Air Transportation Systems Lab

TOZCA
Towards Zero–Carbon Aviation

UCL

Global air freight flow data for aviation policy modelling

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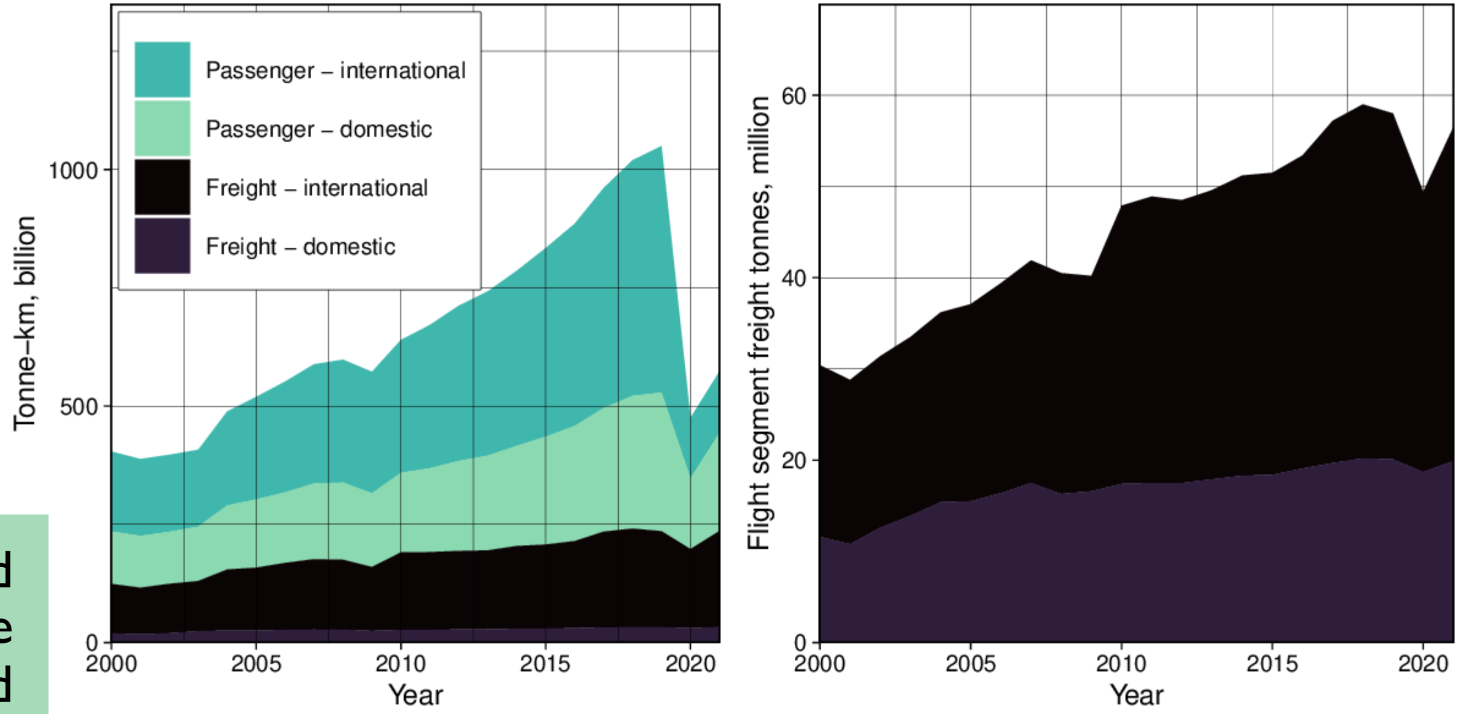
Introduction

- Aviation environmental and policy analysis often focusses on passengers only
- But air freight was responsible for 22% of global TKM in 2019 – more than North American passenger traffic (ICAO, 2023)
  - In 2020-21, Covid19 → freight and mail were **over 40%** of global TKM
- Why is air freight ignored?
  - Smaller total impact than passengers
  - Small fraction of global trade by weight
  - Complexity of operations (Feng et al. 2015)
  - Global nature difficult to incorporate into regional studies
  - **Lack of data**

This study, as part of the ToZCA project led by UCL ATSLab, aims to address this issue by generating a free database of estimated air freight capacity, demand and routing



[Data: ICAO, 2007-2023]

Context of the study

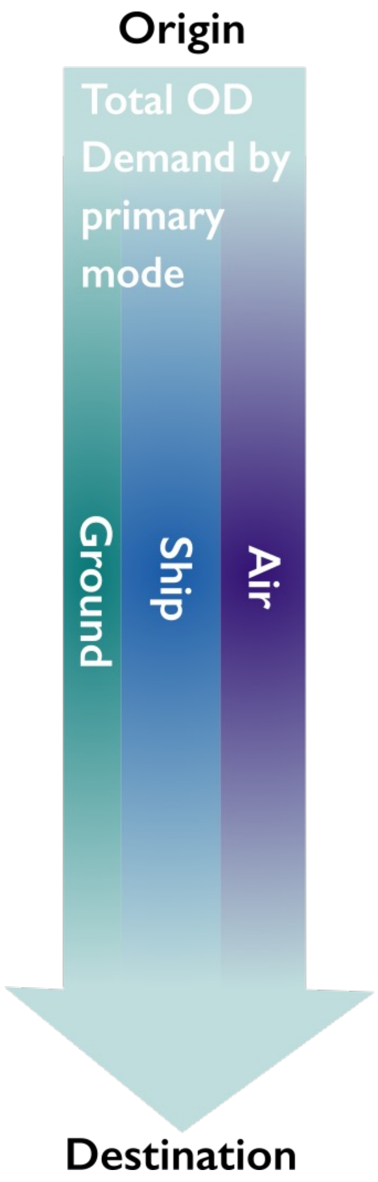
- Air freight is used for (Hummels & Schaur, 2013):
  - Perishable commodities – e.g. fruit, flowers, seafood
  - Time sensitive/just-in-time goods – e.g. fashion, components
  - Valuable goods (high VWR*) - e.g. phones, laptops, pharmaceuticals
- Extra-EU trade, 2019 (Eurostat, 2023) - air <1% of weight, 30% of value
- Air freight is typically more tolerant than passengers of long journeys, roundabout routing, multiple flight legs, … (Feng et al. 2015)
- Passengers take round trips, freight travels one way (Lux, 2011)

[Images: Wikimedia Commons]

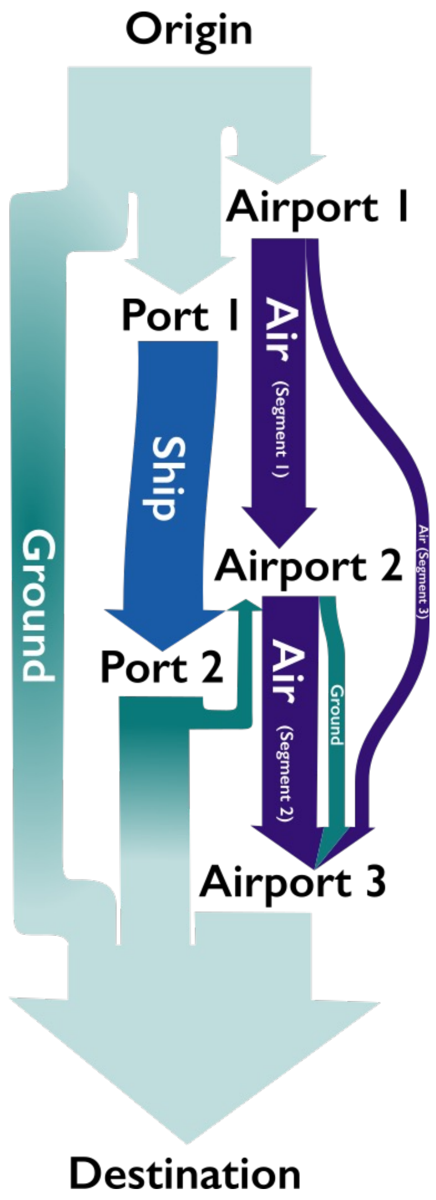
- Multiple types of air freight supply:
  - Passenger hold freight (about 45% of total in 2019; Boeing, 2021)
  - Freighter aircraft (can hold larger items and more types of cargo; Budd & Ison, 2017)
  - Integrators (FedEx, UPS,…) supply integrated service from shipper to consignee – for non-integrator freight airlines, use of forwarders to liase with airlines/customs/etc. is typical

