Oil Tanker Flows Involving the UK to 2050: A Delphi Survey

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Abstract

Predictions of shipping flows underpin forecasts of their likely environmental impacts, and policy debates to develop technologies and operational strategies to manage and regulate emissions. This paper aims to analyse patterns of oil tanker flows involving the UK and by synthesising experts' opinions, to forecast flows to 2050 for this ship type which generates the highest volume of carbon dioxide emissions. Changing import and export requirements define patterns of crude oil and oil product flows which determine port interfaces. Drivers of future shipping flows include economic growth, market changes, haul lengths and energy demands identified in trade press articles which fashioned a Delphi instrument to build consensus regarding future market trends. A panel of 35 experts with long term industrial commitments was recruited to study expert perceptions of likely trends and flows. Market volatility, legislative uncertainty and behavioural change contribute to conservative estimates but invite spatial analysis of flows forecasts and interlinking of flows and their impacts within a holistic systems model.

Keywords: Wet bulk shipping, Delphi study, long term forecasts, UK oil tanker flows

1. Introduction

This paper aims to analyse patterns of oil tanker flows involving the UK and by synthesising experts' opinions, to forecast flows to 2050 for this ship type which generates the highest volumes of carbon dioxide emissions (Buhaug et al., 2009). The demand for shipping crude oil and oil products derives from macro-economic demands for shipping which fluctuate with global economic activity and the dynamic role of shipping in moving raw materials, semi-processed or finished products in fluctuating supply chains (Stopford, 2009). Further, because measures of shipping demand combine tonnage lifted (t) and distance hauled (km), changes in both affect demand in tonne-kilometres (tkm) creating equifinalities. Apparent tkm reductions may reflect reducing oil intensities, shorter hauls arising from localised sourcing or rerouting via upgraded canals. Regional surpluses and deficits of crude oil create tanker loading and discharging areas which determine global spatial flows with Europe, the US and SE, E. and S. Asia in deficit, and the Middle East Gulf (MEG), Former Soviet Union, N and W Africa, Central and S. America and Canada in surplus. Tanker flows remain concentrated but increasing ship sizes have necessitated more offshore terminal developments of loading and discharging facilities. In the North Sea, offshore oil production has generated offshore transfers from production vessels or an undersea oil production facility. Near urban areas atmospheric emissions may influence decisions to establish Emissions Control Areas (ECA; IMO, 2012). After reviewing published flows involving the UK, drivers of markets and haul lengths and some published forecasts, the methodology of a Delphi survey to predict likely trends in flows to 2050 is reported and findings are discussed. Discussion highlights volatility, and legislative and behavioural uncertainties, which explain experts' conservative predictions but invite holistic systems research.

2. Oil Flows Involving the UK and Future Drivers

2.1 Current UK Oil Flows

Published UK maritime commodity flow data is limited and secondary statistics are often incomparable (Glen and Marlow, 2009). Subject to inevitable measurement errors (Dinwoodie and Bhatia, 2004), global flow data emanate from official (e.g. EC, 2008) and private sources including BP's Statistical Review and Energy Outlook (www.bp.com), Exxon Mobil's Outlook for Energy (www.exxonmobil.com) and Shell's Energy Scenarios (www.shell.com), as do national data (e.g. EIA, 2011; DfT, 2009; Dukes, 2009; MDS Transmodal Limited, 2007). In addition aggregate trade flow data is available but changing classifications may frustrate serial commodity comparisons, where for example official UK oil products flow data incorporated liquefied gas until 2000 (DfT, 2009). Aggregations of spatial units vary, commodity sourcing policies are volatile and political changes redefine trading boundaries perhaps as new states accede to the EUs. Data collated for Great Britain (GB; MDS Transmodal Limited, 2007) differs from the UK (e.g. DECC, 2009) principally excluding Northern Ireland which receives one-fifth of UK arriving tanker dwt (Dft, 2009, table 3.6). Port commodity arrivals data which typically fails to identify transhipment flows or an ultimate source or destination further hampers flow reporting and thwarts end-to-end supply chains mapping.

Demand for tankers originating in, destined for, or visiting UK ports varies with the UK supply and demand for crude oil and products. UK crude oil imports peaked in 1973, before declining as North Sea production transformed the UK into a net exporter. By 2010, the UK was again a net importer as Norway supplied 72% and other sources were spatially volatile, including some insignificant MEG supplies (Dukes, 2011). Norway exported 40Mt of crude to the UK in 2004, 60% via the Ekofisk pipeline to Teeside refineries. As Hubbert production-reserve curves predict rapidly diminishing Norwegian production (Al-Husseini, 2009) UK piped imports will reduce at 10% compound annual rates (CAR; MDS Transmodal, 2007). A disconnect between UK production of light high value North Sea oil and UK oil refineries and oil burning power stations designed for heavier MEG oil resulted in simultaneous imports of heavy oil and exports of North Sea production. After peaking in 2001, UK crude oil exports plummeted as North Sea production declined with 40% US market shares reducing to 18% by 2010, the Netherlands' share doubling to 38% and the EU consuming 78%. Eventually UK flows to Europe will decline as North Sea production diminishes. As UK refineries age, UK crude imports will reduce and as new long range products tankers transport supplies from modern refineries in producing countries, UK products imports, LNG and biofuels will rise.

