ART - ENAC 2019

Expansion of International Airline Networks: an Application to US Carriers

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Airline Networks

Airline networks are complex

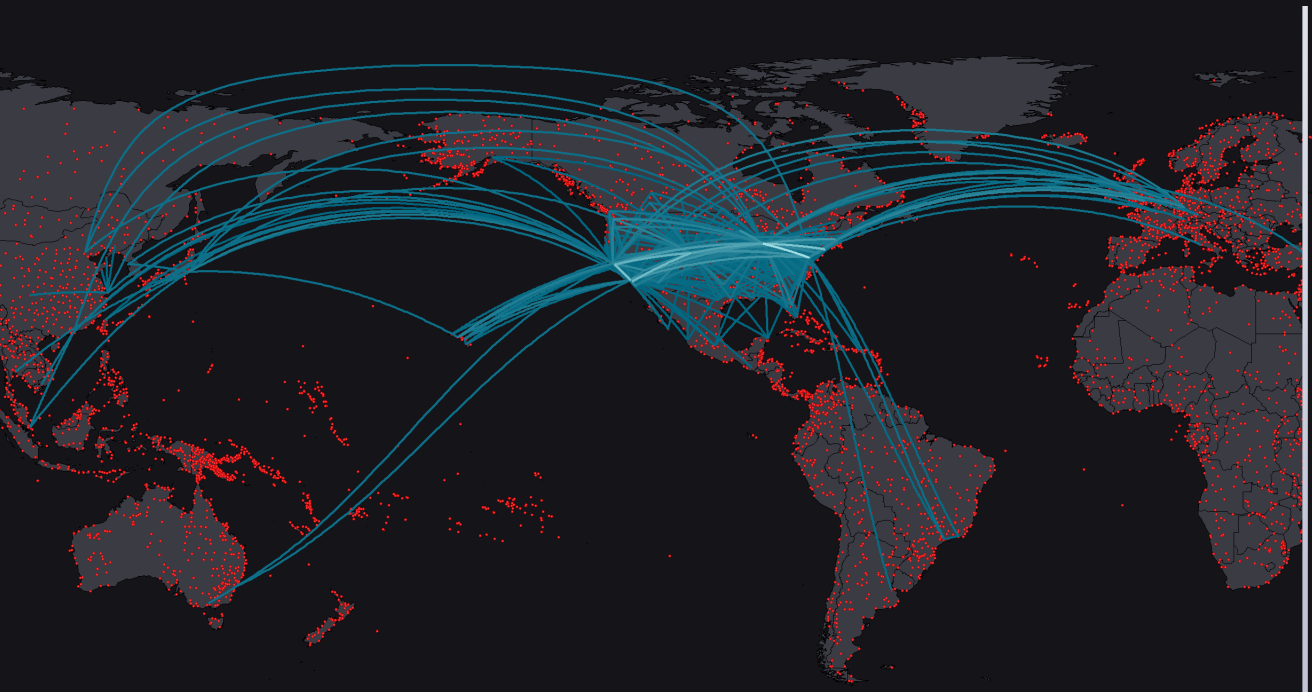
- Number of airports served
- Number of routes served
- Direct or connecting flights, frequencies, …

United Airlines, September 2008

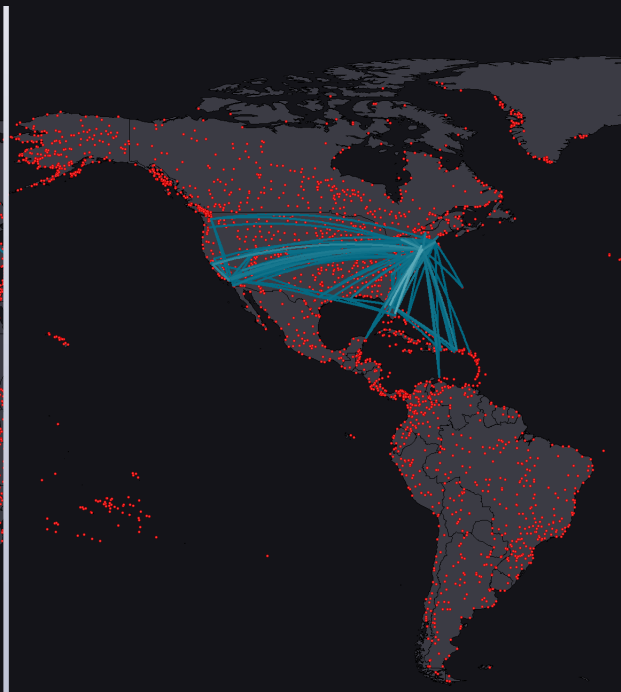
Airline Networks

Airline networks are complex

Airlines make different network choices



United Airlines, September 2008



JetBlue, September 2008

Airline Networks

Airline networks are complex

Airlines make different network choices

Their network decision evolves over time

United Airlines, September 2008

Airline Networks

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United Airlines, September 2013

