a series of general issues and then outlines an analytical framework within which a broad range of policy options can be systematically assessed. The remainder of the paper examines each of these carbon abatement options in turn.

2. General Issues

1. *Lack of data on the freight transport system:* the business mantra 'if you can't measure it, you can't manage it' is especially relevant in the present context. The quantity and quality of macro-level freight data is very patchy. Even in those countries, such as the Netherlands, the US, the UK and France, with large freight datasets, there are significant gaps. In most developing countries there is a serious dearth of freight statistics. Data deficiencies are even greater at an international level and this is a particular concern as an increasing proportion of freight movement is cross-border. Lack of data is therefore impeding macro-level analysis of the carbon intensity of freight operations. At a company level, on the other hand, rapid progress is being made in monitoring carbon emissions. Many businesses are now carbon auditing their internal operations and wider supply chains, often disaggregating CO_2 emissions by activities, premises and even individual products. The public disclosure of this data may provide a valuable new source of information on the carbon intensity of freight transport and logistics.

2. *Limited knowledge of demand elasticities for freight transport*: Forecasting the effect of economic measures on the level and nature of demand for freight transport is currently very difficult given a lack of empirically-based estimates of price elasticity. The few published studies on this subject are dated and / or provide only a partial view of demand elasticity in the freight sector (e.g. Oum et al, 1990; Beuthe et al, 2001). There is a pressing need for new research to provide price elasticity values for both individual modes and cross-modal competition, preferably disaggregated by commodity type and length of haul.

3. *Inter-relationship between freight transport and other economic activities:* As the transport textbooks explain, freight transport is a derived demand. It is intimately connected with other economic activities. Carbon abatement measures applied to the freight sector should therefore be co-ordinated with those developed for other sectors and the economy as a whole. Under some circumstances it may actually be environmentally beneficial to increase CO_2 emissions from freight transport in order to achieve greater CO_2 savings elsewhere. For example, distant suppliers may operate more energy-efficient, less carbon- intensive production facilities than local suppliers and the resulting saving in production-related CO_2 may exceed the additional emissions from longer freight hauls. Although more freight movement may be required, overall CO_2 emissions could be lower. A full life-cycle analysis can explore these environmental trade-offs. This has been done in a comparison of the carbon intensity of sourcing various agricultural products for the UK market from domestic suppliers and exporters in New Zealand (Saunders et al, 2006). It found that the lower carbon-intensity of New Zealand agriculture comfortably justifies, in CO_2 terms, the 18,000 km shipment of these products by deep-sea container to British consumers. This challenges the argument advanced by some 'food miles' campaigners that food should always be sourced locally (Smith et al, 2005).

   Carbon audits of individual companies and the supply chains for particular products often reveal that freight transport represents a very small percentage of total emissions (Carbon Trust, 2006). CO_2 emissions from the production operation typically dwarf those associated with physically moving the products. This partly explains the result of the agricultural sourcing analysis reported above. It can also make it difficult to motivate companies to invest time and effort in decarbonising their freight operations, when other activities offer greater leverage on their total carbon footprint.

4. *Scope of decarbonisation initiatives in the freight sector*: In developing sustainable distribution strategies, some governments accept that the demand for freight transport (expressed in tonne-kms) will continue to grow and direct their attention at ways of cutting CO_2 emissions per tonne-km. This displays a belief that freight demand and economic growth are inextricably linked and a reluctance to jeopardise future economic prospects by constraining the level of freight movement. In its 2001 transport policy document, the European Commission (2001) went further and declared its intention to decouple economic and transport growth trends, preferably without adversely affecting the former. In reviewing carbon abatement options for the freight sector, this paper will consider ways of restraining the future growth of freight tonne-kms. Detailed discussion of the wider issue of freight-GDP decoupling can be found in Tapio (2005), McKinnon (2007a) and Kveiborg. and Fosgerau (2007).

5. *Economic impact of freight decarbonisation measures:* It is generally acknowledged that there is a close correlation in the freight sector, and more generally in business, between cutting carbon and reducing costs. Most measures designed to improve the efficiency of freight transport will also yield carbon savings. As most of these measures involve cutting fuel consumption, recent hikes in the oil price have enhanced their financial benefits and shortened payback periods. Incentivising companies to introduce these decarbonisation measures may only require advice and exhortation from public bodies. Other carbon reduction measures, however, can carry a financial penalty. For example, decentralizing warehousing operations could cut CO_2 emissions but at the expense of increasing inventory and warehousing costs. Switching to less carbon-intensive transport modes may also be sub-optimal in terms of transport cost and / or service quality. Under these circumstances, government financial inducements may be required.

6. *Second-order effects in the implementation of carbon abatement policies*: There is always a risk that the pursuit of one policy objective will have an offsetting effect elsewhere. Encouraging the uptake of carbon reduction measures which yield a net reduction in transport costs per tonne-km, may, perversely, cause a re-adjustment of logistical cost trade-offs and promote developments, such as wider sourcing or greater centralisation, which generate more freight movement. Some decarbonisation measures can also be counteracting. For example, increasing the maximum size and / or weight of trucks can permit greater load consolidation and reduce carbon intensity in the road freight sector but at the expense of diverting freight from lower carbon rail and water-borne services (Arcadis, 2006). In formulating a coherent carbon abatement policy for freight it is necessary to model these inter-relationships and, where necessary, introduce additional taxes and / or regulations to suppress undesirable second-order effects. Alternatively, full internalisation of a social cost / shadow price[1] of carbon in freight transport costs should suppress the second order effects, at least as far as carbon abatement is concerned.

7. *Inter-relationship between CO_2 emissions and other environmental effects:* Climate change is one of many externalities associated with freight transport. Efforts to cut some of these other externalities can conflict with decarbonisation. For example, in January 2008 the European Union adopted a Euro VI emissions 'sub-option' for heavy duty vehicles that will carry a CO_2 penalty of 2-3% (Laguna-Gomez, 2008). As the scale of the climate change problem has become more evident and the social cost of carbon has been revised upwards, greater priority has been given to reducing CO_2 emissions. It may eventually be necessary to accept higher levels of other exhaust pollutants in an effort to maximise fuel efficiency and minimise CO_2.

8. *Interface between passenger and freight transport*: Although personal and freight transport are often considered discrete areas of study, there are important inter-relationships between them which have a major bearing on carbon abatement. The integration of passenger and freight movement in the same vehicles complicates CO_2 auditing in the aviation and maritime sectors.

