Assessing Benefits from Aviation Capacity Investment:

An Equilibrium Approach

Bo Zou, Mark Hansen

National Center of Excellence for Aviation Operations Research
(NEXTOR)
University of California, Berkeley

Outline

- Background
- Equilibrium framework
- Equilibrium models
- Conclusion

Research background

Investment

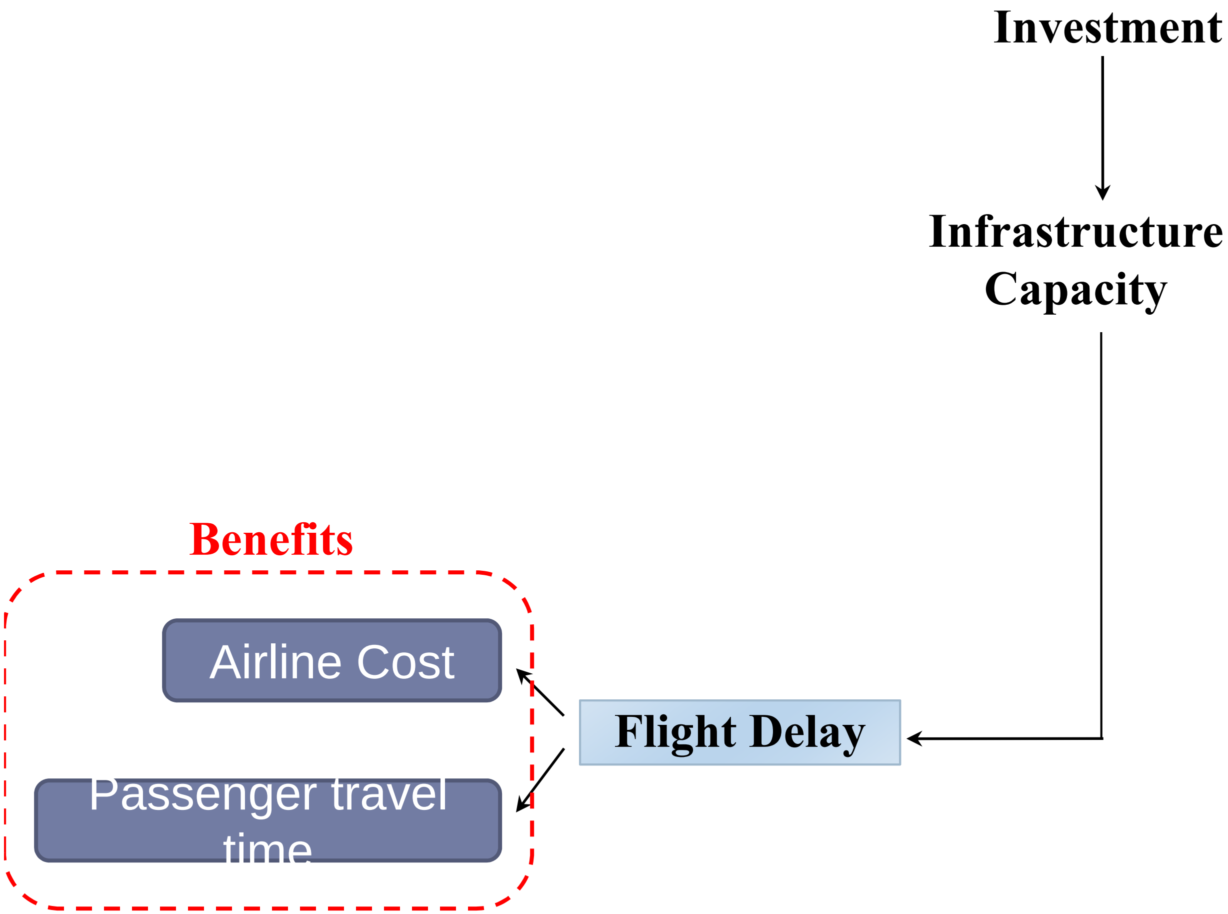
- Dozens of billion-dollar investment under NextGen
- Additional runway construction and airport capacity expansion projects

DOT (2009, 2010); Hansen (2010); FAA (2007)

