I. Introduction

This paper provides an overview of the environmental impacts of the international transport of goods. It was prepared for the Joint Session on Trade and Environment Experts study on trade liberalisation, goods transport and the environment.

A) Defining Environmental Impact

"Environmental impact" may be considered to have three components:

- Environmental stressors such as pollutants, noise, or exotic species are released in natural ecosystems. Each tonne of goods transported places additional stress on the environment; many stressors may therefore be measured in units per tonne of goods transported;

- The total amount of stress placed on the environment depends on the quantity of goods and the distance they are transported; in the simplest form, total stress is the quantity of goods times the distance carried multiplied by the stress per tonne. The second component of stress involves the spatial pattern of goods transported, including the transport mode used;

- The environmental impact of the total stress is determined by the nature of the receiving environment. Ambient characteristics such as physical ecosystem characteristics, density of the human population affected, and whether the receiving ecosystem is considered critical or includes endangered species will determine both the physical impact of the stress and willingness to pay to prevent it.

This paper focuses primarily on the first component of environmental impact, with some attention to the third.

B) Quantifying and Comparing Stressors and Impacts

Some environmental stressors--notably air and water pollutant emissions--are easily quantified, and clearly rise with increases in freight. Others, such as airport noise or the introduction of exotic species, increase with the number of trips made, but not with distance travelled or quantity of goods carried. Moreover, the ecological harm caused by such stressors may not be quantifiable or directly related to quantity of freight. This raises the question of how to address stressors which cannot easily be expressed as emission factors per unit of freight. Three approaches may be taken to this issue:

- Limit the analysis to those stressors which can be easily quantified in comparable terms -- i.e. pollution. These are often considered to be the most harmful environmental impacts of transportation, and limiting the analysis to them may not distort the results significantly;

- Include all kinds of impacts, but be descriptive when quantification is not possible. This acknowledges the importance of all kinds of impacts, but unfortunately can make it easy to disregard those which are not quantified in comparable units;

- Use valuation techniques which convert all environmental impacts to the costs they impose, the costs of avoiding them, or willingness to pay to avoid them. The advantage of this approach is clearly that it provides a common unit of analysis with which to compare different kinds of impacts. The disadvantage is that such valuation is highly subjective and quite difficult to carry out.

This paper does not choose among these approaches, but provides information which could be located to permit any of them. It describes the major environmental impacts of freight in qualitative terms. When emission factors per unit of freight are meaningful and available, it provides them. In some cases estimates have been made of the social costs of environmental harms attributable to transportation; these are given as well.

C) Overview of Impacts by Environmental Medium

This paper is structured by transportation mode. Before beginning that discussion, it is useful to review the major impacts of transportation by environmental medium, in order to discuss the environmental impacts of stressors placed by many transportation modes. Subsequent chapters can then focus on the quantity of stress placed by each mode, rather than reiterating how it affects the environment.

This section also briefly discusses several transportation externalities which will not be addressed further in the paper. These are of several types. Some are too indirect to permit establishment of a clear link to freight. For others, data are not available to examine them in detail by mode of transport, so our consideration is limited to a broader discussion of the issue. Finally, some are not considered to fall within the concept of "environment" used in this paper.

Air Pollution

Air pollution is generally considered to be the most important environmental threat posed by transportation. The table below summarises the major pollutants emitted by moving vehicles, their source, and the harm they can cause to humans, ecosystems, global climate, and property (buildings and materials). Most of these pollutants are emitted by most forms of transportation.

Two points should be borne in mind. First, literature on transportation-generated air pollution generally describes the quantity of pollution and its environmental and health impacts one product at a time. However, in some cases chemicals combine to have additional impacts beyond the problems caused by each individually. The best-known example is that of photochemical oxidants, which form through chain reactions between hydrocarbons and other volatile organic carbon compounds (VOCs), nitrogen oxides (NO_X) and oxygen when in the presence of sunlight. This leads to the formation of photochemical smog, a particular problem in cities such as Athens and Los Angeles.