Oil tanker movements vary with combined domestic and international throughputs of inbound and outbound flows of crude oil and oil products through ports. Major UK ports handling inbound flows of crude include deepwater ports typically proximate to oil refineries, at Milford Haven, Southampton, Liverpool, Grimsby and Immingham, Hull and Humber rivers, London and Clyde. Unsurprisingly, major outbound flows emanate from North Sea oil ports of Forth, Tees and Hartlepool, Sullom Voe and Orkney, often distant from urban areas. The distribution of ports which handle major oil products reveals outflows dependant on the location of refining capacity including Milford Haven, Southampton, Grimsby and Immingham and Forth ports. Major inflows are to London, Grimsby and Immingham, Southampton, Milford Haven and reducing numbers of smaller regional distribution centres which host tank farms to replenish road tanker distribution systems. Policy changes to tax oil ex-refinery rather than ex-distribution centre coupled with scale economies which favour larger coastal tanker fleets closed many smaller port facilities and increased mean road haul lengths.

2.2 Some Drivers of Markets and Haul Lengths

Debateable published drivers of future tanker demand invite evaluation via research strategies such as canvassing experts to build consensus to supplement forecasts based on scenarios of future developments, extrapolation of past trends and analysis of historical patterns (Stopford, 2009). Delphi techniques facilitate remote communication between experts who are recruited to represent key viewpoints (Linstone and Turoff, 1975) typically following literature reviews to generate sets of initial statements. Panellists' evaluations of statements and their responses are iteratively fed back until consensus emerges. Reviews in this study identified numerous drivers of maritime tanker demand which were reduced to eight (D1…D8) for evaluation, to prevent information overload on experts. They span demand estimates (D1) which vary *inter alia* with demand for total freight transport, dependant on: population and Gross Domestic Product (GDP) growth, production and location decisions; sensitivity to shipping costs including bunker prices (D2) which influence routing (D3) and maritime mode shares (D4); sourcing policies; and haul lengths (D5-D8; Stopford, 2009).

Oil tanker movements vary with the supply and demand for crude oil and oil products, dependant on demand for transport, traditionally related to GDP. All scenarios predict global oil demand peaks with timing varying from Shell's *Scramble* scenario in which climate shocks necessitate oil substitution post-2020 to ExxonMobil's forecast (op. cit.) of no oil demand decline pre-2040, as GDP growth in developing countries exceeds 240% of European rates. Longer term forecasts predict reducing European GDP growth and energy consumption and EU demand for freight transport decoupling from GDP growth as economies dematerialise. European oil production will decline (EC, 2008; EIA, 2011). Forecasts of increasing UK real GDP growth (OBR, 2011) exceed earlier estimates but UK oil demand to 2030 will reflect declining energy intensities. Hammer (2009) observed that global oil tanker tonnage in 2008 was unchanged since 1978 but will this continue (D1a, D1b)? Changes in oil intensity, which has halved in industrial nations in 30 years, are debateable (D1c, D1d; Osler 2010), as are estimates of differential population and regional economic growth, but too many questions would overload experts. Estimates of the long and short run impacts of bunker price changes on maritime freight rates (D2a, D2b) underpin maritime policy. Given that shipping costs comprise small proportions of crude oil import values, worldwide demand for maritime transportation of oil and freight rates have been relatively inelastic to bunker price changes (UNCTAD, 2010). Similarly any potential to cut shipping emissions using market-based reduction measures including bunker levies depends on freight rate to bunker price elasticities, which if high, would favour local sourcing, pipeline transportation and reduced demand for maritime transportation.

