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Environmental taxation in the transport sector

Gunnar S. Eskeland (Norwegian School of Economics)
Haakon Lindstad (Norwegian University of Science and Technology)

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Environmental Taxation in the Transport Sector

Gunnar S. Eskeland[1] and Haakon Lindstad[2]

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We associate environment with *public goods* and services; aspects that benefit or harm everyone in a given location, such as air quality, global climate change, the traffic situation. The role of taxes in this context comes out of the textbook by the observation that those who can improve the environment are those who impose costs on others: polluters, drivers or owners of vehicles that are noisy, dirty, risky or unnecessary. By imposing a cost – a tax – on harmful emissions, on driving in rushhour, policy makers elicit provision of public goods by those who can best do it.

In the transport sector, policy instruments will often be indirect; we tax or regulate cars and fuels and toll passage, and we argue that this imposes knowledge requirements in policy makers: they may need to know, for instance, the importance of replacing the vehicle fleet relative to how it is used. Knowledge requirements and multiple instruments are also commanded by observing that transport is associated with multiple public goods. Traffic congestion and fatal accidents, air pollution, noise, greenhouse gas emission, will be of changing urgency, requiring evolution of institutions and policy instruments.

We emphasize in our illustrations emissions of air pollution and greenhouse gases. Two subsecgtors of transport – road and maritime – the first dominant domestically and for passengers, the latter internationally and for cargo – share important aspects, not others. One common theme is that the environment – quite generally – benefits from slowing down movements, from larger shipments, and from higher load factor (capacity utilization). This influences a policy examination that values not only characterisics of new vehicles (cars, trains, ships, planes) and infrastructure, but also how they are used.

In general, there is important scope for environmental improvements in the transport secter, and tax instruments are well suited to elicit many of the desirable responses, if well crafted. A major difference between road and shipping is the greater importance of transnational movements for ships, implying that port states will be watchful of international implications when starting to act through emission control areas (ECA) in regions with waterways and dense populations. We find that due to the obvious powers of port states and coordination between these, there is in general no reason for pessimism regarding environmental improvements in maritime shipping – nor for aviation.

[1] Professor, NHH, Research leader, CenSES, SNF.
[2] PhD, Naval Architecture, Sintef Marintek, NTNU.

I Introduction and summary

Taxes and other environmental policy instruments in the transportation sector will to a great extent be addressing variables that influence the environment indirectly – such as fuel use and vehicle characteristics - rather than variables that in the textbook more directly influence environmental quality variables, such as individual emission of sulfur dioxide, fine dust particles, greenhouse gases, or noisy driving behaviors.

The use of such indirect environmental tax instruments – fuel taxes or taxes applied to vehicle and fuel characteristics – raises knowledge requirements. More than for the textbook ideal of taxes levied on emissions themselves, taxes on fuels and aviators, skippers and locomotives are based on how these variables typically or on average influence the environmental qualities in question. In effect, knowledge about the industry in question and its role in the economy proves important: While emission taxes in the textbook may be introduced with little knowledge of questions such as how users choose between road and rail than rail, when policies are indirect and try to influence such choices directly, policy makers are at a greater loss if knowing little (and know little about how little they know) about which choices can represent important emission reduction options.

In this paper, we examine how environmental taxes can be applied to the transportation sector, illustrating with such knowledge and demonstrating how this informs policy. The emphasis is on the real links to environmental problems and how the sector can be influenced: it goes without saying that fuels and vehicles are taxable, the revenue implications are straightforward, and also beyond the scope of this study is how revenues are applied.

We show, for instance, that in the world's movement of cargo, maritime shipping dominates quantitatively, that this is because of low costs per ton-mile, resulting in low emissions and energy use. We also show, and argue, that very simple responses like slower speeds, larger shipments and more slender vessels offer inexpensive emission reductions; that these largely can be summarized as capital substituting for energy and emissions, and that policy instruments should therefore by swung away from today's narrow approach emphasizing standards for ships. We use the example of maritime shipping also to illustrate the importance of environmental objectives at different scales - local, regional and global – and how current developments can be improved by taking synergies and conflicts between these into account, accepting the difficulties of vessels and fuels moving between jurisdictions.

In the movement of persons, road and domestic dominates, and environmental strategies may more easily be shaped nationally and locally. We show that environmental taxes tend to be indirect – applying to fuels, vehicle and fuel characteristics, including subsidies to public transport and road user charges to manage congestion – and again how it matters what choices are available to sector operators. Traditional approaches in environmental policy involve combining fuel taxes emission standards that influence the emission characteristics of vehicles and fuels, and we show with one example that also vehicle characteristics may be influenced directly with tax instruments, so that high emission vehicles are not impossible but discouraged.

A policy approach often emerges that is two-pronged, with one set of policy instruments such as fuel and emission taxes predominantly influencing how capital equipment is used, and another set of instruments such as vehicle standards and taxes changing the stock of capital at point of purchase. Such an approach is not in the central textbook approach which drives all change through emission costs directly, but can be understood in a practical setting where there is a lot of history in present choices, and where the choices that are available with longer term change are others than those involving present capital.

Importantly, environmental improvements will cost, and we highlight how environmental objectives should be explicit and communicated to anchor the political process that allow such costs – in terms of costlier capital equipment, costlier transport, costlier fuels, transfers to government – to be passed on to the economy. It is then typically not a great problem if local objectives such as air quality, and global ones such as climate change, are pursued without coordination, but problems may arise. Our example from maritime shipping illustrated that iff local air quality goals are pursued powerfully while global objectives are not defended by global cooperation, it is advisable that such local policies also keep climate objectives in mind.

In section II, we briefly discuss the role of transport in the economy. The transport sector is a service provider to the general economy. It provides an input into production as well as a service directly to households, both in their income generation activities – the commute, for instance – and in consumption itself. Domestic transport may constitute two to five percent of the economy, but a fourth to a fifth of total energy consumption; though typically much less in less developed and agriculturally based economies. In most nonpoor economies, personal transport dominates in domestic transport. In international transport , transport of goods dominates traditionally, though personal transport – aviation - tends to expand rapidly with income growth. The fact that speed of transport is associated with higher energy- and emission intensities, and the fact that speed is most critical for personal transport, strengthens the need for environmental management in the transport sector with economic development.

In section III we introduce the notion of public goods as a rationale for intervention in the transport sector. While there are public goods at the local and temporal level (congestion, pollution), and global intergenerational ones (greenhouse gas mitigation), the nation state will often be instrumental in devising policy instruments to provide these goods and services efficiently. Instruments such as fuel taxes will often prove suitable from a national perspective, even though they are imperfect both from the perspective of local and global environmental perspectives, and therefore should be supplemented with other instruments.

In section IV we use the road sector as example.

In section V we use maritime shipping as an example.

In section VI, we bring in other considerations, such as political economy, and conclude.

II The role of transportation in the economy

Transport is a service sector, and grows as a share of the economy when the economy develops beyond primary sectors such as agriculture. Transport becomes more important as we urbanize and as we globalize.

Figure 1 shows – for a select set of countries (see appendix for the whole table) the share of domestic transport in total final energy consumption by country. The graph ranks countries according to income per capita (at purchasing power parity exchange rates), and shows: great variation, lower values for poor countries; a flattening (in share, notice!) for middle income and above, and a very strong dominance of road transport: 24 out of 25 percentage points, or 96 percent of domestic transport's energy use is by road transport. .

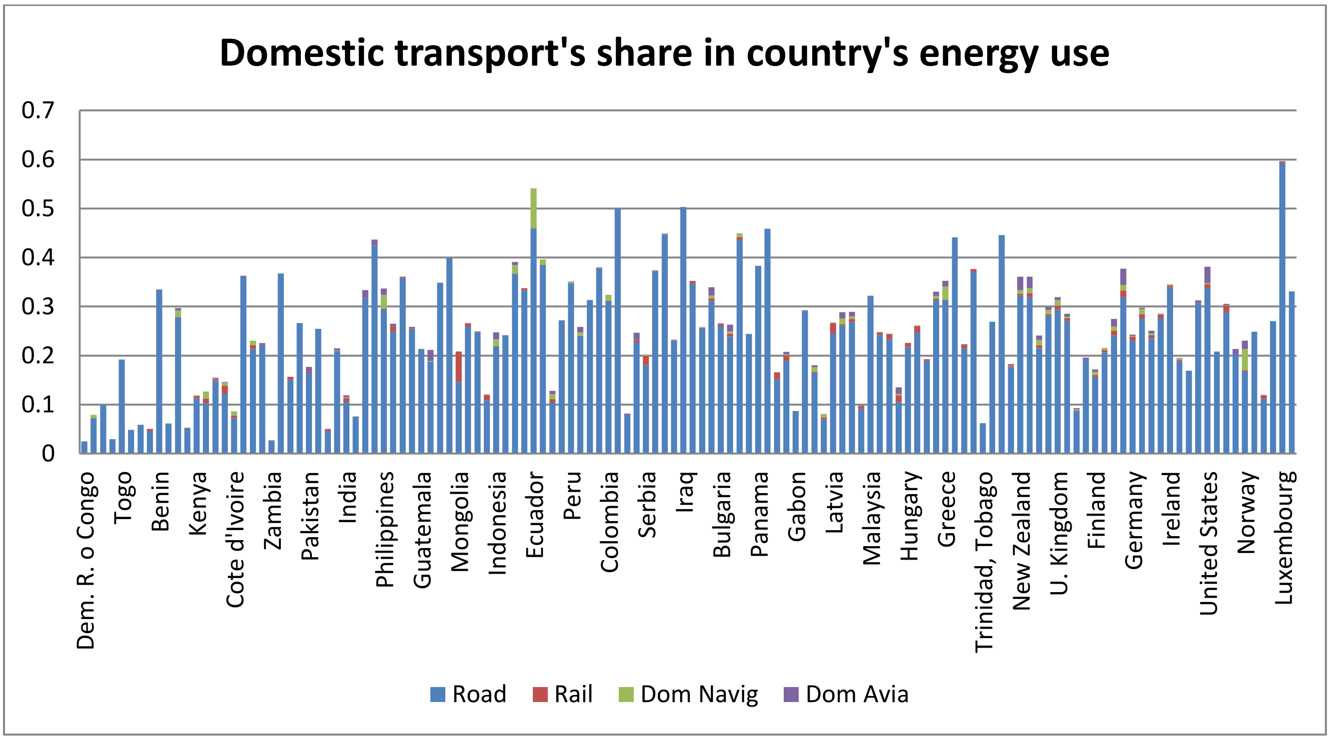

Figure 1: Share of total energy consumption in domestic transport, by countries ranked according to per capita GDP at Purchasing Power Parity. Source, IEA, energy efficiency indicators for transport. Around a quarter of a country's energy use is used in domestic transport.

In addition, there will be international transport, dominated by aviation and maritime shipping, the first taking care of most international passenger movements, the latter of almost all cargo movements (i.e. nonpassenger ton-miles). Aviation and shipping represent 2 to 3 percent of global GHG emissions each, and will thus add about a fifth to this 'world' energy bill for transport, i.e. for many countries – and the world - expanding transportation's share of total energy consumption from about a fourth to about a third, though in countries that are predominantly agricultural and rural, transportation's role will be considerably lower. International transport (aviation and maritime shipping) will, due to the greater distance from concentrations of people and vulnerable ecosystems, have a much lower role in air pollution problems than their two to three percent of greenhouse gas emissions, though in certain port cities and airport locations, they may be very important and even dominant.

We can see from the figure that domestic transport tends to be:

- For many countries, and the world, in the range between a fifth and a quarter of total energy consumption;

- Lower for poor countries
- Lower for small countries, and countries with much coastline and coastal population
- For most countries domestic transport is totally dominated by road transportation

The latter two observations can, to some extent, reflect that transportation that is domestic for a large country with many cities – like the USA – plays roles that international transport plays for countries that are small and with an important coastline, like Norway, Iceland, Philippines and Indonesia. Countries rich in raw materials will be transporting bulk commodities, using road if necessary, rail if possible, and maritime shipping ideally.

This role of transport in total energy consumption will also to some extent transport's role in environmental considerations. For an important concern such as greenhouse gas emissions, if taxed, somewhat more than transport's share in energy use will be carrying the burden, since the transport sector's energy use is typically more dominated by fossil fuels than are other sectors in their energy demand: in poor countries, other energy users will to a greater extent be using biomass for cooking and heating, and in more developed countries, energy carriers such as electricity plays a greater role, and the electricity sector will in most countries include a blend of nonfossil energy sources higher than that in the transport sector.

The transport sector serve needs both as an input into production and directly to households, the sum of which is reflected in the figures above. International transport will mostly be adding aviation, for which passenger traffic dominates, and maritime shipping, for which goods dominate.

Figure 2 and 3 below gives suggestive corrective taxes for vehicle fuels, gasoline and diesel, dollars per liter, regressed against per capita income (Parry et al, 2014).

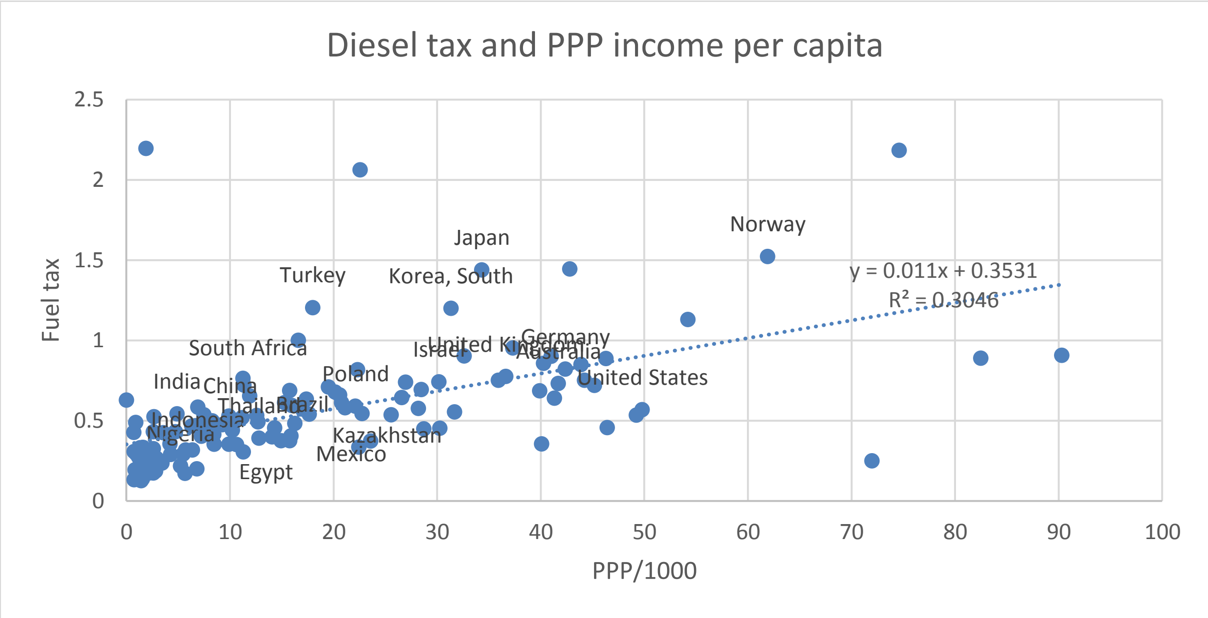

Figure 2: Corrective taxes to be levied on diesel, estimated by Parry et al, 2014.

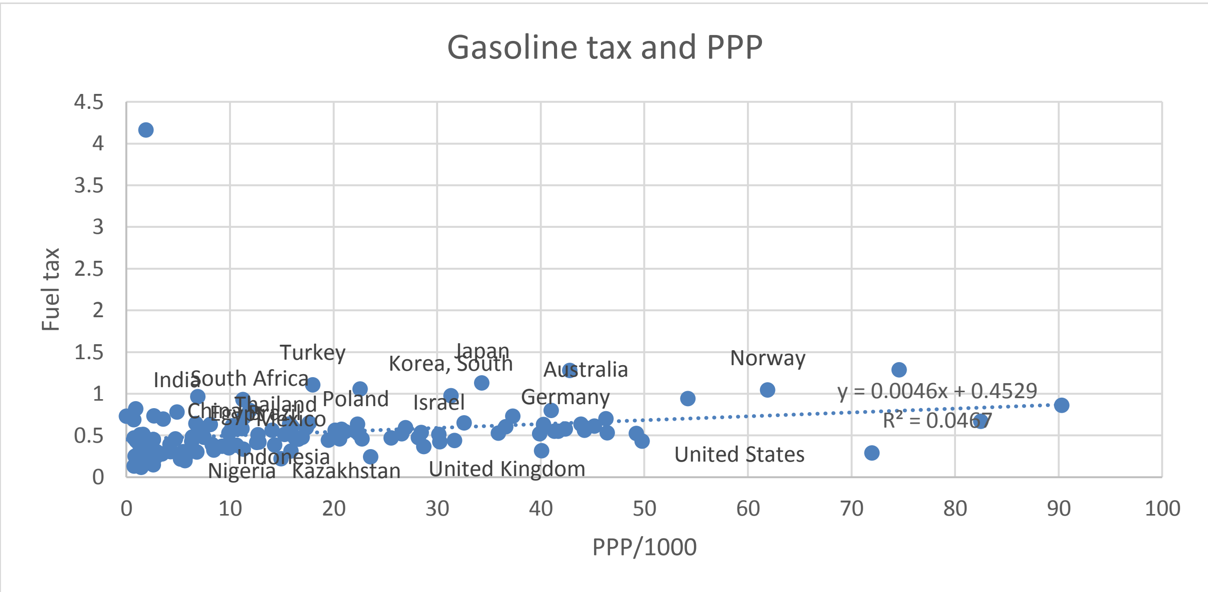

Figure3: Corrective taxes to be levied on gasoline, estimated by Parry et al, 2014.

A difference between these two fuels is that gasoline generally is used by light duty vehicles only (cars, mopeds), whereas diesel to a greater extent serves a range of commercial purposes due to its suitability for heavier loads (not only trucks and buses, but also ships, locomotives, and large engines in general). Before taxation, it will typically be a more economic fuel, in part because of greater calorific content per liter, but taxes, subsidies and regulation are important in practice. Diesel is thus more important in trucking and busing, and the predominance of diesel thus is more important in poor countries. A tendency in actual taxation is – we can see – a clustering around half a dollar and less for both fuels. The corrective taxes – combining objectives of congestion, accidents, air quality, and greenhouse gases - are higher for richer countries, though the slope is steeper for diesel, reflecting higher benefits of reduced congestion and air pollution richer countries, more urbanized, and with higher vehicle density

Transportation is varied along many dimensions, and a main differences highlighted here will be by mode. Figure 4, below, shows the role in cargo transport (i.e. not passenger transport) of modes ranked by speed (declining) and by emissions of CO2 per tonmile (increasing): maritime shipping, inland waterways, rail, road and aviation. As we can see, in terms of transportation work performed, maritime shipping is more than three quarters of the total, while aviation is less than two tenths of one percent. For passenger transport, the picture is quite different (see figure 1, above), since the faster modes – road in particular – are so much more important.

