



Task 3: Marine Fuels Demand

Andre Avelino, Emily Newes

May 5, 2021



Goals for Today

- Provide update on Task 3 Progress
 - Work scope
 - Existing literature review
 - Data acquisition and analysis
 - Methodology
 - Preliminary analysis results
 - Path forward
- Receive feedback on work progress and path forward

Q2 Milestone:

Deliver to sponsors and stakeholders findings-to-date and status update including data and methods.

Introduction

Marine shipping is a global market, where ships decide where to bunker based on fuel availability and prices.



Today:

- This task looks at a major U.S. port (Seattle/Tacoma) and two international ports (Panama and Singapore) to see if there are differences in price elasticity of demand and to formulate a demand curve.
- We would like to also obtain data for a California port (LA/Long Beach) in order to do an analysis on substitution effects.

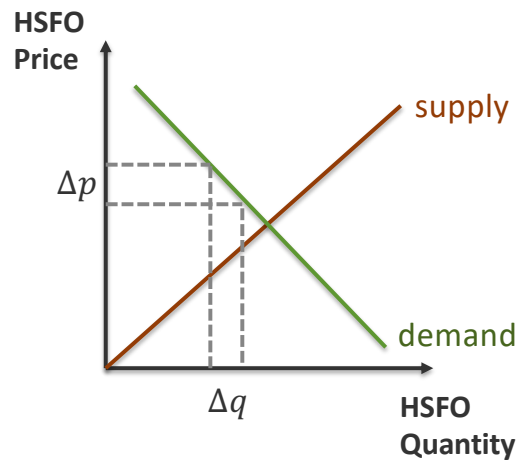
FY2021 Q3-Q4:

- Once we have a better understanding of consumer behavior, we will estimate the potential impacts on the demand curve of different blend levels and fuel quality parameters, coordinating with Tasks 5.1 and 5.2.

Existing Literature on Marine Fuel Price Elasticity

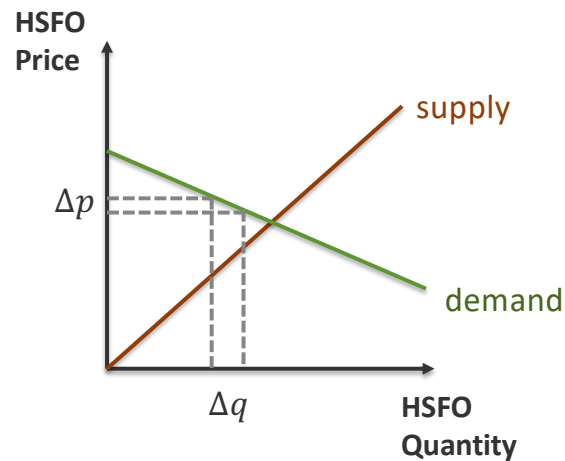
Overview – Price Elasticity of Demand

The price elasticity of demand measures the sensitivity of demand to changes in prices, i.e., the % change in demand due to a % change in prices.

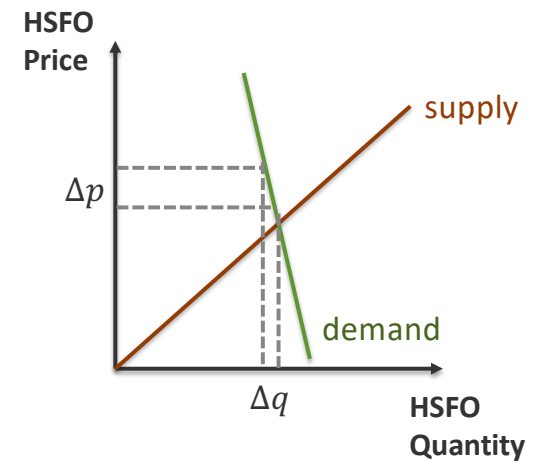


Price Elasticity:

$$\epsilon = \frac{\% \text{ change } q}{\% \text{ change } p} = \frac{p \Delta q}{q \Delta p}$$