Second, trace quantities of many additional pollutants are emitted by transportation; these include benzene (a known carcinogen), toluene, polynuclear aromatic hydrocarbons, formaldehyde, cyanide, hydrogen sulphide, dioxin, and so on (Kürer pp. 485-6). Either because most governments do not yet regulate these emissions, or because much less is known about their impacts (the second point may follow from the first), these pollutants receive relatively little attention in discussions of the environmental threats posed by transportation.

Table 1. Summary of Environmental Damage by Air Pollution

Pollutant[a]	Source	Impact on:			
		Humans	Vegetation	Global Climate	Materials
Carbon monoxide (CO)	Incomplete combustion	Inadequate oxygen supply; heart, circulatory, nervous system		Indirect through ozone formation	
Carbon Dioxide (CO_2)	Combustion			Major greenhouse gas	
Hydrocarbons (HC - includes methane, isopentane, pentane, toluene, etc.)	Incomplete combustion, carburetion	Some are carcinogenic Ozone precursor	Build-up in soil, feed, food crops	Methane has high greenhouse potential, leads to ozone formation	
Nitrogen oxides (NO_x)	Oxidation of N_2 and N-compounds in fuels	Respiratory irritation and other problems.	Acidification of soil and water, over-fertilizing	NO_2 has high greenhouse potential, leads to ozone formation	Weathering, erosion
Particulates	Incomplete combustion, road dust	Respiratory damage, various toxic content	Reduced assimilation		Dirt
Soot (diesel)	Incomplete combustion	Carcinogenic			Dirt
Ozone (formed by interaction of other pollutants)	Photochemical oxidation with NO_x and HC	Respiratory irritation, ageing of lungs	Risk of leaf and root damage, lower crop yields.	High greenhouse potential	Decomposition of polymers

Source: Based on Button p. 30, Table 3.6; Kürer pp. 486-490
[a] Sulphur oxides from diesel engines (trucks and vessels) are also of some concern.

Global Climate Concerns

Transportation contributes to global climate change through emissions of carbon dioxide, methane and other hydrocarbons, nitrous oxide (N_2O), and water vapour discharged by aircraft. These gases absorb radiation in the stratosphere. Though transparent to sunlight, these reflect long-wave radiation normally emitted back into space by the earth. This may raise the temperature of the atmosphere. While the exact impacts of increases in these gases in the earth's atmosphere are not known for sure, the Intergovernmental Panel on Climate Change (IPCC) has predicted that a doubling of CO_2 concentrations could lead to a rise in sea levels by 3.5-5.5 cm per decade due to thermal expansion of ocean waters and melting ice caps and glaciers (Pickering and Owen, p. 72).

For most transportation modes, the same engine emissions have both local and global impacts. Standard data on air pollutant emissions cover all of the major greenhouse gases except CO_2. The Intergovernmental Panel on Climate Control (IPCC) has developed a methodology for estimating carbon emissions based on the amount of carbon in each type of fuel and the efficiency of combustion; the more efficient the combustion, the greater the share of the carbon converted to CO_2. Detailed data on emissions by mode of transportation are not readily available, because they require highly disaggregated data about fuel consumption (US Environmental Protection Agency (US EPA) 1994 p. 19 footnote 7). The information which could be identified on carbon dioxide emissions per ton-kilometre of freight is presented in the discussion of other air pollution by maritime transport, trucks, rail, and pipelines.

Most aircraft emissions data pertain to conventional pollutants emitted during landing and take-off cycles. These emissions contribute to both local pollution and to global climate problems, as do road or marine emissions. In addition, however, aircraft emissions during high-altitude flight, may have further impacts on the global climate, because they are emitted directly into the upper troposphere or stratosphere. The available information on this issue is discussed separately from low-altitude air pollution in the chapter on air transport.