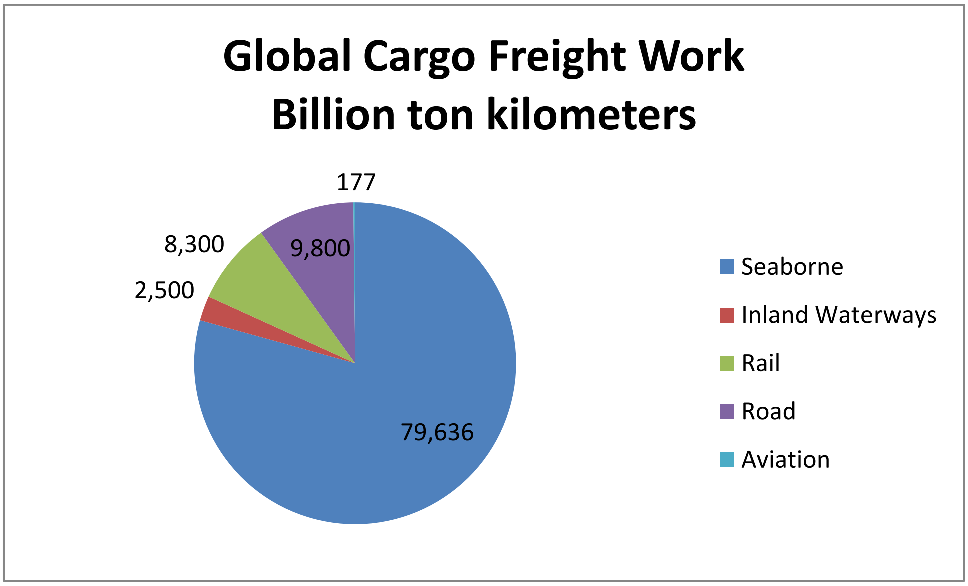

Figure 4: Estimates of the relative roles in global nonpassenger freight by mode of transport, most recent year (2011 and 12). Rail and road figures include only OECD, Russia, China and India, thus missing inter alia Africa, Latin America, and parts of Asia. Source International Transport Forum.

In cargo transport (i.e. nonpassenger), maritime shipping is dominant. A reason is that when maritime transport is possible, it is costeffective, including effective in terms of energy use per unit of transportation work (ton-kilometers, say: table 1). Apart from waterways and ports required, maritime shipping is best suited for goods that are shipped in large quantities (tons or cubic meters) over long distances and do not need to move very fast. These typically are trades for which – on land - rail can compete well against road, and for which aviation is generally not an alternative (fig 4). For transnational shipments, CO2 emissions is a good example of environmental concerns (since only for a global problem is it not too important where emissions occur). Table 1, below, shows the importance of mode choice: if general cargo is moved by ships internationally, CO2 emissions per ton kilometer are between eighteen and 3 grams CO2 per ton kilometer, if moved by truck, emissions will be 85 grams CO2 per ton kilometer (somewhere in between for rail) and if moved by aircraft they will be 550 grams CO2 per ton kilometer. The differences between modes exist also within modes: important factors are speeds, shipment sizes, length of trips, capacity utilization, and technology.

Carrier		Boeing 747 Freighter (1)	Truck & Trailer (2)	Rail (2)	6500 TEU container vessel (1)	18 000 TEU container vessel (1)	Dry Bulk Panamax 80 000 dwt (1)	Dry Bulk Capesize 180 000 dwt (1)
New built price 2014	MUSD	180	0.2	40	80	190	30	50
Annual depr.& financial cost	MUSD	14.4	0.04	4.0	6.4	15.2	2.4	4.0
Annual operational cost	MUSD	18.0	0.14	3.6	3.2	7.6	1.2	2.0
Daily TC-equivalent	USD	93 000	500	21700	27 000	65 000	10 000	17 000
Fuel cost per ton	USD	950	1000	1 000	630	630	630	630
Cargo - weight capacity	ton	115	25	1 500	63 000	160 000	76 000	170 000
Cargo - volume capacity	m^3	857	70	3 000	162 500	450 000		
Utilization of weight capacity	%	50%	50%	50%	50%	50%	62%	55%
Utilization of volume capacity	%	75%	75%	75%	65%	65%		
Average volume payload	m^3	640	53	2 250	106 000	293 000		
Average weight payload	ton	57.5	13	750	32 000	80 000	47 000	93 000
Distance Asia - Europe	km/h	10 000	10 000	10 000	20 000	20 000	20 000	20 000
Voyage speed	km/h	850	60	60	39	39	22	22
CO_2 Emissions per ton km	gram/ ton km	550	85	50	18	13	4	3
CO_2 Emissions per cubic km	gram/ m^3 km	50	21	17	5	4		
Cost per 10 000 ton km		2865	590	444	55	45	13	11
Fuel cost per 10 000 km		1652	275	161	41	30	8	6
TC cost in percentage per ton		42%	53%	64%	25%	33%	39%	43%
Fuel cost in percentage per ton		58%	47%	36%	75%	67%	61%	57%

Table 1. Emissions in transport, emphasizing mode and speed. Notice the approximiate uniformity of fuel cost shares, despite the tremendous differences in emission factors per unit of output.

(1) Lindstad, H. Asbjørnslett, B. E., Strømman, A., H., 2014, *Opportunities for increased profit and reduced cost and emissions by service differentiation within container liner shipping*. Accepted for publication in Maritime Policy & Management

(2) Lindstad, H., Asbjørnslett, B., E. Pedersen, J., T. 2012, Green Maritime Logistics and Sustainability. In Song D., W, Panayides, P., M. (Eds.) Maritime Logistics: Contemporary Issues (2012), Page 227 – 243, Emerald, ISBN 978-1-78052-340-8.

Table 3 also shows that environmental policy instruments such as taxes may, if they work in a way that raises fuel costs, in the outset have potential to raise transport costs significantly: fuel costs in cargo transport can be in the range of half to three quarters of total costs when fuel costs are 600 dollars per ton (about USD 90 per barrel) and vessels move as fast as 21 knots. As we shall see, however, the transportation sector has potential to reduce energy use and (also in other ways) environmental impacts per ton kilometer, so policies need to be shaped to embrace such responses.

Table 2 illustrates growth in global freight maritime transport measured in tons and in ton nautical miles (nm); world trade; and world trade as percentage of GDP. [Lindstad, et al 2015].

Table 2:Development of freight work and Global GDP in billions over the last decades since 1970

Year		1970	1980	1990	2000	2007	2010	2012
Total Dry Bulk except coal	ton nm	1 900	3 000	3 500	4 300	7 200	8 300	9 200
Coal	ton nm	600	900	1 900	2 400	3 900	4 400	5 000
Other Dry cargo	ton nm	2 200	3 500	3 900	7 400	12 400	12 600	14 400
Total oil transported	ton nm	6 500	10 200	7 200	9 600	11 500	11 600	12 200
Other Cargo	ton nm	1 500	2 300	2 200	3 200	4 400	5 300	5 400
Freight Work	ton nm	12 600	19 800	18 700	26 800	39 300	42 200	46 200
Global GDP constant 2005	USD	16 200	23 100	32 300	41 500	52 300	53 900	56 900
Freight increase from 1970			58%	49%	113%	213%	236%	268%
GDP increase since 1970			43%	100%	157%	224%	233%	252%
Freight increase/ GDP Increase accumulated			135%	49%	72%	95%	101%	106%
Freight increase/ GDP Increase per decade			110%	-15%	153%	180%	194%	163%

From this table, it can be seen that over the last four decades, GDP increase and freight increase developed similarly over the years. Over the decades, the relationship of freight work increase to GDP increase has been 1.17, 0.09, 1.20 and 1.63, respectively for the periods 1970-1980, 1980-1990, 1990-2000 and 2000-2010. A number larger than 1 means that sea freight work has increased faster than GDP. This indicates that the general assumption that sea transport freight work only increases with 80% of the growth in sea transport might not be correct and that it should be 100 % or larger instead. It should here be noted that coastal national transport between domestic ports or crude by shuttle tankers to land terminal domestically has been excluded from table 29 and 30 while they are included in all other tables.

For transportation of passengers, many issues will be the same, but their quantitative impacts differ. For passengers, too, scale economy and capacity utilization in 'shipment size' is very important for energy intensity, emission intensity, and environmental intensity: much of the reason why a bus is more environmentally friendly than the car is because a bus may take 20 to 120 persons, while a car is more likely to carry four or eight, and often carries as little as 1. It is the case for passengers as well as cargo that time and convenience is often decisive if smaller and speedier vehicles/modes are chosen, but for for cargo slower modes and larger shipments – maritime vessels – can retain a dominant role without policy intervention. For passengers, in contrast the larger vehicles of public transport typically typically lose market shares much below fifty percent when urban household incomes grow, even when public policies intervene both with environmental taxes and with public transport subsidies.

As for cargo, energy intensity and emission intensity by mode will for personal transportation be determined by local conditions and assumption, for instance regarding fuel mix, capacity utilization (empty seats), etc. Table 3, below, shows calculations from Norway.

	Passenger Transport			Cargo Transport	
	Energy: MJ/pkm	Greenhouse Gases: CO2 g /pkm		Energy:MJ/tkm	Greenhouse Gases: CO2 g /tkm
Train	0,62	8	Train	0,26	12
Moped	0,82	59			
MC	1,29	63			
Bus	1,06	78	Lorry	1,84	135
Car	1,37	100			

Air	2,61	191	Air	30,2	2210
Hurtigruta	5,02	367	Ship	0,8	57
Ferry	8,48	621			
Speed boat	12,35	904			

Table 3: Energy intensity and emission intensity in personal (or passenger) transport, per passenger km (i.e. not including driver who is not 'travel purpose'), Norway, 2004. Source: Thune Larsen et al., 2009. TOI Report 1047, 2009.

While numerical results will differ by country and assumptions, some structural features are fairly general. Passenger traffic, too, demonstrates the importance of a larger vehicle (train leaner than bus leaner than car), the value of capacity utilization (car compared to bus shows that higher/lower seat occupancy for either could upset their ranking), speed (speed boat and aviation are energy- and emission intensive). Also, how much extra you carry, or travel, relative to payload is important. Mopeds are lean because they weigh less per person kilometer than motorcycles and cars, and ferries (including Hurtigruta, the coast-liner) are energy and emission intensive because if they have a high gross weight compared to payload. It is worth noticing that aviation is not very energy- and emission intensive on very long trips, but with statistics on domestic travel in a country where many air trips are 500 km only, cars win almost by a factor of two in terms of CO2 per pkm.

A general communication of the role of size, capacity utilization and speeds is given by figure 5, below, from Berntsen et al.

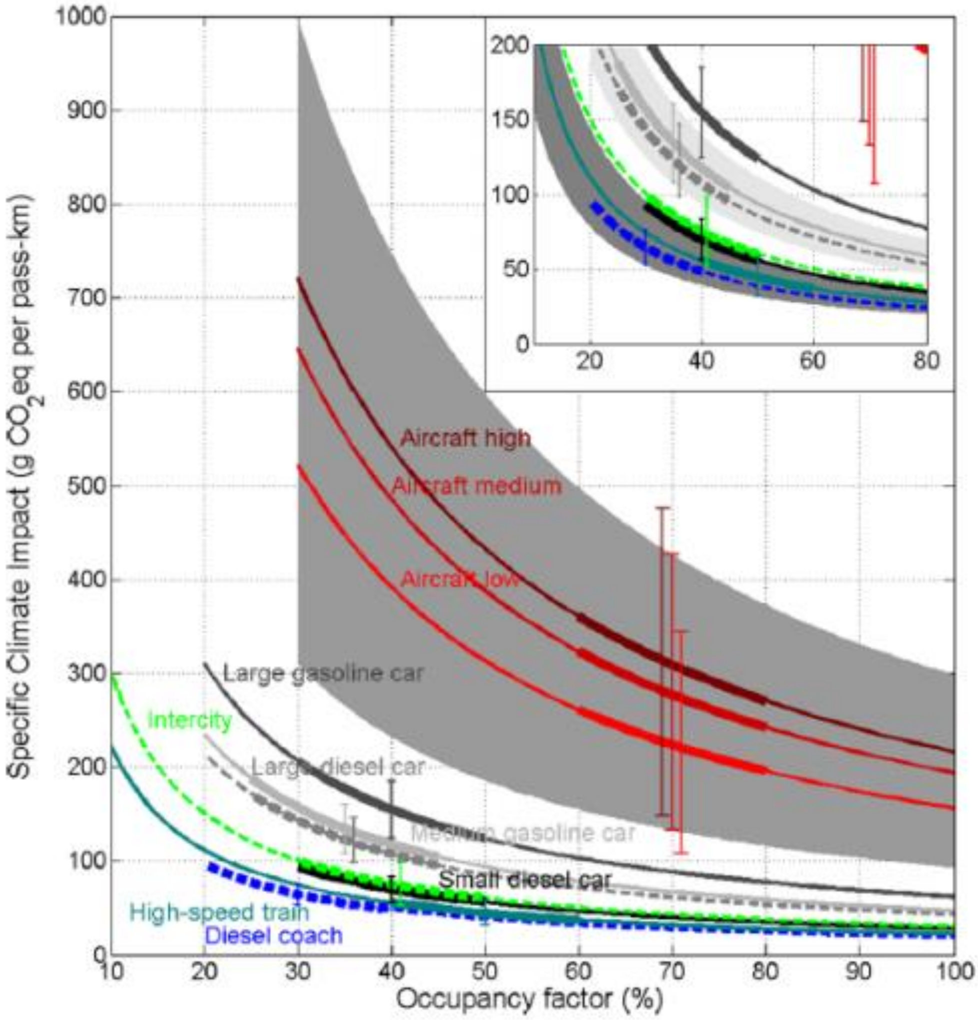

Figure 5: global warming impact, CO2 equivalent, per passenger kilometer. General features appearing in many analyses of environmental improvements from transport – for cargo as well as persons – are beneficial effects of lower speed, greater capacity per 'vehicle', higher load factor. The features also carry over, often, across modes and across technologies, fuel alternatives, etc. Source of figure: Borken-Kleefeld J. , Fuglestvedt J, Berntsen T (2013)

Thinking through what environmental and climate policies will do to transport, these kinds of figures will be important. Environmental and climate policies – for instance through fiscal instruments such as taxes on emissions and fuels – will put pressure on every owner and operator to slim his or her emissions per ton kilometer and passenger kilometer.

The great importance of 'scale economy in vehicle size' or shipment size is also communicated in figure 6, below. Here, the length of the bars illustrates the variation in emission coefficients (per tonmile transported), while the line gives an estimate of the industry average.

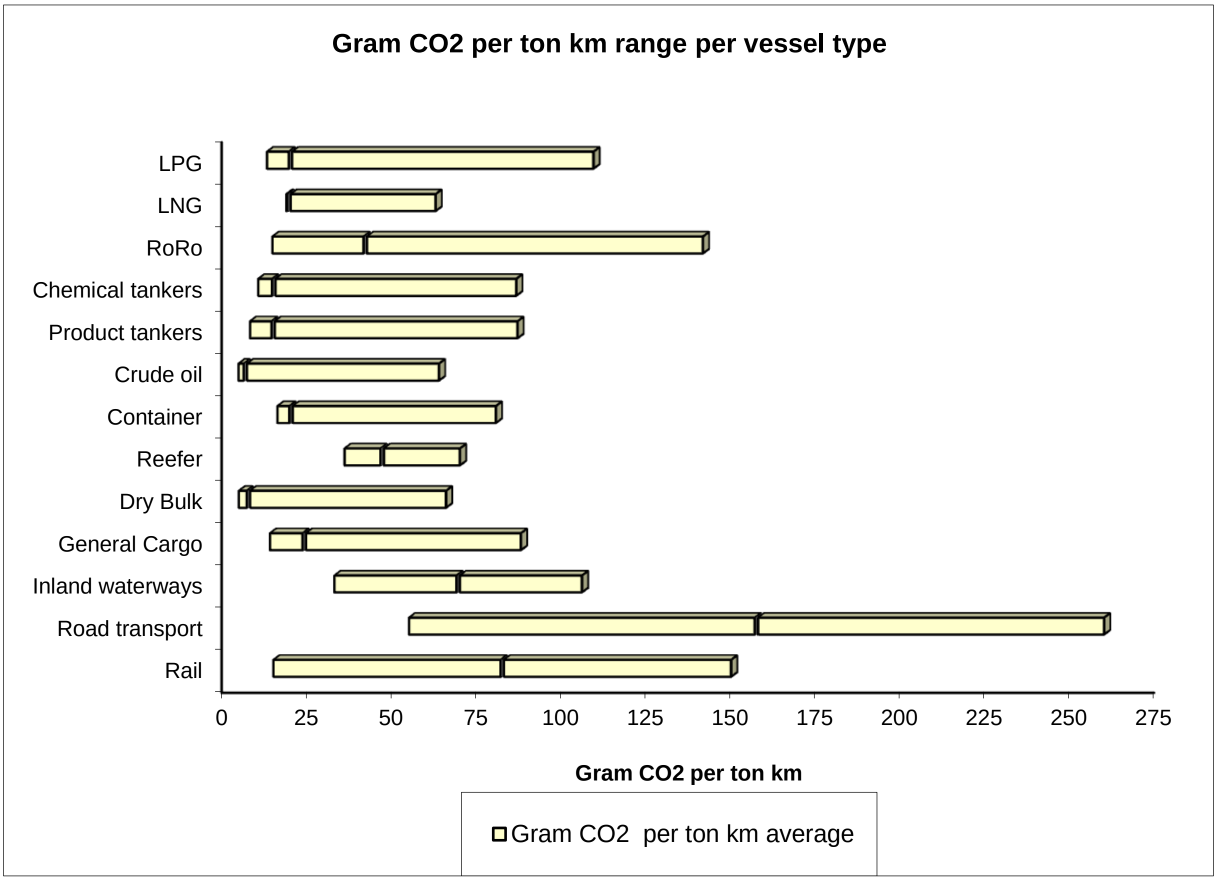

Figure 6: emission factors for CO2 per unit of output, ton km transported, maritime vessels, vary by vessel size

These responses will, for policies regarding emission of air pollutants and greenhouse gases, include:

- Towards nonmotorized modes, and less travel and transport, perhaps denser urbanization
- alternative fuels and technologies
- substitution between modes – in principle – from
  - air to surface,
  - road to rail
  - from rail to sea
- higher capacity utilization (fewer empty seats, containers, trip
- slower movements, at least for seagoing payloads (with the exception of when congestion is addressed and relieved
- larger ‘vehicles’ and loads

For other public goods problems associated with transport, such as congestion, safety, noise, water pollution, recycling, responses will be different in the specifics, but largely follow a similar logic. For instance, larger vehicles have potential, too, to use the road network better and thus reduce congestion, as does higher occupancy or load factor for any vehicle. Safety, too, can be higher per passenger for larger vehicles, in particular in dedicated lanes/rails, but this depends.

In general, each public good, each objective, deserve being sought in itself, with policy instruments suited. We turn to this discussion in the following.

III Analytical framework

III.1 Pure public goods

Environmental goods and services are often *pure public goods*, which has the implication that they may very well need policy intervention – from government, typically – to be protected or provided at efficient levels. Provision of local public goods, such as the establishment of law and crime prevention, may be seen as an *origin* of government, as in ancient city formation. This perspective is also useful in a modern context when environmental problems of increasing importance call for new instruments of intervention and institutions that may support them.

One may think of a mayor or a governor in a city or an airshed, for instance, as acting on behalf of citizens and firms, weighing costs of pollution control against the benefits of improved air quality. Citizens and firms will at stricter air quality policies be harmed by higher costs of cars and energy, lower employment, perhaps, but they will also be benefiting through improved health, quality of life and workers. The Samuelson condition for optimal provision of public goods, which we call efficient provision, is suggesting as a norm that the marginal benefits of environmental improvements, summed across beneficiaries, shall be equal to the marginal abatement costs. Marginal abatement costs shall, according to the cost effectiveness criterion, be equal across polluters, and across abatement options. These two normative criteria, which we associate with *efficiency*, take no account of the distribution of costs and benefits, and distribution will often be called upon when we try to explain departures, descriptively, from efficiency. The textbook rationale for not including distributional considerations in the norms for environmental policies is that other policy instruments may be available that at a lower cost (than the modification of environmental policy instruments), can redistribute income.