Elastic demand
 $\epsilon > 1$



Inelastic demand
 $\epsilon < 1$

Marine Literature – Fuel Price Elasticity

- A large portion of the *marine literature* focuses on *freight price elasticity*, i.e., the % change in demand for marine freight due to a % change in freight rates.
- Limited set of studies provide *marine fuel price elasticities* (at world level):
 - Parry *et al.* (2018): -0.45 for HSFO (derived from the GloTraM model (Smith *et al.*, 2016))
 - Keen *et al.* (2013): -0.33 for HSFO (calibrated theoretical model)
 - Mazraati (2011): -0.01 for HSFO and -0.08 for MDO (econometrically estimated)

These studies suggest that world demand for HSFO has low price sensitivity: for a 1% increase in price, HSFO demand decreases by 0.01%-0.45%.

Marine Literature – Fuel Price Elasticity

- Ocean liners can respond to higher fuel prices in two main ways:
 - *Slow steaming*: reduce speed to increase fuel consumption efficiency; provides significant fuel savings, as fuel consumption in ships is a sharply convex function in relation to speed (Lee *et al.*, 2015). Systematic strategy during the 2002-2008 crude oil price spike (Halff *et al.*, 2019).
 - *Bunkering in different ports*:
 - Acosta *et al.* (2011) and Aronietis *et al.* (2017) indicate that fuel price is the most important factor in deciding which port to bunker.
 - E.g.: 8.5% sales tax on marine fuels in CA in 1991 >> Port of Los Angeles bunker fuel sales declined from 4.5 million barrels/month to 1 million barrels/month, with most ships bunkering in Panama instead (Michaelowa & Krause, 2000).

Model and Data

Data Summary

Data Acquisition:

- We have data for:
 - **World**: annual (1990-2019)
 - **Port of Singapore**: monthly (Jan-1995 to Dec-2019)
 - **Panama**: monthly (Jan-2013 to Dec-2019)
 - **Port of Seattle/Tacoma**: monthly (Jan-2011 to Dec-2019)

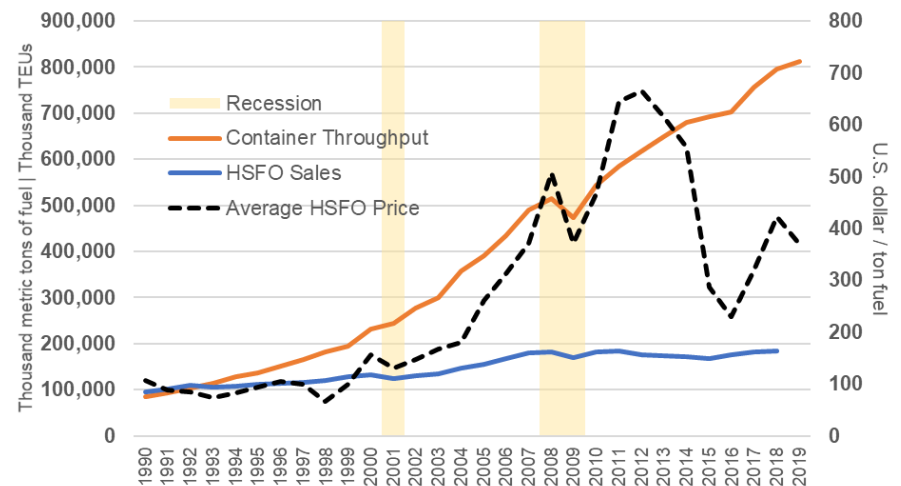
- We have communicated with multiple entities to find better **California data**: California Air Resources Board, California State Lands Commission, California Department of Fish and Wildlife (Office of Spill Prevention and Response), Port of Los Angeles, Port of Long Beach. We continue to search...

Data Summary

Data Insights:

- Maritime transportation has significantly increased over the last 30 years, reflected in the steady growth in container throughput worldwide
- Fuel prices have low impact on maritime transportation volumes
- Economic crisis have significant impacts on container throughput and prices, but lower impacts on fuel demand
- Fuel demand seems detached from price variations in the last decade, especially in Panama and Seattle-Tacoma

Global HSFO Sales, Prices and Container Throughput



Econometric Specification

A model was estimated for the World, as well as for three additional ports: Singapore, Panama and Seattle-Tacoma, where regional specific data was available.

