



ISA Study Day - 'Aviation and the Environment'

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Data-driven airline passenger flight supply comparison using optimal transport theory

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Joint work with Prof. Chantal Roucolle (ENAC), Prof. Paul Rochet (ENAC)





To start with...



Context: Airline competition



Competition plays a central role in shaping firm behavior and market outcomes

Low competition market:

Less demanding operating environment

- Higher ticket prices
- Reduced service frequency or capacity
- Decreased route entry / fewer new destinations




⇒ Lower consumer welfare / reduced choice

Policy:

- Price regulation
- Entry facilitation
- Antitrust enforcement / merger control ...






Context: airline competition

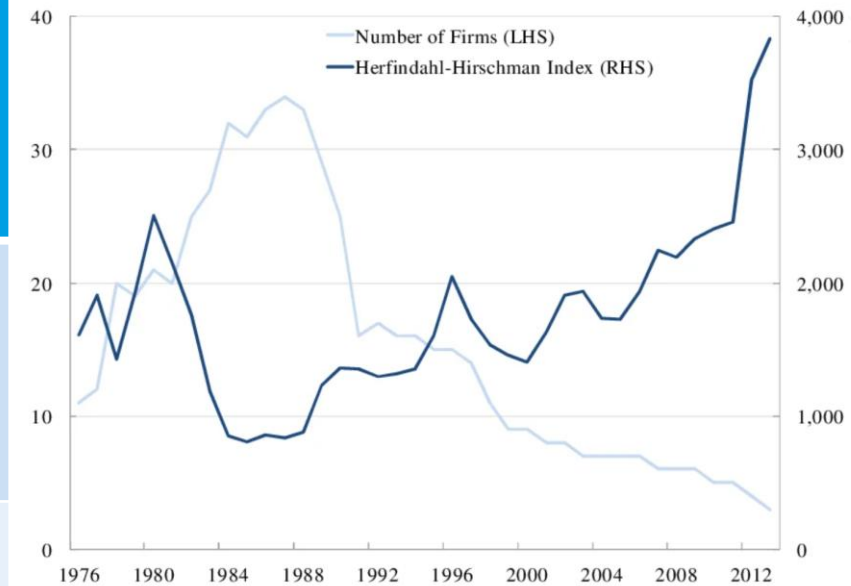
Literature	Airline competition models
type	
 <p>Study focus</p>	<ul style="list-style-type: none"> Strategic reaction on price, quantity
 <p>Description</p>	<ul style="list-style-type: none"> Structural models Oligopoly competition: Bertrand; Cournot Dynamic models Game theory; regression...
 <p>Limitation</p>	<ul style="list-style-type: none"> Computational, complex Strong assumptions



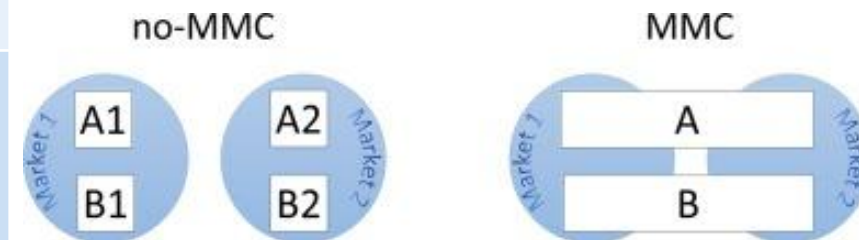


Context: airline competition

Literature type	Airline competition models	Market competition measurement
 <p>Study focus</p>	<ul style="list-style-type: none"> Strategic reaction on price, quantity 	<ul style="list-style-type: none"> Market structure summary statistics
 <p>Description</p>	<ul style="list-style-type: none"> Structural models Oligopoly competition: Bertrand; Cournot Dynamic models Game theory; regression... 	<ul style="list-style-type: none"> Market based concentration measures: HHI; CR Airline based Multimarket contact (MMC); graph-based measures
 <p>Limitation</p>	<ul style="list-style-type: none"> Computational, complex Strong assumptions 	<ul style="list-style-type: none"> Overlook route market heterogeneity