Perceptions of how particular developments will affect total demand are crucial. As global warming heightens drought risks, will more tankers be deployed as water carriers (D3a; Hammer, 2009)? Similarly, how will shorter sea routes arising from Arctic ice-melt (D3b, D3c; Ho, 2011), or an enlarged Panama Canal (D3d, D3e; Stott and Wright, 2012) impact tanker tkm? How will new Energy Efficiency Design Index (EEDI; IMO, 2012; MEPC.1/Circ.681) ship design regulations to encourage improvements in new ship fuel consumption affect demand (D3f, D3g) or rising demand for new fuels including LNG and nuclear power (D3h, D3i)? How will pipeline investments impact oil import mode splits as more pipelines link Canadian tar sands with the US (D4a, D4b), Russian and MEG oilfields with Europe (D4c, D4d), and MEG and Russian oilfields with China (D4e, D4f; Hammer, 2009)? If rising bunker costs induce localised or regionalised oil sourcing with shortened supply chains, global average maritime haul lengths will reduce (D5a; Hammer, 2009). Regulation of the type of fuel that ships may consume in particular areas and undefined future ECA designations may promulgate ship re-routing to avoid them (D5b, D5c; IMO, 2012). To reduce carbon emissions, an Energy Efficiency Operational Index for ships in operation or Ship Energy Efficiency Management Plan which incorporates best practice relating to voyage planning, optimal speed, power and handling, cargo handling and fleet and energy management imply shorter hauls to reduce tkm (D5d, D5e; IMO, 2012). However, multi-sourcing strategies to ensure secure energy supplies may impact haul lengths (D5f). Perceptions of changing specific average haul lengths might usefully span the effects of Arctic ice-melt in creating Northwest (N.W.) and Northeast (N.E.) passages on N.E.Asia-W.Europe routes (D6a, D6b; Ho, 2010) or an enlarged Panama Canal on N.E. Asia-USEC routes (D6c, D6d; Stott and Wright, 2012). Conversely, if droughts induced by global warming create more failed states and foster piracy, suboptimal routing to avoid trouble spots may lengthen maritime hauls (D6e; Osler, 2010).

2.3 Forecast UK Demand

Oil products tanker movements involving the UK depend on demand for various oil products, the capacity and location of refineries, export demand and the availability of other modes such as pipeline networks. In 2010, UK consumption of oil products comprised mainly transport fuel including petroleum and increasingly diesel by road users, dependent on car ownership levels and use; kerosene for air travel; and some heating kerosene (Dukes, 2011). Pre-recession, MDS Transmodal (2007) predicted 2% less demand for oil products by 2030, which drives demand for crude oil flows. Fixed UK refining capacity specialised in gasoline production, reducing domestic demand, constant gasoline exports and rising domestic demand for aviation fuel were expected. Outward flows of GB oil products to 2030 were expected to flat-line for exports, mainly to North America and Europe, as were domestic flows outwards and inwards. Imports, principally transhipments from Rotterdam or aviation fuel from the Middle East, would rise 7% to 2020 before stabilising (MDS Transmodal, 2007). With recession however, 2010 outturn import and exports were 5Mtpa below expectations (Dukes, 2011).

Predicted rapid reductions in North Sea oil production will diminish GB crude oil exports and raise imports (MDS Transmodal, 2007). In 2006, one-fifth (16Mt) of UK North Sea crude was shipped to coastal terminals and four-fifths piped to storage terminals in Orkney, Shetland, Scotland's E. Coast and Teesside. Tonnages shipped ashore will decline but market shares rise as fewer pipeline networks serve increasingly remote small oil field developments. Whether carbon storage in redundant North Sea oilfields will generate significant tanker movements in technically robust new low-emission product-size tankers to transport captured carbon is debateable (D7a; Eason, 2010). UK demand for road transport has historically been fuel price-inelastic as fuel prices rise, but the Stern Review linked per capita GDP with CO2 emissions and proposed a hypothetical relationship between income and local pollutants, defined by environmental Kuznets curves. Beyond a certain point, rising per capita incomes stimulate local abatement incentives and appropriate political and regulatory mechanisms to control pollutants (HM Treasury, 2006, p.191). Perceptions of speculative Kuznets curve behavioural effects in a UK growing less tolerant of fossil fuels (D7b) and changing energy intensity (D7c) could signify systemic attitude shifts. Many controversies underpin drivers of UK average haul lengths including localisation influences (D8a), politico-institutional developments whereby trading relationships in the Russian Arctic may reconfigure oil supply chains and sourcing (D8b, D8c; Parker, 2011), and piracy which may discourage MEG sourcing (D8d). Further some ships may re-route to avoid EU regulatory pressures and ECA designations which seek to minimise emissions in intra-European waters (D8e).

UK ports mirror transportation drivers, which combined, might imply reducing requirements for deep-water UK oil terminals (D7d). By 2030 MDS Transmodal (2007) predicted marginally increased port storage capacity for oil products as capacity at intermediate storage locations at Sullom Voe and Flotta becomes available as North Sea pipeline inflows diminish. Pipelines, coastal shipping and rail tankers link UK oil refining capacity to inland terminals and airports and since the 1940s, oil products have been piped internally across England (Dukes, 2011). Assumptions of unchanged supply chain configurations (MDS Transmodal, 2007) coupled with facilities-inertia arising from high fixed costs and spatially inert deep-water estuaries create spatially stable configurations of major crude oil and oil product flows. Regional market shares for crude oil flows through GB ports dominated by Scotland and the East Coast, adjacent to North Sea oil fields, were predicted to flat line to 2030 with slightly reduced volumes as were regional oil products flows mainly in Wales and Eastern England (MDS Transmodal, 2007). However 2010 production of 73Mt was14Mt below forecast levels (Dukes, 2011).