Infrastructure Capacity

Flight Delay

Conventional method



Investment

Infrastructure Capacity

Flight Delay

Benefits

Airline Cost

Passenger travel time

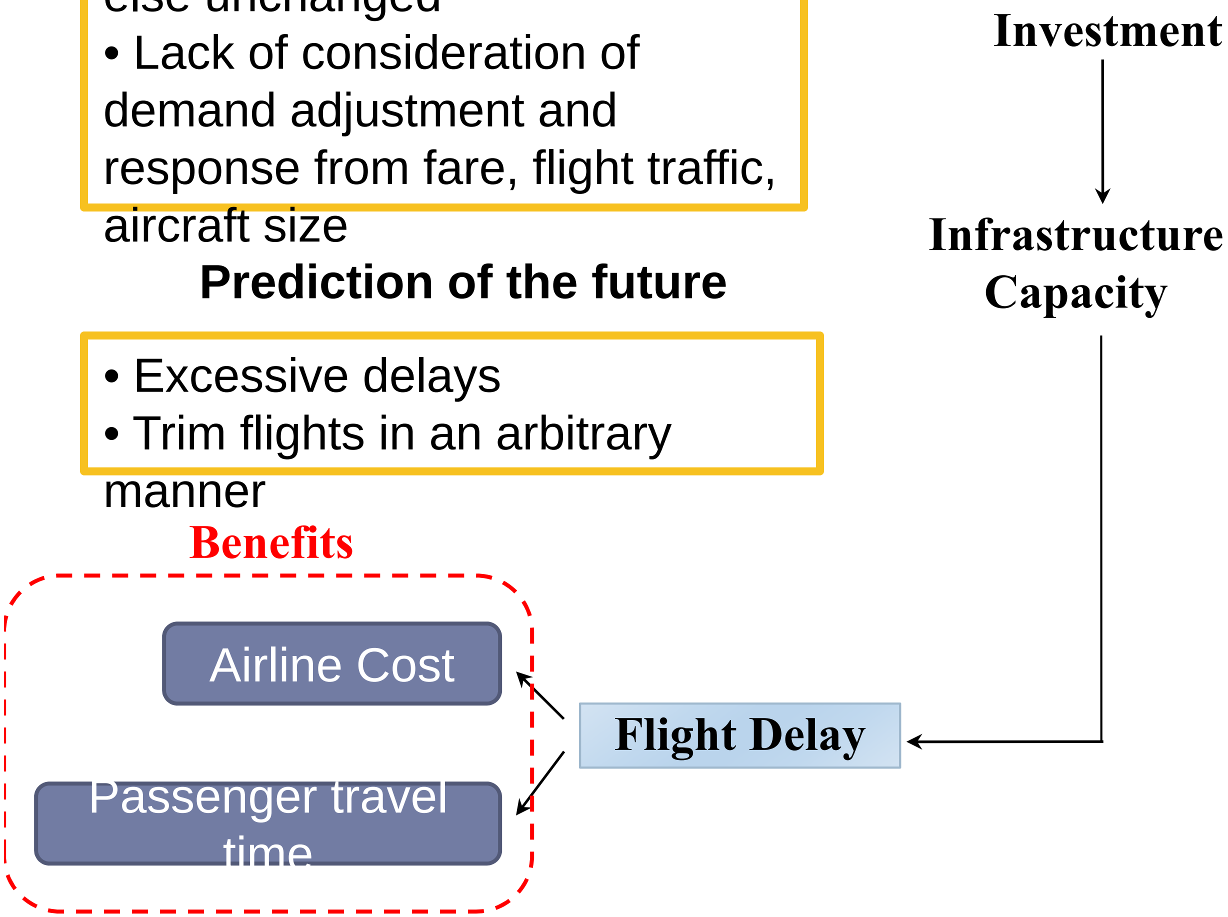
Problems with conventional method

***Ceteris paribus* assumption**

- Except capacity and delay, all else unchanged
- Lack of consideration of demand adjustment and response from fare, flight traffic, aircraft size