*VWR: Value-to-Weight Ratio

Context of the study



- Work for the ToZCA freight study is still in progress
- For this paper/presentation, we will discuss our estimates of:
- **Air freight supply:**
  - Where is flight segment freighter and hold capacity available? How much of this capacity is used? How did this change over the course of the pandemic?
- **Air freight demand:**
  - What factors affect the choice of whether to ship by air? What is the OD demand for different commodities by country-pair? How did this change over the course of the pandemic?
- For this work, we compare supply and demand but do not attempt to estimate routing
  - This is the next stage of the project

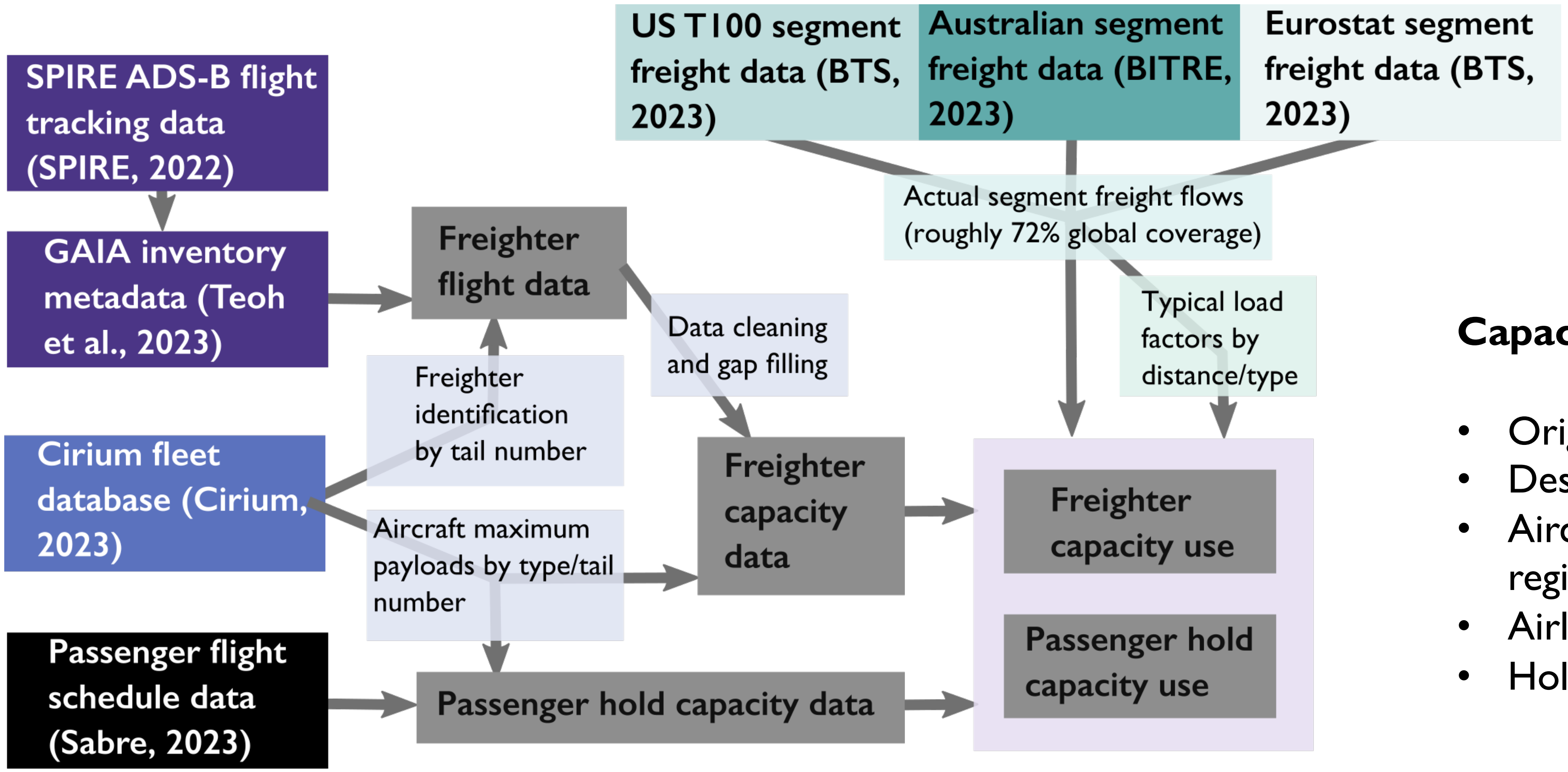


Air freight supply

[Image source: Wikimedia Commons]

- **Hold freight**
  - Number of passenger flights is available in flight schedules (e.g. Sabre, 2023)
  - Aircraft maximum payload available from fleet data (e.g. Cirium, 2023) – we can assume that payload beyond that needed for 100% passenger load factor is available for freight
    - This is a simplification – not all airlines carry freight, extra capacity may be available at lower passenger load factor, less capacity may be available at long distances, etc.
  - For many flight segments, flights and amount of freight transported are available from national databases (BTS, 2023; Eurostat, 2023; BITRE, 2023)
- **Freighters**
  - Often not in flight schedules (particularly for integrators)
  - Are included in flight tracking data (e.g. FlightRadar24, SPIRE ADS-B; Bombelli et al., 2020; Van Bockstaele et al. 2023); data is noisy/gappy
  - Maximum payload can be matched directly to the specific tail number used (Cirium, 2023)
- Note significant disagreement between different data sources for freighter movements (see paper)