Noise

Traffic is a major source of noise, particularly in urban areas. In addition to being unpleasant, noise contributes to such health problems as stress, sleep disturbances, cardio-vascular disease, and hearing loss. Surveys suggest that people feel more directly affected by noise pollution than by any other form of pollution. This has a political dimension which goes beyond the noise itself. German experience has found that as people become annoyed about noise, they become aware of other environmental pollution problems as well (Kürer p. 493).

Measuring the magnitude of noise pollution is complex. Volume is measured in A weighted decibels [dB(A)]; a level above 65 dB(A) is considered unacceptable and incompatible with certain land uses in OECD countries. However, a number of different parameters must be factored into an indicator of noise; volume, pitch, frequency, duration, and variability. Noise indicators are typically an average of volume and duration over a fixed period of time. The context in which the noise occurs is important; a noise which may be considered acceptable in a working environment during the day would be unacceptable in a residential neighbourhood at night. Similarly, noise which is expected, for example the acceleration of a truck which is visible, may be less annoying than that which is unexpected, such as the same truck when the auditor cannot see it (Filippi p. 129). In addition, the same volume of noise may be more tolerable when it is intermittent than when it is constant; thus railway noise can be more acceptable than quieter but more constant noise from road traffic (Kürer p. 494). Exposure is also frequently qualified by the number of people or share of the population exposed to this level of noise, or exposed to it for more than a fixed per cent of the time. However, obtaining data on actual exposures to noise is difficult. In addition, it is somewhat difficult to compare noise from different modes of transportation as these are measured with different metrics.

Water Pollution

The normal operation of transportation vehicles does not generate water pollution in the way that it generates air pollution. However, transportation has both direct and indirect impacts on water quality. Shipping activity, in particular, directly affects the environment in a number of ways. The routine discharge of ballast water from marine vessels, if ballast is not segregated from cargo, introduces oil pollution at sea and in coastal waters, and can lead to introduction of nuisance species transported from the boat's origin to its destination. Shipping is a source of oil and chemical spills at port, in coastal waters, and more rarely at sea. The routine maintenance dredging of ports and inland waterways stirs up toxic sediment and frequently leads to the disposal of dredged material in the open ocean. (Of course the existence of the toxic sediment stems from many sources other than transport; the dredging simply raises the toxics and poses the problem of where to resettle them.) These problems increase with growth in shipping, although they are less directly linked to ton-kilometres of freight than is air pollution.

The water-quality effects of land transportation are less direct. Road accidents and vehicle exhaust are both sources of oil and hazardous chemicals which run off the road into surface and ground water. The roads themselves, as well as parking lots, driveways, and other paved surfaces lead to an increase in impermeable surfaces, particularly in urban areas. Impermeable surfaces interrupt the filtration of rainfall into the ground water. An increase in impermeable surfaces will therefore aggravate flood risk and lead to more pollutant runoff into surface waters in heavy rains. These problems go far beyond the choice of freight transport mode, however. They are primarily linked to ownership of family cars and a preference for single-family homes, which combine to create land use patterns characterised by a dense network of roads in order to access each residence individually. While additional traffic means more highways and more chemicals on the roads, the highways themselves may account for a fairly small share of impermeable surfaces.

Accidents

Defining accidents as an environmental impact raises questions about how we define the environment. Some accidents clearly fit within any definition of the environment. Ship and pipeline oil spills, in particular, have obvious impacts on ecosystems and wildlife. Other accidents, particularly passenger transport accidents like car or plane crashes, have serious impacts on human health which might not fit within a narrow definition of the environment. The possibility of such an accident occurring could be considered a "quality of life" issue, and thus an element of the environment broadly defined. Other accidents fall somewhere in the middle; for example, truck accidents, train derailments, or gas pipeline accidents which release toxic or flammable chemicals. The risks posed here are both to the environment narrowly defined and to human health; separating these two dimensions is not obvious.