[1] The social cost of carbon (SCC) 'measures the full global cost today of an incremental unit of carbon emitted now, summing the full global cost of the damage it imposes over the whole of its time in the atmosphere.' The shadow price of carbon is similar to the SCC but assumes that carbon concentrations in the atmosphere will stabilise at a given level (DEFRA, 2007).

Around 60% of air cargo moves in the bellyholds of passenger aircraft (Soil Association, 2007), making it difficult to decide how much of a plane's CO_2 emissions should be attributed to the airfreight The growth of online retailing is transferring responsibility for the 'last mile' delivery to the home from the consumer to the retailer / carrier, converting a personal shopping trip to freight movement by truck or van. Assessing the net effect of this trend on carbon emissions requires integrated modelling of personal travel behaviour and logistics systems.

9. *Geography of freight decarbonisation*: The freight transport intensity of several western countries, such as the UK, Denmark and Sweden, has been declining in recent years (Jacobs Consultancy, 2006). It is likely that this is partly attributable to the offshoring of production to low labour cost countries (McKinnon, 2007a). When a manufacturing plant is relocated to another country or its output is replaced by imports, many of the upper links in the supply chain also transfer to the foreign country as new overseas vendors are found. Although this reduces the freight-related CO_2 emissions within the 'off-shoring' country, it increases them in other parts of the world by a greater margin, for two reasons. First, freight transport operations in the low labour cost countries to which production capacity is migrating are likely to be less energy efficient and generate more CO_2 per tonne-km. This can be attributed to the greater age of the vehicle fleets, lower standards of driving and vehicle maintenance and poorer infrastructure. Second, transporting the additional imports, often over long distances, generates more CO_2. A Kyoto-based assessment of a country's carbon footprint fails to register the effect on global CO_2 emissions of this geographical displacement of freight transport demand. According to Helm et al (2007) the addition of greenhouse gas emissions from bunker fuel used by international transport services to and from the UK and embedded in imported goods inflates the official Kyoto-based estimate of the UK's carbon footprint in 2003 by approximately two-thirds.

3. Analytical Framework[2]

The framework presented in Figure 1 maps the complex relationship between the weight of goods produced / consumed in an economy and CO_2 emissions from freight transport operations.   This relationship pivots on a set of seven key parameters:

Modal split indicates the proportion of freight carried by different transport modes. Following this split, subsequent parameters need to be calibrated for particular modes. As road is typically the main mode of freight transport, the rest of Figure 1 has been defined with respect to this mode[3].

Average handling factor: this is the ratio of the weight of goods in an economy to freight tonnes-lifted, allowing for the fact that, as they pass through the supply chain, products are loaded onto vehicles several times. The handling factor serves as a crude measure of the average number of links in a supply chain.

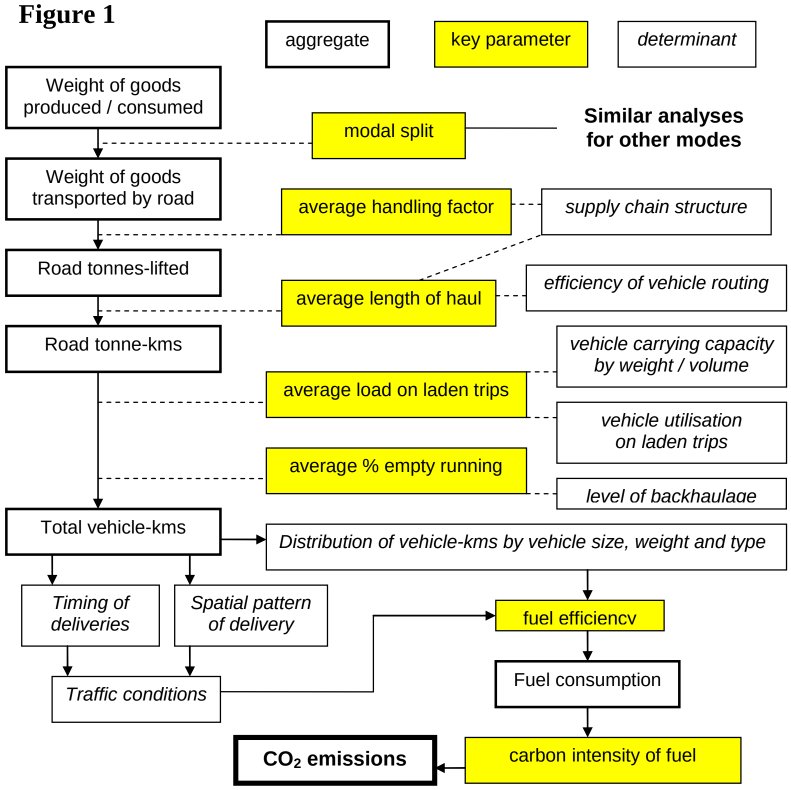
Average length of haul: this is the mean length of each link in the supply chain and essentially converts the tonnes-lifted statistic into tonne-kms.

[2] This framework is adapted from one used in the Green Logistics research project (www.greenlogistics.org)
[3] In the later sections average handling factor and length of haul are discussed before modal split as they are related to freight movement by all modes.

Average payload on laden trips and the *proportion of kms run empty* are the two key vehicle utilization parameters. Average payload is normally measured solely in terms of weight, though as the average density of freight is declining and an increasing proportion of loads are volume- rather than weight-constrained, it would be helpful to measure the physical dimensions of freight consignments.

Energy efficiency: defined as the ratio of distance traveled to energy consumed. It is a function mainly of vehicle characteristics, driving behaviour and traffic conditions.