Fuel demand (E) is driven by fuel price (P) and an activity level indicator (Y)¹:

$$E_t = f(P_t, Y_t, E_{t-1})$$

We specify our lagged endogenous model in natural logs as:

$$\ln E_t = \alpha + \eta \ln P_t + \beta \ln Y_t + \rho \ln E_{t-1} + \varepsilon_t$$

Where η is the own-price elasticity of marine fuel oil and β is the elasticity of demand with respect to maritime transportation volume (proxied by container throughput).²

Additional information is provided in the supplementary slides.

¹General model proposed by Pindyck and Rubinfeld (1991) and widely used in the transport fuel demand literature to estimate aggregate fuel demand (Ajanovic et al., 2012)

²This approach is similar to the one used by Mazraati (2011) to model global marine fuel demand.

Preliminary Results / Next Steps

Preliminary Results – Price elasticity is low or inelastic

	World	Singapore	Panama	Seattle-Tacoma
First Stage				
<i>Oil Price</i>	1.014 [0.076]***	0.812 [0.045]***	1.005 [0.082]***	0.739 [0.066]***
<i>Time dummies</i>	No	Yes	Yes	Yes
<i>R-squared</i>	0.913	0.615	0.708	0.585
<i>Stock and Yogo Test</i>	218.61 (16.38)	389.02 (16.38)	143.68 (16.38)	130.49 (16.38)
Second Stage				
<i>HSFO Price</i>	0.043 [0.032]	-0.142 [0.060]**	-0.267 [0.174]	0.321 [0.391]
<i>Containers</i>	0.456 [0.148]***	0.145 [0.142]	-0.019 [0.121]	0.694 [0.308]**
<i>Lag HSFO Sales</i>	-0.051 [0.161]	-0.260 [0.061]***	-0.236 [0.114]**	-0.448 [0.092]***
<i>Constant</i>	-0.015 [0.014]	0.032 [0.015]**	0.092 [0.051]*	0.145 [0.083]*
<i>Time dummies</i>	No	Yes	Yes	Yes
<i>Frequency</i>	Annual	Monthly	Monthly	Monthly
<i>Observations</i>	28	299	83	107
<i>R-squared</i>	0.408	0.267	0.181	0.219

Notes: the dependent variable is log fuel oil demand. Significance levels: *** 1%, ** 5%, * 10%. Standard deviation shown in brackets. Stock and Yogo test: Cragg-Donald statistic on top, and critical value in parenthesis.

➤ First stage:

- Significant instrument (crude oil prices explain part of the variation in HSFO prices)
- Reject the null hypothesis of weak instruments (see supplementary information for Stock and Yogo test results)

➤ Second stage:

- Only Singapore shows significant own-price elasticity (negative, as expected) and within the range in the literature for HSFO (-0.45 to -0.01)
 - Short-run price elasticity: -0.142
 - Long-run price elasticity: -0.113
- Port activity elasticity is significant and positive for World and Seattle-Tacoma only, indicating that bunkering activity occurs independently from cargo loading/unloading at the Port of Singapore and Panama

Next Steps to Enhance Current Results

- The results might be affected by:
 - *Measurement error*: world data on marine fuel demand varies considerably across sources (EPA, 2008). Marine fuels are usually not properly accounted for in domestic oil demand statistics due to incomplete port reporting and the fact that they are consumed at sea. Hence, different modeling approaches are used to estimate their demand, with large discrepancies between organizations (Halff *et al.*, 2019; Mazraati, 2011)
 - *Short time-series*
 - *Better/additional instruments required*: instruments cannot be correlated with unobserved shocks to HSFO demand (exclusion restriction), otherwise the instrument has the same issue as the endogenous variable. To strengthening the results, we will test additional instruments, such as oil supply shocks in foreign countries.
- Next steps:
 - Search for alternative sources for global marine fuel demand
 - Test additional instruments
 - Test additional model specifications
 - Compilation of data for additional ports

Next Steps For Demand Analysis

Statistical Analysis:

- If California data are found, run statistical analysis on bunker substitution effects
- Complete demand curve estimation
- Finalize draft journal article

Value Proposition for Biofuels:

- What does this analysis mean for potential biofuel market penetration?
- Begin discussion with Task 5 on potential for biofuel blending and impact on the demand curve

Thank you!

www.nrel.gov

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.