Airline Networks

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United Airlines, September 2018

Airline Networks

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Objectives

Build some indicators to measure airline network structure

- Network characterization
- Network evolution

Literature

- Hub-and-spoke versus point-to-point network structure
  - Brueckner (2004), Alderighi et al. (2005), Barla and Constantatos (2005), Flores-Fillol (2009), and Silva et al. (2014)
- Combination of hub-and-spoke and point-to-point
  - Wojahn (2001)
- Use of a unique indicator: graph theory index, connectivity ratio
  - Malighetti et al. (2018), Burghowt and Redundi (2013), Alderighi et al. (2007)

Our focus

- Characterization of any network configuration and connectivity thanks to continuous indicators

Methodology

Airline Network as a graph

- An airline network is represented as a graph
  - Nodes: cities (or airports)
  - Edges: flight segments between two cities (or airports)
  - Main assumptions: undirected and unweighted graphs

→ **Graph theory measures to describe network structure**

Selection of relevant graph theory measures

- Density - completeness of a network
- Transitivity - relative number of triangles
- Degree centrality, maximum and centralization - how well connected are cities
- Harmonic centrality, maximum and centralization - how fast every city in the network can be reached from any other city
- Betweenness centrality, maximum and centralization - gives the highest possible values to cities located at the center of a star graph
- Eigenvector centrality, mean and centralization - how well a city is connected to other well-connected cities

Methodology

Constructing Indicators of Network Evolution

1. Selection of network measures

Relevant graph theory measures

Measures for size and connectivity of an airline network

- Number of flight segments
- Connectivity ratio - ratio between direct and indirect connections supplied by the carrier (Alderighi et al. (2007))

2. Initial characterization of airline networks

PCA on original network measures for the first period of observation (2008)

3. Construction of network evolution indicators using PCA

Seasonal differencing of network measures (2008-2018) to correct for non-stationarity

Principal components: linear combinations of the seasonally differenced variables

Application to US Carriers

Data

- Official Airline Guide, OAG - scheduled traffic
  - US domestic and international flights operated by US carriers
  - Non stop passenger flights
  - 2008-2018, third quarter (July 1st to September 30th)

- Final data set
  - monthly-route information for each operating carrier
  - 140829 observations
  - 20 operating carriers ranging from 14 to 19 per year
  - Number of cities varies from 551 to 713 per year

Application to US Carriers

Initial Characterization of Airline Networks

September 2008

Three principal components
explain 91.8% of the sample variability

Correlations with variables	PC1	PC2	PC3
Connectivity Crit 125	-0.17	-0.43	0.65
Number flight segments	-0.51	-0.48	0.66
Density	0.12	0.97	0.00
Transitivity	-0.04	0.89	0.33
Max. Degree centrality	0.87	0.33	0.33
Degree centralization	0.94	-0.08	0.30
Max. Harmonic centrality	0.81	0.33	0.43
Harmonic centralization	0.90	-0.32	0.24
Max. Betweenness centrality	0.92	-0.25	-0.26
Betweenness centralization	0.92	-0.29	-0.21
Mean Eigenvector centrality	0.37	0.83	-0.20
Eigenvector centralization	0.61	-0.68	-0.27

Three Network Indicators:

PC1: *NetCenter*
From point-to-point network configuration to a topology with a single center