Figure 1



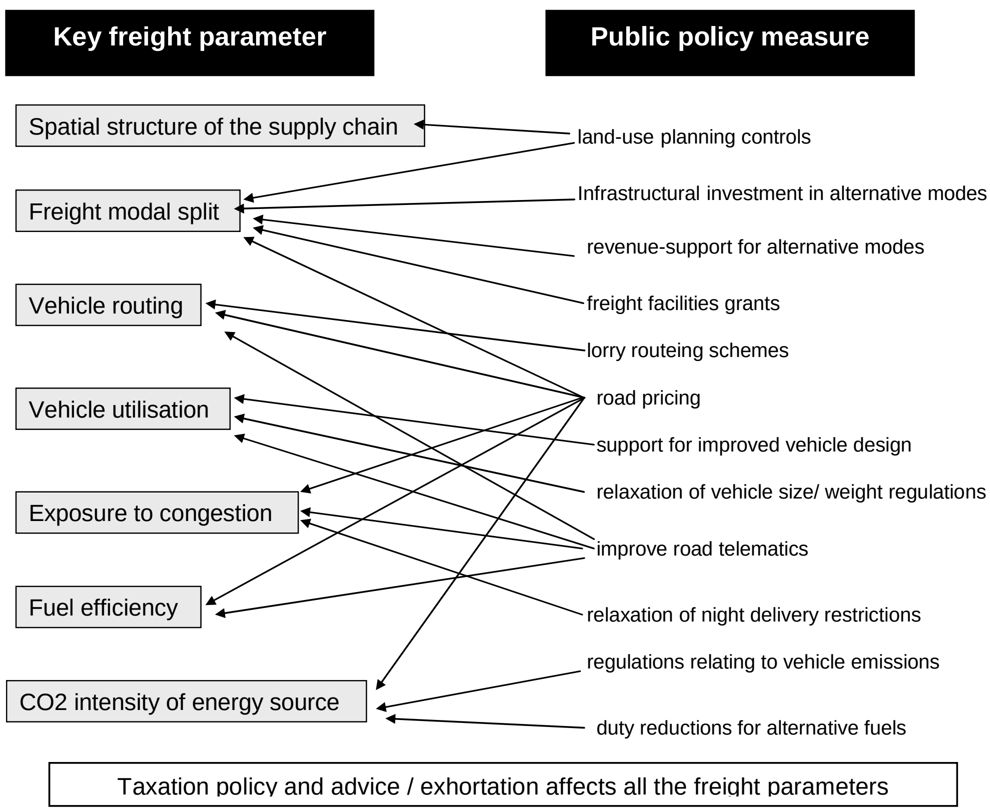
Carbon intensity of the energy source: i.e. the amount of CO_2 emitted per unit of energy consumed either directly by the vehicle or indirectly at the primary energy source for electrically-powered freight operations. For consistency, full well-to-wheel assessments should be made of CO_2 emissions from the various energy sources.

4. Public Policy Measures to Promote CO_2 Reductions from Freight Transport

The key freight parameters in the analytical framework can be modified by a range of public policy measures (McKinnon, 2007b) (Figure 2). Three broad classes of measure (taxation, emissions trading and advisory programmes) can exert an influence on all of these parameters, while others have a more targeted impact on particular variables. Some can reduce the carbon intensity of the freight sector in several ways. Road pricing, for example, can be used to promote a modal shift to rail and water, improved vehicle loading, a rescheduling of freight deliveries into the evening and night and greater use of low carbon vehicles.

The next section examines the three measures likely to have the most wide-ranging effect: internalisation of the external costs of freight transport, inclusion in emission trading schemes and advice / exhortation. Later sections consider the role of other measures in altering specific freight parameters.

Figure 2:



5. General Measures

5.1 Internalisation of the External Costs of Freight Transport

Full application of the 'polluter pays' principle would raise the total tax burden on freight transport while radically redistributing it among the various transport modes. Several studies have estimated the extent to which the tax on each mode would have to rise to fully recover the marginal social costs (e.g. Maddison et al, 1996; Beuthe et al, 2002; INFRAS, 2004). The resulting increases in freight costs would be likely to dampen overall demand for freight transport and promote a shift to cleaner modes. It has been estimated, for example, that the internalisation of marginal social costs in the Belgian inter-urban freight sector would reduce total tonne-kms by around 4%, cut road's share from 71% to 54% and raise the shares held by rail and waterways from, respectively, 16% to 21% and 13% to 24%. Total consumption of energy by all three modes would decline by a fifth (Beuthe et al. 2002).

The climate change component in internalisation calculations will increase as the social cost (or shadow price) of carbon rises, offsetting the decline in the cost of other pollutants (such as NOx and PM10s) subject to tightening exhaust emission standards. It is likely to inflate the total value of external costs attributable to freight transport. Using the official UK government estimate of the social cost of carbon in 2006, internalising the external costs[4] of road freight transport in that year would have required a 50% increase in taxation. Applying the social cost of carbon value advocated by Stern (2006) (adjusted to 2006 prices) would, *ceteris paribus*, have required a doubling of the taxes on road haulage (Piecyk and McKinnon, 2007).

As responsibility for transport taxation rests with national governments, the internalisation of external freight costs would also have to be implemented at a national level to reflect differences in current levels of taxation, the nature and severity of environmental problems and variations in the monetary valuation of external costs. If implemented in accordance with agreed international standards, cross-border differences in the tax rates imposed on freight transport, and related market distortions, might be no greater than at present. Trade bodies representing the road freight industry generally oppose full internalization of external costs on the grounds that this reduces the financial resources that operators have available to upgrade the environmental performance of their fleets.

The tax status of airfreight is particularly anomalous as operators pay no duty on the kerosene used, despite the fact that airfreight is by far the most carbon-intensive freight mode and, as a result of radiative forcing, the emission of CO_2 from planes at high altitude may have between 2 and 4 times the global warming potential of emissions at ground level (Commission for Integrated Transport, 2007). Correcting this anomaly will be difficult as exemption from fuel duty is enshrined in the 1944 Chicago convention and around 3000 bilateral agreements between countries made since then. The inclusion of airfreight services in emissions trading schemes offers an alternative means of internalising the high cost of its carbon emissions.

5.2 Inclusion of Freight Transport in Emissions Trading Schemes

By including the movement of goods into carbon trading schemes and imposing tight caps on CO_2 emissions, the market mechanism could be used to incentivise decarbonisation of the freight sector. The extension of the European emissions trading scheme to aviation in 2012 will include air freight operations. Raux and Alligier (2007) have examined the implications of a further extension to include road freight transport. They envisage entry into the scheme being voluntary, at least initially, with road freight operators being allowed to opt instead for the payment of an additional CO_2 tax. Monitoring of CO_2 emissions would be at the point of fuel purchase and, in the case of for-hire operations, the transfer of CO_2 quotas between shipper and carrier would have to be contractually agreed by both parties.

5.3 Advice and Exhortation

[4] External costs comprised environmental, congestion and infrastructure costs.