Supplementary Information

Overview

- Literature on ***fuel demand*** is primarily focused on gasoline/diesel consumed by light duty vehicles.^{1,2}



Issue: different capital ownership and behavior by economic agents (consumer vs firm) than fuel demand for freight transport

- A small set of studies focused on diesel demanded by heavy duty vehicles (HDV), and an even smaller set focused on marine bunker fuels.

¹Winebrake, J. J., Green, E. H., Comer, B., Li, C., Froman, S., & Shelby, M. (2015a). Fuel price elasticities for single-unit truck operations in the United States. *Transportation Research Part D*, 38, 178–187. <https://doi.org/10.1016/j.trd.2015.05.003>

²Winebrake, J. J., Green, E. H., Comer, B., Li, C., Froman, S., & Shelby, M. (2015b). Fuel price elasticities in the U.S. combination trucking sector. *Transportation Research Part D*, 38, 166–177. <https://doi.org/10.1016/j.trd.2015.04.006>

Marine Literature – Freight Price Elasticity

- A large portion of the *marine literature* focuses on *freight price elasticity*, i.e., the change in demand for marine freight due to a change in freight rates. Studies in this area found:

- Low price elasticity in long-distance transportation
 - High price elasticity in short-distance/inland transportation
- Maritime transportation is the *cheapest option for long-distance bulk freight*.
- Such *comparative advantage diminishes in short distances* due to modal competition.

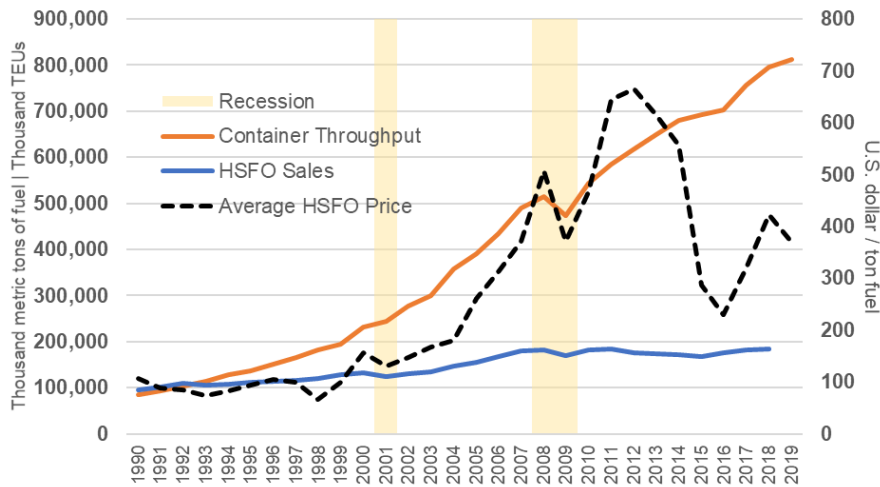
Table 1. Short/long-distance freight price elasticities for selected regions

Region	Short-distance	Long-distance	Reference
Belgium	-2.62	-1.34	Beuthe <i>et al.</i> (2001)
Canada	-0.74		Oum (1979)
Australia	-0.83	-0.25 to -0.06	Bureau of Trans. and Com. Econ. (1990), Saad <i>et al.</i> (1985)
International		-0.23	Meyrick and Associates <i>et al.</i> (2007)