3. Methodology

To canvas expert opinions and synthesize perceptions of future demand for wet bulk shipping flows to 2050, this study identified diverse stakeholders spanning the supply chain. As a holistic interconnected system, international shipping is too complex for one individual to comprehend and individual stakeholder experiences uniquely color views of emerging trends and prospects. Study objectives require a survey technique capable of generating consensus in the face of rapid change, uncertainty and complex multifaceted implementation issues which offers a multidisciplinary perspective and engages diverse knowledgeable experts. A Delphi panel offers such a technique to understand the implications of changing operational environments and empower stakeholders to communicate. Delphi questioning facilitates asynchronous responses and can accommodate geographically dispersed participants, including an international panel. Aside from forecasting, applications suit gathering data to explore planning and potential policy options (Linstone and Turoff, 1975). The prime objective of synthesizing perceptions suits a "Classic" Delphi research design to canvass opinions and achieve consensus, varied slightly to process numerical data. Delphi designs typically aim to ensure anonymity, controlled feedback, iteration and participating experts (Linstone and Turoff, 1975; Nowack et al., 2011; Landeta, 2006). Each expert remains anonymous to deny intra-panel communication and prevent any bandwagon effects whereby one individual or viewpoint may dominate or influence others. In this design, the mean response on each statement was fed back to panelists who were offered an opportunity to revise their initial evaluation. To tap specialist expertise a Delphi panel was established to explore controversial issues (D1:D8). How the Delphi instrument was derived, how panelists were selected, and the administration and analysis of two rounds of Delphi (R1, R2) are considered next.

Analysis of recent articles in the shipping trade press revealed issues driving wet bulk shipping flows (D1-D8; Dinwoodie et al., 2011) which were refined into draft statements and tested amongst eight shipping academics representing five disciplines in four universities. Academics sought split-period quantitative evaluations 2010-2030 ("α") and 2030-2050 ("β") rather than 2010-2050 ("η") comparisons if feasible, suiting a panel comprised of substantial proportions of young professionals with reasonable expectations of maintaining long term industrial commitments, to minimize non-commitment bias. Such a panel was convened to test a draft online Qualtrics software survey instrument. On many questions, panelists were offered modified Likert scales incorporating an 'unable to comment' option to respond to quantitative statements about their perceptions of developments in α and β. In pilot surveys, several incomplete responses connoted a shorter instrument and widespread non-response to β questions necessitated merged η comparisons. Questions to estimate voyage lengths explicitly requested estimates "averaged over all relevant routes, ship sizes and types." To estimate tonnages, elasticities and proportions, groupings within 25, 50 and 67% of a central estimate were canvassed, reduced to 10, 20 and 30% for global demand, and 10, 25 and 35% for voyage length estimates. Using these indicative class intervals to generate assumed midpoints (Table 1) to facilitate computation of mean estimates, mean α=1.07 on question 1, a statement that tonnage would remain unchanged, was considered 7% too low by experts, implying that they anticipated 7% tonnage growth to 2030.

Table1: Response levels and assumed midpoints

Question	Score:	1	2	3	4	5
1,2	level	>50% too high	25-50% too high	about right	25-50% too low	>50% too low
	midpoint	0.60	0.73	1.00	1.37	1.67
3	level	fall >20%	fall 10-20%	change little	rise 10-20%	rise >20%
	midpoint	0.70	0.85	1.00	1.15	1.30
5,6,8	level	>25% shorter	10-25% shorter	little change	10-25% longer	>25% longer
	midpoint	0.70	0.83	1.00	1.175	1.30
4,7	level	fall >50%	fall 25-50%	change little	rise 25-50%	rise >50%
	midpoint	0.60	0.73	1.00	1.37	1.67

Source: Authors

This study is replicable and Delphi statements derived from the trade-press ensured content-coincidence with the object of study. However, because panelists did not generate these statements the validity of the constructs evaluated is not grounded in their expertise and all statements offered an "unable to comment" option. This also ensured that participation was voluntary. To ensure criterion validity statements must correlate with an evaluation, which may be compromised by high drop-out rates. To enhance their awareness of this, R2 panelists were informed that non-return would be assumed to represent confirmation of their initial choices. Regarding external validity, although panelists' perceptions are inevitably temporally idiosyncratic, short-term market distortions have limited influence on long-term perceptions (Piecyk and McKinnon, 2010). Aside from this, recruitment of a committed panel of diverse stakeholders embracing multiple nationalities and disciplinary interest maximizes the likelihood of achieving generalizability.