Air freight supply – data analysis

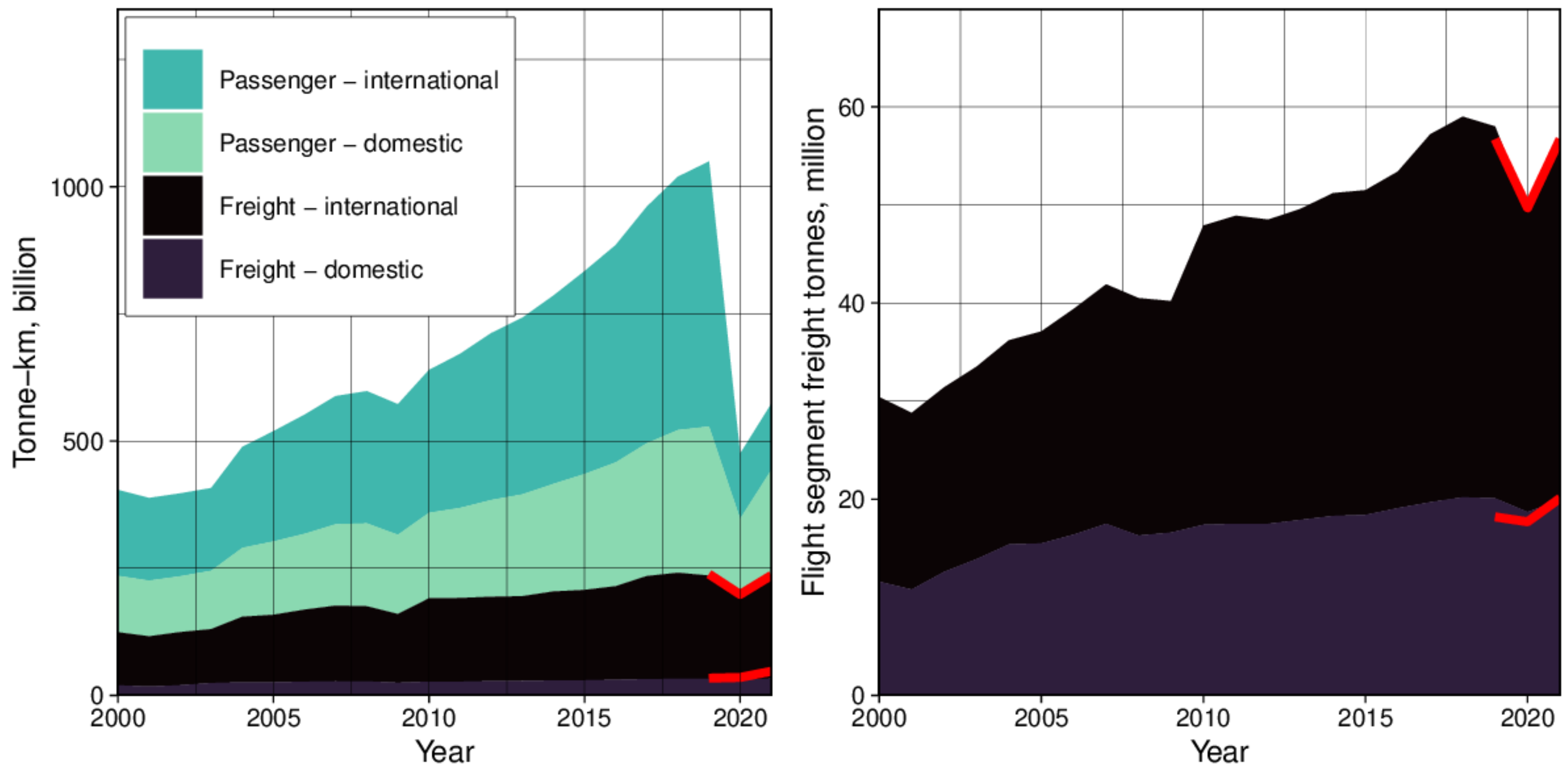


Capacity use by:

- Origin airport
- Destination airport
- Aircraft size class (small regional jet – VLA)
- Airline/alliance*
- Hold/freighter

* Freight alliances only (cf. Boonekamp & Burghouwt, 2017)

Air freight supply

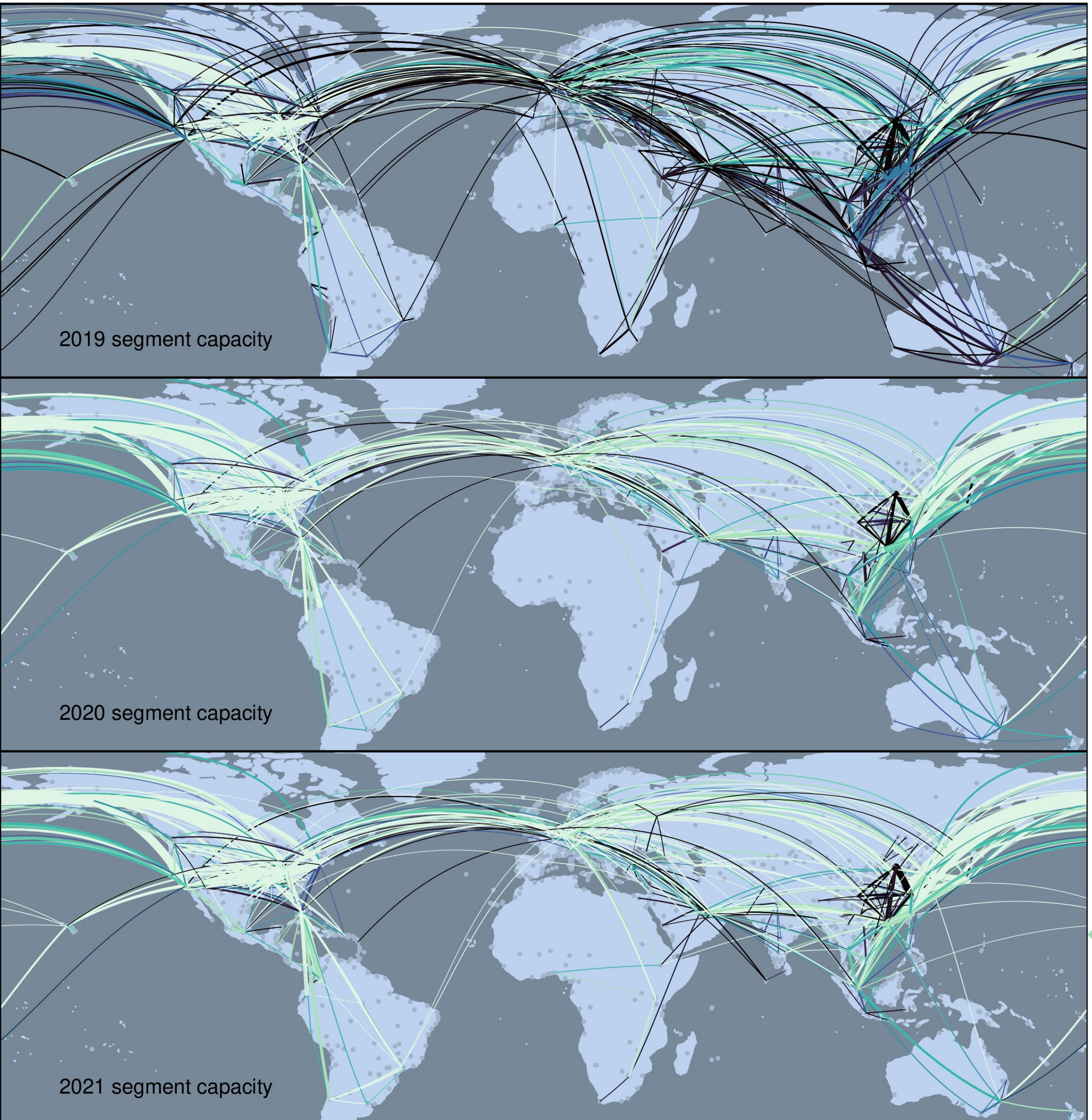


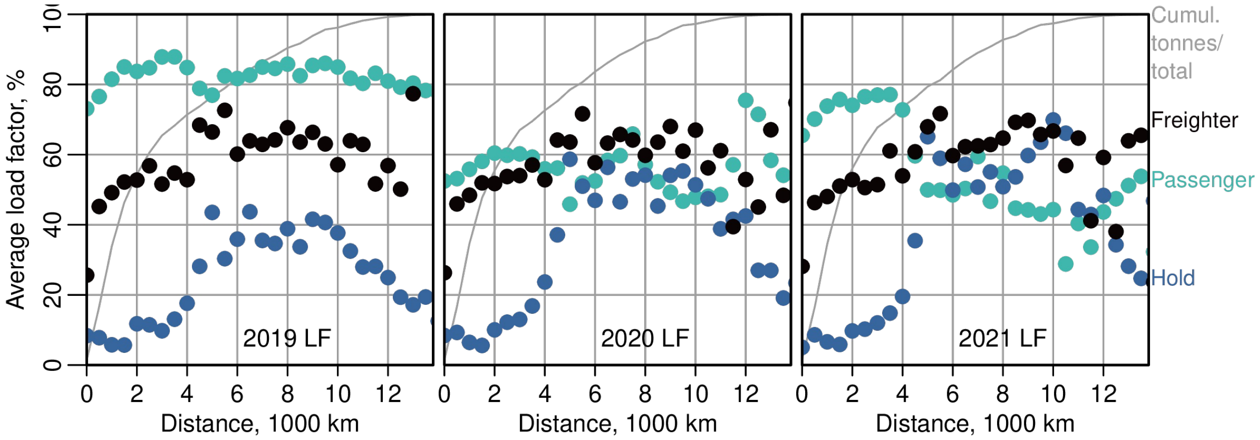
Our estimates if unknown load factor routes behave similarly to known load factor routes

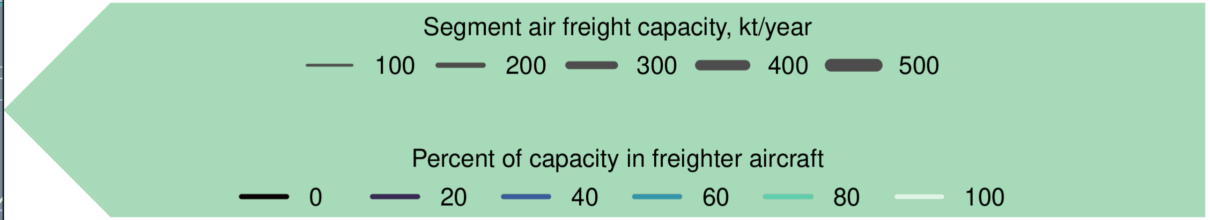
[Data: ICAO, 2007-2023]