This overall framework – placing environmental protection in the body of welfare economics and public finance through the lense of public goods - suggests that analysis and intervention starts and originates not with transport, but rather with the cross-sectoral coordination powers that relate to the public goods themselves (air quality, say). Nevertheless, we direct ourselves to the transportation sectors, and ask which pure public goods, which environmental problems, the transportation sector is typically or often associated with (table 4). While some may not find it obvious that for instance accidents and congestion are categorized as environmental, the public good aspects are quite apparent: your risk of accidents, for instance, is influenced by circumstances you cannot change, such as the general nature of infrastructure, cars, drivers. While you may be small enough in the big picture not to take account of your changing these circumstance,

	Public Good (Benefit) domain		**Important contributor (example/typical)**	
	Geographic/ Jurisdiction	**Time**	**Transport**	**Other**
Air quality	From city to valley to neighboring states	Hours to weeks	Road vehicles (diesel especially), vessels near/in in port	Power generation, manufacturing, waste burning
Water quality	Bay or river to system of rivers and lakes	Weeks to years/decades	Maritime shipping: tank cleaning, spills, ballast water	Industry, households, agriculture
Greenhouse gases	Global only	Cumulative, centuries	Road, maritime shipping	Power generation, cattle, cement, all fuel burning
Noise	Very local to suburban level	Spontaneous	Road vehicles, aviation	
Accidents	Local, also national in prevention policies	Spontaneous, to decades in strategies	Road, rail	Agriculture, industry, homes
Congestion	Local	Hours	Road vehicles	None
Road wear	Local/national	Cumulative/Decadal	Heavy vehicles/studded	None

			tires	

Table 4: Environmental public goods, their benefit domain, and indicatively the main role of transportation modes.

An analytical framework basing intervention in markets on the premise that environmental problems reflect pure public goods at local, national and global levels implies the possibility that intervention can be made at different levels. So urban air pollution management may be the responsibility of city or regional governments, while national government may be intervening both for national public goods and for the country's part in global public goods provision, as with greenhouse gas reductions. From the basis of environmental challenges viewed as problem of providing or protecting pure public goods, including optimality conditions (see Samuelson condition, 1954, below), environmental policy intervention could and should be sector neutral: families and firms in agriculture near the city should be induced to reduce air pollution in the same way (i.e. to the same marginal cost per unit of emissions, or benefits, summed across beneficiaries) as trucks should, and industries should.

For most environmental concerns (congestion, accidents, air pollution), impacts will vary by location. This means that instrument use shall be shaped cognizant of what an instrument can influence. But it will quite generally be the case that environmental policy instruments can be shaped knowingly treating different 'vehicles' uniformly, as when vehicles satisfy the same emission standards even though some travel in a rural pattern, while others travel mostly in a polluted urban area where obviously the benefits of emission reductions are higher. Similarly, it may be the case, that a fuel tax is chosen to discourage fossil fuel use due to local air pollution problems, congestion and greenhouse gas considerations, even though it cannot be differentiated very nicely according to local and temporal issues in congestion and air quality management. In so case, an instrument that is applied because of how it works through an average of emission factors, can be supplemented by other instruments that influence the emission factors themselves (emission standards, for instance, or fuel efficiency standards) and instruments working differently in urban and less polluted rural areas (such as toll rings and congestion charges)[3].

[3] Devarajan and Eskeland, 1996, and Parry and Strand, 2011, and Small, 2011, discuss how imperfect fuel charges can work well when implemented with other environmental policy instruments.

As an example, figure 7, below, shows Parry et al.'s (2014) estimates of suggested environmental taxes applied to automotive fuels, in lieu of five public goods: Carbon (climate), air quality, traffic accident prevention, congestion, and road damage.

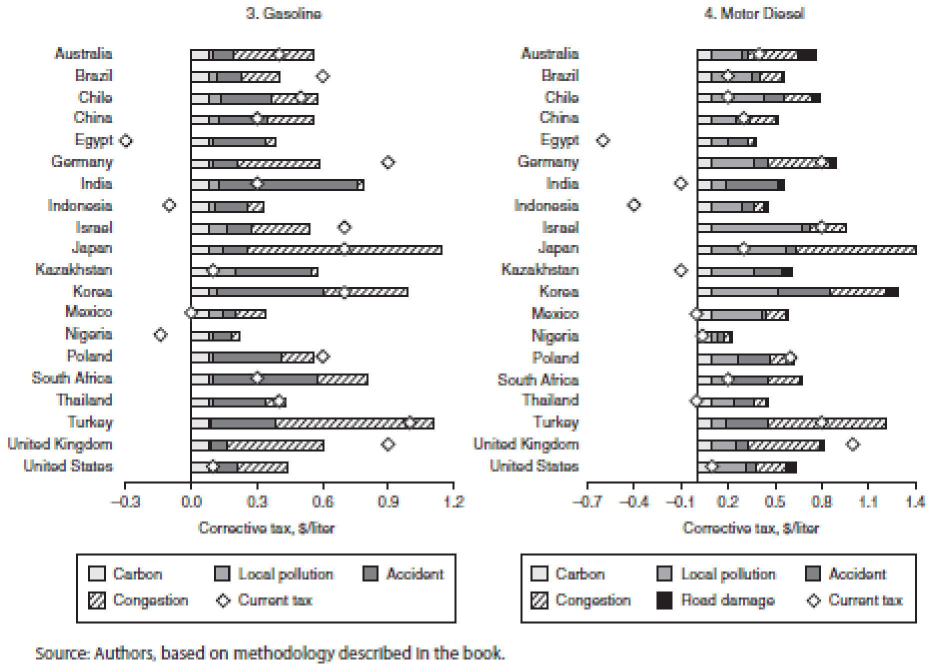

Figure 7, Parry et al. Suggestive environmental taxes, and current taxes (subsidies when negative).

As Table 1 and figure 1 illustrates, the transportation sector is often important in depleting pure public goods, i.e. in causing environmental damage. This is quite typical for energy intensive sectors (sectors with a high share of energy in their costs, or sectors with high energy input per unit of output or value added. Some rules of thumb are important of course, and these will reflect a certain density of contributors (polluters, for instance), and a certain density of beneficiaries. As illustration, a given quantity of transportation fuels will be associated with greater congestion at the margin if much of that consumption is concentrated in roads, places and times that are congested, and with greater air pollution the higher is the share consumed in concentrated urban areas with topographic and climatic conditions giving many people exposure to resulting air quality deterioration. Greenhouse gas emissions, in contrast, are generally thought of as having the same global benefit wherever and whenever they occur, and in the case of Parry et al 2014, a benefit estimate of 35 USD per ton of CO2 is used, translating into 8 US cents per liter gasoline.

Congestion:

Congestion charges should be set such as to internalize the costs that a vehicle imposes on other vehicles by slowing them down . Congestion problems and costs are increasing in the growth of the vehicle stock and its use, and decreasing in better infrastructure capacity and management[4]. Congestion charges, thus, should reflect the state of congestion, and also the precision with which the instrument can be targeted to the problem. For instance, if only national fuel taxes can be (or are) used in part to address congestion problems, then they are hitting very broadly, are not very suited unless congestion is a very widespread and general problem (and would thus be set at fairly low rates). Other instruments that can be used (as supplements) to achieve a more well targeted general intervention can be congestion charges set at urban toll rings (raising fees by time of day, for instance), infrastructure investments, and public transport improvements/subdidies. Congestion often shows up as one major cost drivers and road users impose on others (Parry et al, 2014, our figure 1). Stockholm and London are well-studied and successful cases of congestion fees internationally[5].

Ideally, congestion fees should differentiate not merely by time of day and a cordon or area (both of which are possible in toll rings, and demonstrated in London, Stockholm and Trondheim), but also by the actual traffic situation and how much you drive in given locations. Future schemes and technology developments, including GPS monitoring and seatsharing systems, will certainly expand the possibilities and raise further the net benefits of congestion charges. Present usage of present technologies is, nevertheless, much below what is possible. Toll rings in Norway, for example, would be suitable to charge less from less polluting vehicles, at uncongested hours, and in less polluted months, but do neither.

Road wear

Road wear is highly dependent not only on vehicle usage but also such vehicle characteristics as axel weight (and studded tires). Vehicle characteristics can be and is charged for in taxation (at registration: new sales and annually), and should then ideally include a mileage fee based on odometer reading. Leaving the use-variable element to the diesel tax will be overtaxing light duty diesel vehicles relative to heavy ones, but may of course still raise the desirable revenue and discourage road damage suitably on average.

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[4] Parry and Strand, 2011, provides arule and an application to Chile, including speeds in peak and offpeak conditions, share of driving occurring in urban areas.

[5] See, for instance, Leape, 2006. Since road and congestion charges are amongst recommendations strong historically from economicsts (Vickrey, for instance), analysts of the Stockholm and London examples have emphasized not only the net benefits (substantial) but explanation of their political success: congestion problems that are severe, communicating the rationale, and accompanying public transport improvements.

Germany's truck toll, motivated in part by the many foreign vehicles passing through or operating in the country, combines vehicle characteristics such as axel load and pollution class in a distance based charging system. The system is certainly not only impressive but also promising in terms of indicating applicability for similar challenges elsewhere.

Road damage and congestion may have in common that charging becomes more important with time, as road network expansion decelerates. This may provide a descriptive interpretation of their emergence in policy reform. There is normative basis not to charge for congestion on uncongested roads – free capacity should be freely provided – but there is no known basis not to charge for road wear when wear raises maintenance costs or brings them nearer in time, even if repairs are not immediate.

The role of agglomeration benefits

Agglomeration benefits exist when activities similar to each other benefit from being located next to each other. Shoemakers can be more productive if operating next to each other, for instance because of improvements in input supplies, infrastructure, distribution and skill formation then improve. Also, households may be better served by a good environment and infrastructure such as water, sanitation and schools in a fairly homogenous neighborhood without polluting and risky activities, rather consisting of other families with similar needs. Agglomeration benefits may not be fully internalized in themselves, thus providing a rationale for zoning, for subsidies (locate here, to help us share costs!). Since agglomeration benefits may raise commuting requirements, they may be relevant in transport policy (see Lucas and Rossi-Hansberg, 2002, 2044: an implication of agglomeration benefits is zoning or subsidies that will, to some extent, contribute to the commute, thus counteracting congestion charges and emission charges). A spatial theory of city formation trades off agglomeration benefits against costs of transport, including congestion and pollution. If the costs of alleviating these costs at some point prevents further city growth (giving rise to other cities, for instance), then there should also be an increasing role to be played by policy instruments such as emission charges and congestion charges, as other means are increasingly costly (road capacity, for instance).

Accidents

Accidents prone behaviors could in principle be internalized to some extent through insurance premia and liability (see a recommendation of pay-as-you-drive insurance premia). Thus, drivers and vehicle owners can be incentivized to drive and operate responsibly through the consequence that driving and accidents to others have for them in terms of higher insurance premia, liability, and responsibility more generally. Governments will want to do more than this, though, not only because of the public good nature of an accident-lean traffic system, but also because certain measures (police presence, fines, and infrastructure – including design) are suited for government[6]. Over and above this, since accidents are increasing in driving, simplistic measures such as fuel taxes can be used as discouragement, but they will of course not be very well directed at reducing accidents apart from through reduced traffic (see, for instance, Parry et al, 2014, for the distinction between reduced driving and more fuel efficient cars, which is relevant when fuel taxes are used also for those externalities that are connected to vehicle kilometers). Insurance contracts rich in information – including actual kilometers driven, for instance, and accident record – likely show promise, but so does public policies in road design, driver education, vehicle requirements, etc. Accidents, especially deaths, per vehicle kilometers and passenger kilometer tend to first increase then decrease impressively at higher income levels. Important elements of the rise is when first driving increases in roads filled with pedestrians, and important elements in the subsequent decline is separation of pedestrians from drivers, improved roads and road design, car standards, public education, less drunk driving, strict enforcement.

Air pollution.

In air quality problems, human health issues are typically the main political driver of environmental policy. Such problems can be very local and temporal (Carbon monoxide, mostly from gasoline driven vehicles, vary by streetcorner and by hour), to a more typical pattern in which problems such as small dust particles are important to a city and a season (winter in Santiago de Chile, Bergen, Norway) to air quality problems that are regional. Urban air quality issues, whether for a single city or for several that share the same airshed (topographic and climatic conditions), thus can in principle be addressed by a city or several, but will generally involve national authorities, not the least because local policy instruments often are not powerful enough, even for simple reasons that vehicles and fuels travel in and out. Health improvements due to air quality improvements often turn out to be important in policies addressing fossil fuel use, even as ‘cobenefits’ to climate policies, attractive

[6] See Kopitz and Cropper, 2008, for an analysis of traffic accident rates internationally. Apart from vehicle numbers and kilometers driven, the literature emphasizes quality of cars and infrastructure, exposure of pedestrians, driver age and education, law enforcement, alcohol and (other) substance abuse.

analytically in part because climate change mitigation may suffer from freeriding (not only between individuals and firms, but also between nations, generations), while local and national cobenefits still justify some greenhouse gas mitigation. While the health benefits of improved air quality themselves might be more effectively pursued alone, two undervalued environmental objectives may benefit from being pursued jointly.

Urban air pollution – as well as regional problems such as acidic depositions – have demonstrated Kuznetz curve phenomena of first getting worse, then better, both in the long term and from many sources (as with London Smog) and from motor vehicles specifically. Reductions in vehicular emissions have been driven by emission standards alone in the US, and with a greater combination of fuel taxes (at two to four hundred percent of producer prices) and public transport policies in Europe. Still, even wealthy and successful cities struggle with air quality and health, depending on not only traffic but also topographic and climatic conditions. Air quality health benefits then most heavily emphasize diesel vehicles (See .

Greenhouse gas emissions.

The climate problem challenges the world to reduce its use of fossil fuels, which is arguablu particularly challenging for the transport sector. It also challenges nations to cooperate, as nations not only face a freeriding problem in the public good itself if acting without a firm treaty, but also face carbon leakage responses, by which those who act see other nations use the fuel they saved and produce the cement they refrained from making.

Transport spans well the issues of coordination in the following way, exploited in our examples. In road transport, which is dominant in domestic transport, nation states intervene with ease and good justification both environmentally and jurisdictionally. There are local – within-nation environmental challenges, and countries can with ease both impose taxes on fuels, vehicles and tolls, including in ways that influence the characteristics of imported vehicles. When acting for greenhouse gas mitigation, as with fuel taxes, standards or taxes on new vehicle characteristics, the road transport sector's emission reductions will also be with no or very little carbon leakage: most of a country's domestic transport will not shrink and make other countries' transport grow in response. Aviation and maritime shipping activities are, in contrast subject to leakage, and in two ways. First, visitors and cargo might choose alternative destinations and routings if flying or sailing into or via a country becomes costly or cumbersome. Secondly, a country wanting to be visited by cleaner ships or planes have less of chance to influence it, if the ones in question largely plan for visiting other countries. Keen, Parry and Strand (2013) find the exclusion of fees in international aviation and shipping highly anomalous, and resting on international coordination issues. They also find, however, that greenhouse gas taxes will initially not change these industries much, so their significance will be greater in terms of revenue than in terms of environmental/climate improvement. Our study indicates that these international transport sectors will be improving environmentally gradually, due to port state powers and coordination across these. But it may prove to be true that the importance of emission taxes/fuel taxes itself is hampered to some extent by the transnational coordination and jurisdictional problems, for instance that bunker purchase locations are substitutable.

Water pollution.

Water pollution impacts is not a major issue in transport, though it is in certain special settings, as with spills from accidents and the cleaning and emptying of tanks. Quite typically, these are targeted with polices aiming for prevention, including detection, fines, and liability, so fiscal instruments will not in themselves play a major role, even though they may be important in funding enforcement and cleanup efforts, for instance[7]. When these are included as part of port fees, for instance, they are more a means of financing a service for the sector than they are themselves a major force in inducing desirable behavior. They can, however, if they are duly differentiated (lower for ships with less spill potential), also have some incentive effects[8].

Conflict and coordination among environmental problems

Important environmental problems range from local and spontaneous – say accidents or carbon monoxide in a hightraffic neighborhood – to global and intergenerational, such as greenhouse gas emissions. In such a setting, one would envisage a city acting on local air quality with policy instruments that effectively induce vehicles and firms to reduce emissions of dust particles, national authorities acting with another type of instruments that squeeze nitrogen oxides and sulfur according to national priorities, and also national authorities acting according to international agreements for public goods that are transnational either as regional issues – NOx and SOx in Northern Europe – or as global intergenerational issues, the example

[7] Kolstad et al, 19xx, provides an analytical framework to compare ex ante regulation with ex post liability, emphasizing incentives, observability and assignment of responsibility.
[8] Ports are starting to give port fee discounts to 'greener' ships, an example is Oslo, Kristiansand and Stavanger, discounting fees for vessels with an Environmental Ship Index (ESI).

being the Montreal Protocol on protection of the ozone layer or – as will be much of our attention in the current paper – greenhouse gas emissions.

A storyline to illustrate this point (section V) is the consequence currently of requirements from ECA's in North America (US and Canada) and Europe, who both seek standards for vessels from 2016 onwards to strive for their goals of SOx and NOx reductions. These are worthy regional goals, though perhaps illustrative of the 'local first' tendency in institutional evolution. Reductions in SOx and NOx are to some extent achieved at cost of combustion efficiency, and thus will have a consequence of greater global warming potential in the sum of their emissions.

Such tradeoffs are not necessarily neither bad nor unavoidable, but illustrate the dangers of uneven institutional developments. While reductions in SOx and NOx possibly are important goals for Europe and US, it is probably a good discipline for regional approaches to think through how they can be pursued without making more difficult international cooperation on global challenges. IMO, similarly, could be well advised not to ignore local agendas and advancements such as ECAs, in designing its policies. As it happens, the conflict between goals can to some extent be said to exist *because* they both emphasize standards, while their joint agendas would to a greater extent be advanced by instruments that (also) emphasize fuel use, scale of operations, and energy efficiency, speed, for which tax instruments and tradable quotas would be more suitable, or at least should be included in the toolbox. Conflict and counterproductive initiatives would in consequence also be reduced if and when other policies were complemented by fuel use oriented instruments, such as fuel taxes.

II.2 the textbook rationale for using market based instruments like emission taxes

The textbook proposition that environmental problems are best addressed through market based instruments such as tradable quotas or emission taxes is a sophisticated one, and often misunderstood.

Avoidance of costs.

Persons and companies try to avoid costs to the extent they can. If emissions are priced, as when they are taxed, persons and companies will try to reduce emissions, as if the costs those emissions cause to others have become their own.

Efficiency in provision (or protection) of public goods.

A mayor, or an environmental protection agency, should try to attain any environmental goal at the lowest possible cost. When exposing all persons and firms to an emission tax at the same rate, everyone is asked to contribute up to the point where it costs them the same at the margin. There is nothing 'fair' about this, in the sense that the policy will cost some more than others, but it constitutes cost effective provision of public goods, or protection of the environment.