To ensure content validity, Delphi panels should incorporate knowledgeable and interested experts who represent multidisciplinary stakeholder interests and viewpoints. To ensure commitment to a 2050 study horizon in an international industry, many young professionals were recruited including an international group undertaking specialist postgraduate study. Panel membership by invitation avoided self-selection bias, drawn from a sampling frame comprised of 51 heads of either wet bulk or research at member shipping organizations of the Institute of Chartered Shipbrokers, plus 15 personal contacts. Following piloting, additional invitations to specialist international postgraduate students at Plymouth University generated 24 R1 replies to supplement 11 practitioners. An overall invitation to participation rate of 4.3 (23%), closely matches average rates of 4.4 (Nowack et al., 2011, 1611). Practitioners included two consultant marine researchers, a senior marine planner in a petroleum company, managing director of an oil credit broker, manager of oil projects in a major oil company, a senior oil credit analyst, one shipping company managing director and one chief executive, a senior market analyst, a classification society specialist, and a tanker segment manager. Interests and industrial experience spanned procurement to logistics, most wet bulk shipping specialisms, three continents, and experience of most professional interests and ship sizes (Table 2).

Table 2: Profile of Delphi panellists

Trait	Group	%	Group	%
Nationality	Non-UK Europe	34	UK	22
	Asia	34	Africa	10
Profession	Miscellaneous supply chain	35		
	Logistician	31	Shipbroker	3
	Researcher	19	Port manager	3
	Government or regulation	6	Ship owner	3
Ship size	Various	48	Panamax (2011)	6
	Suezmax	29	Handysize	6
	Very large	11		

Source: Authors

Invitations to participate were emailed because this method is flexible, convenient and empowers response when convenient to the recipient and 35 R1 responses were analyzed. To ensure credibility, personalized R2 questionnaires were compiled, incorporating the individual's R1 response, mean response and an invitation to respond finally alongside an emboldened statement that non-return would be presumed to represent confirmation of initial choices. Of 14 R2 responses, 11 showed changes, an acceptable rate given the presumption that non-response represents continued participation. Tables (3 and 4) show R2 mean scores. On all but four statements standard deviations in R2 reduced, testifying to increased consensus. Because some variables exhibited skewness a non-parametric independent samples Mann-Witney U-test was deployed to test for differences in the central tendency of the distributions of responses between practitioner-student sub-groupings, revealing significant differences on only one statement and making further disaggregation inappropriate. Tests for consistency between early and late respondents comparing the first quartile of early responses with the last quartile revealed a significant difference on only one R1 variable, and none in R2. Given this finding, non-response bias is unlikely to be present in this panel (Piecyk and McKinnon, 2010).

4. Results

Experts' mean considered responses anticipated modest initial rates of tanker demand growth reducing later (α=7%, 0.34%CAR compound annual rate; β=4%, 0.195%CAR, Table 3). If the oil intensity of production in OECD economies continues to halve in 30 years (-2.29%CAR) then by 2030, current output levels would require 63% of current oil consumption compared with panelists' estimates of 64.4% (α=-2.176%CAR) and 40.9% by 2050 (β=-2.241%CAR). If correct, with oil consumption in OECD and non-OECD economies currently similar, 2010 global oil consumption would meet a 250% increase in industrial output in developing economies to 2050. However, ceteris paribus, with expected energy intensity reducing quicker in non-OECD economies (η=-2.9%CAR) than in OECD economies (η=-2.1%CAR, EM, 2012) current oil consumption levels could support trebled output in developing economies by 2050. Regarding the impact of bunker price changes on wet bulk freight rates, considered mean panel estimates of the short run spot freight rate elasticity for oil in relation to doubled real bunker fuel prices imply 19.2% rates rises. Coupled with a long run elasticity estimate of 0.216 these findings imply a tanker market relatively unresponsive to bunker price changes and imply that for example market based measures to influence shipping emissions would be relatively ineffectual both short and long term. Very substantial bunker fuel levies would be required to significantly impact freight rates, even ignoring cost pass-through effects to import and final market prices. However, if operators could not avoid bunker fuel levies, they apparently offer policy makers high revenue-raising potential.