Data Sources – World

Annual, 1990 to 2019

- E_t : world annual bunker fuel oil consumption (in thou metric tons) from IEA (OECD, 2020)
- Y_t : world annual container throughput (in thou TEUs) (UNCTAD, 2020)
- P_t : average annual price of marine fuel oil 380cst/180cst for the Port of Singapore (Argus, 2021)
- Z_t : average annual global price of Brent crude oil (International Monetary Fund, 2021)

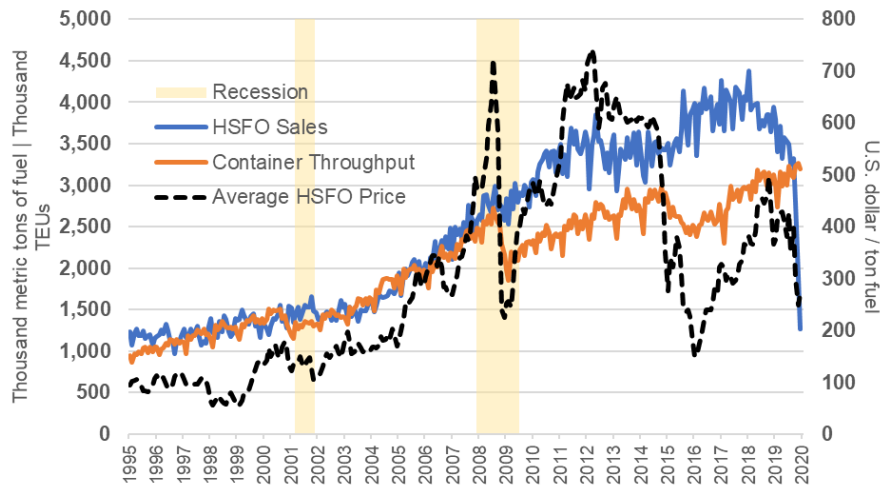


	HSFO Sales (thou tons)	Containers (thou TEUs)	HSFO Prices (\$/ton)	Oil Prices (\$/barrel)
Freq.	A	A	A	A
N	29	29	29	29
Mean	145,639	382,273	266	49
Std. Dev.	31,186	232,638	192	33
Min.	94,438	85,597	66	13
Max.	184,052	795,736	665	112

Data Sources – Port of Singapore

Monthly, Jan-1995 to Dec-2019

- E_t : monthly bunkering fuel sales (in thou metric tons) (Maritime and Port Authority of Singapore, 2021)
- Y_t : monthly container throughput (in thou TEUs) (Maritime and Port Authority of Singapore, 2021)
- P_t : average monthly price of marine fuel oil 380cst/180cst for the Port of Singapore (Argus, 2021)
- Z_t : average monthly global price of Brent crude oil (International Monetary Fund, 2021)

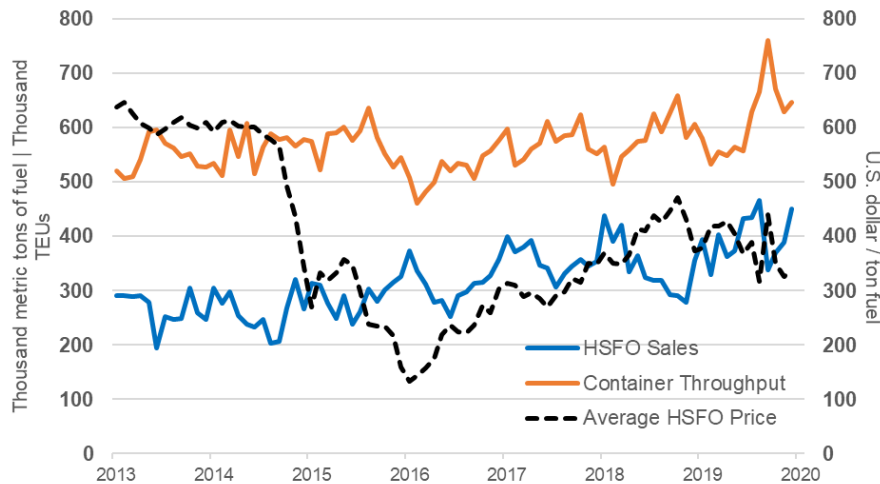


	HSFO Sales (thou tons)	Containers (thou TEUs)	HSFO Prices (\$/ton)	Oil Prices (\$/barrel)
Freq.	M	M	M	M
N	300	300	300	300
Mean	2,452	2,056	305	55
Std. Dev.	1,028	670	191	33
Min.	972	867	55	10
Max.	4,379	3,268	742	134