Behaviour at all levels in the freight sector, from logistics director to lorry driver, can also be modified by specialist advice and encouragement. The UK government's Freight Best Practice Programme, for instance, provides guidance on how to manage and operate freight transport systems more efficiently, mainly to cut fuel consumption and CO_2 (see www.freightbestpractice.org.uk). Few other countries, if any, have such a broad portfolio of fuel saving initiatives. A recent evaluation of this £2 million programme estimated that, over a four year period, it had helped road freight operators cut their CO_2 emissions by 65,500 tonnes and saved £83 million in vehicle operating costs (Anon, 2008). The Dutch government has run a 'Transport Avoidance Project' which advises companies on how to reduce their total demand for freight transport. The European Commission's Marco Polo II programme also contains a similar scheme which aims '*to integrate transport into production logistics to avoid a large percentage of freight transport by road*'. The options for reducing the underlying demand for freight movement are explored in the next section.

6. Reducing the Demand for Freight Movement

The overall demand for freight transport is basically a function of three variables:

- Production and consumption of material goods
- Number of supply links connecting points of production and consumption (handling factor)
- Average length of these links (average length of haul)

Trends in the first variable are outside the scope of this paper. They are partly related to economic growth, but also reflect changes in the nature of the production process, industrial structure, the commodity mix and patterns of consumption. For the purposes of this discussion, we will take this wider economic context as given and concentrate on the second and third variables.

6.1 Average Handling Factor

The transport intensity of a supply chain can be reduced by cutting the number of separate journeys that a product makes in travelling from raw material source to final point of sale or consumption. This number of journeys or links in the supply chain, as measured by the handling factor, has been subject to counteracting pressures whose relative strength varies by industrial sector, commodity group and country.

Some business trends have been reducing the handling factor, such as:

1. *Disintermediation:* this occurs where a particular level in a supply chain is bypassed and goods are distributed more directly to customers.

2. *Vertical integration*: where inter-related processes are co-located on the same site. This has been occurring in some production sectors, such as the chemical industry. The recent development of 'port-centric logistics' has also seen the clustering of processing, storage and goods handling activities at ports as their role changes from that of a basic modal interchange point to a value-adding hub within the supply chain (Carbone and De Martino, 2003).

   Many more trends, however, have been adding links to supply chains:

4. *Globalisation*: wider sourcing of product, particularly from foreign suppliers, generally adds extra links to ‘end-to-end’ supply chains.

5. *Vertical disintegration of production operations* which occurs when companies outsource to other plants activities that were previously undertaken on the same site. Semi-finished products must then weave of path between more production nodes.

6. *Insertion of additional stages in the production process*. For example, as our appetite for refined, pre-prepared, ready-made and / or refrigerated food increases, the average unit of agricultural output passes through more processing facilities between field and shop.

7. *Switch in consumption to the products of more complex manufacturing systems.* An increasing proportion of consumer expenditure is going on products whose manufacture is inherently more complex and multi-tiered, such as electronic equipment, automobiles and fashion clothing.

8. *Growth of online retailing*. This effectively extends the supply chain from the shop to the home, replacing a personal shopping trip with a freight delivery. Freight carried on shopping trips has never been statistically visible. The use of vans and trucks on the last link to the home makes this more explicitly a freight movement.

9. *Development of primary consolidation and centralized sortation*: In response to downward pressures on average consignment size, largely associated with just-in-time delivery, companies are channeling more consignments through upstream (or ‘primary’) consolidation centres where their orders can be combined with those of other suppliers to maintain / improve vehicle load factors. Over the past quarter century there has also been a major shift away from traditional ‘echelon-type’ distribution systems, in which products are channeled through several tiers of storage / break-bulk points before reaching the final point of sale, to hub-and-spoke networks through which products are moved in small LTL consignments, such as parcel or pallet-loads, via sortation hubs. All these changes have added extra nodes and links to supply chains.

10. *Development of new reverse logistics channels for waste products:* efforts to recycle and reuse a much larger proportion of waste is strengthening the return of flow products back along the supply chain. Instead of being transported to local landfill sites for disposal, often on a single direct journey, waste products are now channeled through more complex reverse channels for sorting and often several stages of reprocessing.

11. *Growth in demand for intermodal services*: where a company’s premises are not directly connected to a railway line or waterway, switching mode inevitably means adding extra road feeder movements to and from railhead terminals / jetties / ports.

On the basis of available statistics, it is very difficult to determine the net effect of these various trends on the handling factor. Several European studies, such as REDEFINE (Netherlands Economic Institute et al., 1999) have used data from different sources to calculate handling factors and found significant differences in handling factor trends by commodity group and country. Little attempt has been made, however, to assess the effects of changes in the number of links in supply chains on their overall carbon intensity.

Any strategy to streamline supply chains would have to recognise that the existence of some nodes and links is environmentally beneficial. Primary consolidation and centralised sorting points improve vehicle utilisation, intermodal interchanges facilitate the transfer of freight to lower carbon modes like rail and water while waste recycling centres conserve materials and energy. So some of the recent increases in handling factors (trends 9-11 above) can probably be justified on carbon abatement grounds. Trends 4-7, on the other hand, generally increase freight transport intensity and CO_2 emissions. Several studies have suggested that internet retailing offers the potential to cut carbon emissions (e.g. Matthews et al, 2001; Cairns, 2005), though this conclusion is conditional and requires further investigation.

Some of the main drivers of handling factor increases in recent years have been business mega-trends such as globalization, off-shoring, outsourcing, new product development and changing patterns of consumption. It would be beyond the scope of freight transport policy to try to arrest or reverse these trends. As freight transport generally accounts for only a small proportion of total production and distribution costs, economic instruments targeted solely on the transport operation would exert very little leverage on these wider business trends.

6.2 Average Length of Haul

Increases in the average length of haul (i.e. length of individual links in the supply chain) have traditionally been the main cause of freight traffic growth, particularly in developed countries. The growth of freight movement has been due more to each unit of freight being transported over greater distances than to the physical mass of goods in the economy expanding. This trend is affected mainly by two processes:

> *Wider sourcing of supplies and expansion of market areas*: this is a process intrinsic to economic development and has widened its extent from national to continental to global markets. As transport and communication networks have improved, companies have extended their ‘logistical reach’ to find better, cheaper and more diverse sources of supply and sell their products to more distant customers.
>
> *Centralisation of economic activity:* This enables companies to exploit economies of scale in the construction and operation of production, storage and distribution facilities. By reducing the number of stockholding points in their logistical systems firms can also take advantage of the so-called ‘square root law’, cutting the amount of safety stock required to provide a given level of customer service (McKinnon, 1989). The concentration of international freight traffic on hub ports and airports is also expanding hinterlands and lengthening land-based feeder movements. By increasing the average distance from the supply point or terminal to the customer, centralisation usually generates more freight movement and CO_2 per tonne of product distributed. Recent research, however, has shown how CO_2 emissions can be reduced within more centralized distribution systems (Kohn and Huge Brodin, 2007).