Panelists' predicted increased total global demand (tkm) solely due to increased demand for water carriers (η=11%), an enlarged Panama Canal (η=6%) and rising demand for LNG (η=4%). Demand would reduce due to EEDI regulations (η=-11%), nuclear power (η=-4%) and shorter Arctic sea-routes (α=-2%), implying 4% net growth from the drivers listed. Panelists expected oil pipelines to reduce the proportion of US oil imports moved in ships, (α=-7%, β=-12%) as they link the US to Canadian tar sands. The expected proportion of European oil imports moved in ships would reduce due to more Europe-MEG and Russia-MEG oil pipelines (α=-4%, β=-8%). Oil pipelines China-MEG and Russia-MEG will reduce the proportion of China's oil imports moved in ships (α=-4%, β=-4%).

Table 3 Freight demand estimates

1. *How accurate are the following freight demand estimates for wet bulk shipping?*	Period	Mean R2
1a,b. Global wet bulk tonnage will remain unchanged.	α β	1.07 1.04
1c,d. The quantity of oil used in each unit of industrial output in developed economies will halve in 30 years	α β	0.95 1.03
2. *How accurate are these estimates of wet bulk freight rate changes in relation to bunker price changes?*		
2a. In the long run the spot freight rate for oil will rise 20% if bunker fuel prices double in real terms		1.08
2b. In the short run the spot freight rate for oil will rise 20% if bunker fuel prices double in real terms		0.96
3. *How will solely the driver shown affect total global demand (tkm) for wet bulk maritime transport?*		
3a. more demand for water carriers will cause TOTAL tanker tkm to	η	1.11
3b,c. Shorter sea routes due to Arctic ice-melt will cause TOTAL tanker tkm to:	α β	0.98 1.00
3d,e. An enlarged Panama canal will cause tanker tkm to:	α β	1.03 1.03
3f,g. IMO Energy Efficiency Design Index regulations which require ships to emit less carbon will cause tanker tkm to:	α β	0.95 0.94
3h rising demand for LNG will cause tanker tkm to	η	1.04
3i. changed demand for nuclear power will cause tanker tkm to	η	0.96
4. *Solely because of more oil pipelines the proportion of the specified oil imports moved in ships will*:		
4a,b. oil pipelines linking the US to Canadian tar sands, will cause the % of US oil imports moved in ships to:	α β	0.93 0.88
4c,d. more oil pipelines from Europe and Russia to MEG will cause the % of European oil imports moved in ships to	α β	0.96 0.92
4e,f. more oil pipelines from China and Russia to MEG will cause the % of China's oil imports moved in ships to	α β	0.96 0.96

Source: Authors

Taken individually, no single driver would radically impact voyage lengths globally but cumulatively, their impacts mount. By 2050, predicted shortening of tanker haul lengths to counter rising bunker costs (η=-7%, Table 4), ocean routing (η=-9%), multi-sourcing to ensure secure energy supplies (η=-4%) and ECA-avoidance impacts (η=-2%) imply cumulative reductions of 22%. Drivers affecting specific average voyage lengths included N.E. Asia-W. Europe hauls shortened by a Canadian N.W. Passage created by Arctic ice melt (η=-15%) and a Russian N.E. Passage (η=-17%). An enlarged Panama Canal shortens hauls (α=-8%, β=-6%) but ship re-routing to avoid piracy caused by droughts and failed states would lengthen N.E. Asia-W. Europe hauls (η=5%).

Table 4: Voyage length and UK demand estimates

5. *How will solely the driver shown affect the global average voyage length of wet bulk hauls (km)?*	Period	Mean $R2$
5a. rising bunker costs by favoring sources close to demand locations will cause global average tanker hauls (km) to be:	η	0.93
5b,c. more ECAs may induce ship re-routing to avoid them, causing hauls (km) to be:	α β	1.01 0.97
5d,e. Ocean Routing and operating measures to reduce carbon emissions, will cause hauls (km) to be	α β	0.95 0.96
5f. multi-sourcing to ensure secure energy supplies, will cause hauls (km) to be:	η	0.96
6. *How will solely the driver shown affect specific average voyage lengths of wet bulk hauls (km)?*		
6a. due to a Canadian NW Passage created by Arctic ice melt, average voyage lengths N.E. Asia-W. Europe (km) will be:	η	0.85
6b. due to a Russian N.E. Passage arising from ice melt, average N.E. Asia- W. Europe voyage lengths (km) will be:	η	0.83
6c,d. due to an enlarged Panama Canal, N.E. Asia-USEC voyage lengths (km) averaged over all routes used will be:	α β	0.92 0.93
6e. due to ship re-routing to avoid piracy caused by droughts and failed states, voyage lengths (km) N.E. Asia-W. Europe averaged over all routes will be:	η	1.05
8. *How will solely the driver shown affect the average lengths of UK wet bulk shipping hauls?*		
8a. rising bunker costs which favor oil sourced closer to the UK will cause average lengths (km) of UK oil import hauls to be	η	0.94
8b,c. sourcing more oil from Russian oil fields will cause average lengths (km) of UK oil import voyages to be:	α β	0.94 0.94
8d,e. ship re-routing to avoid increased piracy will cause average voyage lengths (km) MEG-UK to be:	α β	1.07 1.03
8f,g. ships diverting to avoid more ECAs will cause average lengths (km) of UK wet bulk maritime hauls to be:	α β	1.04 1.00
7. *From 2010 to 2050 how will SOLELY the driver shown affect the specified components of UK demand for wet bulk shipping?*		
7a. Use of redundant North Sea oil fields to store captured carbon will cause total UK demand (tkm) for wet bulk shipping to:		0.99
7b. UK society becoming less tolerant of using fossil fuels to produce energy will cause UK demand (tkm) for ships to import fossil fuels to:		0.89
7c. Requirements for less energy to make each unit of UK output will cause UK demand (tkm) for ships to import fossil fuels to:		0.91
7d. Declining UK crude oil imports will cause the number of operational UK deep water oil terminals to:		1.00