Prediction of the future

- Excessive delays
- Trim flights in an arbitrary manner



Investment

Infrastructure Capacity

Flight Delay

Benefits

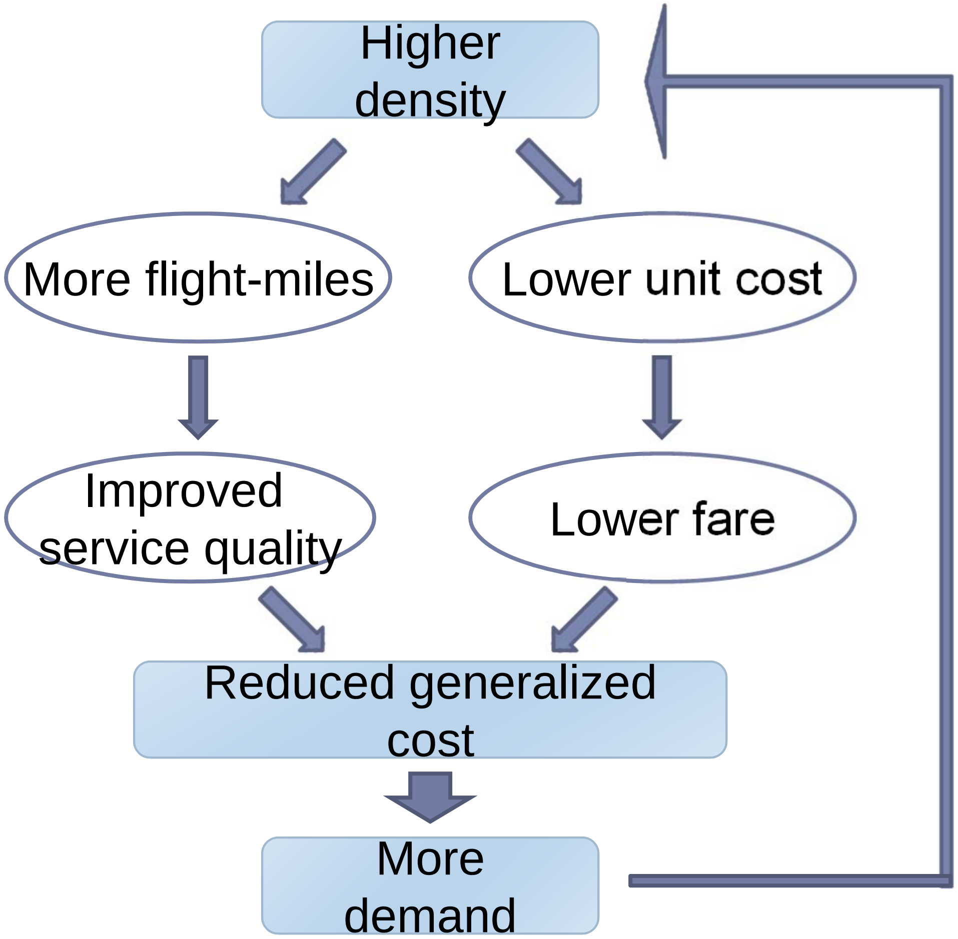
Airline Cost

Passenger travel time

Research Objective

Develop a new benefit assessment methodology that better captures the system response to capacity change