Herfindahl-Hirschman Index (HHI) of the Global HDD Market



Model: Optimal Transport

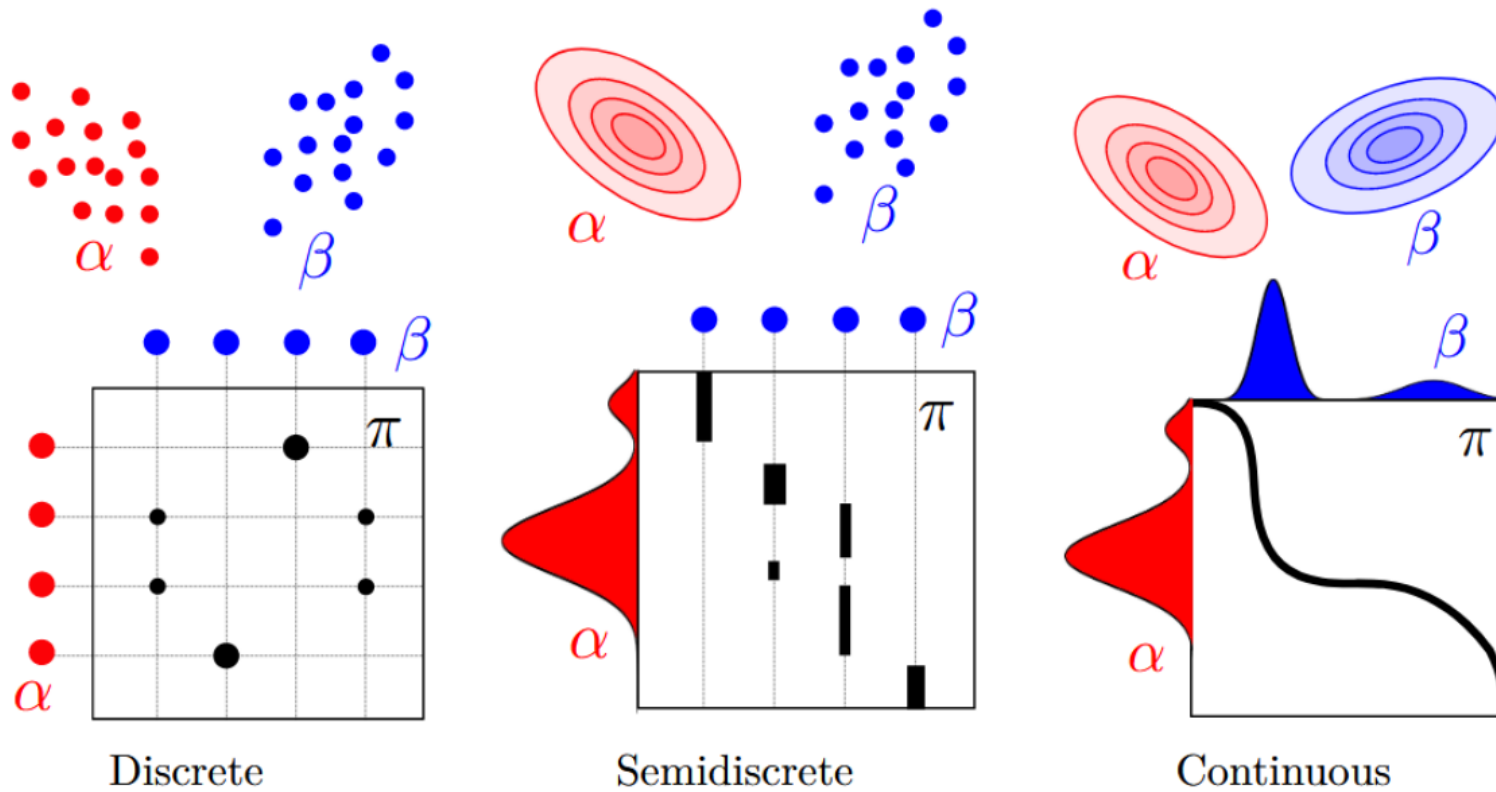





Image: Gabriel Peyré and Marco Cuturi. Computational Optimal Transport.

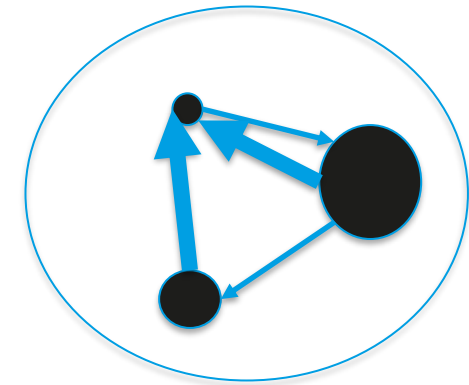
Motivation: optimal transport theory (OT)

Literature		<i>Airline competition models</i>	<i>Market competition measurement</i>	<i>Optimal transport theory</i>
		<i>type</i>		
	Study focus	<ul style="list-style-type: none"> Strategic reaction on price, quantity 	<ul style="list-style-type: none"> Market structure summary statistics 	<ul style="list-style-type: none"> In transportation Design and optimize network structures In applied economics Resource matching and allocation
	Description	<ul style="list-style-type: none"> Structural models Oligopoly competition: Bertrand; Cournot Dynamic models Game theory; regression... 	<ul style="list-style-type: none"> Market based concentration measures: HHI; CR Airline based Multimarket contact (MMC); graph-based measures 	<ul style="list-style-type: none"> Measure dissimilarity between distributions
	Limitation	<ul style="list-style-type: none"> Computational, complex Strong assumptions 	<ul style="list-style-type: none"> Overlook route market heterogeneity 	<ul style="list-style-type: none"> Not used in supply analysis



Research Question

- For who? Airlines or authorities
- **Question:**
 - Improve airline-based pairwise supply analysis using OT framework?
- **Answer:**
 - Domain-specific cost functions from 3 aspects:
 - Route strategic positioning
 - Spatial supply competitive intensity
 - Operational cost





How exactly?