Data Sources – Panama (Pacific ports)

Monthly, Jan-2013 to Dec-2019

- E_t : monthly bunkering fuel sales (in thou metric tons) (Autoridad Maritima de Panama, 2021)
- Y_t : monthly container throughput (in thou TEUs) (Autoridad Maritima de Panama, 2021)
- P_t : average monthly price of marine fuel oil 380cst for the Panama Canal (Argus, 2021)
- Z_t : average monthly global price of Brent crude oil (International Monetary Fund, 2021)

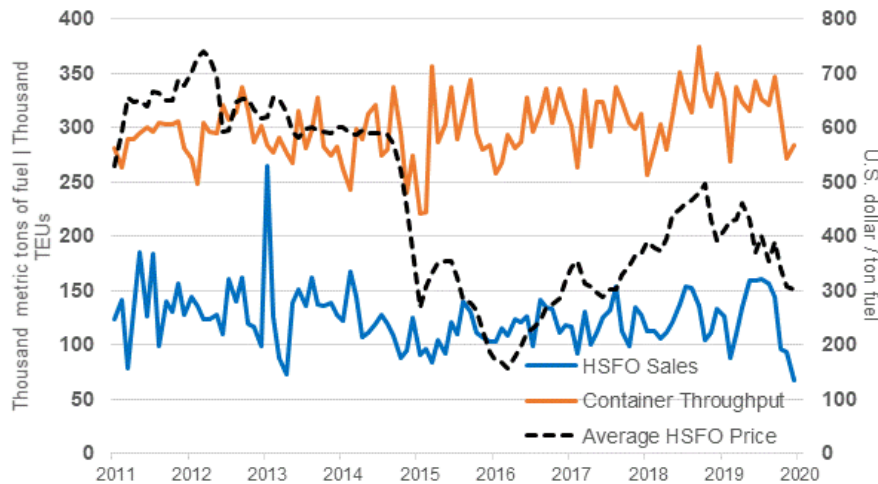


	HSFO Sales (thou tons)	Containers (thou TEUs)	HSFO Prices (\$/ton)	Oil Prices (\$/barrel)
Freq.	M	M	M	M
N	84	84	84	84
Mean	245	233	393	71
Std. Dev.	51	32	143	24
Min.	142	178	133	31
Max.	362	322	646	116

Data Sources – Port of Seattle-Tacoma

Monthly, Jan-2011 to Dec-2019

- E_t : monthly bunkering fuel sales (in thou metric tons) (State of Washington, 2021)
- Y_t : monthly container throughput (in thou TEUs) (The Northwest Seaport Alliance, 2021)
- P_t : average monthly price of marine fuel oil 380cst for the Port of Seattle-Tacoma (Argus, 2021)
- Z_t : average monthly global price of Brent crude oil (International Monetary Fund, 2021)



	HSFO Sales (thou tons)	Containers (thou TEUs)	HSFO Prices (\$/ton)	Oil Prices (\$/barrel)
Freq.	M	M	M	M
N	108	108	108	108
Mean	98	300	459	80
Std. Dev.	19	28	161	27
Min.	56	221	157	31
Max.	146	374	740	125

Estimation Procedure – 2SLS

- Potential endogeneity issue with fuel prices:
 - Estimation using two-stage least square (2SLS) approach
 - Instrument (Z_t): global crude oil prices
 - The validity of this instrument relies on the assumptions that: (1) crude oil prices are related to marine fuel prices, and that (2) marine fuel oil demand should not impact crude oil prices.
 - (1) Crude oil is the feedstock used in the refining process, hence should be related to bunker prices (also checked via the significance of the instrument in the first stage);
 - (2) Residual fuel oil is generated as a by-product and is one of the lowest-value products of the refining process. Refiners' production decisions tend to rely on high-value products, such as gasoline and diesel, hence we can assume that crude oil demand and supply is primarily driven by these products, other than marine fuel oil.
- Additionally, we test for weak instruments using Stock & Yogo (2010) method.