Source: Authors

Drivers of UK haul lengths included rising bunker costs which favor localized sourcing, expected to reduce UK oil import hauls (η=-6%), and increased sourcing from Russian oil fields (α=-6%, β=-6%). Transneft shipments of Urals crude through the Baltic Ust-Luga terminal near St Petersburg opened 2012, rather than through Novorossiysk on the Black Sea will shorten UK hauls. Ship re-routing to avoid piracy would lengthen MEG-UK hauls (α=7%, β=3%) but affects few UK imports and adds little to oil import tkm (α=0.34%, β=0.15%). ECA avoidance would lengthen average UK hauls (α=4%). Panelists forecast reduced UK demand for wet bulk shipping (tkm) attributable to diminished social tolerance of using fossil fuel to produce energy (η=-11%), reducing energy intensities of UK output which reduce demand for ships to import fossil fuels (η=-9%), and using redundant North Sea oil fields to store captured carbon (η=-1%). Panelists predicted eight operational UK deep water oil terminals in 2050, unchanged from 2010.

5. Conclusion

Behavioral forecasts, including Delphi results attract criticism (Stopford 2009, 739). To discourage respondents from offering precise wrong answers which might appear more authoritative than vague right answers, this work offered no precise response categories. Similarly a panel incorporating many young professionals reduced the likelihood of status quo bias where implicit assumptions that past trends and institutional frameworks will endure may color responses. Statements about short term developments were omitted to counter any herding instinct which drives optimism during peaks and pessimism during troughs. Universal uncertainty may generate similarities in expert predictions, creating apparent but incorrect consensus. In this research, if conservative opinions do imply universal uncertainty, this endorses the complexities of forecasting long term in volatile markets where expressions of forecast certainty in this environment are irrational.

Overall, expected global tanker demand to 2050 will rise only modestly despite increasing demands to ship more water, avoid pirates and ECAs and satiate rapidly developing economies. Demand offsets including shorter sea-routes via Arctic passages and upgraded canals have limited impact on UK crude, but shorter haul lengths attributable to localized sourcing and more efficient ship operating plans to reduce carbon emissions, reducing oil intensity, and modal shifts to pipelines present decision regulators for policy makers. Unknowns include unpredictable variable marginal rates of drivers which may shift significantly including for example bunker costs and levies which may cut shippers' margins and render global demand for maritime transport more responsive to bunker cost changes. Demand for liquid biofuels, not considered here, may become significant. Perceptions of modest global change coupled with reducing energy intensity of UK industrial output imply a rapidly diminishing UK tanker market share. Perceptions of accelerating global preferences for pipelines over maritime flows and increasing demand for nuclear power, combined with reducing tolerance of fossil fuels in UK energy production may signify that as an advanced industrial nation, the UK will lead on systemic post-oil dependence behavioral shifts. However, based on this evidence, Kuznets curve concepts remain speculative stated intentions. Longer term, tanker movements in UK waters may vary with unknowns such as ice-strengthened hull availability, the incidence and political fall-out of oil spills incidents in Arctic waters, and the accessibility and cost of pipelines from Russia and MEG. A likely spatial momentum of expected oil tanker flows involving the UK reflects geographically inert configurations of deep-water ports, urban areas, refining capacity and pipeline systems. However, spatially variable future oil tanker flows are inevitable given regionally differentiated growth rates, dynamic oil sourcing policies and spatially unpredictable socio-political drivers such as piracy. Necessarily speculative forty-year projections combine with volatile markets to amplify uncertainty. Because of this complexity, future research might usefully attempt to frame maritime flow forecasts within a holistic systems framework which encourages complex scenario dependent testing of combinations of vessel technologies, operational strategies and regulatory decisions taken across and beyond the shipping sector.