Model: Optimal Transport

Data: Scheduled flights EU

Model:

route space $R := \{r_1, \dots, r_N\}$

cost matrix C

transport plan T

$$f^a = \sum_{r \in R} f_r^a$$

$$\mu = (p_r^a)_{r \in R} \text{ with } p_r^a = f_r^a / f^a$$

$$I(\mu, \nu) \stackrel{\text{def}}{=} \min_{T \in \Gamma(\mu, \nu)} \sum_{r, r' \in R} c(r, r') T(r, r')$$

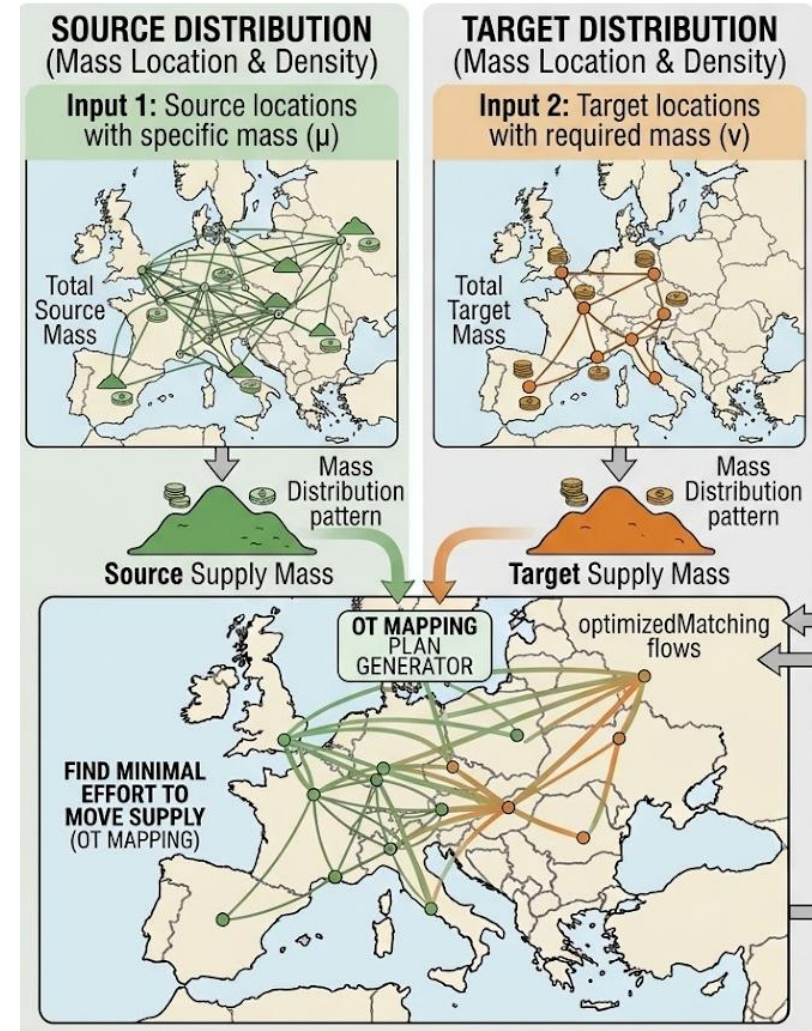


Image: Google Gemini

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Application 1: Route strategic positioning

- **Focus:** *Do the two airlines have similar supply strategies for routes with similar seasonal fluctuations?*