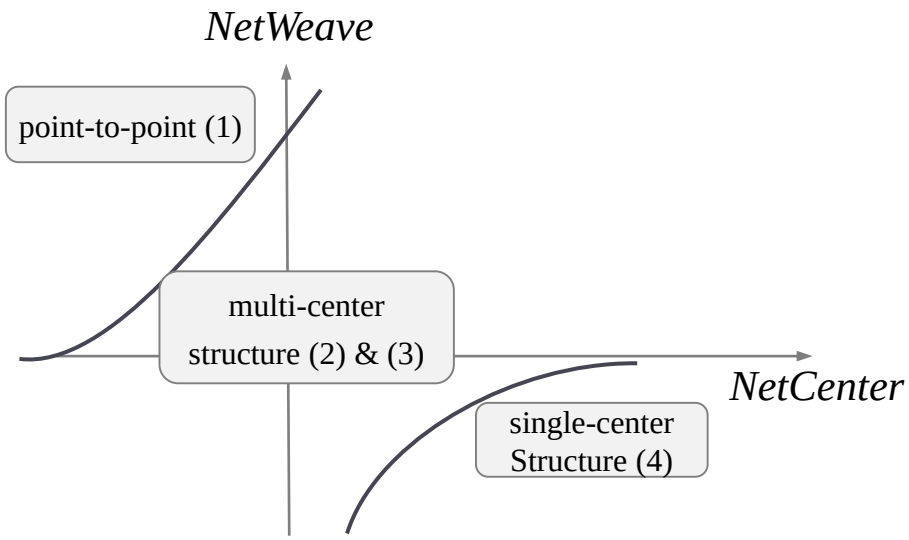
PC2: *NetWeave*
Network interlacing

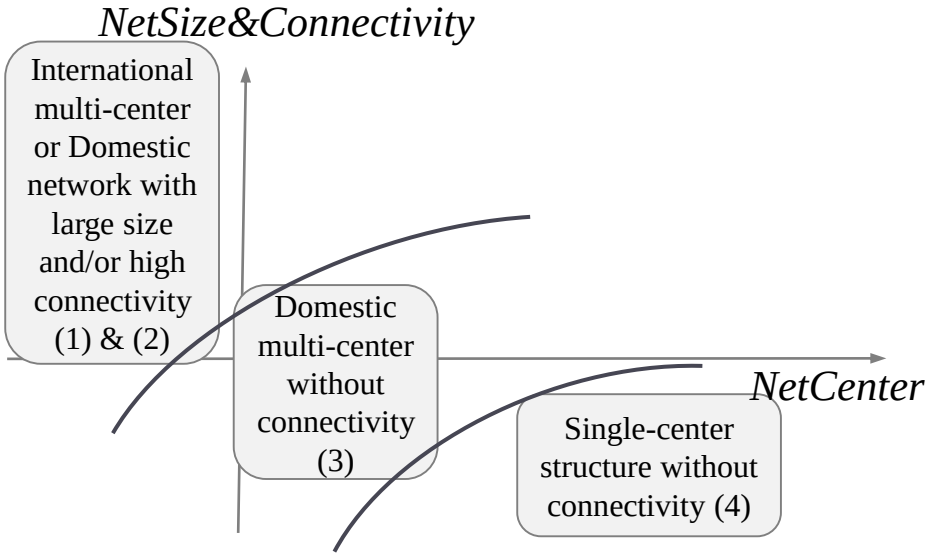
PC3: *NetSize&Connectivity*

Takes positive values for either large size networks and/or network with high flight connectivity