Benefits: Emission taxes as an example

Even when cost effective, such protection of the environment has a cost to persons, firms, to society. For this reason, it should be justified by environmental benefits. A disciplined route to such valuation is the Samuelson condition (1954) for optimal provision of pure public goods, which asks the emission tax to be set at a level equal to the sum across individuals of marginal benefits from environmental improvements

(1) $t_{el} = \sum_{h=1}^{n} b_{el}^{h} = n_l b_e,$

or, when the emission tax is levied not on grams emissions but for instance on a polluting fuel like gasoline, per liter:

(2) $t_{eql} = \sum_{h=1}^{n} b_{el}^{h} = n_l b_{el} e_{ql}.$

Here, b_{el}^{h} is marginal benefits locally (in a city, say) to individual (or household) h from being exposed to reduced emissions in its area (as when h has fewer air pollution related health problems, and these are valued by h), and nb_{el} expresses the same with an average of marginal benefits for all the *n* individuals in the city. e_{ql} is the emission coefficient for grams of locally damaging emissions per liter of gasoline, q.

We can, in the same spirit, include taxes that reflect global benefits of greenhouse gas reductions, times the three billion or so households n_g that on average over time will experience these benefits, so that a liter of gasoline in the city is taxed at the sum of the two rates:

(3) $t_{eq} = t_{eql} + t_{eqg} = n_l b_{el} e_{ql} + n_g b_{eg} e_{qg}.$

Here, b_{eg} is the average per capita benefit of emission reductions, $n_g b_{eg}$ has multiplied this with the global population to get the social cost of carbon, and the full expression $n_g b_{eg} e_{qg}$ has the social cost of carbon expressed per liter of gasoline. Gasoline, here, is only an example, of course, but the basic idea is that a fuel like gasoline will be taxed for several reasons, and perhaps by governments at different levels, here illustrated by a locally motivated tax reflecting air quality concerns (national or large urban area) and a globally motivated tax. The locally motivated tax will in principle be levied to discourage emission that are damaging locally, such as a weighted sum of substances contributing to dust formation and ozone, and the globally motivated tax will be levied on a weighted sum of greenhouse gas emissions, weights typically reflecting global warming potential. Global warming potential has weights that are much higher per gram for gases other than CO2, but since co2 is predominant in the combustion residuals for fossil fuels, CO2 will be the most important part, and more than 50% for most fossil fuel combustion. GHG emissions are thus often expressed in CO2 equivalents.

III.3 A useful distinction: reducing the *scale* and *the emission factors* of polluting activities

Here, let us first start with a simple idea: It could be that an environmentally harmful activity, such as road transport that pollutes, can be reformed to be less harmful by being suppressed to a lower activity level (everyone or someone drives less). But it could also or alternatively become less environmentally harmful by modifying the vehicle, the driving, or the fuels. If we call this 'less driving' and 'cleaner cars and fuels' figure 4, below, illustrates how an output or input tax (fuel tax) would scale down the activity, an emission standard would push cars and fuels to be less polluting per mile, and an even better policy combines cleaner cars with less driving. A policy of less driving and cleaner cars and fuels could be implemented by a skillfull combination of two instruments – such as a combination of fuel taxes with emission standards - or with such a theoretical textbook ideal as a tax on individual emissions themselves – or tradable quotas. These theoretically ideal instruments of emission taxes or tradable quotas are feasible in ways very close to the ideal in applications such as addressing sulfur emissions from large plants (USA) or greenhouse gas emissions (USA, Europe, China), but for cars combinations of instruments are more suitable at present (see below)[9].

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[9] For cars, it is feasible to ask manufacturers that new cars sold satisfy emission requirements, and also – as the Mexico City experience demonstrates, to ask car owners to pass mandatory inspections (annually, for instance). But such measures of emission *rates* (emissions per liter or per vehicle kilometer) do not fulfill the requirements of an emission tax, which should be levied on the emission rate *times* the liters consumed per year or the vehicle kilometers driven per year. Thus, in most settings, authorities impose a binary requirement on the emission rate (called an emission standard) by which the car is either allowed to drive or not. Those cars can (and often should) be charged fuel taxes, road tolls, congestion charges, but those instruments, discouraging use of the vehicle at certain strengths, are generally not based on (multiplied by) any measure of

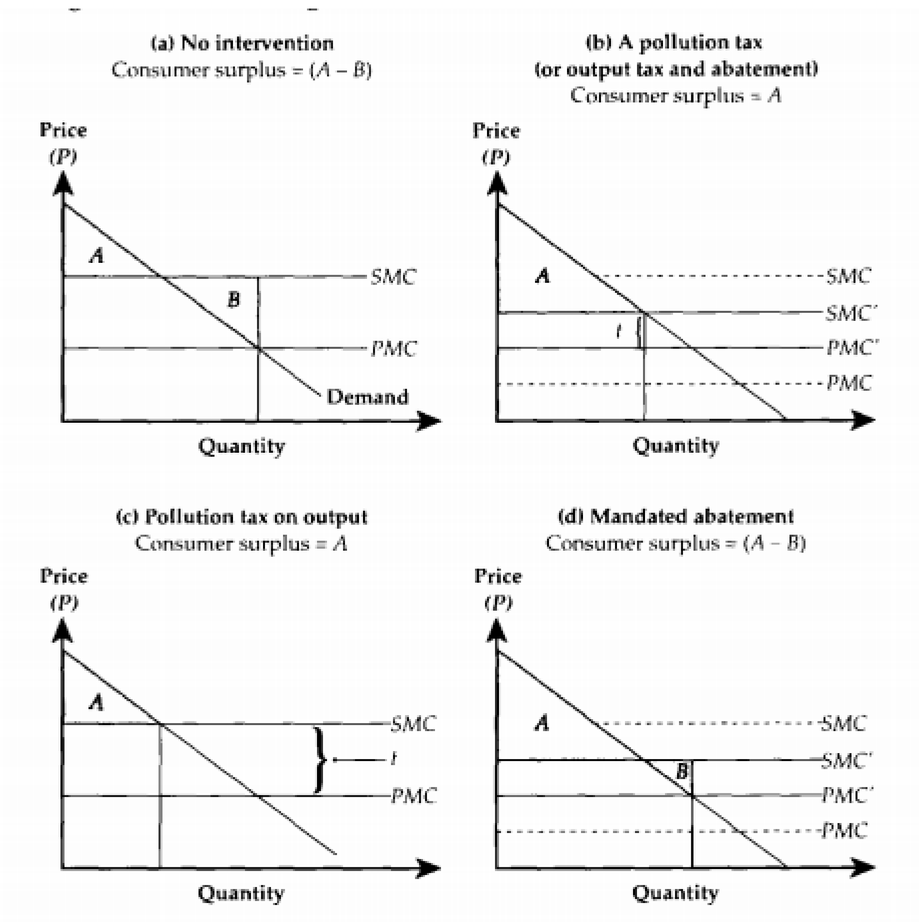

Figure 8. A combination of two instruments, one making cars and fuels less pollutiong per unit (of fuel use, for instance), and the other discouraging driving, can come close to mimicking the textbook ideal of an emission fee.

Figure 8, from Eskeland and Devarajan: Panel A shows how a polluting activity becomes 'too large' when pollution damages are not part of market conditions or regulations, a setting called 'no intervention'. In panel C, an input or an output tax is used to reduce the scale of the activity, without changing anything else: an obvious improvement relative to A. In panel D, an instrument applied to vehicles or fuels, such as an emission standard, is used to make vehicles and fuels cleaner. The policy is an improvement relative to A in that it reduces emission factors and also the scale, since emission standards also raise costs of cars and fuels. In panel B, both responses are combined, either through a skillful combination of fuel taxes and emissions standards (or vehicle taxes based on car emission characteristics, see below), or through taxes or quotas applied to emissions themselves, when feasible.

the emission rate. Urban toll rings applying zero tolls for electric vehicles exist in Norway. Germany's truck fees apply to kilometers driven, by vehicle characteristics such as axel load and emission category, and thus points to a greater level of sophistication presently feasible.

It is mostly from the point of view of *policy intervention* and *policy instruments* that is useful to try to figure out both how an activity or a product or a technology can be made less harmful to the environment. In a textbook perspective, the kind of distinction made in figure 4 (only an example) is rarely made, and the reason is an assumption that policy instruments can be elegant enough to address environmental harm directly.

In the case of transport, for instance, one may tax fuels to address environmental problems associated with fuel use, but one will then discover that vehicles can be made less polluting in ways that are not suitably stimulated by fuel taxes (i.e. not suitably sought through reduced fuel use), for instance through catalytic converters. This lends a role to supplementary instruments such as emission standards or vehicle taxes applied to vehicle emission characteristics. Then, one may discover that policies need a tightening in urban polluted areas which is not necessary in other areas, and one may discover that neither fuel taxes or emission standards are suitable for such purposes, choosing to use toll rings to seek this geographical differentiation, perhaps also giving them a rush-hour feature. Such combinations of instruments thus follow from each individual policy instrument displaying its imperfections, imperfections that become more important as environmental ambitions rise.

The above distinction between 'abatement' and 'input taxes' are themselves overly simplifying. We shall see that for maritime shipping, 'simple changes' like going more slowly and in larger vessels is very important, and for passenger transport, higher capacity utilization in each vehicle (car sharing) and larger vehicles (minibuses, buses, rail, air) also is very important. Thus, while the theoretical ideal of an ignorant but well informed emission tax is important – it would stimulate all sensible responses – in practice it will often take some knowledge to envisage which are the important possibilities for environmental improvements. Then, still, it is good discipline to think through what policy instrument combinations will give the most generally welcoming incentives, so that market participants are given a choice and a challenge in terms of offering environmental improvements in the way they find most cost effective.

III.4 Indirect taxes: Fuel taxes coupled with other policy instruments

Pollution and other problems are in general not proportional to output nor to fuel use, and 'simplistic' tax approaches such as a tax on fuel use will to some extent incentivize some of the responses sought for the environment, but not others. We illustrate this with two important examples.

The Mexico City example (figure, below) illustrated that important gains in a cost effective air quality control program for transportation polluters were available through technical modifications of vehicles and fuels. We called these cleaner cars and fuels, and – when ranked according to cost effectiveness (incremental costs per incremental weighted emission reductions) we called the result the technical control cost curve. In fact, most of these improvements could be induced through such instruments as emission standards for new vehicles and mandatory inspection and maintenance programs. The study also provided a rule for how fuels should be taxed, so that the city exploited reduced driving in a cost effective combination with cleaner cars and fuels. Briefly put, the rule states that the fuel tax, per unit of emissions in a liter of fuel, shall equal the marginal cost of emission reductions for technical controls:

(4) $t_{eq}/e_{ql} = c_e'$

Where c_e' is the marginal cost of emission reductions along the technical control cost curve. Simply put, a cost effective pollution control program views the demand for polluting fuels – or trips – as a supply curve for emission reductions in the same way as the technical control cost curve, and sets the tax rate on fuels, per unit of emissions, equal to the marginal abatement costs. While this characterizes a cost effective pollution control program, an optimal program also sets environmental quality optimally:

(5) $t_{eq}/e_{ql} = c_{el}' = n_l b_{el} e_{ql}$

IV: Road Transport, environmental impacts, and tax instruments

IV.I Air pollution control in Mexico City: Fuel taxes combined with emission standards

We here use examples from road transport – passengers mostly and cars mostly –- to illustrate considerations in practice of using fiscal instruments for environmental purposes.

Road vehicles have been an important target of air quality policies for many decades, and quite impressive advances have been made in terms of emissions that are harmful to public health locally. Many of these advances are in a fuel-economy improving direction (such as improved ignition systems, reducing pollutants that represent incomplete combustion), but many are not (such as reduced sulfur in diesel, removal of lead in gasoline, and catalytic converters for gasoline vehicles).

Thus, it is fair to say, the modifications that can make cars and fuels less polluting must be induced through policy instruments other than fuel taxes. To be simplistic, one can think differently about those policy instruments that can make cars and fuels cleaner, and those policy instruments that discourage car use. Figure 9, below, is from a study which made this point (Eskeland, 1994), and highlighted that policy instruments that make cars and fuels cleaner should be complemented with a gasoline (and diesel) tax to manage the level of driving. While emission standards can make cars anf fuels less polluting, the study highlighted, an efficient policy regime still implements gasoline taxes in order to discourage driving due to the damages from pollutants that still remain to be emitted per liter. The study estimated that to reach a given air quality target for Mexico City would be thirty percent more expensive (in welfare terms) if one chose not to use demand management instruments such as gasoline taxes, since then more expensive technical controls would need to be employed.

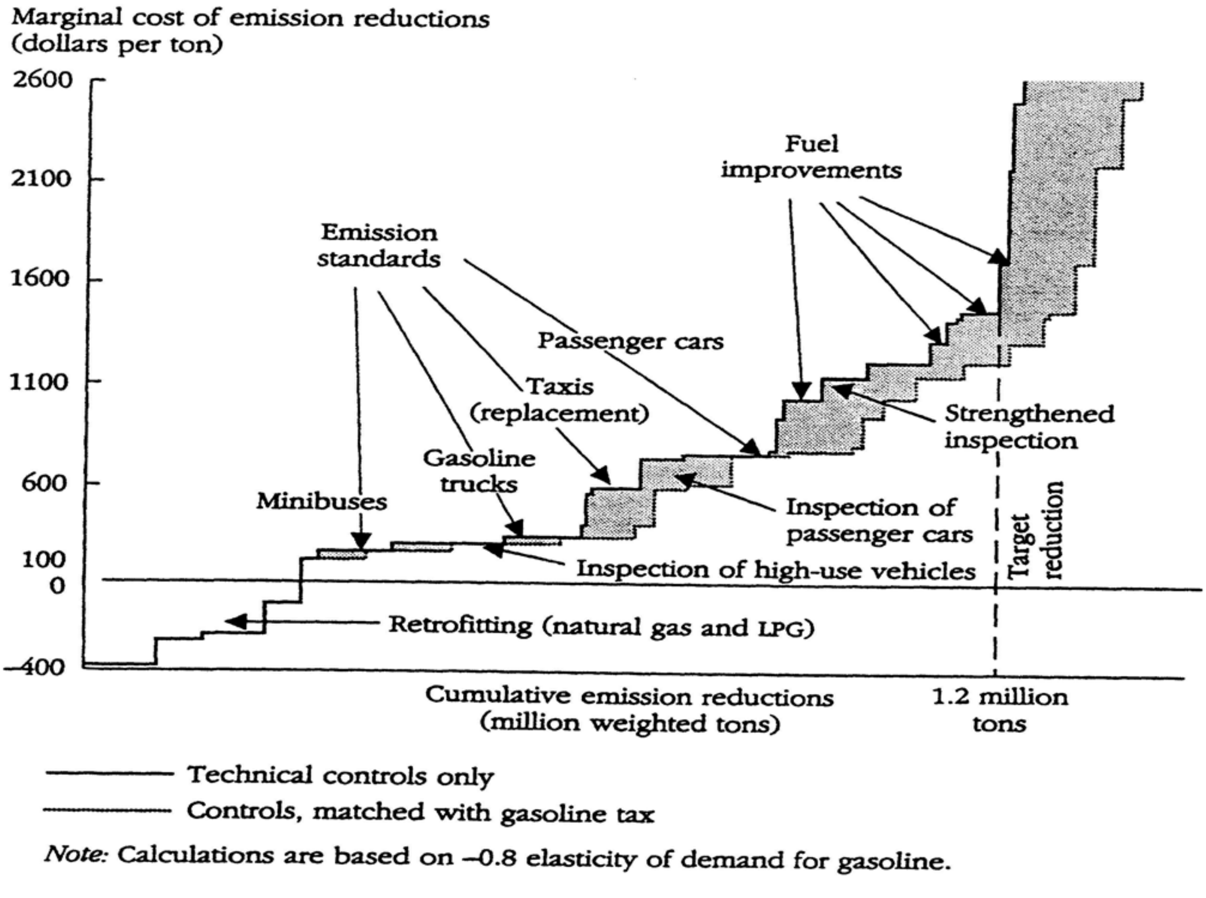

Figure 9. Supply curve for emission reductions in Mexico City, from Eskeland, 1994. The curve displays optimal interventions – a supply curve for emission reductions - depending on ambition level, using a weighted sum of pollutants. When also applying the principle of a matching gasoline tax, the grey area shows hos demand management adds to the options,

offering the same emission reduction at a lower cost. About 25% is the added cost of not using the matching gasoline tax, i.e. of not asking citizens to economize on polluting trips, thereby invoking costlier technical controls to achieve cleaner cars and fuels.

The example serves to highlight two other points. First, many emission-reducing initiatives entail a fixed cost – at manufacture, or retrofit – which then yields emission reduction benefits proportional to the vehicle's annual usage. This has the implication that if one can devise policy instruments that target high-use vehicles first (taxis before cars in ordinary family use, for instance) these will be more cost effective. Similarly, policies that can be phased in with the speed of vehicle purchases (including replacements) will be easier and cheaper than policies trying to move faster or slower.

Such knowledge is not needed by policymakers in the theoretical textbook case when an emission tax is available, one that is levied on emissions (emission factor times use). In that case, a vehicle that is used intensively would face a greater pressure to reduce emission factors, so policy makers can to a greater extent afford ignorance: letting low cost abatement opportunities reveal themselves.

Another point is made when one moves from emissions of air pollutants to greenhouse gases. Greenhouse gas emissions are to a much greater extent strictly proportional to fuel consumed, so fuel taxes alone will be providing much more complete incentives for management of greenhouse gas emissions then for management of local air quality. Greenhouse gas emission management need to take account of differences across fuels (GHG emissions are higher per unit of energy for gasoline than for diesel and higher for diesel than for natural gas, and zero for renewable fuels), but this differentiation is easily built into fuel taxation.

Third, the Mexico City example also proved powerful regarding the value of market based instruments for the scale of an environmentally damaging activity. Above, we used the example of a fuel tax, matching the marginal costs of cleaner cars and fuels, to illustrate the value of combining policy instruments that reduce the scale of a polluting activity with those that make cars and fuels less polluting per trip, or per vehicle kilometer. This contrasted a regulatory scheme 'hoy no circula' (today, not driving), which used license plate numbers to ban driving by each car one workday per week. Theoretical analysis pointed out that market based instrument such as fuel taxes (or rush hour congestion charges) have the advantage of discouraging driving in a way that selects the least important trips, while the driving ban could have much less desirable selection properties. In addition, sadly, the driving ban has the disadvantage (beyond making cars less useful) that it raises the value of an additional car, and many Mexico City households made such acquisitions. The regulation increased driving rather than reducing it, and by more polluting cars, since the traditional flow of used cars from the capital to the rest of the country was reversed by the regulation: from an export of seventy thousand used cars in the three years before, to an import of used cars of eighty thousand used vehicles in the years under the regulation[10].

IV.2 The example of CO2 leaner cars in Norway, with fiscal instruments

Figure 10, below, shows the average CO_2 intensity (CO_2 grams per vehicle kilometer) for new cars sold in European countries. European countries generally have quite high fuel taxes, often including a tax specifically called a CO_2 tax, and this is a suitable instrument according to textbook environmental economics: a fuel tax will induce an efficient combination of ‘carbon-leaner cars and fuels’ and ‘less driving’. European countries have, in addition to fuel taxes, set specific goals for the car fleet to become ‘carbon-leaner’, and the figure shows that cars have indeed become leaner over the period[11].

In Norway, the policy instrument has since 2006 been a specific levy in the new car tax schedule for co2/vkm, and it works together with specific levies on effect (horsepower) and weight to stimulate leaner cars. As the figure indicates, Norway has had a somewhat more rapid progress than the others, about 27% (from 183 g/vkm to 134) against Europe’s 20%, and more visibly in the years from 2006). Further analysis shows that this slimming is at similar rates within each car segment, with only minor shifts between segments, such as from SUVs to mediums size, for instance[12].