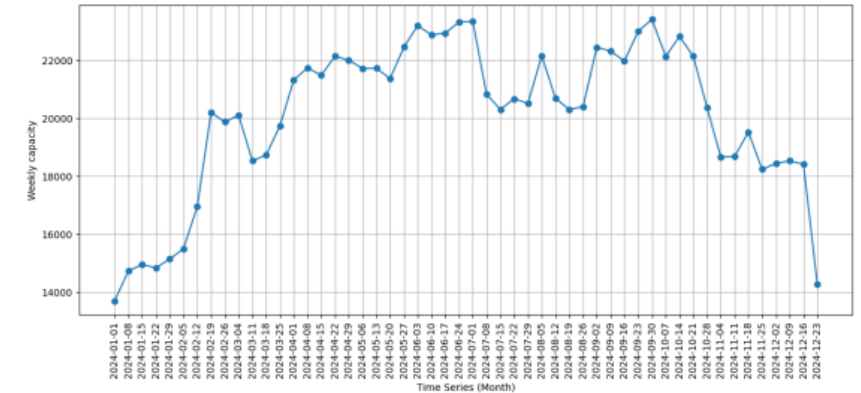
- **Cost matrix:**

$$W(S^r, S^{r'}) \stackrel{\text{def}}{=} \min_{T \in \Gamma(r, r')} \sum_{n, n'=1}^{52} |n - n'| \cdot T_{nn'}, \quad \text{subject to } T\mathbf{1} = r, T^T\mathbf{1} = r'$$

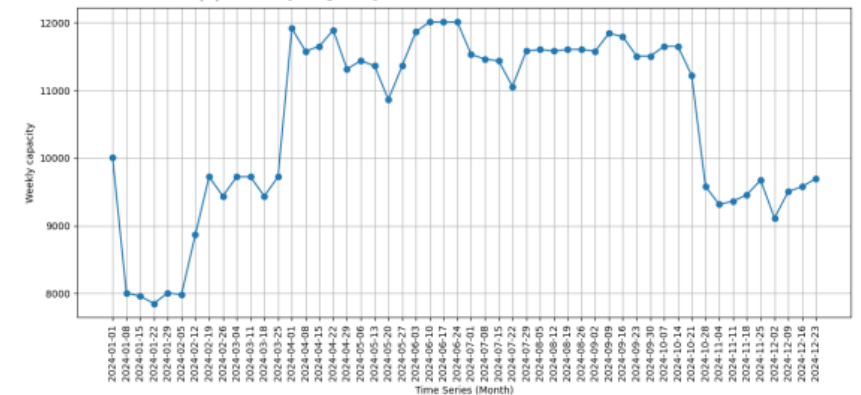
- T : the transport plan
- $|n - n'|$: the absolute difference between the week numbers in a year

- **Index with capacity:**

$$I_1(\mu, \nu) \stackrel{\text{def}}{=} \min_{T \in \Gamma(\mu, \nu)} \sum_{r, r' \in R} W(S^r, S^{r'}) T(r, r')$$



(a) Weekly capacity evolution of route CDG-FRA.



(b) Weekly capacity evolution of route CDG-FLR.



Application 2: Competitive intensity

- **Focus:** *Do the two airlines have overlapping territories?*

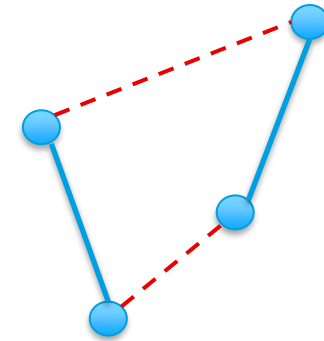
- **Cost matrix:**

$$d_2(r, r') \stackrel{\text{def}}{=} \min \left\{ d(O, O') + d(D, D'), d(O, D') + d(D, O') \right\}$$

$$c_2(r, r') \stackrel{\text{def}}{=} 1 - \exp \left(-\frac{d_2(r, r')}{\lambda} \right), \quad \lambda > 0$$

Suppose catchment area of 100 km for all airports, fix $c_2 \approx 0.99$, $d_2 = 230$ km: obtain

$$\lambda = 50$$



- **Index with capacity:**

$$I_2(\mu, \nu) \stackrel{\text{def}}{=} \min_{T \in \Gamma(\mu, \nu)} \sum_{r, r' \in R} c_2(r, r') T(r, r')$$



Application 3: Operational cost

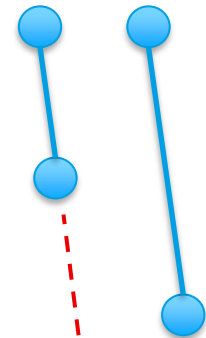
- **Focus:** *Do the two airlines operate similar route lengths (which are highly correlated with operating costs)?*

- **Cost matrix:**

$$d_3(r, r') = |\text{len}(r) - \text{len}(r')|$$

- **Index with frequency:**

$$I_3(\mu, \nu) \stackrel{\text{def}}{=} \min_{T \in \Gamma(\mu, \nu)} \sum_{r, r' \in R} d_3(r, r') T(r, r')$$





Results



Data

- Official Airline Guide (OAG), 2024 scheduled passenger flights in Europe [1]
- Flight annual operating months ≥ 4 ; Annual total frequency ≥ 52
- Focus on **top 20** airlines:

Low-cost (L)	Mainline (M)
D8 – Norwegian Air International (IE, Ireland)	A3 – Aegean Airlines (GR)
DY – Norwegian Air Shuttle (NO)	AF – Air France (FR)
EW – Eurowings (DE)	AY – Finnair (FI)
FR – Ryanair (IE)	AZ – ITA Airways (IT)
U2 – easyJet (GB, United Kingdom)	IB – Iberia (ES)
V7 – Volotea (ES)	KL – KLM Royal Dutch Airlines (NL)
VY – Vueling (ES)	LH – Lufthansa (DE)
W4 – Wizz Air Malta (MT)	OS – Austrian Airlines (AT)
W6 – Wizz Air (HU)	SK – Scandinavian Airlines (SE)
	TP – TAP Air Portugal (PT)
	UX – Air Europa (ES)

Table 2: Top 20 airlines by total annual **capacity** in 2024, with OAG carrier type labels, IATA airline codes, airline names, and headquarters country codes.

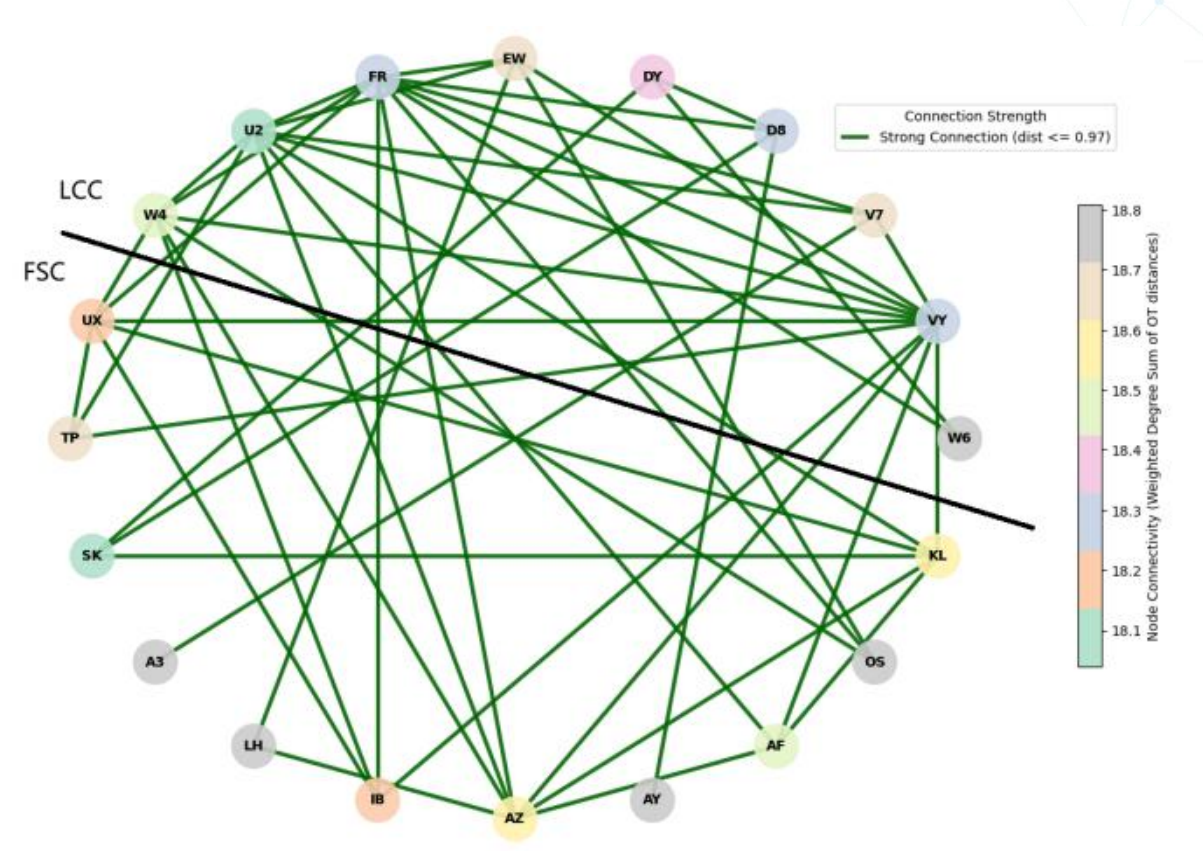
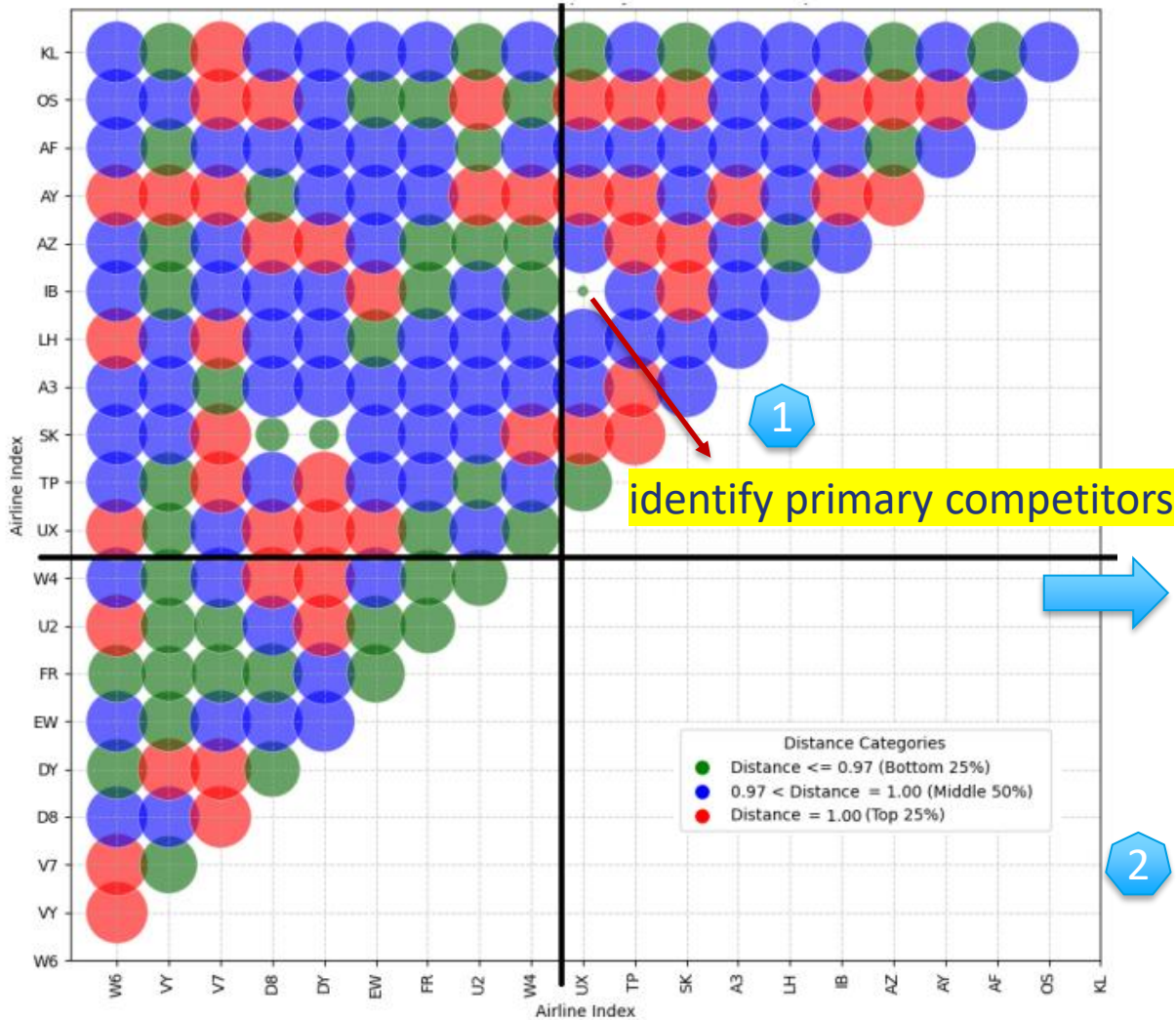
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	LO – LOT Polish Airlines (PL)
	NT – Binter Canarias (ES)
	OS – Austrian Airlines (AT)
	SK – Scandinavian Airlines (SE)
	TP – TAP Air Portugal (PT)
	WF – Widerøe (NO)