Routeing of freight flows: For a given set of origins and destinations, routeing can have a significant influence on tonne-kilometres. The directness of the route partly depends on the density and capacity of the transport / service network. Freight is often routed circuitously to gain access to more frequent and / or cheaper services or to avoid congested nodes and corridors. The tonne-km figure is also influenced by the methods used to plan the freight route. For example, it has been estimated that the use of computerised vehicle routing and scheduling (CVRS) software can cut distances travelled by trucks on multiple-drop delivery rounds by around 5-10% (Department for Transport, 2005). Minimising the distance that freight travels need not minimise the related carbon footprint, however, as the shortest or quickest route may not be the most fuel efficient.

The first two processes cannot continue indefinitely. Eventually supply chains will become fully extended. International and inter-regional differences in factor costs may also narrow, reducing the economic incentive to trade with distant suppliers and distributors. This 'market saturation' effect is likely to occur first at a national level and then at the level of continents / trading blocs and eventually the world as a whole. There is some evidence that in developed, mature economies such as the UK (McKinnon, 2007a), the expansion of sourcing / market areas is now at an advanced state. At the continental and global levels, however, this expansion is continuing apace and even accelerating in some areas and sectors. The development of ecommerce, advances in ICT, improvements in transport infrastructure, the strengthening capability of logistics service providers, trade liberalisation and the international standardization of business practices are likely to continue facilitating the process of globalisaion for the foreseeable future.

The centralization of economic activity is also finite, as ultimately production and distribution facilities will reach their maximum economic size, though this process has still some way to run. Within developed countries with well established transport infrastructure, there is limited scope for further spatial concentration. Within less developed countries, the process of centralization is at an earlier stage, while at continental and global scales higher level centralization of production, stockholding and distribution is currently active.

The trend in average length of haul, like that of the average handling factor, is largely a consequence of major global business processes which will be relatively insensitive to the typical range of freight transport policy measures. It would be very difficult to reverse the geographical concentration of production, given the magnitude of the scale economies that firms achieve. Simulation modelling of logistical systems indicates that the cost trade-offs which companies make between transport, inventory and warehousing are very robust. Tilting these cost trade-offs sufficiently to induce a return to more localised and decentralised patterns of production and distribution would require very large increases in transport costs. If the environmental costs of freight transport were internalised (at current valuations) in higher taxes on freight operators, the increment in transport operating costs would be unlikely to cause much logistical restructuring. The social cost / shadow price of carbon would have to be substantially inflated to justify, in economic terms, a return to more decentralized systems, particularly in sectors producing higher value goods.

7. Promoting a Shift to Less Carbon-Intensive Transport Modes

Carbon intensity (expressed as gm of CO_2 per tonne-km) varies widely between transport modes. Shifting from modes with relatively high carbon intensities, such as air and road, to those with much lower carbon emissions, such as rail and water-borne services, can help to decarbonise freight transport operations. The scale of the potential CO_2 savings from switching modes depends mainly on four factors:

1. *Energy intensity of the mode*: this is determined mainly by its inherent technological features, the age of the equipment, the efficiency with which it is operated and the nature of the related infrastructure.

2. *Carbon intensity of the power source:* with the exception of a relatively small amount of electric traction of freight trains, all freight movement is directly powered by fossil fuels. In particular countries, such as Switzerland and France, where rail has a significant share of the freight market and much of the rail network is electrified, the nature of the primary energy source can have a significant impact on the carbon savings achievable from modal shift.

3. *Utilisation of the equipment:* Many estimates of CO_2 emissions from freight transport are based on standard mode-specific ratios of gms of CO_2 per tonne-km. These estimates are underpinned by assumptions about the utilisation of vehicle capacity. The amount of fuel consumed, and hence CO_2 emitted, is very sensitive to vehicle load factors, particularly in the case of road transport. Agencies promoting particular transport modes as being more 'green' sometimes base CO_2 calculations for their mode on high levels of utilisation while using average load factor data for competing modes.

4. *Energy use and CO_2 emissions associated with modal interchange*: modal CO_2 intensities are often quoted on a line-haul basis assuming that freight moves between points on mode-specific networks. Where feeder movements by other modes are required and the intermodal transfer itself consumes a significant amount of energy, a full 'door-to-door' assessment of the carbon footprint is essential.

Estimates of the carbon intensity of freight modes vary quite widely (Table 1). There can even be inconsistencies in official figures for individual freight modes in a single country (McKinnon, 2007b). Disparities partly reflect underlying assumptions about vehicle load factors, fuel efficiency and fleet composition and international differences in power sources, network quality and the types of freight carried by particular modes. As modal CO_2 differentials are specific to particular countries, it can be risky extrapolating values between countries.

As the IPCC (2007) acknowledges, trucking and airfreight have been increasing their share of the worldwide freight market while the relative position of rail and waterborne services has been weakening. To achieve substantial reductions in carbon emissions from the freight sector it will be necessary to reverse these trends. Various economic measures can be used to promote the desired modal shift. Full internalisation of the marginal social costs of transport, incorporating a realistic valuation of the social cost / shadow price of carbon, would be likely to induce a significant shift to cleaner modes. In the absence of such a policy, these modes can receive various forms of economic support, such as:

- Infrastructure investment mainly to expand network and terminal capacity, improve access and facilitate intermodal transfer.

- Capital support for the acquisition of rolling stock and vessels

- Revenue support, particularly in the form of risk-funding for start-up services.

Table 1: Estimates of the CO2-intensity of Freight Transport Modes (g CO_2 per tonne-km)

-	Air (short haul < 452kms)	Air (medium haul 452 to 1600 kms)	Air (long haul > 1600 kms)	Inland Waterway	Sea (short sea)	Sea (ocean ship)	Road (>35 t)	Rail (Diesel)	Rail (Electric)
Dings and Dijkstra 1997	1420	800		40	13		100	69	38
WBCSD-WRI GHG Protocol	1,580	800	570		35	10	72	20	40
INFRAS/ IWW 2004		673			31		91	38	19
NTM	1,925	867	633		-	15	51	17	
IFEU 2005				10		4	69		34

Sources: Dings and and Dijkstra, 1997; INFRAS / IWW, 2004; IFEU, 2005; online calculators were used to derive average values for NTM (www.ntm.a.se) and WBCSD-WRI GHG Protocol (http://www.ghgprotocol.org/calculation-tools)

Such support can be provided at both national and supra-national levels. In the UK, for example, the Freight Facilities Grant scheme has supported the installation of rail sidings since 1974 where it can be demonstrated that the use of rail rather than road yields environmental benefit. In appraising applications for FFGs monetary value is attached to 'Sensitive Lorry Miles' saved on different classes of road. Climate change has represented only around 5% of this value though it is likely to be revised upwards in the near future. Company Neutral Revenue Support has been used to attract inter-modal container traffic to rail and was estimated in 2005-6 to have removed around 710,000 lorry journeys from UK roads. In April 2007 a new 'mode-neutral' system of government financial support was introduced to promote sustainable distribution, with rail and water likely to be the main recipients of this state aid.