This paper implicitly takes the narrow view of the environment in its treatment of accidents. It considers marine and pipeline spills, but does not address issues of human life lost to transportation accidents. This is a somewhat arbitrary choice, of course and a different strategy might be taken. Spill data are easily quantified and can be related to the quantity of product transported; this makes it conceptually straightforward (though sometimes practically difficult, due to data availability) to compare the accidents associated with different modes of transport.

Land Use and Habitat Fragmentation

Land transportation systems are a cause of habitat fragmentation, the disruption of wildlife habitats and their division into smaller area (van Bohemen). Habitat fragmentation has four components. First, transportation lines cause direct destruction of habitat by replacing it with roads, rails, or other infrastructure. Second, a transport right-of-way will disturb adjacent habitat through chemical pollution, noise, light, or other impacts. Third, the right-of-way creates a barrier separating functional areas within a habitat. Many plants or animals will not cross such a barrier, so a road can have the effect of cutting their ecosystem in two. Ecosystem species diversity is a function of the total size of the area of uninterrupted habitat; thus dividing an area with a road could cut diversity in half rather than reducing it only by the actual area used by the road. Fourth, a transport right-of-way can lead to direct collisions between animals and moving vehicles.

The importance of road, rail lines, or pipelines as sources of habitat fragmentation will be related to their length and width and to the habitats through which they pass. Direct habitat loss, externalities like pollution and noise, and road kill will be directly affected by the volume of traffic and width of the road. Measures are available to minimise these impacts, by designing infrastructure such as roads and road barriers so as to minimise pollution or light, and so on. These problems are somewhat analogous to the water pollution problems discussed above, in that it may be possible, although difficult, to relate their growth to increased freight use.

The creation of barriers which divide ecosystems is much harder both to analyse and to manage. Moreover, the importance of such barriers is very much related to the nature of the surrounding environment. A road or rail line running through an urban area is not likely to cause ecosystem harm, since the area is already not in a natural state. Roads through sensitive areas like the Alps, or protected forest areas in the United States, however, can cause significant ecological harm. A rigorous analysis of the impact of different transport modes on land use and habitat fragmentation would require detailed knowledge of local ecology and land use patterns. Even with such information about particular ambient conditions, it is will be hard to establish a direct correlation with increased goods transport.

Summary data on land consumption by different transportation modes suggest that roads may cause more problems than other modes of transport. OECD 1993 (p. 30) indicates that the road network in the European Community consumes 28 949 km^2 of land, while the rail network consumes only 706 km^2. (Of course most goods shipped by rail -- as well as most rail passengers -- also rely on the road network to get between their origin or destination and the railhead.) However, while issues of land use and habitat fragmentation are an important component of the environmental impacts of both road and rail transport, analysing them adequately may not be possible in the context of a model of increased demand for freight.

II. Shipping

Shipping poses threats to the environment both on inland waterways and on the ocean. These problems come from six major sources; routine discharges of oily bilge and ballast water from marine shipping; dumping of non-biodegradable solid waste into the ocean; accidental spills of oil, toxics or other cargo or fuel at ports and while underway; air emissions from the vessels' power supplies; port and inland channel construction and management; and ecological harm due to the introduction of exotic species transported on vessels.

A) Operational Oil Pollution

Ships are designed to move safely through the water when they are filled with cargo. When empty, they fill their tanks with ballast water in order to weigh them down and so stabilize them as they cross the ocean. Before entering the port where they are to load up, they discharge the ballast water, whose weight will be replaced with freight. The water discharged is typically somewhat unclean, being contaminated with oil and possibly other wastes within the ballast tanks. Its discharge is therefore a source of water pollution. It should be noted, however, that segregated ballast tanks, which are required on newer tank vessels, reduce or eliminate the oily ballast problem. A similar source of pollution is bilge water; this is seepage which collects in the hold of a ship and must be discharged regularly. On oil tankers the bilge water is typically contaminated with oil which seeps out of the cargo tanks; thus this is also a source of oil pollution. Such discharges are referred to as “operational” pollution because they have long been considered a part of the normal operating procedures both of oil tankers and of other ships managing their fuel.

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