Table 3: Top 20 airlines by total flight **frequency** in 2024, with OAG carrier type labels, IATA airline codes, airline names, and headquarters country codes.

[1] European Economic Area (EEA) and the Schengen Area



Results of I2: Spatial competitive intensity (LCC)

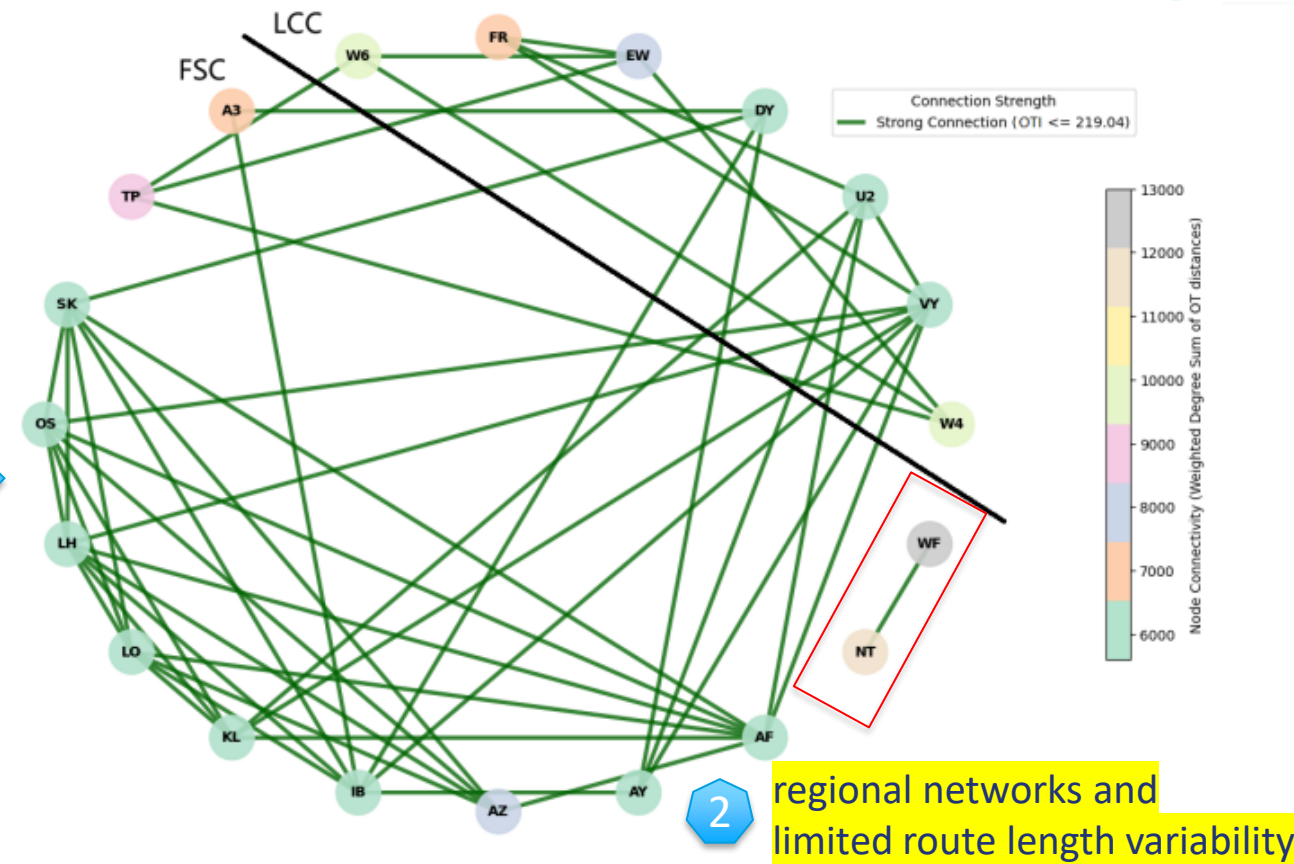
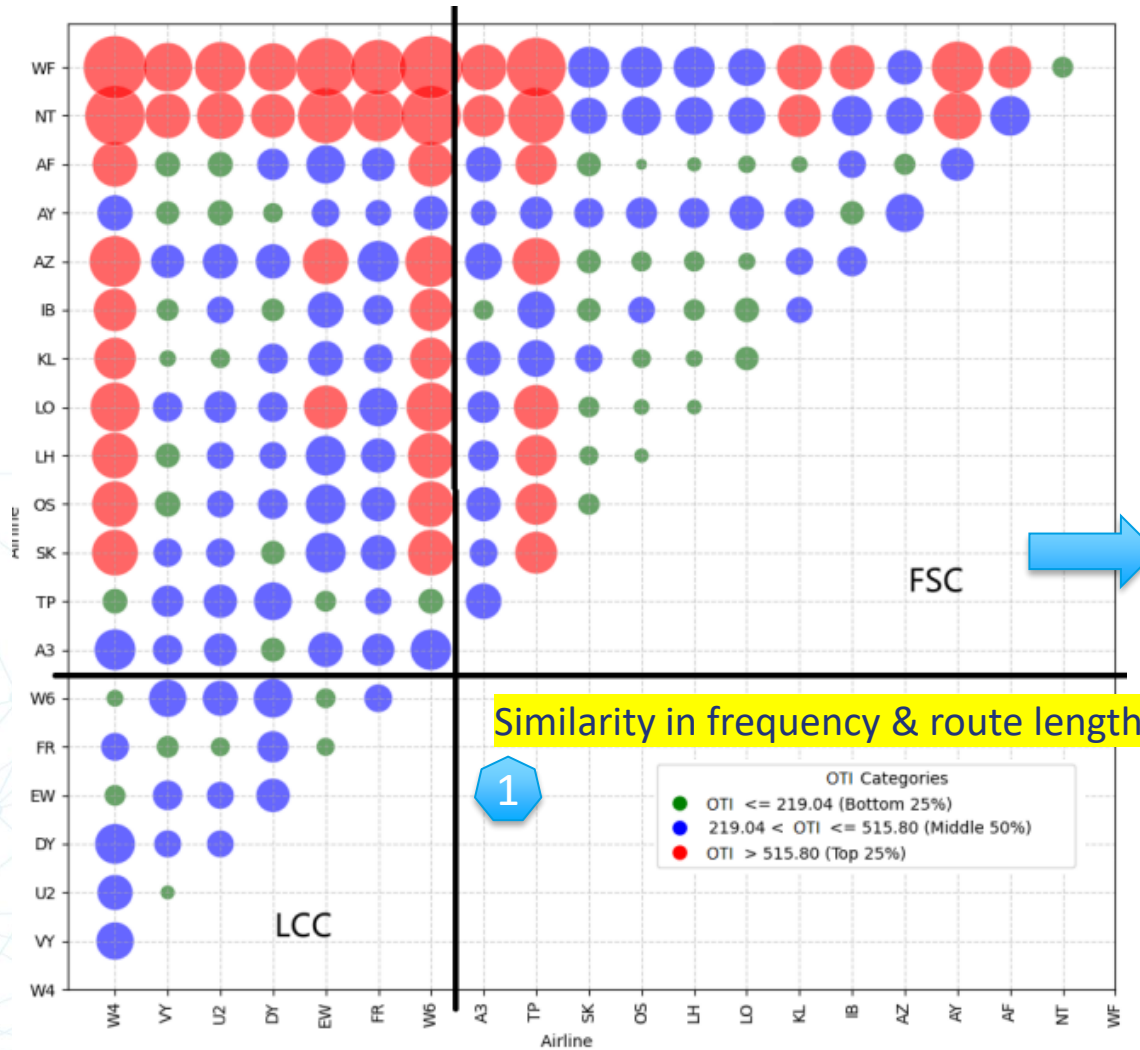