Application to US Carriers

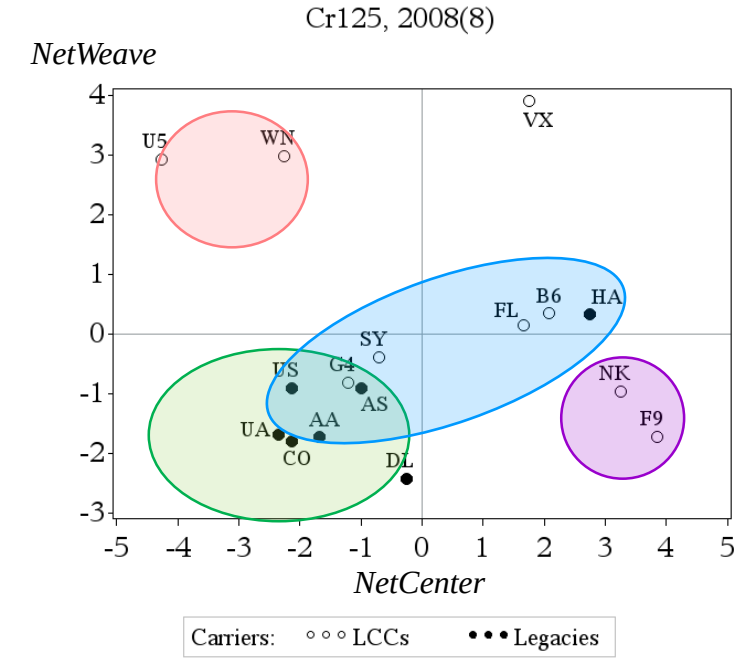
Four Main Airline Groups

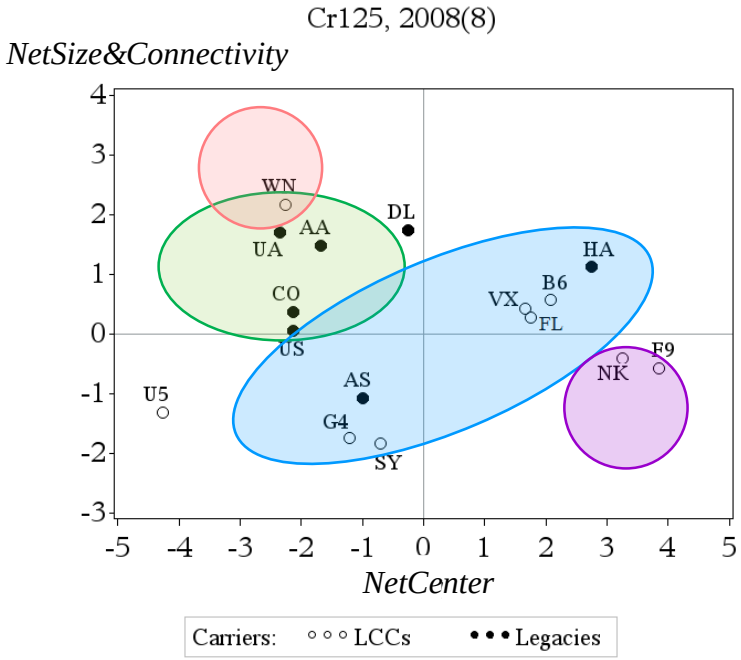




1. Domestic large point-to-point network without connectivity	2. International multi-center network with connectivity	3. Domestic multi-center network without connectivity	4. Single-center network without connectivity
NetCenter negative	*NetCenter* negative	*NetCenter-NetWeave* location near the first diagonal	*NetFocus* high
NetWeave positive	*NetWeave* negative		*NetWeave* close to zero
NetSize&Connectivity high	*NetSize&Connectivity* positive	*NetCenter-NetSize&Connectivity* near the first diagonal	*NetSize&Connectivity* close to zero

Application to US Carriers
in September 2008





1. Domestic large point-to-point network without connectivity	2. International multi-center network with connectivity	3. Domestic multi-center network without connectivity	4. Single-center network without connectivity

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Application to US Carriers

Four Indicators of Network Evolution

2008-2018 Seasonal differences in variables, Δ_{12}, because of stationarity
Four principal components explain 85,4% of the sample variability

Correlations with variables

	PC1	PC2	PC3	PC4
Δ_{12}Connectivity Crit 125	0.006	0.012	0.993	0.107
Δ_{12}Number flight segments	-0.320	0.319	-0.106	0.837
Δ_{12}Density	0.638	0.672	0.004	-0.183
Δ_{12}Transitivity	0.008	0.782	0.034	-0.250
Δ_{12}Max. Degree centrality	0.932	0.086	-0.028	0.081
Δ_{12}Degree centralization	0.898	-0.135	-0.033	0.161
Δ_{12}Max. Harmonic centrality	0.953	0.198	-0.021	0.093
Δ_{12}Harmonic centralization	0.888	-0.230	-0.029	0.096
Δ_{12}Max. Betweenness centrality	0.807	-0.358	0.034	0.057
Δ_{12}Betweenness centralization	0.798	-0.403	0.029	0.083
Δ_{12}Mean Eigenvector centrality	0.801	0.380	0.011	-0.161
Δ_{12}Eigenvector centralization	-0.035	-0.881	-0.009	-0.209

Principal component interpretation

PC1: *NetCenterGrowth*
evolution of *NetCenter*

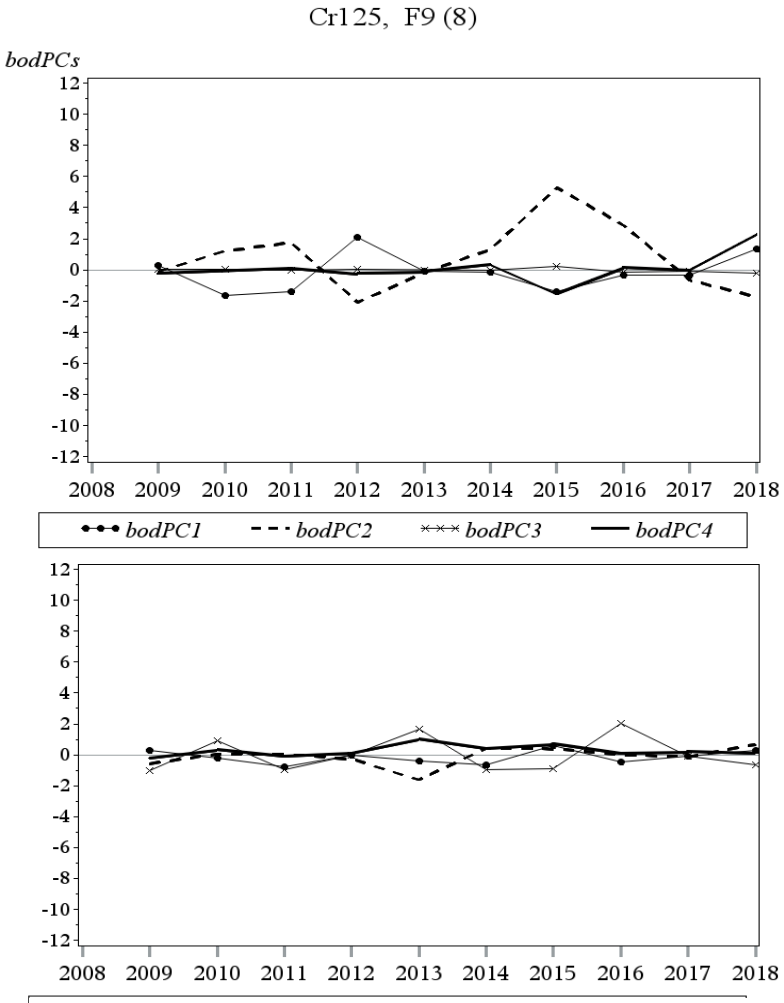
PC2: *NetWeaveGrowth*
evolution of *NetWeave*