At an EU-level the Marco Polo programme which ran between 2003 and 2006 is reckoned to have achieved its target of shifting 12 bn tonne-kms from road to rail and water, with annual ratios of public expenditure to external costs saved of between 11.4 and 15.7 (Millan de la Lastra, 2007). The Marco Polo II programme has the objective of shifting the equivalent of the forecast increase in cross-border road tonne-kms (20.5 bn) between 2007 and 2013 onto rail or water. Based on the experience of the initial programme, the maximum subsidy for use of these alternative modes is 1 Euro per 500 tonne-kms transferred from road. This financial support can be used to 'provide aid to start up a service or develop an existing service' (*modal shift action*s), 'overcome structural barriers in the market' (*catalyst actions*), 'improve co-operation and sharing of know-how' (*common learning actions*) and 'shift freight from road to short sea shipping or a combination of short sea shipping with other modes of transport' ('*motorways of the sea' actions*).

The use of subsidies to bring the cost of alternative modes down to that of road is clearly a second best to fully internalizing the marginal social costs of all modes and should be seen as a temporary measure. It effectively reduces, *ceteris paribus,* the average cost of freight movement at a time when, in the interests of carbon abatement, it should be rising.

Use of rail and waterborne services is, however, inhibited by factors other than cost which economic incentives alone cannot correct. Intrinsically, these modes have lower flexibility and accessibility and, in the case of short sea shipping and inland waterways, slower transit times. They are also subject to tighter regulatory regimes and lower inter-operability, though these constraints can be relaxed. Their competitiveness can also be impaired by inadequate service quality, lack of proactivity and poor service resilience, shortcomings that could also be overcome with more effective management.

It is arguable that freight transport policy has traditionally given too much priority to the modal shift option and under-estimated the potential environmental benefits of other freight initiatives. While the potential exists to engineer a substantial switch of freight to low carbon modes, modifying other freight parameters in Figure 1 can yield equally large carbon savings.

8. Improving the Utilisation of Vehicle Capacity

By raising vehicle load factors it is possible to reduce the amount of traffic (measured in vehicle kms) needed to move a given quantity of freight (measured in tonne-kms). There is a corresponding reduction in energy consumption and CO_2 emissions. Most of the discussion of vehicle utilisation is confined to road transport, partly because it is the dominant mode but also because relatively little data is available on the loading of other modes. There is, nevertheless, considerable scope for improving load factors on rail, sea and air.

The utilization of vehicle capacity is subject to five sets of constraints: regulatory, market-related, inter-functional, infrastructural and equipment-related (McKinnon, 2007c). One of the most critical factors affecting utilisation is the inter-functional relationship between transport and other activities such as production, procurement, inventory management, warehousing and sales. Companies often quite rationally assign these other activities priority over transport efficiency. For example, inventory savings from just-in-time replenishment or reductions in handling costs accruing from the use of roll-cages may exceed the additional cost of running a truck only part-loaded. It can also be economically justifiable to deliver small orders to important customers in an effort to secure their longer term loyalty. Much under-utilisation of vehicle capacity, however, is not based on careful analysis of logistical cost trade-offs or any related sales benefits. It is often unplanned and reflects the relatively low status given to transport within corporate hierarchies dominated by production, marketing and sales departments. The most that a logistics manager can do is to optimise transport within the targets and constraints set by other departments. This inevitably limits the opportunity for cutting fuel consumption and CO_2 emissions by rationalizing the transport operation. There are, nevertheless, a series of measures that companies have been taking, within broader organizational constraints, which can markedly improve vehicle loading, save fuel and cut CO_2 emissions. These include:

Improved backloading: through the use of load matching agencies, online freight procurement, factory-gate pricing or other logistical initiatives (McKinnon and Ge, 2006).

Use of more space-efficient handling systems and packaging: to squeeze more product into the available space, without sacrificing energy-efficiency in loading and unloading operations.

Consolidation of loads in larger / heavier vehicles: some enlargement of vehicles is possible within existing regulations, as illustrated by the steep growth of double-deck road trailers in the UK. Other step-changes in capacity require some relaxation of construction and use regulations. It is estimated that the increase in maximum truck weight in the UK from 41 to 44 tonnes has cut CO_2 by around 170,000 tonnes per annum (McKinnon, 2005). Within Europe, longer and heavier vehicles (LHVs) 25.5 metres long and capable of operating with gross weights of 50 tonnes or more currently operate in Sweden, Finland and the Netherlands and have been shown to offer significant reductions in CO_2 emissions per tonne-km (Arcadis, 2006; Vierth et al, 2008). As discussed earlier, however, net CO_2 savings can be reduced by any associated displacement of freight from rail and shipping (German Environment Ministry, 2007).

Adoption of more transport-efficient order cycles: By encouraging customers to adhere to an ordering and delivery timetable and concentrating distribution in particular zones on particular days companies can achieve much higher vehicle load factors. Replacing the monthly payment cycle with a system of rolling credit can also improve average vehicle utilisation and cut CO_2 emissions per tonne delivered.

Inter-company collaboration: To reach high levels of vehicle loading it is often necessary for companies to collaborate both vertically and horizontally across supply networks. This can either be done directly or through outsourcing the freight transport to logistics service providers.

In addition to reducing externalities, improved loading increases the efficiency of delivery operations. It can therefore have the advantage of yielding economic as well as environmental benefits and, in many cases, be self-financing. Several industry-sponsored initiatives, such as the ‘transport optimisation’ programme of ECR Europe (2000) and, in the US, the pursuit of Collaborative Transportation Management (Esper and Williams, 2003), have encouraged the dissemination of best practice in the management of vehicle capacity. There need only be a minor role for government in exhorting wider adoption of these practices. The UK government’s Freight Best Practice programme, for example, provides guidance on ways of improving vehicle loading and helps companies to benchmark the load efficiency of their vehicles in terms of weight and volume.