Data Adjustments

- We performed an augmented Dickey-Fuller test on each variable to check for non-stationarity of the time-series and we could not reject the null-hypothesis of a unit-root process for any of the them.
 - A first-order differentiation resolved the non-stationarity issue, so the model previously described was computed in first differences.
- Additional monthly dummies were added to capture any seasonal effects.
- A model was estimated for the World, as well as for three additional ports: Singapore, Panama and Seattle-Tacoma, where regional specific data was available.

OLS Results

	World	Singapore	Panama	Seattle-Tacoma
<i>HSFO Price</i>	0.037 [0.030]	-0.126 [0.046]***	-0.298 [0.144]**	-0.112 [0.295]
<i>Containers</i>	0.469 [0.145]***	0.137 [0.141]	0.028 [0.263]	0.767 [0.301]**
<i>Lag HSFO Sales</i>	-0.041 [0.160]	-0.258 [0.061]***	-0.234 [0.114]**	-0.441 [0.091]***
<i>Constant</i>	-0.016 [0.013]	0.032 [0.015]**	0.090 [0.051]*	0.142 [0.082]*
<i>Time dummies</i>	No	Yes	Yes	Yes
<i>Frequency</i>	Annual	Monthly	Monthly	Monthly
<i>Observations</i>	28	299	83	107
<i>R-squared</i>	0.409	0.268	0.181	0.237

Notes: the dependent variable is log fuel oil demand. Significance levels: *** 1%, ** 5%, * 10%.
Standard deviation shown in brackets.

References

- Acosta, M., Coronado, D., & Cerban, M. del M. (2011). Bunkering competition and competitiveness at the ports of the Gibraltar Strait. *Journal of Transport Geography*, 19(4), 911–916. <https://doi.org/10.1016/j.jtrangeo.2010.11.008>
- Ajanovic, A., Dahl, C., & Schipper, L. (2012). Modelling transport (energy) demand and policies—An introduction. *Energy Policy*, 41, iii–xiv. <https://doi.org/10.1016/j.enpol.2011.12.033>
- Argus. (2021). *Marine Fuels Prices* [Data file]. <https://www.argusmedia.com/>
- Aronietis, R., Sys, C., van Hassel, E., & Vanelslander, T. (2017). Investigating the bunkering choice determinants: The case of the port of Antwerp. *Journal of Shipping and Trade*, 2(8), 1–13. <https://doi.org/10.1186/s41072-017-0025-7>
- Autoridad Maritima de Panama. (2021). *Estadísticas* [Data file]. <https://amp.gob.pa/estadistica/>
- Beuthe, M., Jourquin, B., Geerts, J.-F., & Ndjang’Ha, C. K. (2001). Freight transportation demand elasticities: A geographic multimodal transportation network analysis. *Transportation Research Part E: Logistics and Transportation Review*, 37(4), 253–266. [https://doi.org/10.1016/S1366-5545\(00\)00022-3](https://doi.org/10.1016/S1366-5545(00)00022-3)
- Halff, A., Younes, L., & Boersma, T. (2019). The likely implications of the new IMO standards on the shipping industry. *Energy Policy*, 126, 277–286. <https://doi.org/10.1016/j.enpol.2018.11.033>
- Harris, C. (2012). *Senate Bill 1243 (Lowenthal) Regarding Bunker Fuel*. State Legislation Committee. http://www.longbeach.gov/globalassets/city-manager/media-library/documents/government-affairs/state-resolutions/2012/bunker-fuel_070312-r-21sratt1