PC3: *NetConnectivityGrowth*
evolution of *NetConnectivity*

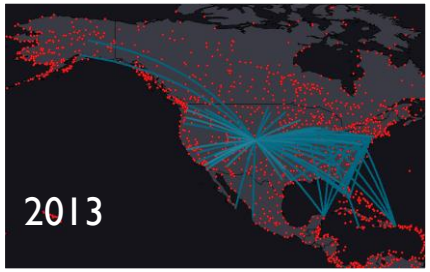
PC4 : *NetSizeGrowth*
evolution of *NetSize*

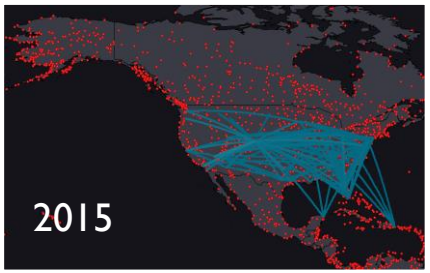
Application to US Carriers

Network Evolution



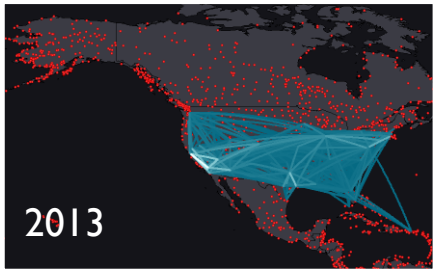
FRONTIER AIRLINES

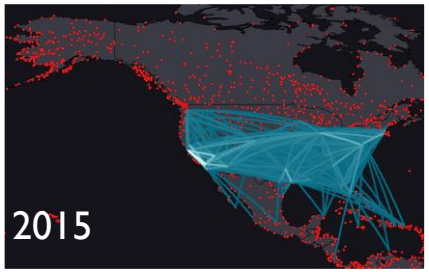




Group switch: from 4 (single-center network without connectivity) to 2 (International multi-center with connectivity)