Air freight supply

- Type of capacity provided changes 2019-2021
- Locations of provided capacity remain similar

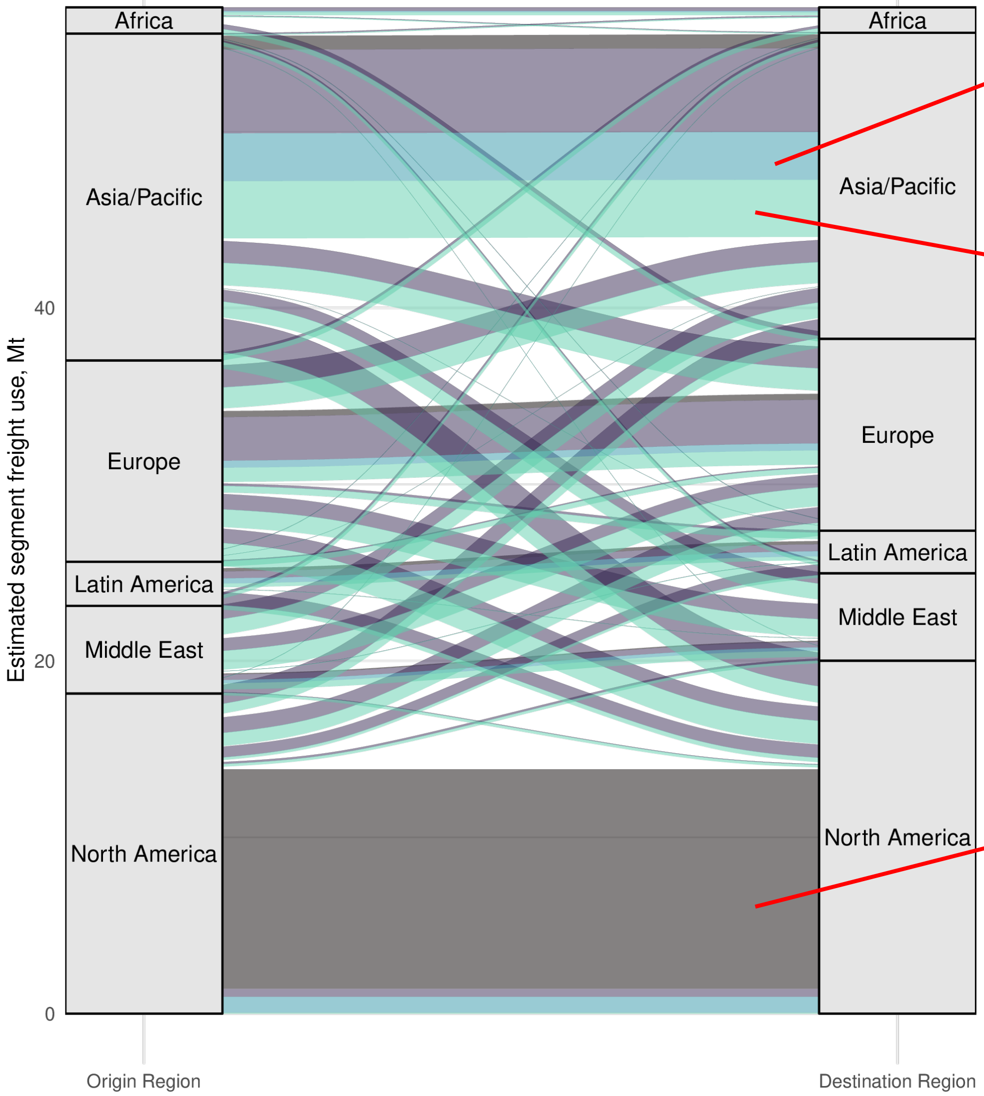






Air freight supply – 2019 vs. 2021

2019

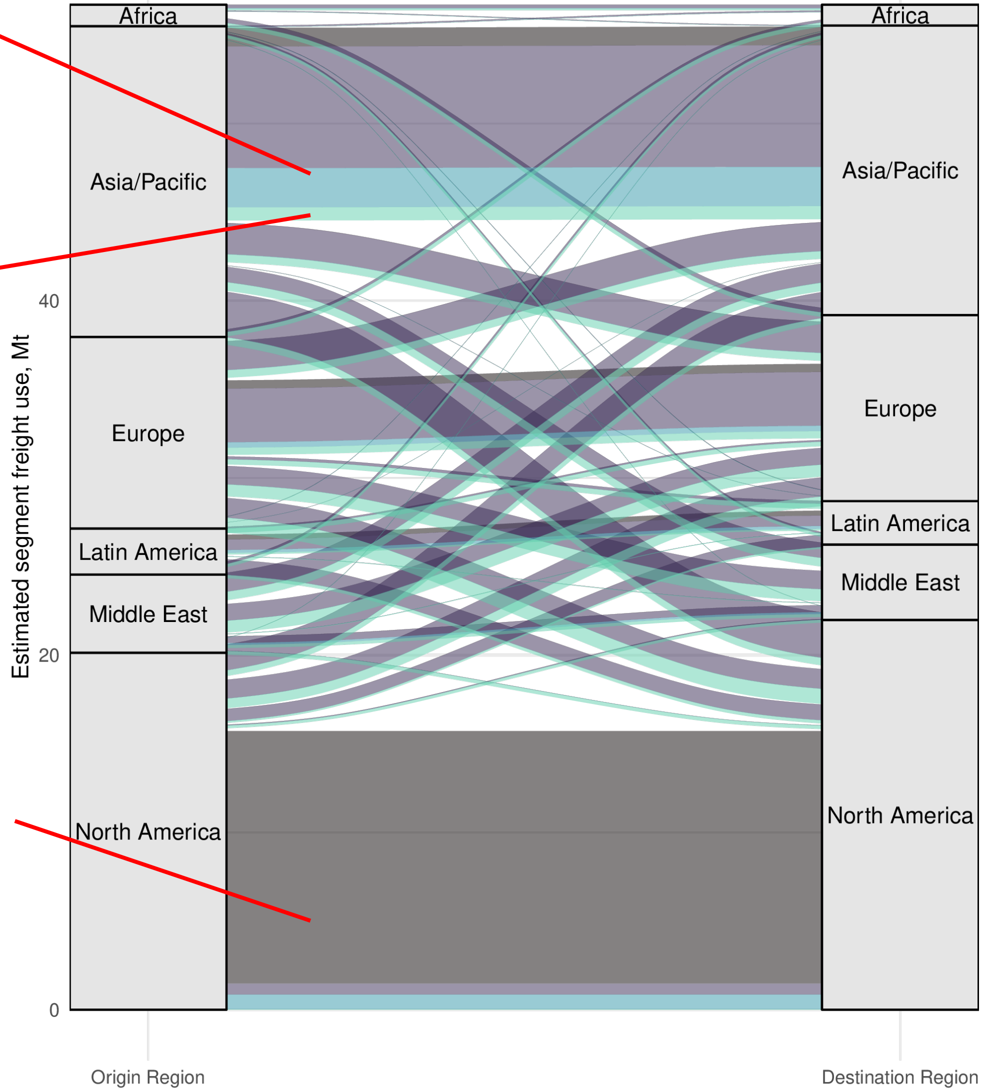


Little change in domestic hold freight

International hold freight decreases

More freight in freighters (where supply allows)

2021



Air freight demand

- International trade can choose ship, air or ground (or a mixture of these)
  - Choice depends on time, cost, commodity, etc.
- Global country-pair trade data with limited mode information is available from UN (2022)
  - Regional databases with mode information include Eurostat COMEXT (2023); FAF (2023); US Census Bureau (2023); ECLAC (2023)
  - These can be used to estimate models of mode choice and value/weight ratios to fill gaps in global data (e.g. UNCTAD, 2022; ITF, 2019)
- To simplify this, we aggregate HS6/SCTG codes to to 19 commodity groups