Increases in taxation give companies an added incentive to use vehicle capacity efficiently, particularly when taxes are charged by the kilometer. The introduction of truck tolling systems in

Germany, Austria and Switzerland has demonstrated how km-based charges can promote better vehicle loading. By capturing some of the economic benefit of load consolidation in larger and / or heavier vehicles, higher taxes can also suppress the adverse second-order effects of modal shift from lower carbon modes.

9. Raising the Energy Efficiency of Road Freight Transport Operations

As trucks account for at least two-thirds of the total energy consumed by freight transport, this section will focus on the potential for improving their fuel efficiency.

Over the past 40 years the average fuel efficiency of new trucks has been improving at a rate of around 0.8-1% per annum (Duleep, 2007). The main improvements were made in the 1970s and 80s and since 1990 the rate of fuel efficiency improvement has been relatively slow. This is partly because the incremental improvements from the refinement of existing vehicle technology have been diminishing, but it is mainly because of the need to meet tightening emission controls, particularly on NOx. This illustrates the environmental trade-off that has been made in giving the reduction of noxious emissions priority over fuel economy and CO_2 savings.

Only in Japan has the government introduced a fuel economy standard for new trucks. Its 'top runner' concept aims to make the best-in-class performance the average by a target date. For trucks this will entail improving the average fuel efficiency from 6.30 kms / litre in 2002 to 7.09 kms / litre in 2015. Average CO_2 emissions will fall from 415 to 370 per vehicle-km, a 12% decrease (Konuma, 2007). Purchase tax is being reduced for more fuel efficient trucks to accelerate the move to these higher standards.

Increases in the fuel performance of new trucks is only one source of fuel savings. Potentially greater savings can accrue from improvements in the subsequent operation and maintenance of vehicles. It is very difficult to assess the overall potential for improving the average fuel efficiency of road haulage operations for several reasons:

- there are many different sources of efficiency improvement
- there is a complex interaction between different improvement measures: in some cases they are mutually reinforcing while in others they are counteracting
- there are often wide variations in estimates of potential fuel savings from different sources
- it is often unclear from what baseline potential savings are being calculated, particularly when they are generalised at an international level

Many of the checklists of fuel economy measures give the impression that all the resulting savings are additive. Individual measures have been shown to yield fuel savings of 0.5-8%, averaging around 3% (Ang-Olson and Schroeer, 2002). In theory, if a freight operator implemented ten of these measures, they might cut their fuel consumption by 30%. In practice, this is unrealistic. Some measures, after all, are counteracting. For example, cutting maximum speed will reduce the effectiveness of improved trailer and tractor aerodynamics.

The most promising fuel efficiency measures in the road freight sector can be divided into four categories: vehicle design, vehicle maintenance, driver performance and delivery scheduling.

9.1 Vehicle design:

Engine and exhaust systems: It has been predicted that about two-thirds of future fuel efficiency gains in trucks will come from improvements to engine and exhaust systems, particularly turbocharging, the application of hybrid technology in smaller rigid vehicles, energy savings in auxiliary equipment and the use of technology to correct poor driving practice (IEA / ITF, 2007).

Aerodynamic profiling: A series of good practice guides and case studies (e.g. Dept for Transport, 2006) have reported potential fuel savings of 6-20% for improved aerodynamic styling of trucks.

Reduction in vehicle tare weight: Fuel efficiency can also be enhanced by reducing the tare weight of the vehicle, partly through the use of lighter materials, such as aluminium or carbon fibre, and removal of unnecessary fittings.

Improved tyre performance: The so-called 'next generation' tyres should be able to raise fuel efficiency by 3.5-8% by reducing 'rolling resistance'. Potentially larger % fuel savings can be achieved by ensuring that existing tyres are properly inflated.

For these technical improvements to be widely diffused and truck manufacturers to be incentivised to make them, operators will have to attach greater importance to fuel efficiency and carbon emissions in their vehicle purchasing decisions. Research in Finland has found variations of 5-15% in the fuel efficiency of different brands of new truck (Nylund and Erkkila, 2007). Increases in oil prices and greater internalisation of external costs will make life-time fuel costs a more important purchasing criterion. A well-targeted government advisory programme would reinforce these price signals.

9.2 Vehicle Maintenance:

There is a wide range of technical imperfections which can prevent a truck from operating at optimum fuel efficiency. Typical defects include: poor combustion, fuel leaks, under-inflated tyres and axle mis-alignment. A 1 degree misalignment of a single axle on a multi-axle trailer can raise fuel consumption by roughly 3%, while a 2 degree misalignment will increase it by 8% (Department for Transport, 2006).

9.3 Driver Performance

A broad range of fuel economy measures can be adopted, including:

Improved driver training: it is generally accepted that, for a particular vehicle fleet, driving style is the single greatest influence on fuel efficiency. The UK government's Safe and Fuel Efficient Driving (SAFED) programme achieved an average fuel efficiency improvement of 10% across 6179 truck drivers trained (SAFED, 2008). In terms of carbon mitigation, these schemes are relatively cost-effective. Truck simulators have also been used to provide training in safe and fuel efficient driving techniques, though UK experience suggests that they yield much poorer returns and two experimental schemes have been discontinued.

Driver incentive schemes: To derive longer term benefit from driver training companies have to give drivers an incentive to continue driving fuel-efficiently. It can, nevertheless, be difficult to implement such schemes in a manner that is fair and consistent to drivers.

9.4 Delivery Scheduling

Traffic conditions strongly affect average fuel efficiency. For example, CO_2 emissions per vehicle-km from a Euro 4 44 tonne truck are around 45% lower at 70 kms per hour than at 20 kms per hour. By rescheduling deliveries into the evening / night and using telematics systems to avoid heavily congested roads, companies not only cut emissions, they can also achieve substantial vehicle operating cost savings and ease day-time traffic congestion. Such rescheduling is often constrained, however, by the need to synchronise deliveries with production and distribution operations, by night delivery curfews and driver working time restrictions

9.5 Benchmarking Fuel Efficiency, Energy Intensity and CO_2 Emissions.

One method of estimating the opportunity for CO_2 savings is to benchmark companies' road freight operations against a series of energy-related key performance measures (KPIs). Over the past decade the British government has funded transport KPI surveys in eight sectors[5]. Most of these surveys have employed a similar methodology. Participating companies monitor the efficiency of their vehicle fleets over the same 24 or 48 hour period against a standard set of five KPIs (vehicle fill, empty running, time utilisation, fuel efficiency and deviations from schedule). By combining KPIs it is possible to calculate composite indices such as energy intensity, expressed as ml of fuel consumed per pallet-km or tonne-km. This essentially combines vehicle utilisation and fuel efficiency parameters into a single metric. The correlation between energy intensity and fuel efficiency is often quite weak, suggesting that some companies achieving relatively high fuel efficiency squander some of this benefit by their under-loading vehicles (McKinnon and Ge, 2005).