(b) Network representation of airline pairs within the lowest 25% of I_2 values. FSC concentrate around their hubs, while LCC are everywhere

(a) I_2 indices of airlines represented by bubble size and categorical colors.



Results of I3: Operational cost (2 clusters)



(b) Network representation of airline pairs within the lowest 25% of I_3 values.

(a) I_3 indices of airlines represented by bubble size and categorical colors.



To sum up...



Conclusion

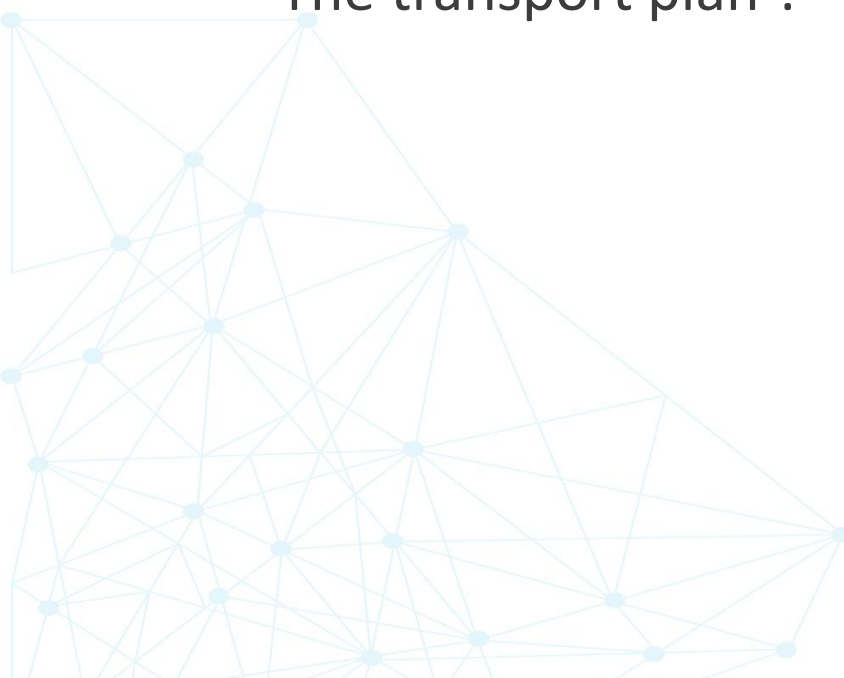
Contributions:

1. Introduce optimal transport (OT) to airline pairwise supply comparison.
2. Presents three data-driven applications with simple and interpretable cost functions: *strategy, competition, and operational cost*.
3. The method can potentially be generalized to other transport sectors, such as urban transit, maritime shipping, and rail.



Discussion

- Connecting flights ?
- The transport plan ?





Future Research

- Extend the framework with alternative cost functions
- Interpret the transport plan: an adaptive response?
- Relation between supply similarity & emission?

Thank you!

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