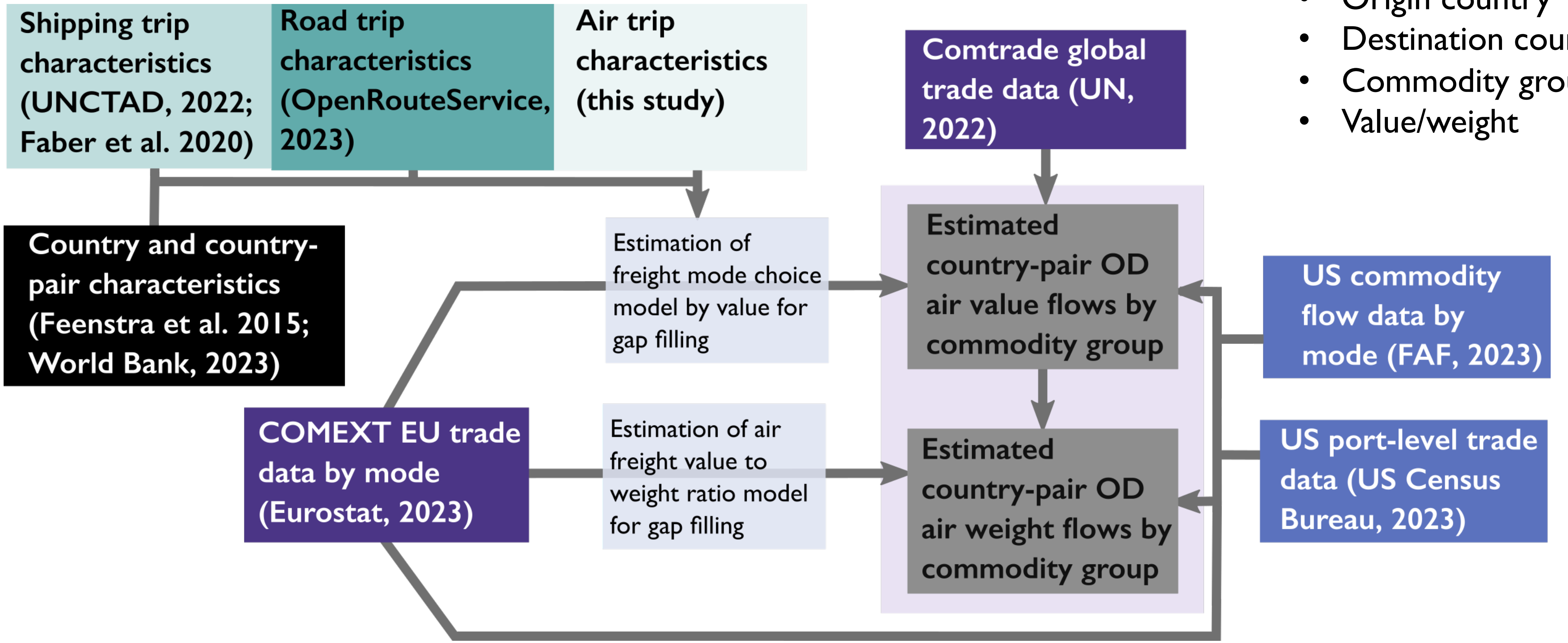

Commodity	Mean value/ weight in 2019 ($\$_{2019}$/kg; UN, 2022)	Total 2019 global int'l export trade value (weight), bln $\$_{2019}$ (Mt)	Typical % COMEXT int'l trade air value (weight) in 2019
Live animals	3.2	23 (7)	38 (3.1)
Meat & fish	3.6	307 (88)	4 (1.4)
Other food	2.2	302 (131)	5 (0.9)
Fruit, vegetables & flowers	1.2	217 (185)	10 (3.4)
Other	0.3	1540 (5540)	6 (0.1)
Chemicals	1.3	485 (405)	31 (0.4)
Pharmaceuticals	101	579 (6)	55 (13)
Chemical products & perfumes	3.3	522 (157)	21 (1.4)
Plastics & Rubber	2.5	752 (295)	10 (0.9)
Clothes, shoes & textiles	7.9	1010 (112)	22 (4.5)
Books & papers	1.4	199 (142)	11 (0.7)
Misc. manufactured products	1.0	941 (911)	69 (3.0)
Base metals	1.4	1010 (697)	7 (0.3)
Base metal implements	8.5	130 (15)	27 (3.4)
Mechanical equipment	17	2110 (125)	37 (5.6)
Electrical equipment	36	2470 (68)	45 (8)
Vehicles & parts	11	1810 (176)	9 (1.2)
Precision implements	93	579 (6)	69 (28)
Excluded	0.3	2190 (9760)	0.03 (0.004)

[Data: UN, 2022; Eurostat, 2023. Images: Wikimedia Commons]

Air freight demand – data analysis

OD demand by:

- Origin country
- Destination country
- Commodity group
- Value/weight



Air freight demand – gap filling

Mode choice:

The value by mode *m* from available modes *M* between origin and destination countries *o* and *d* for commodity group *c*, $S_{m,odc}$, is given by:

$$S_{m,odc} = e^{V_{m,odc}} \Big/ \Sigma_{i \in M} e^{V_{i,odc}} \text{, where}$$

$$V_{m,odc} = ASC_{mc} + \beta_{GCD,mc} D_{od} + \beta_{CB,mc} CB_{od} + \beta_{LL,mc} LL_{od} + \beta_{SL,mc} SL_{od} + \beta_{VWRO,mc} VWR_{oc} + \beta_{VWRD,mc} VWR_{dc} + \beta_{Speed,mc} SPG_{m,od} + \beta_{TA,mc} TA_{od} + \beta_{INT,mc} INT_{od} + \beta_{GCO,mc} GC_{o} + \beta_{GCD,mc} GC_{d} + \beta_{CL,mc} CL_{od}$$

i.e, a function of distance, common border, landlocked o/d, same landmass o/d, o/d country typical VWR, mode speed, o/d trade agreement, integrator service, o/d GDP/capita, o/d common language (costs excluded due to endogeneity)

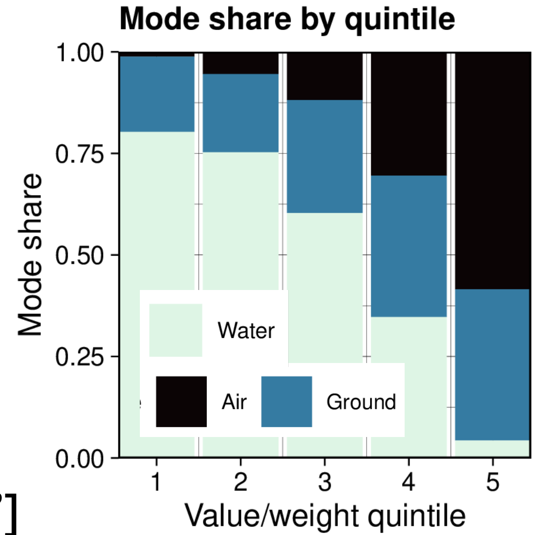
Value to weight ratio (VWR):

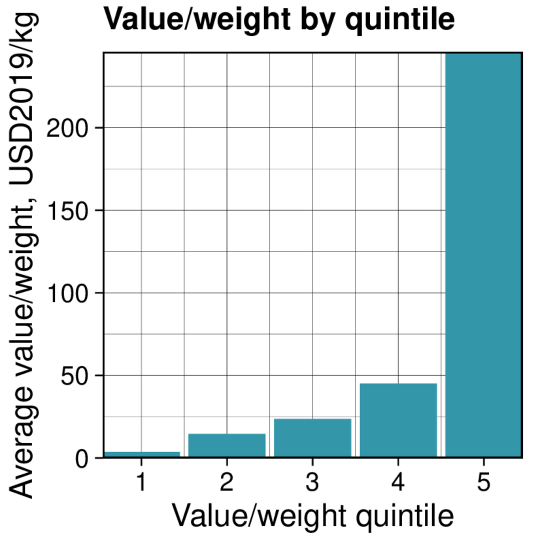
Air VWR calculated using VWR quintile shares given total o/d/commodity flow VWR distribution by quintile:

$S_{air,q} = max(min(\alpha(q - q_{min}), S_{air,sat}), 0)$, s.t.