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[10] Eskeland and Feyzioglu, 1997, and Davis, 2008.

[11] The US Corporate Average Fuel Economy (CAFÉ) standards have had similar features to those appearing in Europe now. Such an approach will lower fuel consumption mer vehicle kilometer, thus risking a ‘rebound’ if accompanying fuel taxes are low. Small, 2011, analyses for the US tighter fuel efficiency standards (or steeper feebates, similar to the Norwegian system) compared to higher fuel taxes, finding fuel taxes to offer fuel (and emission) reductions at a lower welfare cost. Greater efficiency is because the fuel tax influences the existing vehicle stock and its use, including limiting a rebound, Eskeland and Mideksa explore why fuel taxes are not allowed to work alone, but often with fuel economy standards for the vehicle, or similar instruments.

[12] «85 g CO2/km in 2020 - Is that achievable?” Figenbaum, Eskeland et al, Transport Economics Institute, Report no 1264, 2013.

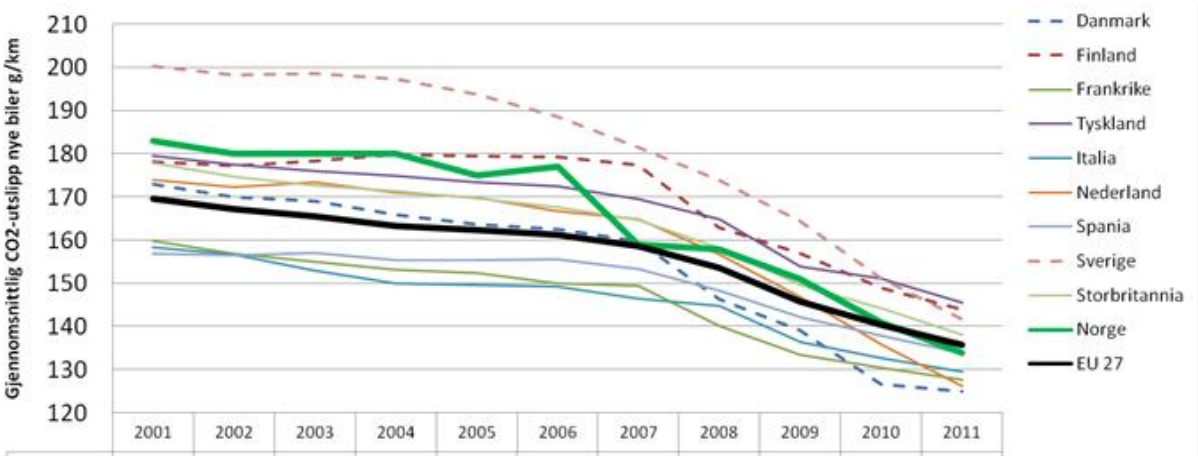

Figure 10. decline in the average CO_2-intensity for new cars in Europe.

Figure 11, below, shows the prices of car models offered in Norway 2012 (blue dots), plotted against their co2 intensities, with the green curve showing the sum of the new-car taxes, the purple curve showing the co2 tax element itself. As can be seen, the taxes in sum contribute to co2 intensive being more expensive, but more co2 intensive cars are more expensive for other reasons too.

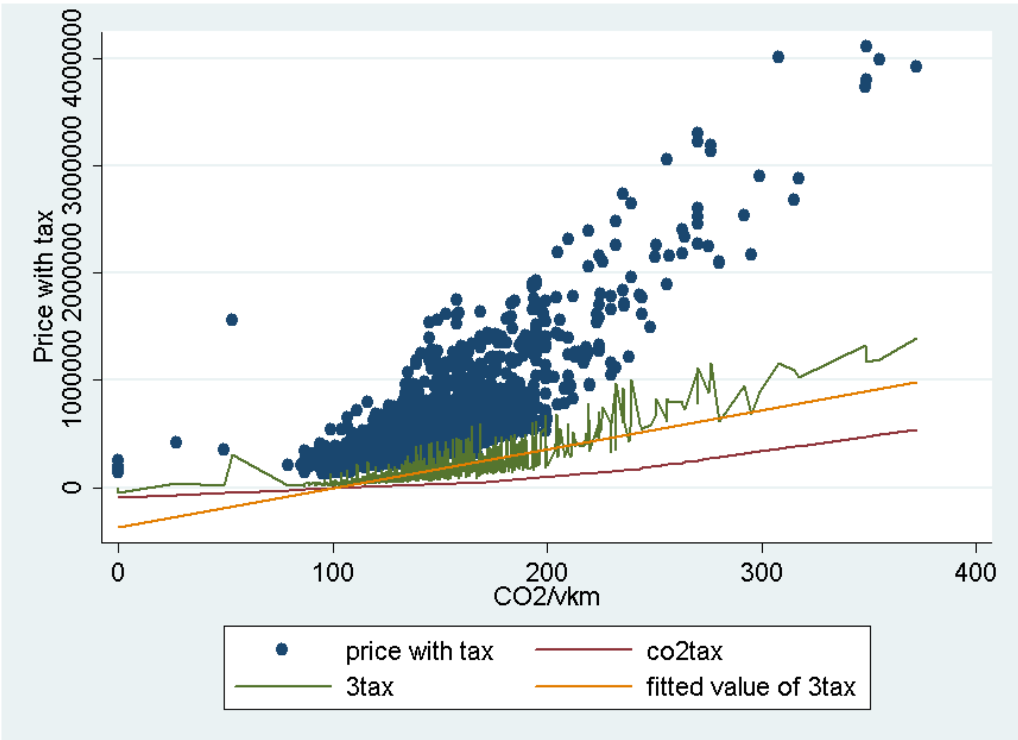

Figure 11. With Co2 intensity along x axis, the dots show the price of car models offered in Norway. Cars are typically – or on average - costlier the more co2 intensive they are, but the CO2 element in the taxes on new cars (purple) tell only part of the story. Since other taxes

(weight, horsepowers) apply to variables that correlate, both the sum of the taxes (green, or yellow) and producer prices work in the same direction – giving people reason to buy co2 lean (and demonstrating that CO2 offers something, if not of direct interest.

Figure 12, below, shows how the average co2 intensity shifted downward in the distribution of car sales over the four year period 2008 to 2012, under the influence both of a rising tax rate for co2 intensity and of technological change and changes in the cars offered. The two curves are histograms, i.e. showing the sales of cars at each intensity. We can see that the whole distribution is shifted to the left, or leaner end, and also that some zero-emission vehicles show up as electric vehicles are entering the market (they have been additionally stimulated).

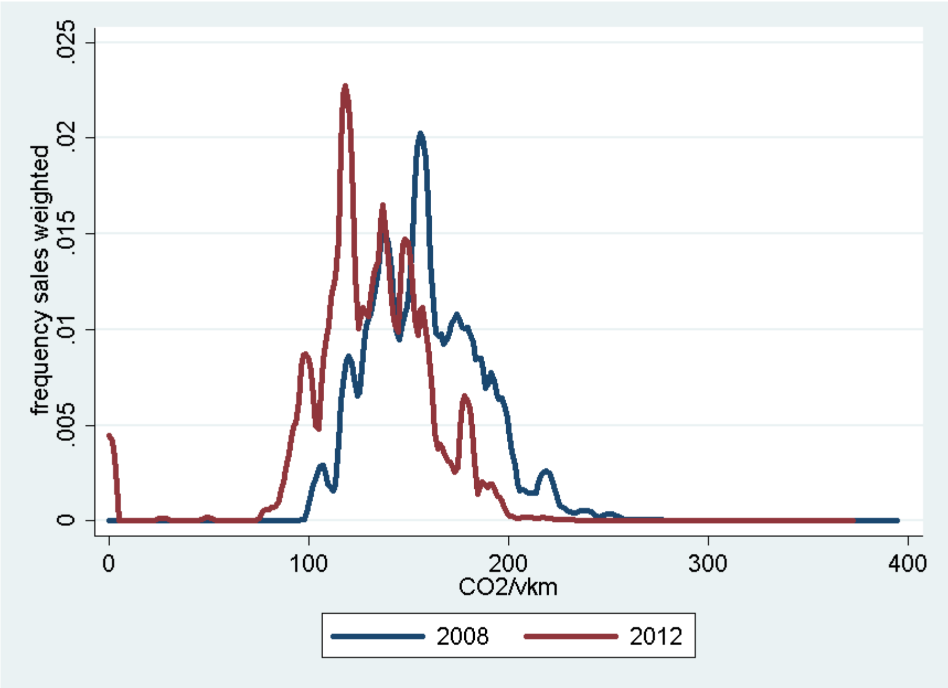

Figure 12. Distribution of cars sold sorted by CO2 intensity (grams per vehicle kilometer, for 2008 and 2012, under heavy and increasing taxation of CO2/vkm in new car registrations (see figure above). Kilde: OFV AS.

While these reductions in co2 intensity are noticeable, it should be noticed that the policy instruments in use are heavy handed, and there are of course welfare costs of asking people to buy leaner cars. A welfare analysis that takes into account that certain desirable quality characteristics are harder to deliver (costlier to deliver) with less co2 intensity (four wheel drive, for instance, and size: two not-too-hidden love affair of Norwegians), is illustrated in figure 13, below. The figure assumes that a given further reduction in co2 intensity requires a 5o percent increase in the co2 tax. Such a change raises government revenue with D minus B, and if that transfer is valued at zero (so government revenue is not worth more than private income), the welfare cost of the tax change and the co2 reductions is E plus B. These calculations assume an elasticity of co2 with respect to price of minus 20% (so a tax increase of 50% causes a co2 slimming of 10%). This calibration seemed reasonable based on some years of experience in Norway, though trend and time delay likely gives a greater response over time[13].

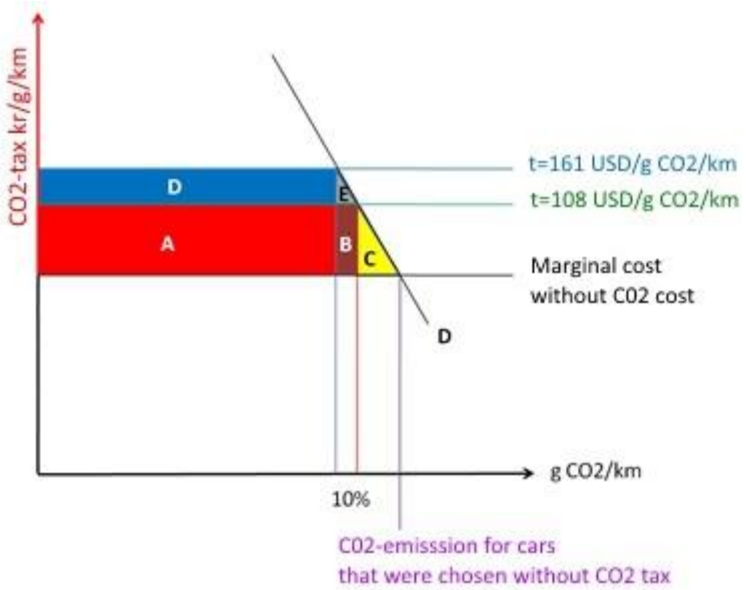

Figure 13: schematic treatment of the welfare costs of using taxes to get CO2-leaner cars, assuming resources have the same value in the hands of government as in households.

Quite generally, greenhouse gas emissions – and especially CO2, the most important one – are proportional to fuel use, independent on location and many other parameters that in greater detail are important for other environmental problems. For this reason, fuel taxes reflecting the co2 content of fuels (or tradable quotas), come very near to being suitable policy instruments alone.

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[13] To illustrate the welfare cost of suppressing co2: Using new car sales in European countries over ten years, an elasticity of co2 intensity in cars with respect to *per capita income* was estimated at 25%, correcting for trend but not for policy changes nor technological changes.

Nevertheless, the practical world of policy has shown interest in other instruments, such as fuel economy standards (CAFÉ standards, in the US, allow averaging for a vehicle manufacturer, and a gas guzzler tax for fuel-intensive vehicles), and the now evolving similar instruments for new vehicles in EU. The literature points out that such strategies may be finding their support in consumer myopia or asymmetric information (people do not trust or do not give sufficient weight to future fuel costs when buying durables such as cars), and the Norwegian strategy of taxing CO2/vkm in new vehicle sales is an example. In Norway (as in Europe more generally) these vehicle oriented instruments work in conjunction with taxes on transportation fuels (In Norway, part of fuel taxes, too, bear the name of CO2 taxes) that amount to about two thirds of retail prices for gasoline and diesel. The combined effect of these taxes is higher than what can be justified as matching the pressure on CO2 in other areas (many time the quota price in the European quota market, for instance, and also many times the frequently applied benchmark of 35 dollars per ton CO2, in Parry et al, for instance). Thus, while one notices that this is a powerful way to reduce emissions, one should also notice that the level itself is not justified by cost effectiveness considerations[14].

V Maritime shipping: CO2 focus will slow down and increase size of vessels.

The value of environmental taxation depends on the extent to which the sector can change its ways – or activity levels - in response. In this example for maritime transport, dominant in the movement of goods globally (in terms of transportation work, i.e. ton-miles or tonkilometers, figure 4, above) we illustrate with two inquiries. First, emphasizing greenhouse gas emissions, we explore how maritime shipping can become more climate friendly, emitting less per unit of transportation work, through such responses as lower speeds, larger shipments, and more slender vessels. We show that these options alone, leaving additional potential in for instance alternative technologies, fuels etc. can make transportation more emission effective, largely through substituting capital for emissions (and energy, or fuel).

Second, an important issue in maritime shipping is that its somewhat international nature interacts not only with global climate concerns but also with more local pollution concerns in ports or in shipping-intensive regions such as Nordic-Baltic and US Canadian waters. We point to synergies, but also tradeoffs between objectives, as port cities and emission constraint areas (ECAs) start acting on local and regional issues.

[14] Eskeland and Mideksa discusses

To the extent that global climate concerns are lagging in political intervention, there will be ways in which regional initiatives also help climate objectives, but there will also be conflicts, as when NOx pressures lead to greater CO2 emissions, and when reduced Sox reduces the cooling elements of emissions from the heavy fuels traditionally used in shipping.

We examine the question of how much it can cost to reduce carbon emissions, emphasizing that substituting energy with capital is central in ‘three ways’ to reduce carbon emissions in maritime transport: First carbon emissions per ton mile transported are reduced through slower speeds, at the cost of more capital tied up in vessels and cargo. Second, larger vessels also reduce energy use and emissions, also at the cost of more capital tied up in port infrastructure and cargo (though less in vessels). Third, through more slender vessel designs, at the cost of more capital tied up in the vessels (when cargo carrying capacity is reduced). These responses may be called upon together by higher bunker costs or CO_2 taxes, which could be forthcoming because of efficient climate policy. Approaches through emission standards, in contrast, risks failing in important ways in eliciting these responses.

A historical background for the focus on speed reductions is that ships have typically been built to operate at or close to their maximum speeds (Silverleaf and Dawson, 1966). For an average crude oil tanker, power requirements go towards infinity for speed above 16 – 17 knots (Lindstad et al 2014). High prices of fuel and increased environmental concerns have challenged this practice and slowed down ships, with a growing interest in the relationship between speed and emission (Corbett et al., 2009; Seas at Risk and CE Delft, 2010; Psaraftis and Kontovas, 2010, Lindstad et al, 2011; Jonkeren et al 2012, Assmann et al, 2014). The core insight is straight-forward: in major speed segments the power output required for propulsion is a function of the speed to the power of three. This implies that when a ship reduces its speed, the fuel consumption and emissions per freight work performed (ton miles) is reduced. This first reduction, speed only, is a very ‘pure’ substitution by capital for labor: lower speeds basically require more capital tied up in vessels and cargo between ports, the costs of which are included in our analysis.

Second, large ships tend to be more energy efficient per freight unit (per ton mile of goods transported) than smaller vessels (Cullinane and Khanna, 2000; Sys et al., 2008; Notteboom and Vernimmen, 2009; Stott and Wright, 2011; Lindstad et al., 2012; Lindstad 2013). If the ship’s cargo-carrying capacity is doubled, the required power increases with about two thirds, and fuel consumption and emissions per freight unit is reduced. Other costs to vessel owner, too, tend to rise less than proportionally with cargo capacity, though there may be port- and canal- considerations that allow small and medium size vessels a role, despite the scale advantages in terms of costs and emissions.

Third, while speed reductions and economies of scale often require changes of the supply chain due to longer transport times, or due to larger storage and port needs with larger shipments, it is possible to introduce energy efficient designs without changes to the logistics. Lindstad et al. (2013) and Lindstad (2013) have investigated potential cost and emission reductions for Panamax bulkers by increasing the vessel beam (width) to enable longer bow sections and more slender hull forms, while maintaining the cargo carrying capacity. These changes reduces the block coefficient and raise the boundary speed, i.e. the vessel can either sail at a higher speed without increasing fuel consumption or reduce fuel consumption at a given speed. Canal considerations may then require lowering cargo capacity, which is then factored in. These slender designs outperform the traditional full bodied designs even with bunker fuel prices as low as 300 dollars per ton, or present 2015 prices (50 dollars per barrel).

The vessel types chosen for illustration are ocean going tankers which transport crude oil from oil producing areas to the refineries. In total these vessels performs nearly 20 - 23 % of the global seaborne freight work, measured in ton miles (UNCTAD 2014). More than 90 % of the crude is transported by Aframax, Suezmax or Very large crude carriers, VLCC. The typical size of an Aframax is 90 – 120 000 dwt, where deadweight (dwt) expresses the weight in ton for how much a vessel can carry at most. For Suezmax, which are the largest tankers which can pass the Suez Canal, typical sizes are 140 – 200 000 dwt, while VLCC tankers are around 300 000 dwt. Table 5 shows the main characteristics of typical Aframax, Suezmax and VLCC vessels, and the same values for the alternative slender designs. The cost of fuel is 600 USD/ton, which is close to the average for the period from 2012 to 2014 (crude in excess of USD 100 per barrel).

Table 5: *Main vessel characteristics*

	Dwt	Main Dimmensions	Block coefficient	New-building price	Time Charter eqvivalent - TCE
	ton	meter		MUSD	USD/day
Aframax 110' dwt	110 000	234 x 42 x 15.5	0.83	54	16 400
Aframax 100' dwt - Slender	100 000	234 x 42 x 15.5	0.75	50	15 400
Aframax 110' dwt - with Suezmax Length & width	110 000	264 x 48 x 15.5	0.66	60	17 800
Suezmax 158' dwt	158 000	264 x 48 x 17.2	0.82	65	19 100
Suezmax 158' dwt - Long & wide	158 000	303 x 50 x 17.2	0.70	70	20 300
VLCC 300' dwt	300 000	320 x 60 x 21.5	0.81	95	27 500

One important element which influences the speed decision is the financial cost for the goods to be transported, i.e. the value of the crude oil multiplied with the required return on tied up capital. When this cargo inventory cost is included, high oil prices shifts the cost curve and its cost minimizing speed somewhat to the right, as illustrated by Fig. 14, showing optimal speed when the value of the cargo was included. The magnitude of this shift is given by the ratio of capital cost of the goods relative to the time charter and fuel costs, and a VLCC costing one hundred million dollars may carry cargo worth two hundred million dollars, with an implied value of a day’s early arrival in the range of ten thousand dollars. Figure 14 shows that the impact of including the financial cost of the crude onboard raises the cost minimizing speed from 11 to 13 knots when the fuel price is at the present level, i.e. 600 USD per ton.