Southwest



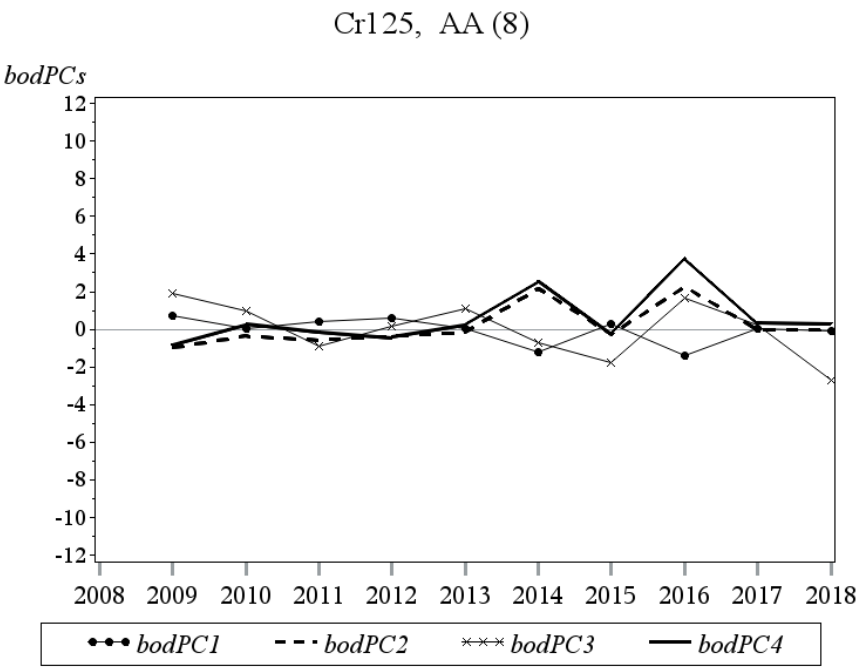


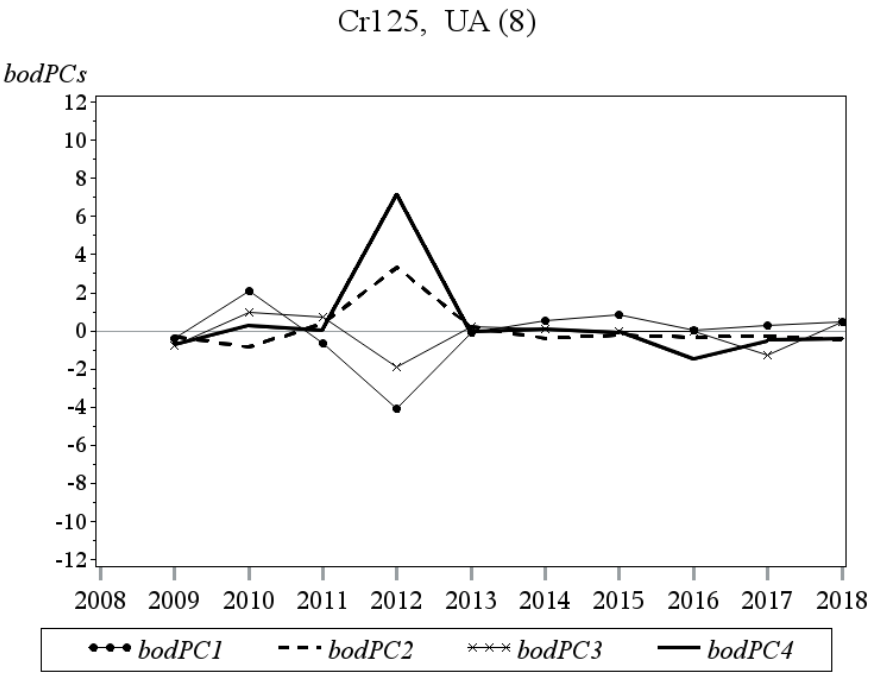
Stability: Group 4 (domestic point-to-point large network without connectivity)

- Four indicators of network evolution allow to trace significant changes in the network structure

Application to US Carriers

Network Evolution





- Four indicators of network evolution allow to capture changes in networks following mergers

Further Research

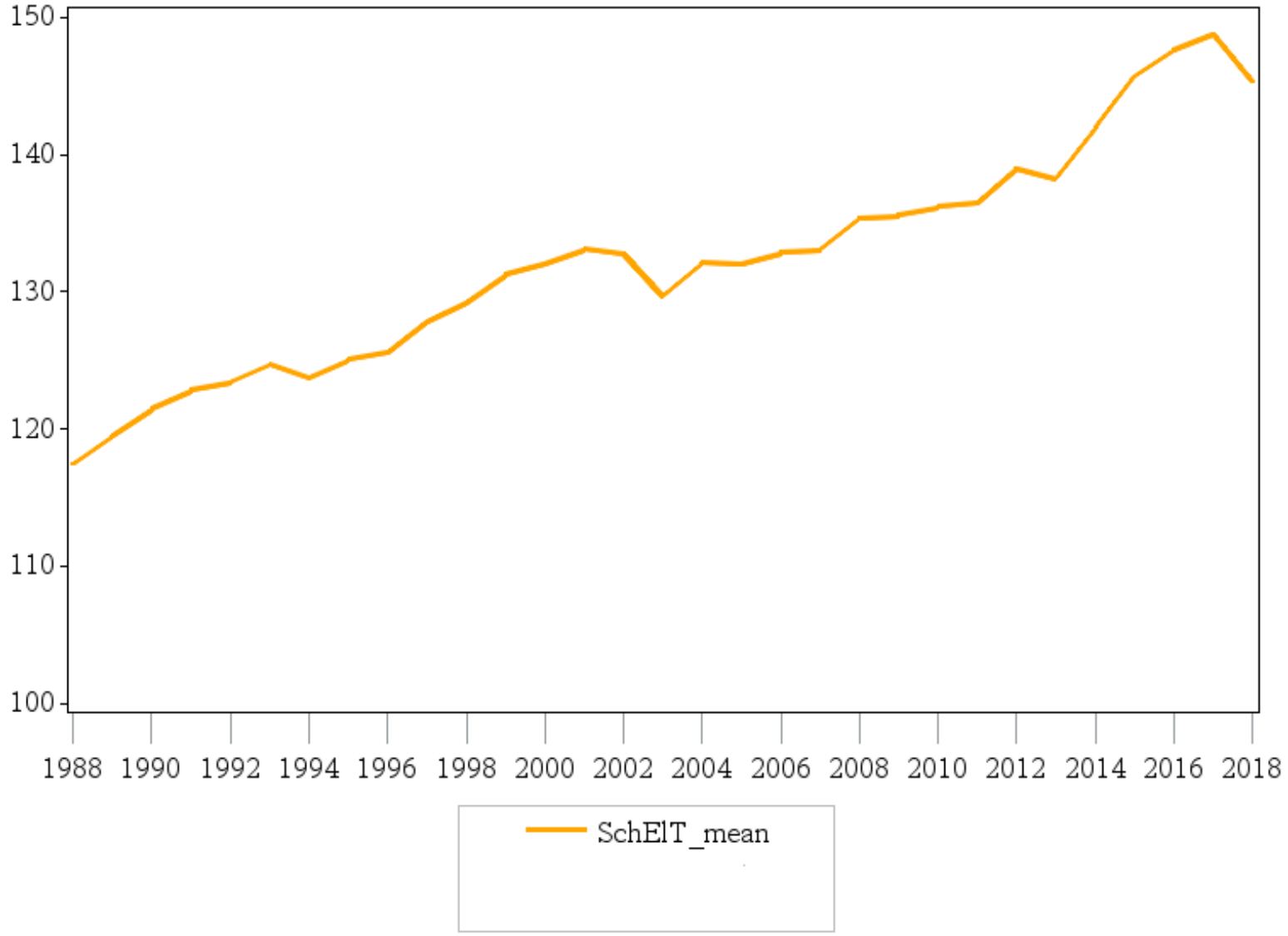
- Impact of these indicators over the airline's cost structure Pels et al. (2000), the level of competition (Hendricks, Piccione, and Tan 1997), the prices (Tan and Samuel 2016), the level of congestion and delays (Mayer and Sinai 2003; Brueckner 2002; Fageda and Flores-Fillol 2016)