$\sum_q S_{air,q}/q = S_{air}$,

where $S_{air,sat}$ is a saturation level for air share and q_{min} is the lowest quintile with significant air share



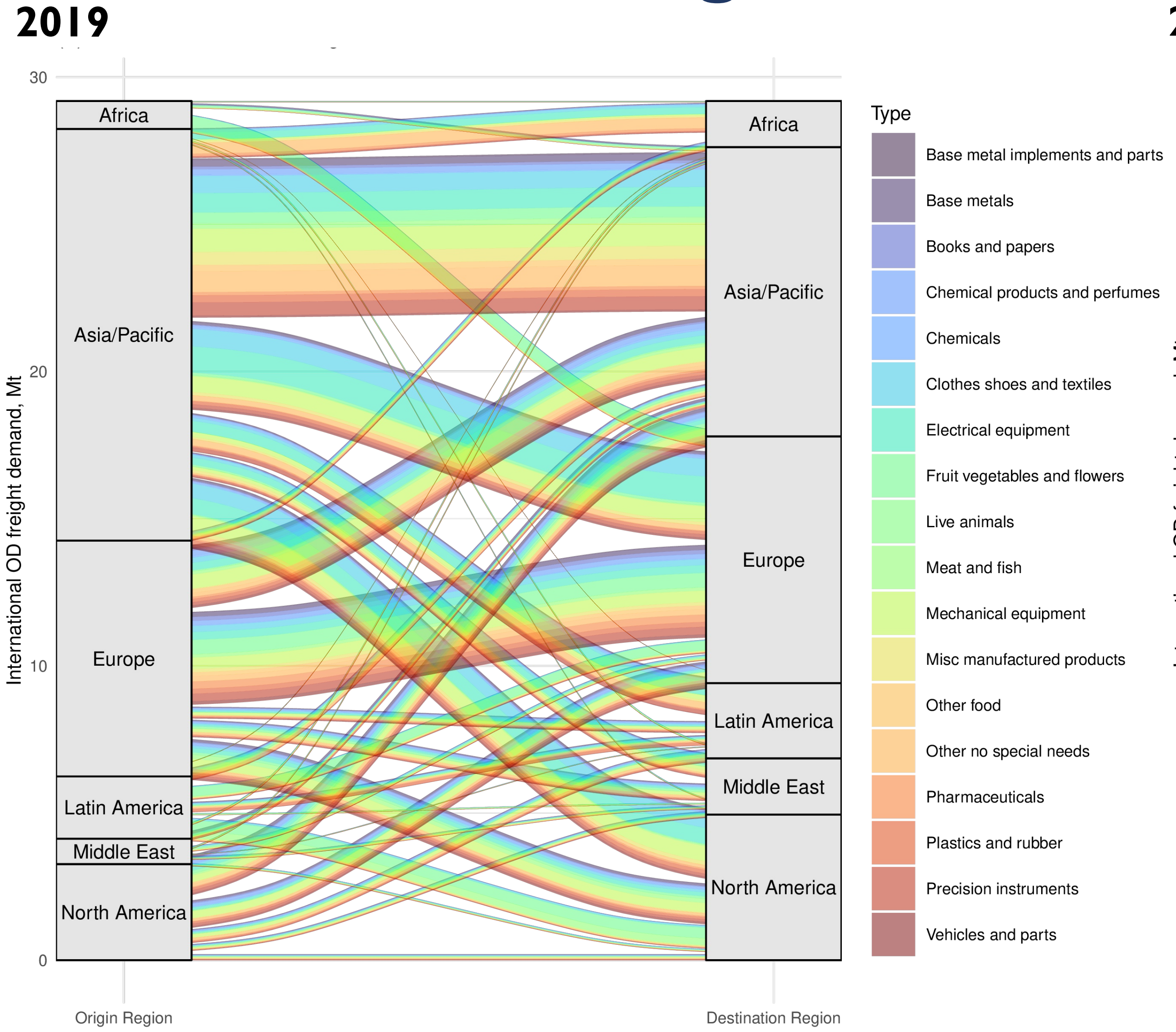


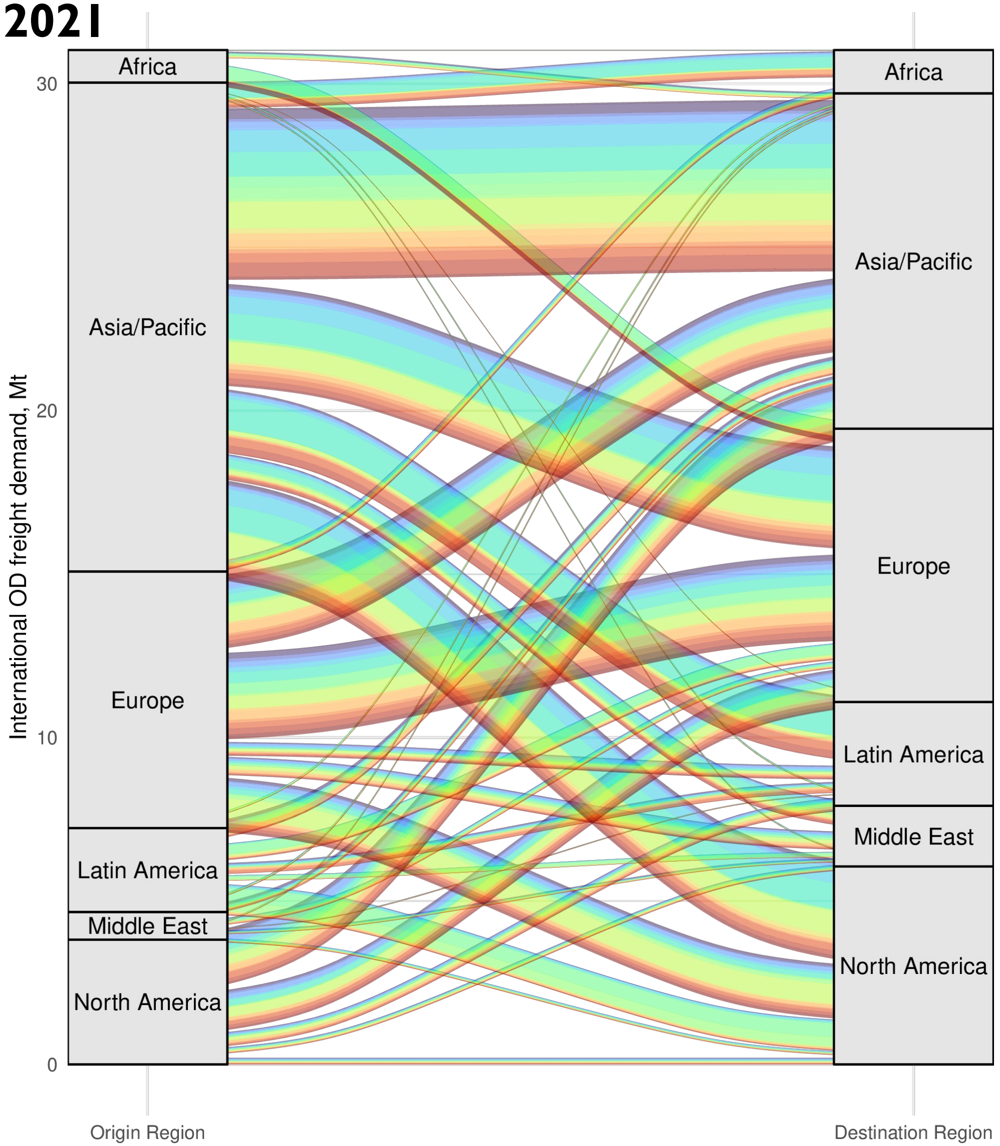
[Data: Eurostat, 2023 for group 'clothes, shoes and textiles']