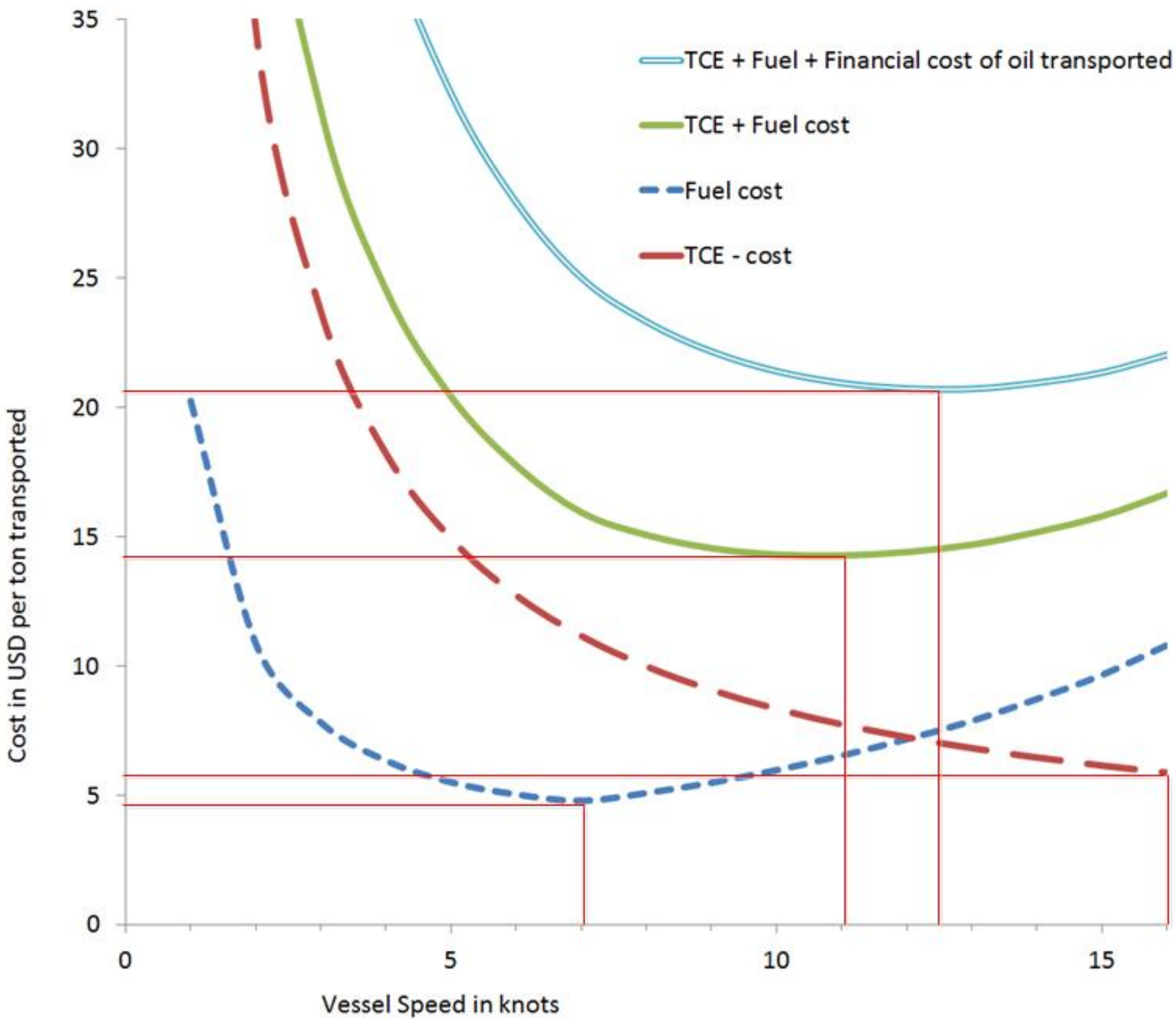

Fig 14: *Fuel and cost per ton transported as a function of speed and cost terms*

It is worth using the example of crude oil carriers to analyze a market based measure such as a fuel tax or a CO_2 cost scheme in reducing fuel consumption and hence emissions. In Figure 15 the effect of fuel price only is compared with a scenario where a CO_2 cost of 100 USD per ton of CO2 is introduced on top of the fuel price. The CO2 tax is such as to raise the fuel cost from 600 to approximately 900 USD per ton.. Fig. 15 shows that a 50 % increase in the fuel price from 600 to 900 USD reduces the cost minimizing speed from 13 to 12 knots and fuel consumption from 13 to 12 kg per ton of crude transported. In comparison, if the fuel cost is increased similarly through a CO_2 fee – the value of the cargo not increasing commensurately - the cost minimizing speed reduction is greater: from 13 to 11 knots. In this latter case of a CO_2 tax, fuel consumption falls from from 13 to 11 kg per ton of crude transported (and per ton mile, since these are roundtrip figures). These results indicate that CO_2 fees are more efficient measures than fuel price alone for vessel types that transport crude oil and oil products. Also, inference based on observations of speed adjustments through bunker price changes underestimate the responsiveness in emissions to emission fees, overestimating the marginal abatement costs.

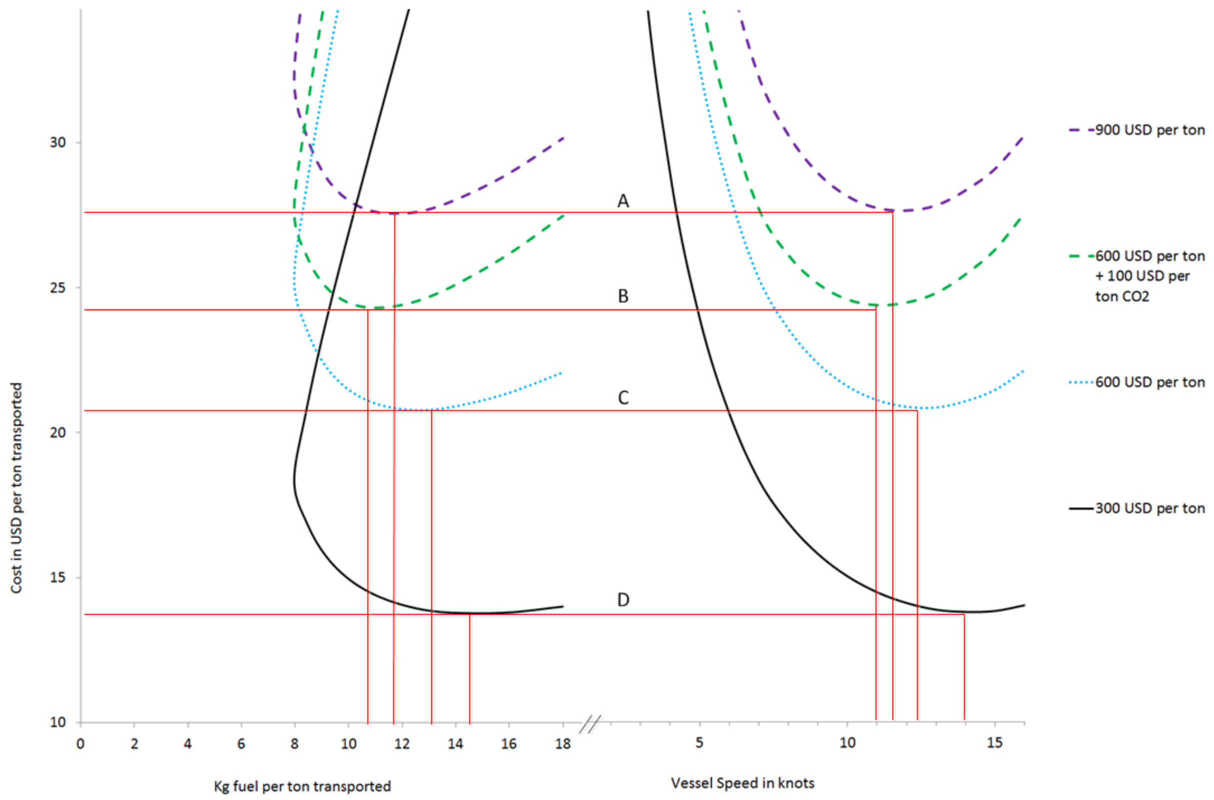

Fig 15: *Fuel and cost per ton transported as a function of speed and fuel and carbon price*

Going one step further, we analyse the potential to reduce carbon emissions through more slender vessels, through larger vessels and the combined effect of all these three responses. Fig. 16 estimates the potential cost saving through more slender vessels, through larger vessels and the relationship between these measures and the speed.

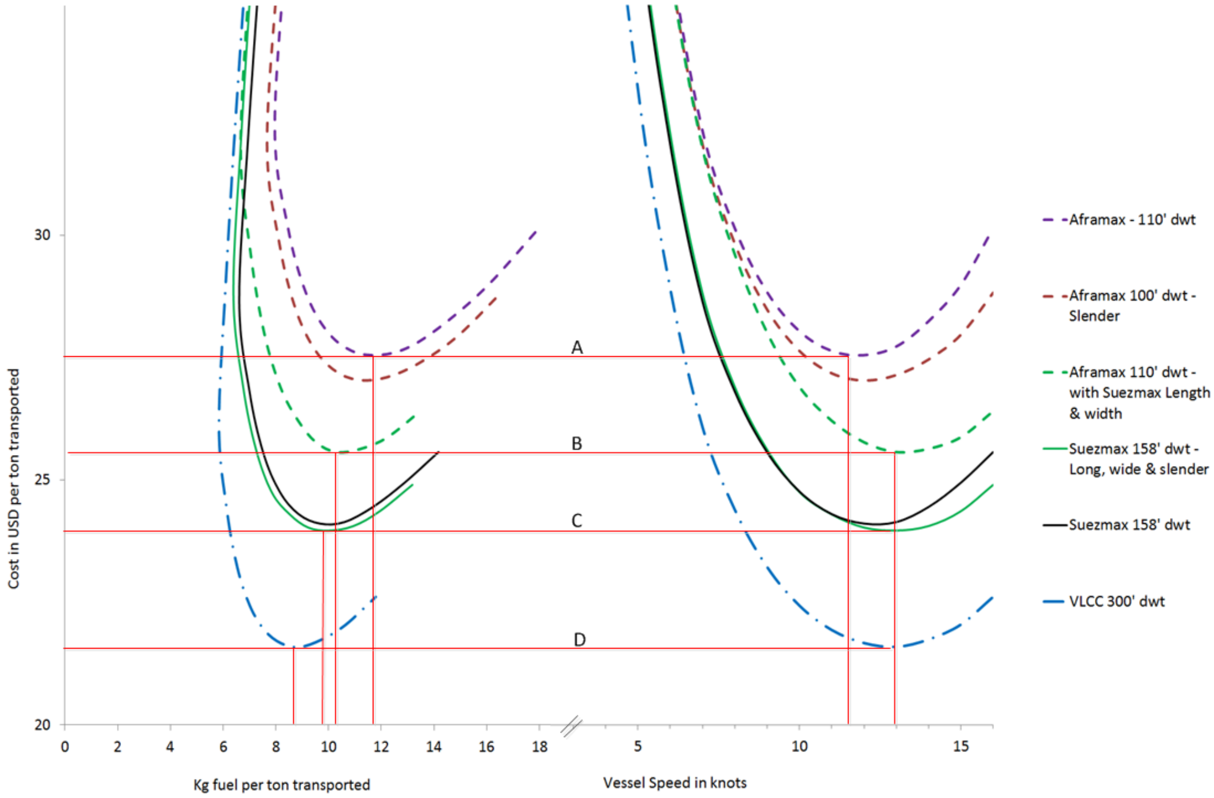

Fig 16: *Fuel and cost per ton transported as a function of speed and vessel size and design (Fuel price = 900 USD per ton)*

Our results indicate: First, the current operational speed of the crude oil tankers – having fallen over the years with higher oil prices - is in the same range as the cost minimizing speeds at 2012 to 2014's fuel prices (Tristan et al. 2014); Second, introduction of more slender vessels is a cost efficient measure to further reduce emissions; Third, comparing large and slender the advantage of larger vessels is more cost saving; Fourth; when the fuel price increases, the cargo value of the crude increases proportionally and gives a financial encouragement to increase speed, partly counteracting the bunker price rewards to slowing down. Fifth, CO_2 taxes or fees reduce speeds and emissions more than indicated through past oil price movements, since CO2 taxes will not be associated with higher cargo values.

Our results are encouraging: Even though maritime shipping is an emission efficient way of transporting, the potential for further reductions is substantial. One might believe that an activity for which fuel costs are half of total costs would become 25 percent more costly if carbon taxes were raised to the equivalent of raising fuel costs by 50% (100 USD per ton CO2, raising bunker costs from 600 to 900 dollars per ton), but the responsiveness of the sector (only counting slower, larger, more slender) will contain such cost increases, especially as time gives fleet adjustments in addition to the more immediate speed adjustments. Present overcapacity in the fleet due to global slowdown helps contain abatement costs if these opportunities are exploited, but it will also be important to show commitment and patience to benefit maximally from longer term fleet renewal, both in size composition and in slender designs.

The International Maritime Organization (IMO) is debating technical, operational and market-based measures for reducing greenhouse gas releases from shipping, including mandatory Energy Efficiency Design Index (EEDI) and a Ship Energy Efficiency Management Plan (SEEMP). In addition, IMO has been discussing market based measures (MBM) in the form of emissions trading, a fuel levy, or a combination of the two. While the EEDI only will reduce emissions from new vessels (possibly at risks, such as decelerating renewal), the MBM's would have more immediate and broader effect, through such responses as speed, size and slenderness. Emission costs have been indicated at CO_2 price levels of 20 – 50 USD per ton. Our estimates indicate that a CO_2 price level of 100 USD per ton will reduce emissions with 10 % in the short term, more in the long term in line with (Anger et al. 2010) who estimate that CO_2 prices of 50 USD per ton would reduce emissions by approximately 5%.

V.2 Conflict and coordination among environmental problems

Important environmental problems range from local or regional – say health problems from air pollution – to global and intergenerational, such as greenhouse gas emissions or ozone layer depletion. In such a setting, one would envisage a city acting on local air quality with policy instruments that effectively squeeze vehicles and firms for emissions of dust particles, national authorities acting with another type of instruments that squeeze nitrogen oxides and sulfur according to national priorities, and also national authorities acting according to international agreements for public goods that are transnational either as regional issues – Nox and Sox in Northern Europe – or as global intergenerational issues, the example being the Montreal Protocol on protection of the ozone layer or – as will be much of our attention in the current paper – greenhouse gas emissions.

In the following, we use maritime shipping to elucidate some of the opportunities and conflicts associated with such concurrent challenges. An important part of the setting is that greenhouse gases is a global challenge, but limited global coordination makes it likely – or factual – that greenhouse gas mitigation will be lagging, not the least in maritime shipping due to its international features. Ships typically connect ports in different national jurisdictions, and bunker purchase arbitrage represents one among many issues that can make addressing maritime shipping challenging. Nevertheless, port cities will to some extent act to address local environmental problems, and port states or groups of these will act on regional problems, such as NOx emissions.

Traditionally, assessment and regulation of environmental performance of maritime transport and ships in general has been based on fuel consumption converted to amount of carbon dioxide (CO_2), while other trace emissions in the exhaust gas which are small in terms of volume have been ignored. However, it has become increasingly clear that emissions of aerosols (black carbon, or BC) and aerosol precursors (SO_2) from shipping are strong climate forcers (Lauer et. al, 2007; Jacobson, 2010; Bond et al, 2013). Local and regionally motivated current emissions policies provide limits for SOx and NOx (for health and environmental reasons), but not for the global warming effects. NOx and SOx, contrary to intuition, mitigate against global warming (they have a 'cooling' effect) while the unregulated emissions such as BC and CH_4 contribute to global warming. Thus, these locally well motivated policies actually contribute to the warming from shipping emissions. The problem is not that local and regional authorities put pressure on emissions that matter to them, but rather that global pressures on warming agents are missing, not the least in international waters.

In response, IMO supports tightening the emission limits for NOx, SOx and CO_2. First, IMO has defined the coast around North America and the North Sea and the Baltic as Emission Control Areas (ECA) with stricter SOx rules beginning in 2015, i.e. 0.1 %, and globally with stricter Sulphur rules from 2020, i.e. 0.5 %. Second, IMO requires that by 2016, new-built vessels that plan to operate in the North American ECA shall reduce their NOx emissions by 75 %, measured in gram per kWh, compared to the IMO tier II standard for vessels built after 2011.

A consequence currently of requirements from ECAs (North America and Europe), who both seek standards for vessels from 2016 onwards to reduce Sox and NOx emissions, is greater emissions of the warming emissions and reduced emissions of the cooling emissions. Reductions in NOx are to some extent achieved at cost of combustion efficiency, and thus will have a consequence of greater global warming potential in the sum of their emissions. Fig 17, below, compares emissions as they will result from vessels built by ECA standards (left panel) and by IMO guidelines (right panel).

The fuels to be compared are: Heavy Fuel oil (HFO-2.7%) with an allowed maximum Sulphur content up to 3.5 %; Heavy Fuel oil 0.5 % (HFO-0.5%) with sulphur content up to 0.5 %; Light Fuel Oil (LFO) with sulphur content up to 0.1% and Liquefied Natural Gas (LNG).

The reduction of the SOx and NOx through the IMO legislation – both the tighter ones in ECA and the less tight tightening internationally - will change shipping from contributing to climate cooling to instead contributing to warming.

While there is no need to question the reduction in SOx and NOx close to land, sensitive ecosystems and especially dense human populations, it is worthwhile asking if it is possible (and costly) to fulfil the requirements for reducing harmful emissions in ports and coastal areas without giving away the overall cooling effect of maritime shipping.

Fig 17 shows the CO_2 equivalent emissions in kg per ton transported, for fuel and engine setups that comply with Tier 3 requirements in the North American ECA both for a standard engine setup and a hybrid engine setup. Outside ECA, i.e. the Atlantic, also fuels which do not fulfil the IMO regulations after 2020 are included, such as HFO 2.7%.