The general message to emerge from these surveys is that even within relatively homogenous sub-sectors there are significant variations in fuel efficiency, energy intensity and CO_2 emissions. Similar companies competing in the same market can require widely varying amounts of fuel to move the same quantity of product the same distance. By benchmarking other companies against the most energy-efficient operators in their sector, it is possible to estimate the potential for fuel savings. One survey in the UK grocery supply chain revealed that if companies whose energy-intensity value was above the average for their sub-sector could bring it down to this mean total CO_2 savings of 5% could be achieved.

10. CO_2 Intensity of Freight Transport Energy Sources

The use of biodiesel has been strongly promoted as a means of decarbonising freight transport operations. Some studies (e.g. Mortimer et al 2002, Concawe et al. 2006) have estimated well-to-wheel savings of greenhouse gas emissions of around 52-53% from the substitution of biodiesel derived from rape-seed oil for conventional low sulphur diesel. More recent work has suggested that net carbon savings could be much smaller and possibly negative (ITF, 2007). Concern has also been expressed about the wider adverse effects of biodiesel production on global agricultural markets and delicate ecosystems, particularly in tropical countries where land is being extensively deforested for palm oil production. Second-generation biodiesel, derived from food waste and forest products grown on land unsuited to agricultural production, may overcome these problems though large-scale commercial production may take many years to develop and doubts have also

[5] Food, drink, non-food retailing, automotive, pallet-load networks, parcel networks, road movement of air cargo and building supplies.

been expressed about its net carbon benefits. Fargione et al. (2008) argue that, 'At least for current or developing biofuel technologies, any strategy to reduce GHG emissions that causes land conversion from native ecosystems to cropland is likely to be counter-productive'.

In the light of recent reappraisals of the role of biofuels in carbon abatement strategies some companies, such as the UK retailer Marks and Spencer, have suspended their plans to switch trucks to a high biodiesel mix until the environmental sustainability of biodiesel can be validated. The uptake of biodiesel by freight operators has also been limited by supply-side constraints and uncertainty about the effects of higher biodiesel mixes (above 5%) on vehicle performance, maintenance and warranties.

Some firms have introduced or are planning measures which undeniably cut CO_2 emissions from logistics energy consumption. McDonalds is powering some of its delivery vehicles on waste vegetable oil arising from its fast food operations. The UK retailer Tesco is erecting wind turbines at some of its windier premises to generate at least enough electricity to recharge the batteries on its electrically-powered home delivery vehicles. DHL is also proposing to construct small wind farms on land adjacent to many of its distribution facilities in the UK.

Until the environmental case for a major switch of freight operations to biofuels is firmly established, it will be premature to use economic instruments to incentivise their operation. Indeed, the European Renewable Transport Fuel Obligation, which will require 5.75% of transport fuels to come from renewable sources by 2010 may have been implemented prematurely. As the ITF (2007) has stated, *'Improving energy efficiency in transport has much greater potential, and at lower cost, than promoting biofuels for reducing energy supply vulnerability and reducing greenhouse gas emissions'*.

11. Cost-effectiveness of Carbon Abatement Measures in the Freight Sector

Few attempts have been made to estimate the cost-effectiveness of carbon abatement measures relating to freight transport. In its assessment of abatement costs in the German transport sector, for example, McKinsey & Company (2007) include only four freight-specific measures out of thirty-six. Of these four, improved heavy truck aerodynamics was by far the most cost-effective, yielding significant CO_2 savings and economic benefit. Hybridisation of light trucks, on the other hand, was found to require a large financial investment but offer only limited abatement potential.

An assessment of several sustainable distribution measures in the UK has revealed wide variations in their cost per tonne of carbon saved (Table 2) (McKinnon, 2007b). Two points must be borne in mind when interpreting these figures, however. First, a reduction in carbon emissions is only one of several economic and environmental benefits that will accrue from these initiatives. They would not, therefore, be justified solely on the basis of carbon mitigation. Second, the analysis is based on a limited amount of time-series data making it difficult to project the level of behavioural change over the medium to long term. These estimates are therefore very approximate. They, nevertheless, highlight the relative 'carbon cost-effectiveness' of on-the-road fuel-efficiency training for drivers and using financial incentives, such as rail-siding and track access grants, to promote greater use of rail freight services.

Table 2: Estimates of the Cost-effectiveness of Carbon Abatement Measures

Measure	Appraisal period (years)	£ / tonne of carbon saved
Driver training in fuel efficient driving (over 5 years)	5	65-75
Financial incentive for modal shift to rail (over 3 years)	3	90
Aerodynamic profiling of HGVs (over 5 years)	5	130
Company advice on HGV fuel efficiency (over 5 years)	5	190
Company advice on vehicle routing and telematics	5	240
Use of truck simulators for driver fuel efficiency training	5	650

12. Conclusion

This paper has reviewed a broad range of options available for cutting CO_2 emissions from freight transport. The combined impact of these measures, even allowing for some countervailing effects, could be enough to reverse the recent growth in CO_2 emissions from the freight sector. By getting companies to switch transport modes, raise vehicle load factors and improve fuel efficiency, it is possible to decouple CO_2 emissions from the growth in tonne-km, reducing the need for more draconian measures to suppress the total demand for freight movement. If the climate change problem becomes so grave that such measures became necessary, either the cost of freight transport will have to rise very steeply or physical controls will have to be imposed on the quantity of freight moved. A return to quantitative licensing of freight operators is not, however, being seriously contemplated at present.

Instead, for the foreseeable future, policy-makers are likely to rely on economic measures to contain the growth of CO_2 emissions from freight transport. As the cost of moving most products represents a small share of their final selling price, even quite large increases in transport costs would exert limited leverage on the fundamental business trends that are making the global economy ever more freight transport-intensive. Carbon abatement measures targeted on modal choice, vehicle fill and fuel efficiency, on the other hand, are likely to prove more effective, especially as companies are realising that cutting the carbon footprint of freight operations usually saves money and improves competitiveness.

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