Air freight demand – gap filling

- Mode choice estimated using the Apollo library in R (Hess & Palma 2019)
- See the paper for parameter estimates (also in annex to this presentation)
- All mode choice parameters are consistent with theory and are significant at at least a 90% level (most 95%)
  - Longer distance – more sea and air
  - Common border, landlocked country, same landmass – less sea and air
  - Trade agreement → more road (easier border crossings; ITF, 2019)
  - Higher typical trade VWR or GDP/capita → more air
  - Faster journey → more demand, particularly for time-sensitive commodities
  - Integrator service, common language → more air, but only for relevant commodities
  - ASC parameters effectively include impact of costs and imply shipping is lowest cost, air highest for most commodities
- R^2 of air predictions is > 0.6 for all commodity groups (typically > 0.9 for air-intensive commodity groups)
- VWR model calibrated using Levenburg-Marquadt (minpack.lm library in R; Elzhov et al., 2022)
  - R^2 of air predictions varies – most are above 0.6
  - For low air shares the fit is less good and we use ‘typical’ air VWR values instead (Eurostat, 2023)

Air freight demand - 2019 vs. 2021





[Note: these have been updated from the figures in our paper due to improvements in reconciling input databases which disagree]

Conclusions

- **Supply**
  - Segment estimates match well to global totals, imply typical freight leg distances of around 4,000 km (over twice passenger)
  - 2019 → 2021 – FTK in freighters 53% → 73%, and load factor changes, but overall flows similar
- **Demand**
  - Around $3.2 tln OD air flows by value in 2019 – similar to UNCTAD (2022) but lower than some literature estimates which may be by flight segment
  - 2019 → 2021 – higher value, slightly higher weight by air, (OD) increases in pharmaceuticals and plastics
  - Implied 1.5-1.8 flight segments per average trip (including domestic segments; FAF, 2023); 1.16 for passengers (Sabre, 2023)
  - Significant diversity in commodities carried by region and asymmetric routing is implied – but with high uncertainty
- **Policy implications**
  - Freight policy response likely to vary by route group due to commodity diversity
  - Cannot ignore multi-leg complex journeys
- **Next steps**
  - Optimisation-based matching of supply and demand
  - Generation and release of free database
  - Use in airline behaviour modelling (cf. Doyme et al., 2019)

More information: www.atslab.org

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Annex: parameter estimates (mode share model, ground and sea)

	N	Ground	Sea										
		Speed	ASC	Distance	CB	LL	SL	VWR_O	VWR_D	Speed	TA	GDP/cap_O	GDP/cap_D
Live animals	551	0.012 (0.007)	1.33 (0.78)	2.7e-4 (7.5e-5)	-2.15 (0.84)	-2.02 (0.37)	-1.37 (0.35)	-0.018 (0.004)	-	0.051 (0.025)	-	-2.3e-5 (9.5e-6)	-
Meat and fish†	929	0.032 (0.006)	1.83 (0.39)	5.0e-4 (4.5e-5)	-0.90 (0.52)	-2.21 (0.32)	-1.18 (0.27)	-	-	0.035 (0.014)	-	-	-1.2e-5 (3.4e-6)
Other food**	3016	0.024 (0.004)	2.83 (0.26)	4.7e-4 (2.7e-5)	-1.61 (0.47)	-1.61 (0.10)	-1.55 (0.13)	-0.21 (0.05)	-0.21 (0.04)	-	-	1.3e-5 (2.9e-6)	-
Fruit, veg, flowers‡	1291	0.027 (0.005)	1.04 (0.40)	5.7e-4 (4.0e-5)	-1.50 (0.51)	-1.46 (0.17)	-1.58 (0.19)	-	-	0.027 (0.011)	-	2.4e-5 (4.1e-6)	-
Other**	6732	0.024 (0.004)	2.31 (0.29)	3.9e-4 (2.4e-5)	-1.75 (0.31)	-1.75 (0.10)	-1.26 (0.13)	-	-0.25 (0.03)	0.017 (0.007)	-0.18 (0.09)	4.8e-6 (2.3e-6)	-
Chemicals	1175	0.058 (0.012)	3.22 (0.04)	2.2e-4 (3.6e-5)	-1.91 (0.27)	-2.04 (0.17)	-2.04 (0.17)	-0.056 (0.012)	-	0.041 (0.009)	-	-	-
Pharmaceuticals	2257	0.017 (0.004)	2.42 (0.30)	2.1e-4 (3.4e-5)	-1.39 (0.49)	-1.46 (0.13)	-1.88 (0.15)	-	-	-	-0.76 (0.15)	-1.4e-5 (3.2e-6)	-
Chemical products	1906	0.025 (0.003)	1.36 (0.26)	4.4e-4 (2.5e-5)	-1.88 (0.38)	-1.53 (0.12)	-1.38 (0.13)	-	-	0.018 (0.003)	-	9.7e-6 (2.5e-6)	-
Plastics & Rubber	2788	0.022 (0.003)	2.31 (0.26)	4.9e-4 (2.3e-5)	-2.23 (0.48)	-1.45 (0.10)	-1.51 (0.12)	-0.166 (0.024)	-0.090 (0.043)	-	-	1.0e-5 (2.1e-6)	-
Clothes & textiles	1882	0.034 (0.003)	2.29 (0.29)	4.2e-4 (3.1e-5)	-1.50 (0.43)	-1.20 (0.12)	-1.32 (0.13)	-0.013 (0.005)	-0.018 (0.004)	-	-0.49 (0.14)	1.1e-5 (2.7e-6)	4.7e-6 (2.6e-6)
Books & papers	1799	0.026 (0.004)	1.43 (0.33)	5.3e-4 (3.8e-5)	-1.90 (0.41)	-1.98 (0.14)	-1.52 (0.17)	-	-	0.022 (0.008)	-	1.33e-5 (3.4e-6)	-
Misc. m. prods	1243	0.0060 (0.0029)	0.95 (0.17)	2.4e-4 (2.4e-5)	-2.23 (0.57)	-1.41 (0.17)	-1.13 (0.18)	-0.0025 (2.7e-4)	-	-	-	-	-
Base metals	1596	0.018 (0.004)	1.88 (0.32)	3.3e-4 (4e-5)	-1.37 (0.26)	-1.71 (0.13)	-1.11 (0.16)	-	-	0.022 (0.007)	-0.32 (0.01)	5.6e-6 (2.8e-6)	-
Base m. impl.	1484	0.019 (0.004)	2.10 (0.31)	3.1e-4 (3e-5)	-2.25 (0.53)	-1.68 (0.14)	-1.67 (0.15)	-	-	-	-0.55 (0.17)	-	-
Mechan. equip.	2454	0.020 (0.003)	1.11 (0.23)	3.5e-4 (2.1e-5)	-1.58 (0.36)	-1.49 (0.09)	-1.18 (0.11)	-	0.016 (0.006)	0.009 (0.005)	-	4.7e-6 (2.1e-6)	-8.4e-6 (1.2e-6)
Elec. equip.	1860	0.021 (0.003)	1.26 (0.17)	2.8e-4 (2.5e-5)	-1.86 (0.49)	-1.24 (0.11)	-1.32 (0.13)	-0.0038 (0.001)	-	0.033 (0.007)	-0.44 (0.13)	1.1e-5 (2.5e-6)	-
Vehicles†† & parts	1399	-	1.32 (0.18)	9.6e-5 (2.4e-5)	-1.91 (0.38)	-1.36 (0.17)	-0.94 (0.18)	-	-	-	-	-	-
Precision impl'ts	2436	0.011 (0.003)	1.25 (0.27)	2.3e-4 (2.6e-5)	-1.69 (0.55)	-1.01 (0.11)	-1.60 (0.12)	-0.0021 (5e-4)	-	0.013 (0.006)	-0.49 (0.11)	-	-

* Significant at 90%.

† For Meat and Fish, air utility is also modelled as a function of the fraction of fish by value in the total OD freight flow (F_{TS}). Additionally, dummy variables for flows originating in the UK and Denmark are used in the air utility. Parameters (standard errors) are 1.43 (0.24; air, F_{TS}) 1.46 (0.27; air, UK origin) and -2.69 (0.28; air, DK origin).

** For Other Food and Other, dummy variables for OD flows to and from China respectively are used in the air utility, values (standard errors) 0.47 (0.28) and -0.37 (0.12).

‡For Fruit, Vegetables and Flowers, utility is also a function of the fraction of flowers in the total OD freight flow (F_{TS}). Parameters (standard errors) are 0.95 (0.34) for air, -2.18 (0.33) for sea.