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References

Al-Husseini, M. (2009), World production of conventional petroleum liquids to 2030: A comparative overview, GeoArabia, 14(1): 215-267

Broadstock, D.C. and Hunt, L.C. (2010), Quantifying the impact of exogenous non-economic factors on UK transport oil demand, Energy Policy, 38(3): 1559-1565

Buhaug, Ø., Corbett, J.J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D.S., Lee, D., Lindstad, H., Mjelde, A., Pålsson, C., Wanquing, W., Winebrake, J.J. and Yoshida, K. (2009), Second IMO Greenhouse Gas Study, International Maritime Organization: London.
DECC, (2009), UK low carbon transition plan emissions projections URN 09D/678, Department of Energy and Climate Change: London.
DfT, (2009), Maritime Statistics, annually, London: Department for Transport.
Dinwoodie, J. and Bhatia, R. (2004), Daily oil losses in shipping crude oil: Measuring crude oil loss rates in daily North Sea shipping operations, Energy Policy, 32(6): 811-822.
Dinwoodie, J., Tuck, S., Sanchez-Rodrigues, V. and Mangan, J. (2011), Low carbon shipping: oil tanker movements involving the UK, IAME Annual conference, Santiago Chile, October.
Dukes, (2011), Digest of United Kingdom Energy Statistics, Annual, Department of Energy and Climate Change, London: The Stationary Office, website www.decc.gov.uk/en/content/cms/ statistics/ publications/ dukes/dukes.aspx., last accessed in February 2012.
Eason, C. (2010), Shipowners press on with carbon storage vessels, Lloyds List, 13 July.
EC, (2008), European energy and transport trends to 2030 - update 2007, European Commission Directorate-General, Office for Official Publications of the European Communities: Luxembourg, website, http://ec.europa.eu/dgs/energy_transport/ figures/trends_2030_update_2007/ energy_ transport_ trends_2030_update_2007_en.pdf. , last accessed in January 2011.
EIA, (2011), International Energy Outlook, Annual, Office of Integrated Analysis and Forecasting, Energy Information Administration, Department of Energy: Washington, DC, website, www.eia.doe.gov/oiaf/ieo/index.html last accessed January 2011.
Glen, D.R. and Marlow, P. (2009), Maritime statistics: a new forum for practitioners, Maritime Policy and Management, 36(2): 185-195.
Hammer, J. (2009), Long-term oil tanker demand, Managing Risk, 2, Det Norske Veritas: Oslo, website : http://www.dnv.com/industry/maritime/publicationsanddownloads/publications/ dnvtankerupdate/2009/2_2009/Longtermoiltankerdemand.asp last accessed in February 2011.
HM Treasury (2006), Stern Review: The Economics of Climate Change, HM Treasury: London website, http://webarchive.nationalarchives.gov.uk/+/http://www.hm-treasury.gov.uk/stern_review report.htm last accessed January 2011.
Ho, J. (2010), The implications of Arctic sea ice decline on shipping, Marine Policy, 34(3): 713-715.
IMO (2012), IMO, International Maritime Organisation: London, website http://www.imo.org. last accessed in January 2012.
Landeta, J. (2006), Current validity of the Delphi method in social sciences, Technological Forecasting and Social Change, 73(5): 467–482.
Linstone, A. and Turrof, A., (1975), The Delphi Method: Techniques and Applications, Addison Wesley: Reading, MA.
MDS Transmodal Limited, (2007), Update of UK port demand forecast to 2030 and economic value of transhipment study, website http://www.dft.gov.uk/pgr/shippingports/ports/ portspolicyreview/ 207015_Final_ Report_2.pdf, last accessed December 2010.
Nowack, M., Endrikat, J. and Guenther, E. (2011), Review of Delphi-based scenario studies: quality and design considerations, Technological Forecasting and Social Change, 78(9): 1603–1615
OBR, (2011), Fiscal Sustainability Report, Office of Budget Responsibility: London, July, website, http://www.imo.org. last accessed January 2012.
Osler, D. (2010), Tomorrow's world, Lloyds List, 30 June.
Parker, B. (2011), Rosneft and BP brokershare-swap agreement, Lloyds List, 20 January.
Piecyk, M.I. and McKinnon, A.C. (2010), Forecasting the carbon footprint of road freight transport in 2020, International Journal of Production Economics, 128(1): 31-42.
Stopford, M. (2009), Maritime Economics, 3rd edition, Routledge: London.
Stott P.W. and Wright P.N.H. (2012), The Panama Canal expansion: business as usual or game changer for ship design? Port Technology International, 53: 27-28.
UNCTAD (2010), Oil Prices and Maritime Freight Rates: An Empirical Investigation, Technical report UNCTAD/DTL/TLB/2009/2, April, UNCTAD.