Further Research

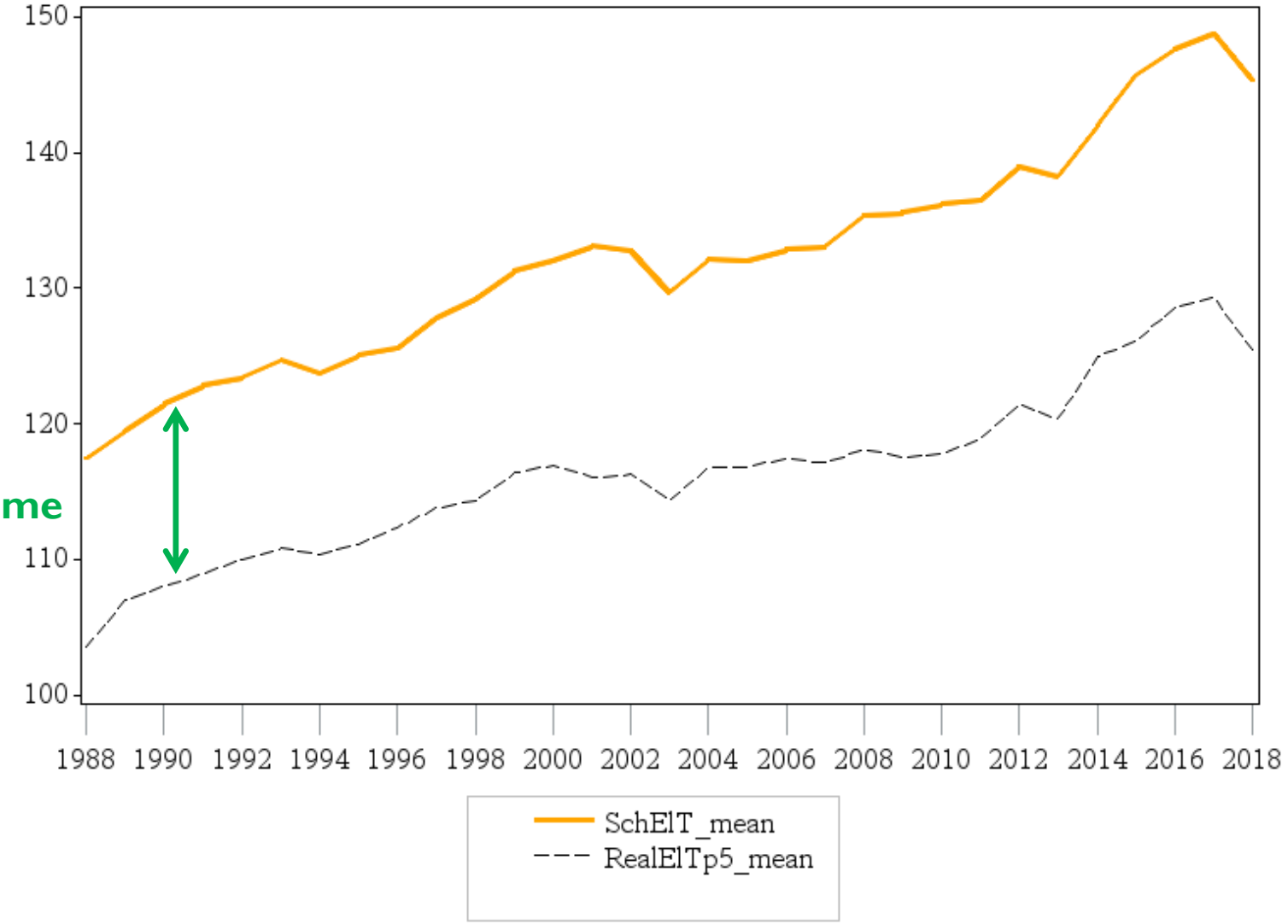
- Impact of these indicators over the airline's cost structure Pels et al. (2000), the level of competition (Hendricks, Piccione, and Tan 1997), the prices (Tan and Samuel 2016), the level of congestion and delays (Mayer and Sinai 2003; Brueckner 2002; Fageda and Flores-Fillol 2016)