†† For Vehicles and parts, sea utility is also a function of the fraction of aircraft parts in the total OD freight flow (F_{TS}) and a dummy variable for flows to and from Germany is used in the air utility. Parameters (standard errors) are -3.5 (0.17; sea, F_{TS}) and -0.56 (0.12; air, DE origin/destination).

Annex: parameter estimates (mode share model,air)

	Air													LogLik	R^2
	ASC	Distance	CB	LL	SL	VWR_O	VWR_D	Speed	TA	INT	GDP/cap_O	GDP/cap_D	CL	Initial, Final	All, Air
Live animals	-0.72 (0.55)*	7.1e-4 (6.3e-5)	-1.99 (0.89)	-1.57 (0.24)	-0.86 (0.28)	-0.004 (7.7e-4)	-	-	-	-	-	2.2e-5 (4.3e-6)	-	-563, -312	0.66, 0.75
Meat and fish	-2.66 (0.53)	5.0e-4 (4.4e-5)	-3.81 (0.54)	-0.62 (0.38)*	-1.67 (0.34)	-	0.28 (0.05)	8.6e-4 (3.2e-4)	-0.93 (0.19)	-	1.4e-5 (3.8e-6)	-	-	-895, -433	0.92, 0.61
Other food	-2.03 (0.29)	4.0e-4 (2.9e-5)	-2.26 (0.49)	-0.49 (0.14)	-1.21 (0.16)	-	-	7.1e-4 (1.9e-4)	-	0.19 (0.11)	1.5e-5 (3.3e-6)	-	-	-2946, -1361	0.95, 0.70
Fruit, veg, flowers	-1.59 (0.41)	5.7e-4 (4.2e-5)	-5.74 (0.57)	-0.68 (0.21)	-1.58 (0.22)	-	-	7.0e-4 (2.5e-4)	-	-	1.1e-5 (5.1e-6)	1.9e-5 (2.9e-6)	-	-1259, -693	0.76, 0.62
Other	-2.02 (0.31)	4.4e-4 (2.2e-5)	-2.73 (0.38)	-0.83 (0.11)	-0.88 (0.14)	0.25 (0.04)	-	5.9e-4 (2.3e-6)	-		2.3e-5 (2.8e-6)	-	-	-3162, -1579	0.97, 0.60
Chemicals	0.91 (0.40)	3.2e-4 (3.8e-5)	-2.31 (0.50)	-1.0 (0.18)	-1.18 (0.19)	-	-	-	-	0.40 (0.17)	7.0e-6 (2.6e-6)	-	0.45 (0.19)	-1164, -796	0.80, 0.85
Pharmaceuticals	1.71 (0.28)	2.5e-4 (3.4e-5)	-1.95 (0.39)	-0.73 (0.11)	-1.29 (0.13)	-	-	-	-0.67 (0.14)	-	1.3e-5 (2.8e-6)	-	-	-2224, -1711	0.95, 0.97
Chemical products	-0.47 (0.26)	4.94e-4 (2.6e-5)	-1.61 (0.30)	-0.79 (0.12)	-1.07 (0.14)	0.011 (0.004)	-	2.2e-4 (1.3e-4)	-	-	1.6e-5 (2.7e-6)	-	-	-1896, -1344	0.87, 0.69
Plastics & Rubber	-1.80 (0.27)	5.1e-4 (2.4e-5)	-2.20 (0.25)	-0.99 (0.12)	-1.22 (0.13)	-	0.113 (0.046)	-	-	0.23 (0.07)	2.3e-5 (1.2e-6)	-	-	-2765, -1567	0.95, 0.81
Clothes & textiles	-1.0 (0.29)	4.3e-4 (3.1e-5)	-2.23 (0.28)	-1.01 (0.13)	-1.08 (0.13)	0.029 (0.004)	0.011 (0.005)	8.6e-4 (1.5e-4)	-0.52 (0.15)	0.56 (0.09)	2.0e-5 (2.7e-6)	4.6e-6 (2.8e-6)	0.56 (0.09)	-1874, -1321	0.92, 0.76
Books & papers	-1.43 (0.35)	5.6e-4 (4.0e-5)	-1.86 (0.47)	-1.12 (0.16)	-1.28 (0.18)	0.084 (0.013)	-	7.0e-4 (1.6e-4)	-	-	2.8e-5 (3.8e-6)	-	0.40 (0.12)	-1779, -1040	0.94, 0.70
Misc. m. prods	-	2.0e-4 (2.2e-5)	-1.65 (0.27)	-0.75 (0.15)	-0.80 (0.16)	-	0.025 (2.9e-4)	4.5e-4 (1.6e-4)	-	-	1.2e-5 (2.0e-6)	-	-	-1233, -1010	0.88, 0.93
Base metals	-2.64 (0.39)	3.7e-4 (3.9e-5)	-2.46 (0.32)	-1.51 (0.20)	-1.32 (0.18)	0.17 (0.04)	-	4.3e-4 (1.8e-4)	-0.48 (0.20)	0.97 (0.16)	2.9e-05 (3e-6)	-	-	-1596, -802	0.93, 0.74
Base m. impl.	-0.52 (0.32)	3.3e-4 (3e-5)	-1.79 (0.33)	-1.08 (0.13)	-1.25 (0.15)	0.057 (0.004)	-	6.8e-4 (1.4e-5)	-0.61 (0.23)	0.38 (0.09)	-	-	-	-766, -563	0.90, 0.75
Mechan. equip.	-0.80 (0.22)	3.6e-4 (2.1e-5)	-1.69 (0.29)	-1.18 (0.09)	-1.10 (0.11)	-	0.027 (0.007)	2.6e-4 (1.0e-4)	-	0.25 (0.06)	1.9e-5 (2.2e-6)	-	0.31 (0.09)	-2426, -1925	0.87, 0.88
Elec. equip.	-	3.5e-4 (2.4e-5)	-1.70 (0.21)	-1.01 (0.11)	-0.91 (0.12)	-	-	3.2e-4 (1.2e-4)	-0.56 (0.12)	0.53 (0.07)	2.3e-5 (2.2e-6)	-	-	-1849, -1491	0.84, 0.90
Vehicles & parts	-1.06 (0.27)	5.8e-5 (2.7e-5)	-1.85 (0.34)	-0.94 (0.18)	-0.89 (0.19)	-	-	2.9e-4 (1.7e-4)	-0.58 (0.12)	-	-	-	-	-2060, -1315	0.93, 0.74
Precision impl'ts	0.93 (0.23)	2.6e-4 (2.4e-5)	-1.34 (0.21)	-0.78 (0.08)	-0.98 (0.10)	0.0028 (7e-4)	0.0022 (5e-4)	-	-0.36 (0.10)	0.21 (0.06)	-	6.9e-6 (1.3e-6)	-	-2402, -1740	0.97, 0.99

* Significant at 90%.

Annex: parameter estimates (air VWR model)

Commodity	q_{min}	$S_{air,sat}$	R^2	Low air share VWR, $\$_{2019}$/kg
Live animals	4	1	0.42	73.2
Meat & fish	4	1	0.93	11.8
Other food	4	1	0.97	12.8
Fruit, vegetables & flowers	4	1	0.94	4.34
Chemicals	3.94 (2.6)	0.33 (0.02)	0.20	201
Pharmaceuticals	4	0.67 (0.02)	0.82	777
Chemical products & perfumes	3.43 (0.17)	0.64 (0.01)	0.78	65.4
Plastics & Rubber	4	0.65 (0.01)	0.75	34.0
Clothes, shoes & textiles	2.01 (0.05)	0.61 (0.02)	0.94	58.4
Books & papers	4	1	0.32	22.4
Misc. manufactured products	2.13 (0.10)	0.43 (0.01)	0.74	797
Base metals	4	0.56 (0.01)	0.53	36.9
Base metal implements	4	0.64 (0.02)	0.67	84.5
Mechanical equipment	4	0.53 (0.01)	0.74	132
Electrical equipment	0	0.36 (0.04)	0.70	149
Vehicles & parts	2.83 (0.12)	0.53 (0.05)	0.42	118
Precision instruments	3	0.41 (0.06)	0.89	300

For the commodity group ‘other’, due to typically low air mode shares, an average low air share VWR ($44/kg) was used throughout