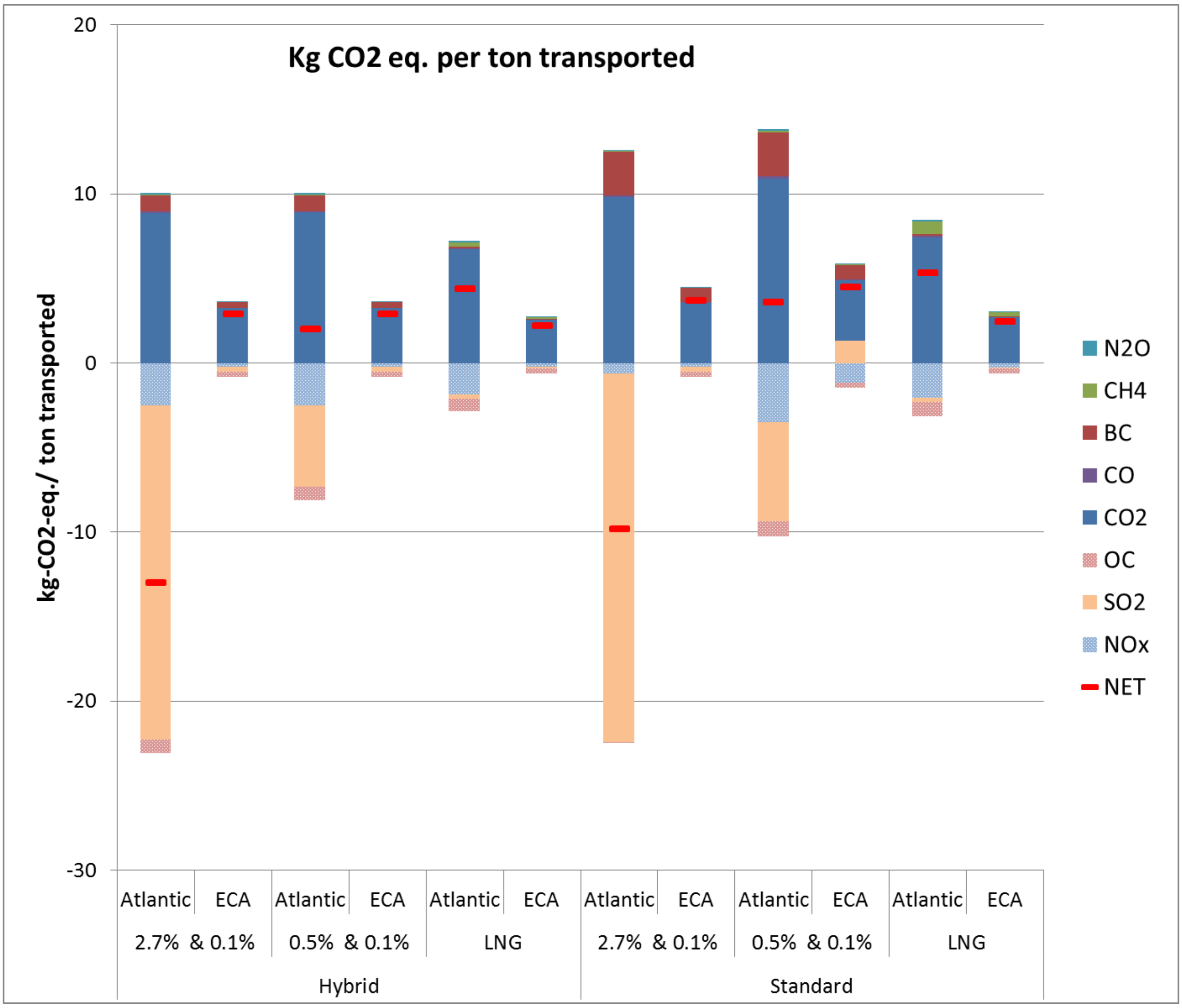

Fig.17: *Emissions in kg CO2 eq. per ton transported based on* GWP_{20}

The main observations are: first that ECA compliance gives higher warming (or less cooling) for all fuels (except LNG, in rare applications); second that hybrid setup gives lower impact for the fuel options allowed after 2020; third, continued use of heavy fuel oil (HFO 2.7% Sulphur) outside but clean fuels inside the ECA will maintain both the cooling effect of shipping and the need for reducing harmful emissions close to land.

Table 6 shows the annual figures for each of these options for trades between Europe's and North America's emission control areas. The estimates are for vessels based on ten roundtrip voyages per year, with typical sailing conditions, according to Smith et al. (2014). The 2015 fuel prices used are HFO 2.7% = 300 USD/ton; HFO 0.5% = 375 USD/ton; LFO 0.1% = 450 USD/ton; LNG = HFO price. In comparison the 2012 – 2014 prices was twice this level.

Table: 6 Key figures for the investigated options

Operation	Fuel	Region	Tier	GWI_{20} per ton trans-ported	Annual kg CO_2 eq.	Fuel in ton per voyage	Annual fuel cost 2015	Cost Increase	Cost saving Hybrid 2015 Fuel price	Cost saving Hybrid 2012-2014 Fuel price
Hybrid	2.7%	Atlantic	Tier 2			156				
	&0.1%	ECA	Tire 3	-10	-2 020 000	54	1 422 000	180 000	129 000	258000
	0.5%	Atlantic	Tire 2			156				
	&0.1%	ECA	Tier 3	5	980 000	54	1 656 000	414 000	155 000	310000
	LNG	Atlantic	Tier 2			156				
		ECA	Tier 3	7	1 320 000	54	1 260 000	18 000	120 000	240000
Standard	2.70%	Atlantic	None			156				
		ECA	None	-17	-3 400 000	51	1 242 000			
	2.7%	Atlantic	Tier 3			173				
	&0.1%	ECA	Tier 3	-6	-1 240 000	57	1 551 000	309 000		
	0.5%	Atlantic	Tier 3			173				
	&0.1%	ECA	Tier 3	8	1 620 000	57	1 811 000	569 000		
	LNG	Atlantic	Tier 3			173				
		ECA	Tier 3	8	1 540 000	57	1 380 000	138 000		

These results indicate: First that hybrid solutions give cost reductions; Second that continued use of HFO 2.7 % in high seas will give a significant cooling even after the warming effect of fulfilling the ECA requirements has been included; Third the 2015 fuel prices cut the hybrid saving potential compared to the 2012 – 2014 fuel price level.

This study have challenged the traditional environmental and regulatory framework for shipping by investigating if it is possible to fulfil the requirements for low emission levels of harmful emissions in ports and in coastal areas without giving away the benefits of lower bunker prices and an overall cooling effect of shipping at high seas.

One incentive to be offered could be that vessels that want to burn heavy fuel oil with high sulphur content in high seas have to install hybrid engines systems or advanced engine control and reporting systems. This could ensure that the dirty fuel is burned only at high seas, and that the vessel complies with SOx and NOx obligations in the ECAs. Such systems, now entirely feasible, would be a great advance in themselves, probably with repercussions into both other shipping segments and other industries, and introducing them via such an incentive thus seems a worth considering. As a more general point, approaches by ECAs as well as national, local and global will benefit from managing environmental problems not only through the characteristics of vessels and fuels, not only through bans and regulations, but also through policies – taxes included – that also influence how vessels are operated, maintained, and used.

The larger picture is that even an activity like maritime shipping – dependent on international movements – will be affected by ports, port states and port states in coordination. The involvement of IMO is important, not the least because it indicates that international coordination will not be absent. This is promising not only because of global problems such as climate change (not the only important example), but also because other problems need understanding and a facilitating hand when an industry is truly transnational.

For global environmental challenges, transport is not an overwhelmingly important issue: only about half a percent of an oil tanker's 'cargo' is consumed in a VLCC shipment from the the Arabian Gulf to the US, so 99,5% of the fuel is consumed at destination, and emits there. Nevertheless, we have shown that potential improvements exist, and so do intervention opportunities. It is possible that the international issues themselves, such as bunker shopping arbitrage, will influence the ease with which tax instruments are important in initiating change the industry. Since ports charge port fees, environmentally differentiated fees are easy entrance steps, but charges that also influence speed, fuel choice are natural extensions. Monitoring and enforcement challenges likely are important, but likely also diminishing both with technology developments and with increasing international coordination, such as through ECAs and IMO.

VI Discussion and concluding remarks.

From the perspective of basic principles, transport is like any other activity, and there is soundness to the idea that such an activity should pay – i.e. should be held responsible – for the costs that it imposes on society. This does not mean that the activity and the sector does not serve society, it simply means that it can serve society best if it economizes not only on its use of machinery, fuel and personnel costs, but also makes efforts at the right level and in the right direction to manage such public goods as air quality locally, greenhouse gas emissions globally, congestion, noise and accidents.

For the four transport modes moving goods and passengers, some big picture statements are that environmental taxes will raise activity-internal costs in patterns that slow transport speeds, increase the exploitation of scale economiesand change the direction of accelerate technological change. Since demand for transport generally if found not to be very price elastic *and* there is generally potential for environmental improvements, we consider these responses more important than a potential reduction in transport intensity in the general economy.

Environmental responsiveness initially will be high but eventually slow down, so there is scope for revenue generation. Revenue neutral reform may thus be a useful frame for policy proposals, at least if an obstacle to environmental taxation otherwise is resistance to raising government revenues.

Cost increases and incidence: households and firms

Environmental policies, such as those to reduce emission of air pollutants and greenhouse gases, will generally carry a cost. Exceptions exist, such as when fuel subsidies are to be removed. More typically though, raising environmental taxes require reference to an objective of environmental improvements, and such analysis and communication is necessary.

There will thus be a cost associated with environmental policies, as when fuels and cars become more expensive both because even cleaner technologies will carry some taxes, and because the cleaner technologies carry a cost themselves. The policies hould therefore be justified by the value of environmental improvements, for instance in terms of improved public health, reduced crop loss, reduced ecosystem damages, etc. We do not explore further the cost benefit analysis here, merely noting that the political economy of reform may require not only that the reform passes the benefit cost test, but also that the benefits are well communicated.

Expenditure patterns From the perspective of optimal taxation, the burden of a policy change will be borne by population groups according to their patterns of consumption expenditures, employment, etc. Net benefits from environmental improvements may be analysed with a similar perspective. Along the consumption expenditure axis, for instance, transport expenditures are typically increasing with income, but more so in a poor country than in a rich country. An illustration will be car ownership which is absent among the poor in poor countries, whereas car ownership can be important to the middle class and even the poor in rich countries, as it is in USA. Poor farmers spend little on transport, and even urban poor in a poor country setting spend little of their resources on transport, including buses, minibuses, mopeds.

For transport of goods and raw material, higher costs of transport through fiscal environmental instruments will have a very small impact on general costs and competitiveness (the share of transport costs in most businesses is small, and transport industry changes in environmental direction will soften if not nullify the cost increases, as our examples illustrate.

Goods transport of course also is important for households, in particular through two links: First, goods and services become costlier through transportation costs in the supply chains, and second some industries become less competitive and offer less income for households if transportation costs rise. For both, these costs will often be found to be small, and the partial equilibrium analysis of what environmental improvements cost directly – not analyzing how they are distribute throughout the economy – will often be found sufficient. Nevertheless, politics are important: many have experienced that truck drivers and taxi drivers can have political clout in certain urban settings.

How are revenues from environmental taxes used: revenue neutral reform

Revenue neutral reform is a suitable benchmark for environmental tax reform, since the purpose of environmental taxes neither is to expand net revenues for government (or need not be), nor is their objective to raise revenue for environmental purposes. The objective of environmental taxes is simply that the efforts made by households and firms to reduce all costs will – in the case of environmental taxes – result in contributions to public goods and environmental protection, since the promise of environmental taxes saved present them with a benefit of doing so.

Often, in practice, environmental taxes are dedicated to some environmental objectives, such as to fund an enforcement or protection agency. This is not advisable in general, but is also not a big problem if the discipline in spending – not spending too much, and executing well – is not thereby being lax or ineffective.

Studies of environmental tax reform generally make some important observations:

- Optimal taxes include environmental taxes only to the extent they are justified by benefits of environmental improvements. A focus on 'double dividends' or 'fiscal improvements' may thus be unhelpful and lead astray.
- Effects of environmental tax reforms depend highly on how the revenues are used: which other taxes are reduced, so one may want to analyse and communicate these
- Highest net benefits result– quite obviously – when proceeds from environmental taxes are used to reduce other tax rates that are particularly distorting, often labor taxes trade tariffs, or capital taxes.
- Subsidies to fossil fuels – while often a puzzle also from narrow perspectives of fiscal soundness, poverty alleviation and efficiency – are strengthened as targets of reform once environmental objectives are taken into account.

While revenue neutral reform is a good benchmark for proposals, it may also prove fruitful to combine reforms. Policies to improve public transport may make environmental taxes that affect car owners and drivers more acceptable, for instance. An example is congestion taxes in Stockholm and London, which were popular and effective in part because congestion was very damaging, but also because significant improvements in public transport were introduced simultaneously. For urban settings in developing countries, since mobility likely is important for productivity and competitiveness (agglomeration), complementary policies like urban transport infrastructure and public transport improvements are likely important.

Political economy

The way distributional issues are dealt with in the public finance tradition of environmental economics is typically via a fairly static notion of incidence: who pays for the environmental improvements either through their consumption patterns and taxes, and who benefits from the reform in terms of improved environmental quality, home values, etc. A major proposition in the literature in political science (Mancur Olson) and political economy (Tullock and Buchanan), namely that concentrated interests have greater policy influence than dispersed interests, could have clear implications for policy: Either to indicate either that environmental problems are poorly addressed (since beneficiaries are many), or that when addressed, they will be inbalanced, rather imposing costs on many small polluters (car owners, home owners) than on more concentrated emitters such as major factory chimneys. Buchanan and Tullock used this perspective to interpret the limited adoption of emission taxes in favor of emission taxes (the latter would be more efficient, but benefiting general tax payers, which are many and dispersed. To our knowledge, there are no definite studies concluding that major emitters are spared emission reduction requirements (or taxes), nor that environmental problems are generally ill addressed. An alternative argument, of course, could be that democratic institutions in modern societies are mechanisms well suited to channel dispersed interests of many into action.

Two additionally important questions, often not addressed in great depth, is which stakeholders are politically influential, and how does the dynamics of reform proceed, for instance in the sense of changing values of existing assets and holdings, relative to assets and positions to be held in the future. It can be the case, for instance, that if environmental improvements in the vehicle fleet is pushed through in a transition mainly through fuel and emission taxes applying to all, then current vehicle owners will suffer losses – since they own long lived assets that are less efficient in converting fuel to transport services. In contrast, a transition strategy relying on new vehicle requirements (emission standards, for instance, or the Norwegian scheme with an emission-differentiated tax scheme for new vehicle registrations) and a gradual increase in emission fees or fuel taxes can be more gentle with existing asset owners, though at a cost of insufficiently changing the use of existing assets.

The role of existing assets, sectoral exposure and trade issues will be important. In maritime shipping, for which assets are more long-lived than in road vehicles, their long remaining lifetime heightens the importance of how existing ships are allocated and used (slower speeds and routing is but one example, maintenance, fuel and engine change are others) in combination with how old ones are phased out and new ones equipped. If global cooperation is weak, efforts that can start nonglobally will often be limited and selective. Still, environmental improvements may start from local objectives in densely populated areas with much maritime transport, focusing on technological change, some locally important trades and strengthening of global cooperation. For road and passenger transport, the need for global cooperation is less restraining, and local issues can be more of a driving force, so again the examples serve to illustrate important features of the real world in the policy analysis.

An important issue for political economy is transition: first because economies are in rapid transition if they observe income growth, sectoral change and urbanization; second because people are affected by policy reform in part through stakes and positions they have with long-lived assets. A list of typical lifetimes of assets – differing by settings of course – cars lasting shorter than vessels and planes, all lasting shorter than housing – tells part of this story.

One interpretation of emission standards for new equipment (vehicles) is that it changes political economy of fuel deprivation (Eskeland Mideksa): If the higher fuel prices that would reduce consumption are resisted by owners of existing cars , then a) those same owners will be in need of less fuel if they have first been pushed into more efficient cars; b) the cost increases (of more efficient cars) are imposed 'only' on those who buy new cars; c) the somewhat higher fuel taxes will meet less resistance over time (rebound can be even less significant). The issue that for durables equipment, only a few need equipment in any given year gives policies addressing new equipment - standards or taxes alike – a slightly unpalatable feature in the case of an industry with competition and potential competition: such policies can increase the costs of expanding and entering the business, thus being attractive to established owners who will see higher net income from their existing assets due to less. Thus, policies that raise the costs only or mostly for new establishments or assets will often meet no resistance from the largest established parties.

Competitiveness and leakage

For local and national public goods, transjurisdictional leakage of pollutants may not be important, and differing environmental policies need not reflect a costly 'race to the bottom' but can be reflection of comparative advantage (air ports in lowpopulation areas with low environmental fees can be an example). For transnational problems, however, leakage of emissons – and of jobs – will be important concerns in formation of environmental policy. Examples here can be that to Europe, it is unattractive politically to take steps that remove jobs and GHG emissions if the consequence is not global emission reductions but simply transfer of emissions. This clearly influences Europe either to be discouraged from emission reductions or to modify policies towards sectors with less leakage – domestic transport for instance – or to press for globally coordinated policies.

Some particular features in which climate policies in Europe have differed from textbook recommendations of tradable permits and taxes bear traces from concerns for competitiveness and leakage. As one example, a sector neutral emission tax would be optimal in a closed economy or in a world of global cooperation on climate mitigation. But Europe may be more willing to place costs of mitigation in sectors not subject to carbon leakage – such as energy for buildings and domestic transport and power generation – than to sectors producing energy intensive tradeable goods, such as metals. Thus, when energy intensive tradables retain, for a longer period, an allocation of free quotas, an interpretation is that simply shutting metal smelters down would not give global emission reductions, but simply move emissions overseas. Economists like Hoel, Rosendahl and Sinn have pointed out that under imperfect global cooperation, greenhouse gas mitigation will depart from first best principles. Europe presently pursues greenhouse gas policies not like in the textbook with the emission trading system (ETS) as the only instrument, but in a blend with renewables support, energy efficiency standards, public transport policies, etc. Part of this is seen and should be seen as some sectors protecting their interests more effectively than other, but part of it is also that the textbook is overly simplistic, for instance in not treating seriously the issue of mitigation under nonglobal cooperation.

In an international context, taxation on transport in principle will in principle harm specialization and trade, favoring local sourcing and 'short traveled consumption'. But we have shown that under sensible policies, transportation will typically change quite a lot to become more environmentally friendly, so a rise in transport costs due to environmental taxation will be moderate. In addition, for most goods, transportation costs are a minor cost to the buyer, and not very sensitive to travel distance, since the long hauls are quite effective. As an example, bringing oil from the Arabian Gulf to Houston in a supertanker, you burn less than half a percent of the cargo (not the cargo, of course), so the total cost of that haul (including the vessel hire, personnel, etc) will not be more than one percent of the value of the shipment to the buyer. For other goods than oil, the shipping operation is more expensive, but so are cargo values. In short, transportation costs are unlikely to be a threat to the benefits of globalization, and certainly not due to environmental taxation if it is imposed at sensible levels and in sensible ways.

Coordination

Both for transnational regional – ECA in Europe and North America – and for global, policy coordination are important issues. There are important challenges and interactions, and a dimension emphasized in our study is what freedom and tradeoffs exist nationally depending on the level and type of international cooperation. As an example, health, as a local concern, is important in road transport and this can be addressed nationally/locally. Why is it different for maritime shipping, if it is?

As a part of local pollution problems, maritime transport plays a role much more selectively, most maritime activity and fuel combustion is far from people and sensitive ecosystems. Maritime transport is often smaller in a local context – though not in important port cities, such as Bergen, Singapore, Hong Kong. Just as importantly, for most visiting vessels, the specific port city is less important, thus less powerful. Port city action will thus to an important extent be dependent on coordination with other port cities/nations. This leads to some attention to emission control areas (ECA)s and other developments of importance historically, including how IMO plays a role environmental improvements in shipping, and in lending ECA's some powers.

Part of this difficulty is real and substantive beyond of the politics of coordination. It is simply less valuable to reduce emissions of sulfur and particles from a vessel that spends much of its time in international waters or ports, unless it can be done only in coastal waters and in ports. Depending on abilities in monitoring and enforcement, ships may be exposed to environmental taxes according to where they are, and solutions such as cleaner fuels, equipment, port electrification may be realized.

A part which is clearly political and challenged by the extent of global cooperation is greenhouse gas mitigation, and in particular the part which is accomplished through fuel or emission taxes: slower speeds and a gradual restructuring towards more emission efficient vessels (size, slenderness, for instance). Could a country or a region impose carbon taxes on vessels coming and going, in the way tried in Europe for aviation? It would involve monitoring and enforcement challenges (where did you bunker, what did you pay), it would be challenged on trade policy grounds. It is easily argued that if fuel taxes are introduced from port states before global cooperation in the issue, it will first be based on local environmental benefit. But the world has seen before environmental policies for vessels that start in certain areas before they expand in regional coverage.