- Next objective: impact of network structure on buffer time and delays
  - Following first Mayer and Sinai (2003)

Evolution of average scheduled time (august)

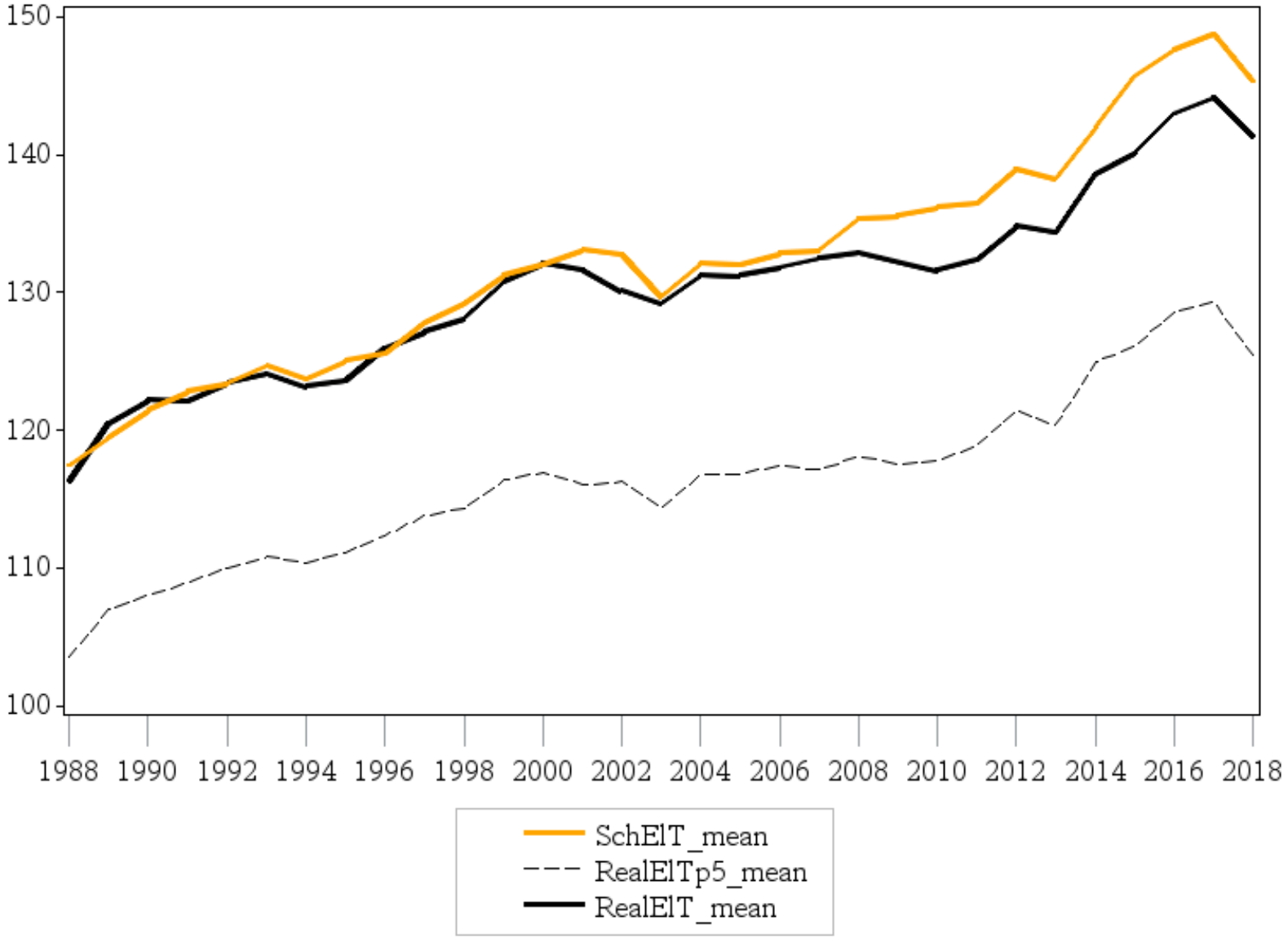


Evolution of average scheduled and percentile 5 real time (august)



Buffer time

Evolution of average scheduled, percentile 5 and average of real time (august)



Conclusion and next steps

We construct indicators

- characterizing network structure at international level
- measuring network evolution

Main findings for US airlines

An airline network structure can be characterized with **four measures**:
NetCenter, NetWeave, Netconnectivity, NetSize

4 indicators of network evolution: *NetCenterGrowth, NetWeaveGrowth, NetconnectivityGrowth, NetSizeGrowth*

A new airline classification is proposed based on network indicators: **4 main Airline Groups**

Next step: use of the network indicators to explain airline performances, in particular delays.

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Assumptions

1. Airlines make decisions at the city level rather that at the airport level.
2. A graph associated with an airline network is undirected and unweighted.
3. Major airlines and feeders coordinate their network decisions.