References

- International Monetary Fund. (2011). *Market-Based Instruments for International Aviation and Shipping as a Source of Climate Finance* (p. 66). International Monetary Fund.
- International Monetary Fund. (2021). *Global price of Brent Crude* [Data file].
<https://fred.stlouisfed.org/series/POILBREUSDM>
- Keen, M., Parry, I., & Strand, J. (2013). Planes, ships and taxes: Charging for international aviation and maritime emissions. *Economic Policy*, 28(76), 701–749. <https://doi.org/10.1111/1468-0327.12019>
- Lee, C.-Y., Lee, H. L., & Zhang, J. (2015). The impact of slow ocean steaming on delivery reliability and fuel consumption. *Transportation Research Part E*, 76, 176–190. <https://doi.org/10.1016/j.tre.2015.02.004>
- Maritime and Port Authority of Singapore. (2021). *Port Statistics* [Data file].
<https://www.mpa.gov.sg/web/portal/home/maritime-singapore/port-statistics>
- Mazraati, M. (2011). Challenges and prospects of international marine bunker fuels demand. *OPEC Energy Review*, 35(1), 1–26. <https://doi.org/10.1111/j.1753-0237.2010.00182.x>
- Michaelowa, A., & Krause, K. (2000). International Maritime Transport and Climate Policy. *Intereconomics*, 35(3), 127–136.
- Odey, F., & Lacey, M. (2018). *IMO 2020—Short term implications for the oil market* (p. 10). Schrodgers.

References

- OECD. (2020). *OECD Library—IEA World Energy Statistics and Balances* [Data file]. <http://dx.doi.org/10.1787/enestats-data-en>
- Oum, T. H. (1979). Derived Demand for Freight Transport and Inter-Modal Competition in Canada. *Journal of Transport Economics and Policy*, 13(2), 149–168.
- Parry, I., Heine, D., Kizzier, K., & Smith, T. (2018). *Carbon Taxation for International Maritime Fuels: Assessing the Options* (IMF Working Paper WP/18/203; p. 39). International Monetary Fund.
- Pindyck, R. S., & Rubinfeld, D. L. (1991). *Econometric Models and Economic Forecasts*. McGraw-Hill.
- Saad, M. M., Austen, S., & Taylor, S. (1985). Demand for Australia's International Sea Freight Task. *Forum Papers of the 10th Australian Transport Research Forum*, 2, 71–92.
- Smith, T., Raucci, C., Haji Hosseinloo, S., Rojon, I., Calleya, J., Suarez De La Fuente, S., Wu, P., & Palmer, K. (2016). *CO2 emissions from international shipping: Possible reduction targets and their associated pathways* (p. 61). UMAS.
- State of Washington. (2021). *Vessel to Vessel Oil Transfer*. Department of Ecology.
- Stock, J. H., & Yogo, M. (2010). Testing for Weak Instruments in Linear IV Regression. In *Identification and Inference for Econometric Models* (pp. 80–108). Cambridge University Press.

References

- The Northwest Seaport Alliance. (2021). *Cargo Statistics* [Data file]. <https://www.nwseaportalliance.com/about-us/cargo-statistics>
- UNCTAD. (2020). *UNCTAD Stat—Maritime Transport* [Data file]. <https://unctadstat.unctad.org/wds/ReportFolders/reportFolders.aspx>
- U.S. Environmental Protection Agency. (2008). *Global Trade and Fuels Assessment—Future Trends and Effects of Requiring Clean Fuels in the Marine Sector* (No. EPA420-R-08-021; p. 197). U.S. Environmental Protection Agency.
- Winebrake, J. J., Green, E. H., Comer, B., Li, C., Froman, S., & Shelby, M. (2015a). Fuel price elasticities for single-unit truck operations in the United States. *Transportation Research Part D*, 38, 178–187. <https://doi.org/10.1016/j.trd.2015.05.003>
- Winebrake, J. J., Green, E. H., Comer, B., Li, C., Froman, S., & Shelby, M. (2015b). Fuel price elasticities in the U.S. combination trucking sector. *Transportation Research Part D*, 38, 166–177. <https://doi.org/10.1016/j.trd.2015.04.006>