Annex

Anger, A. Barker, T. Pollitt, H. Lindstad, H. Lee D. and Eyring, V. (2010). *International Shipping and Market Based Instruments*. IMO - International Maritime Organization. London.

Assman, L et al. 2014. Missing in Action: Slow-steaming in maritime shipping.

Borken-Kleefeld J, Fuglestvedt J, Berntsen T (2013): Mode, Load, And Specific

Climate Impact from Passenger Trips. Environmental Science & Technology 47: 7608-

7614.

Buhaug, Ø.; Corbett, J.J.; Endresen, Ø.; Eyring, V.; Faber, J.; Hanayama, S.; Lee, D.S.; Lee, D.; Lindstad, H.; Markowska, A.Z.; Mjelde, A.; Nelissen, D.; Nilsen, J.; Pålsson, C.; Winebrake, J.J.; Wu, W.–Q.; Yoshida, K., 2009. *Second IMO GHG study 2009.* International Maritime Organization, London, UK, April

Corbett, J, J. Wang, H, Winebrake, J, J. 2009. *The effectiveness and cost of speed reductions on emissions from international shipping.* Transportation Research D, 14 (2009), Page 593-598.

Cullinane, K., Khanna, M. 2000. *Economies of scale in large containerships: Optimal size and geographical implications*. Journal of Transport Geography, 8 (3), Page 181-195.

CUTR, 2008. Exploration of a shift in household transportation spending from vehicles to public transport. National center for transit research, 2008, Center for urban transportation research, University of South Florida, Tampa.

Davis, L. . W. 2008. The Effect of Driving Restrictions on Air Quality in Mexico City *Journal of Political Economy*, Vol. 116, No. 1 (February 2008), pp. 38-81

Energy Efficiency Indicators Fundamental on Statistics. 2014. OECS and IEA. www.iea.org

Eskeland, G. S. 1994. A Presumptive Pigovian Tax on Gasoline: Complementing Regulation to Mimic and Emission Fee. World Bank Economic Review.

Eskeland, G. and Feyzioglu, T. 1997. Rationing Can BackfireL The 'Day without a Car' in Mexico City. World Bank Economic Review, v 11, no 3, 383-408.

Figenbaum and Eskeland, et al. 85g.

Eskeland and Devarajan. Taxing Bads by Taxing Goods: Emission Reductions with Presumptive Charges. World Bank, 1996.

Eskeland, 2012. Which emissions are ours: electrification of road transport in Norway. Samfunnsøkonomen, Norwegian. Eskeland and Devarajan, 1996.

Eskeland and Mideksa, 2007. Emissions standards and fuel taxes. World Bank Policy Research Working Paper.

Eskeland and Lal, S. A Crowded City: Urban Development and Mobility.

Faltinsen, O., M. Minsaas, K, J. Liapis, N. Skjørdal, S, O. 1980, *Prediction of Resistance and Propulsion of a Ship in a Seaway*. In Proceeding of 13th Symposium on Naval Hydrodynamics, Tokyo, the Shipbuilding Research Association of Japan, 1980, Page 505-529

Faltinsen, O.F. 1990. *Sea Loads of Ships and Offshore Structures*. Cambridge University Press.

Goulder, Williams, Parry, Burtraw: incidence of environmental policies, transp in particular, to be included in January.

Holtrop, Mennen, 1984. *A statistical re-analysis of resistance and propulsion data.* ISP, Vol. 31, No. 363, November 1984.

Jonkeren, Olaf, Jos van Ommeren, and Piet Rietveld, 2012. Freight prices, fuel prices, and speed. Journal of Transport Economics and Policy, V 46, Part 2. Pp 175-188.

Kolstad, Charles. Environmental Economics. 2009. Oxford.

Kristensen. H.,O.,H., Lutzen, M. 2012. *Existing Design Trends for Tankers and Bulk Carriers – Design Changes for Improvement of the EEDI in the Future.* Conference proceedings at International Marine Design Conference –IMDC, Glasgow, United Kingdom. 2012

Kumar, S. Hoffman, J., 2002, *Globalisation the Maritime Nexus*. In Grammenos, C.T. (editor): The Handbook of Maritime Economics and business. Page 35-64, LLP ISBN 1-84311-195-0

Larson, L., Raven, H., C., 2010. *The Principles of Naval Architecture Series: Ship Resistance and Flow.* SNAME 2010, ISBN 978-0-939773-76-3

Lewis E.D, 1988. *Principles of Naval Architecture, Vol. II.* The Society of Naval Architects and Marine Engineers, ISBN 0-939773-01-5

Lindstad, H. Asbjørnslett, B., E., Strømman, A., H., 2011. *Reductions in greenhouse gas emissions and cost by shipping at lower speed.* Energy Policy 39 (2011), Page 3456-3464.

Lindstad, H. Asbjørnslett, B. E., Strømman, A., H., 2012, *The Importance of economies of scale for reductions in greenhouse gas emissions from shipping.* Energy Policy 46 (2012), Page 386-398.

Lindstad, H., Asbjørnslett, B., E. Pedersen, J., T. 2012, *Green Maritime Logistics and Sustainability*. In Song D., W, Panayides, P., M. (Eds.) Maritime Logistics: Contemporary Issues (2012), Page 227 – 243, Emerald, ISBN 978-1-78052-340-8.

Lindstad, H. Asbjørnslett, B., E., Jullumstrø, E., 2013. *Assessment of profit, cost and emissions by varying speed as a function of sea conditions and freight market*. Transportation Research Part D 19 (2013), Page 5-12.

Lindstad, H., Jullumstrø, E., Sandass, 2013a. *Reduction in cost and emissions with new bulk ships designed enabled by the Panama Canal expansion*. Energy Policy 59 (2013), Page 341–349.

Lindstad, H., Steen, S., Sandass, I. 2014. *Assessment of profit, cost, and emissions for slender bulk vessel designs*. Transportation Research Part D 29(2014) 32-39

Lindstad, H, 2013. *Assessment of Bulk designs Enabled by the Panama Canal expansion*. SNAME Annual meeting, Conference Proceedings. Seattle, Nov 2013. Selected for inclusion in the 2013 volume of the SNAME Annual Transactions

Lindstad, H., Eskeland. G., Psaraftis, H., Sandaas, I., Strømman, A., H., 2015 *Maritime Shipping and Emissions: A three-layered, damage based approach.* Submitted to Ocean Engineering

Lindstad, H., Eskeland. G., S., 2015 *Low carbon maritime transport: A synthetic inquiry into capital energy substitution.* Submitted to Transportation Research Part D

Lloyd, A., R., J., M. 1988. *Seakeeping, Ship Behaviour in Rough Weather***,** 1998, ISBN 0-9532634-0-1

Notteboom, T.E., Vernimmen, B., 2009. *The effect of high fuel liner service configuration in container shipping*. Journal of Transport Geography 17 (2009), Page 325–337.

Parry, Ian and D. Heine, E. Lis, and S. Li. 2014. Getting Energy Prices Right. From Principle to Practice. IMF, Washington, DC.

Parry. Is the US or Europe getting gasoline taxes about right?

Psaraftis, H, N. Kontovas, C, A. 2010. *Balancing the economic and environmental performance of maritime transport.* Transportation Research Part D 15 (2010). Page 458-462.

Psaraftis and Kontovas, also Speed models for energy-efficient maritime transportation: A taxonomy and a survey. Transp. Res. Part C, 26 (2013), pp. 331–351

Resolution *MEPC.203 (62),* www.imo.org

Russell, B., A., Wang, H., Zeinali, M. 2010. *Marginal Abatement Costs of CO_2 Emissions Reduction and Market-Based Mechanisms and the Pricing of Credits*.

www.corporateclimate.net/green-transportation-climate/logistics-supply-chain/74-cost-for-a-ship-to-reduce-co2-emissions-or-increase-efficiency.html

Sea at Risk and CE Delft, 2010. *Going Slow to Reduce Emissions,* www.seas-at-risk.org

Silverleaf, A., Dawson, J., 1966. *Hydrodynamic design of merchant ships for high speed operation*. Summer meeting in Germany 12th – 16th of June, 1966. The Schiffbautechnische Gescaft E.V, The institute of marine engineers, The institute of engineers and shipbuilders in Scotland, The North East Coast Institution of Engineers and shipbuilders, The Royal institution of naval architects.

Stott, P., Wright, P., 2011. *Opportunities for improved efficiency and reduced CO2 emissions in dry bulk shipping stemming from the relaxation of the Panamax beam constraint*. Trans RINA, Vol. 153. Part A4, Intl J Maritime Eng. 2011

Sys, C., Blauwens, G., Omey, E., Van de Voorde, E., Witlox, F., 2008. *In Search of the Link between Ship Size and Operations.* Transportation Planning and Technology, August 2008. Vol. 31, No. 4 pages 435 – 463

Thune Larsen, H. et al. 2009. Energy efficiency improvements and CO2 emissions for domestic transport in Norway, 1994-2050. TOI Report 1047, TOI.no.

Samuelson, Paul A. (1954), The Theory of Public Expenditure, in: Review of Economics and Statistics 36, pp. 386–389.

Van der Boom, 2010. Ship *Performance Analysis on Full Scale,* Workshop NMRI-MARIN June 24, 2010 http://www.marin.nl

Annex table: EIA: share of domestic transport in total domestic energy consumption.

Anger, A. Barker, T. Pollitt, H. Lindstad, H. Lee D. and Eyring, V. (2010). *International Shipping and Market Based Instruments*. IMO - International Maritime Organization. London.

Assman, L et al. 2014. Missing in Action: Slow-steaming in maritime shipping.

Borken-Kleefeld J, Fuglestvedt J, Berntsen T (2013): Mode, Load, And Specific Climate Impact from Passenger Trips. Environmental Science & Technology 47: 7608-7614.

Buhaug, Ø.; Corbett, J.J.; Endresen, Ø.; Eyring, V.; Faber, J.; Hanayama, S.; Lee, D.S.; Lee, D.; Lindstad, H.; Markowska, A.Z.; Mjelde, A.; Nelissen, D.; Nilsen, J.; Pålsson, C.; Winebrake, J.J.; Wu, W.–Q.; Yoshida, K., 2009. *Second IMO GHG study 2009.* International Maritime Organization, London, UK, April

Corbett, J, J. Wang, H, Winebrake, J, J. 2009. *The effectiveness and cost of speed reductions on emissions from international shipping.* Transportation Research D, 14 (2009), Page 593-598.

Cullinane, K., Khanna, M. 2000. *Economies of scale in large containerships: Optimal size and geographical implications*. Journal of Transport Geography, 8 (3), Page 181-195.

CUTR, 2008. Exploration of a shift in household transportation spending from vehicles to public transport. National center for transit research, 2008, Center for urban transportation research, University of South Florida, Tampa.

Eskeland, G. S. 1994. A Presumptive Pigovian Tax on Gasoline: Complementing Regulation to Mimic and Emission Fee. World Bank Economic Review.

Eskeland, G. and Feyzioglu, T. 1997. Rationing Can BackfireL The 'Day without a Car' in Mexico City. World Bank Economic Review, v 11, no 3, 383-408.

Figenbaum and Eskeland, et al. 85g.

Eskeland and Devarajan. Taxing Bads by Taxing Goods: Emission Reductions with Presumptive Charges. World Bank, 199x.

Eskeland, 2012. Which emissions are ours: electrification of road transport in Norway. Samfunnsøkonomen, Norwegian. Eskeland and Devarajan, 1996.

Eskeland and Mideksa, 200x. Emissions standards and fuel taxes. World Bank Policy Research Working Paper.

Eskeland and Lal, S. A Crowded City: Urban Development and Mobility.

Faltinsen, O., M. Minsaas, K, J. Liapis, N. Skjørdal, S, O. 1980, *Prediction of Resistance and Propulsion of a Ship in a Seaway*. In Proceeding of 13th Symposium on Naval Hydrodynamics, Tokyo, the Shipbuilding Research Association of Japan, 1980, Page 505-529

Faltinsen, O.F. 1990. *Sea Loads of Ships and Offshore Structures*. Cambridge University Press.

Goulder, Williams, Parry, Burtraw: incidence of environmental policies, transp in particular, to be included in January.

Holtrop, Mennen, 1984. *A statistical re-analysis of resistance and propulsion data.* ISP, Vol. 31, No. 363, November 1984.

Jonkeren, Olaf, Jos van Ommeren, and Piet Rietveld, 2012. Freight prices, fuel prices, and speed. Journal of Transport Economics and Policy, V 46, Part 2. Pp 175-188.

Jones, B., Keen, M. & Strand, J. 2013. Fiscal Implications of Climate Change. *International Tax Public Finance Vol.20*, 29-70

Keen, M., Parry, I. & Strand, J. (2013). Planes, Ships and Taxes: Charging for International Aviation and Maritime Emissions, *Economic Policy Vol. 28(76)*, 701-749.

Kolstad, Charles. Environmental Economics. 2009. Oxford.

Kopits, E. & Cropper, M. 2008. Why Have Traffic Fatalities Declined in Industrialized Countries? Implications for Pedestrians and Vehicle Occupants. *Journal of Transport Economics and Policy Vil. 42(1),* 129-154.

Kristensen. H.,O.,H., Lutzen, M. 2012. *Existing Design Trends for Tankers and Bulk Carriers – Design Changes for Improvement of the EEDI in the Future.* Conference proceedings at International Marine Design Conference –IMDC, Glasgow, United Kingdom. 2012

Larson, L., Raven, H., C., 2010. *The Principles of Naval Architecture Series: Ship Resistance and Flow.* SNAME 2010, ISBN 978-0-939773-76-3

Leape, J. 2006. The London Congestion Charge. *Journal of Economic Perspectives Vol.20 (4), 157-176.*

Lewis E.D, 1988. *Principles of Naval Architecture, Vol. II.* The Society of Naval Architects and Marine Engineers, ISBN 0-939773-01-5

Lindstad, H. Asbjørnslett, B., E., Strømman, A., H., 2011. *Reductions in greenhouse gas emissions and cost by shipping at lower speed.* Energy Policy 39 (2011), Page 3456-3464.

Lindstad, H. Asbjørnslett, B. E., Strømman, A., H., 2012, *The Importance of economies of scale for reductions in greenhouse gas emissions from shipping.* Energy Policy 46 (2012), Page 386-398.

Lindstad, H., Asbjørnslett, B., E. Pedersen, J., T. 2012, *Green Maritime Logistics and Sustainability*. In Song D., W, Panayides, P., M. (Eds.) Maritime Logistics: Contemporary Issues (2012), Page 227 – 243, Emerald, ISBN 978-1-78052-340-8.

Lindstad, H. Asbjørnslett, B., E., Jullumstrø, E., 2013. *Assessment of profit, cost and emissions by varying speed as a function of sea conditions and freight market*. Transportation Research Part D 19 (2013), Page 5-12.

Lindstad, H., Jullumstrø, E., Sandass, 2013a. *Reduction in cost and emissions with new bulk ships designed enabled by the Panama Canal expansion*. Energy Policy 59 (2013), Page 341–349.

Lindstad, H., Steen, S., Sandass, I. 2014. *Assessment of profit, cost, and emissions for slender bulk vessel designs*. Transportation Research Part D 29(2014) 32-39

Lindstad, H, 2013. *Assessment of Bulk designs Enabled by the Panama Canal expansion*. SNAME Annual meeting, Conference Proceedings. Seattle, Nov 2013. Selected for inclusion in the 2013 volume of the SNAME Annual Transactions

Lindstad, H., Eskeland, G.S., Psaraftis, H., Sandaas, I. & Strømman, A.H. Emissions from Maritime Shipping: A three-layered, damage based approach. Working Paper.

Lloyd, A., R., J., M. 1988. *Seakeeping, Ship Behaviour in Rough Weather***,** 1998, ISBN 0-9532634-0-1

Lucas, L. W. 2008. The Effect of Driving Restrictions on Air Quality in Mexico City
Journal of Political Economy, Vol. 116, No. 1 (February 2008), pp. 38-81

Notteboom, T.E., Vernimmen, B., 2009. *The effect of high fuel liner service configuration in container shipping*. Journal of Transport Geography 17 (2009), Page 325–337.

Parry, I.W.H. & D. Heine, E. Lis, and S. Li. 2014. Getting Energy Prices Right. From Principle to Practice. IMF, Washington, DC.

Parry, I.W.H 2012. Reforming the tax system to promote environmental objectives: An application to Mauritius. *Ecological Economics 77*, 103-112.

Parr, I.W.H. & Strand, J. 2011. International Fuel Tax Assessment: An Application to Chile. *IMF Working Paper 11/168*

Parry. Is the US or Europe getting gasoline taxes about right?

Psaraftis, H, N. Kontovas, C, A. 2010. *Balancing the economic and environmental performance*
of maritime transport. Transportation Research Part D 15 (2010). Page 458-462.

Psaraftis and Kontovas, also Speed models for energy-efficient maritime transportation: A taxonomy and a survey. Elsevier, 2012 (edited volume? http://dx.doi.10.1016/j.trc.2012.09.012.

H.N. Psaraftis, C.A. Kontovas **Speed models for energy-efficient maritime transportation: a taxonomy and survey** Transp. Res. Part C, 26 (2013), pp. 331–351

Resolution *MEPC.203 (62),* www.imo.org

Russell, B., A., Wang, H., Zeinali, M. 2010. *Marginal Abatement Costs of CO_2 Emissions Reduction and Market-Based Mechanisms and the Pricing of Credits*. www.corporateclimate.net/green-transportation-climate/logistics-supply-chain/74-cost-for-a-ship-to-reduce-co2-emissions-or-increase-efficiency.html

Sea at Risk and CE Delft, 2010. *Going Slow to Reduce Emissions,* www.seas-at-risk.org

Silverleaf, A., Dawson, J., 1966. *Hydrodynamic design of merchant ships for high speed operation*. Summer meeting in Germany 12th – 16th of June, 1966. The Schiffbautechnische Gescaft E.V, The institute of marine engineers, The institute of engineers and shipbuilders in Scotland, The North East Coast Institution of Engineers and shipbuilders, The Royal institution of naval architects.

Small, A. K. 2011. *Energy Policies for Passenger Motor Vehicles,* Working Papers 101108, University of California-Irvine, Department of Economics.

Small, K.A., & Van Dender, K. 2007. Long Run Trends in Transport Demand, Fuel Price Elasticities and Implications of the Oil Outlook for Transport Policy. *Discussion Paper No. 2007-16, Joint Transport Research Centre.*

Small, K.A., 2007. Urban Transportation Policy: A Guide and Road Map. *University of California at Irvine, Working Paper.*

Stott, P., Wright, P., 2011. *Opportunities for improved efficiency and reduced CO2 emissions in dry bulk shipping stemming from the relaxation of the Panamax beam constraint*. Trans RINA, Vol. 153. Part A4, Intl J Maritime Eng. 2011

Sys, C., Blauwens, G., Omey, E., Van de Voorde, E., Witlox, F., 2008. *In Search of the Link between Ship Size and Operations.* Transportation Planning and Technology, August 2008. Vol. 31, No. 4 pages 435 – 463
Thune Larsen, H. et al. 2009. Energy efficiency improvements and CO2 emissions for domestic transport in Norway, 1994-2050. TOI Report 1047, TOI.no.

Samuelson, Paul A. (1954), The Theory of Public Expenditure, in: Review of Economics and Statistics 36, pp. 386–389.

Van der Boom, 2010. Ship *Performance Analysis on Full Scale,* Workshop NMRI-MARIN June 24, 2010 http://www.marin.nl