A congestion-free air transport system with economies of density


Higher density

More flight-miles

Lower unit cost

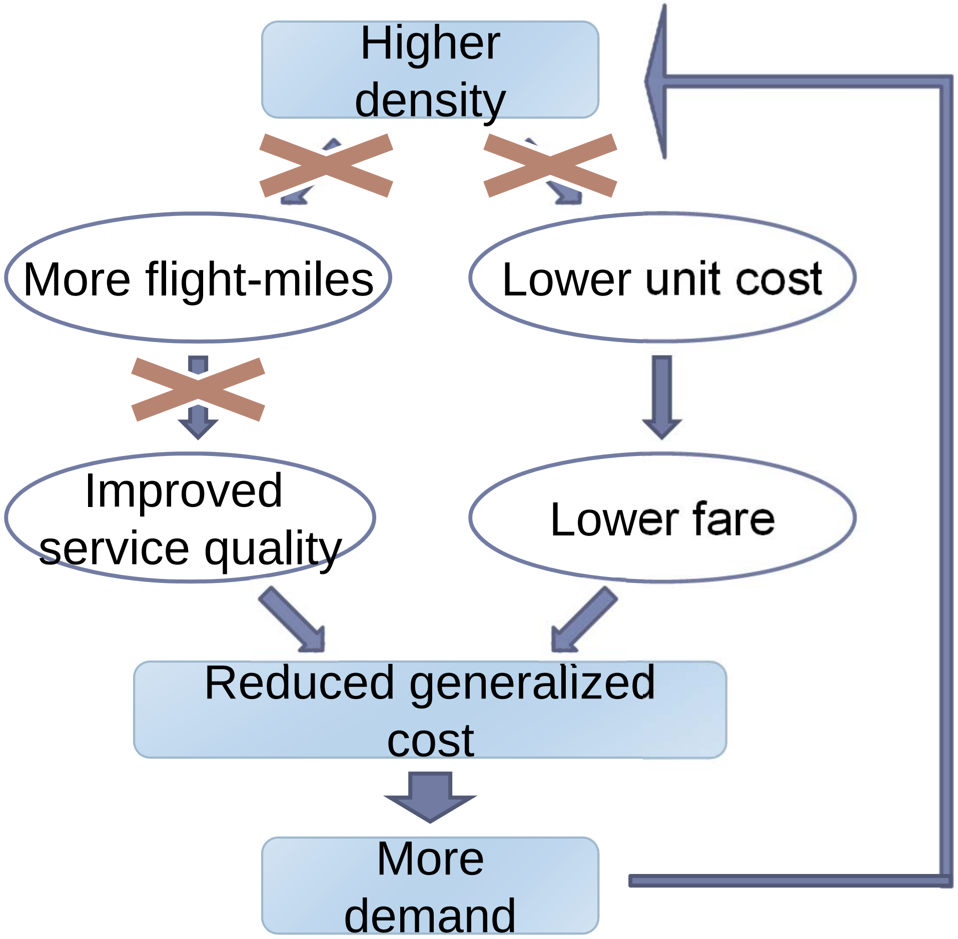
Improved service quality

Lower fare

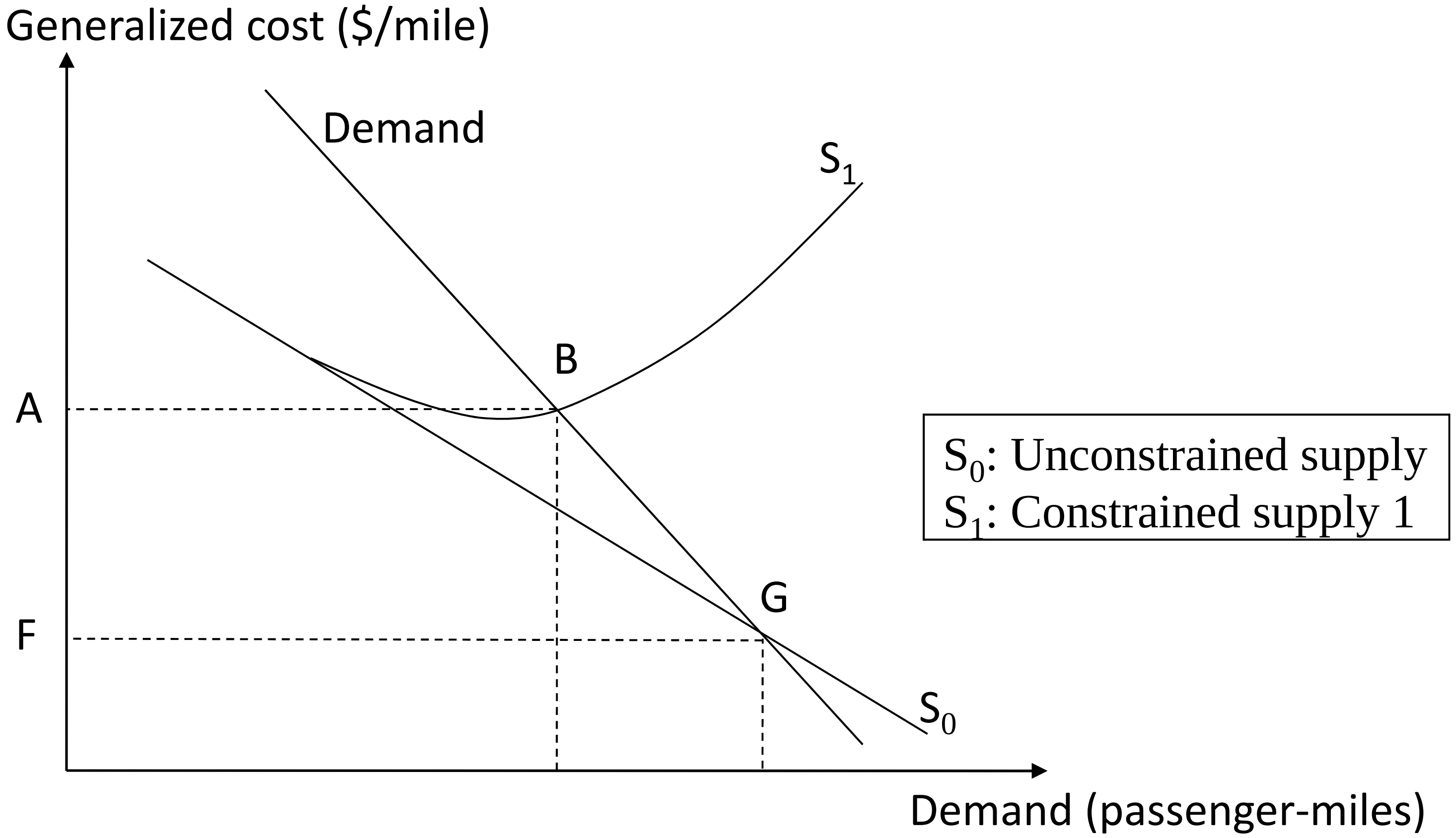
Reduced generalized cost

More demand

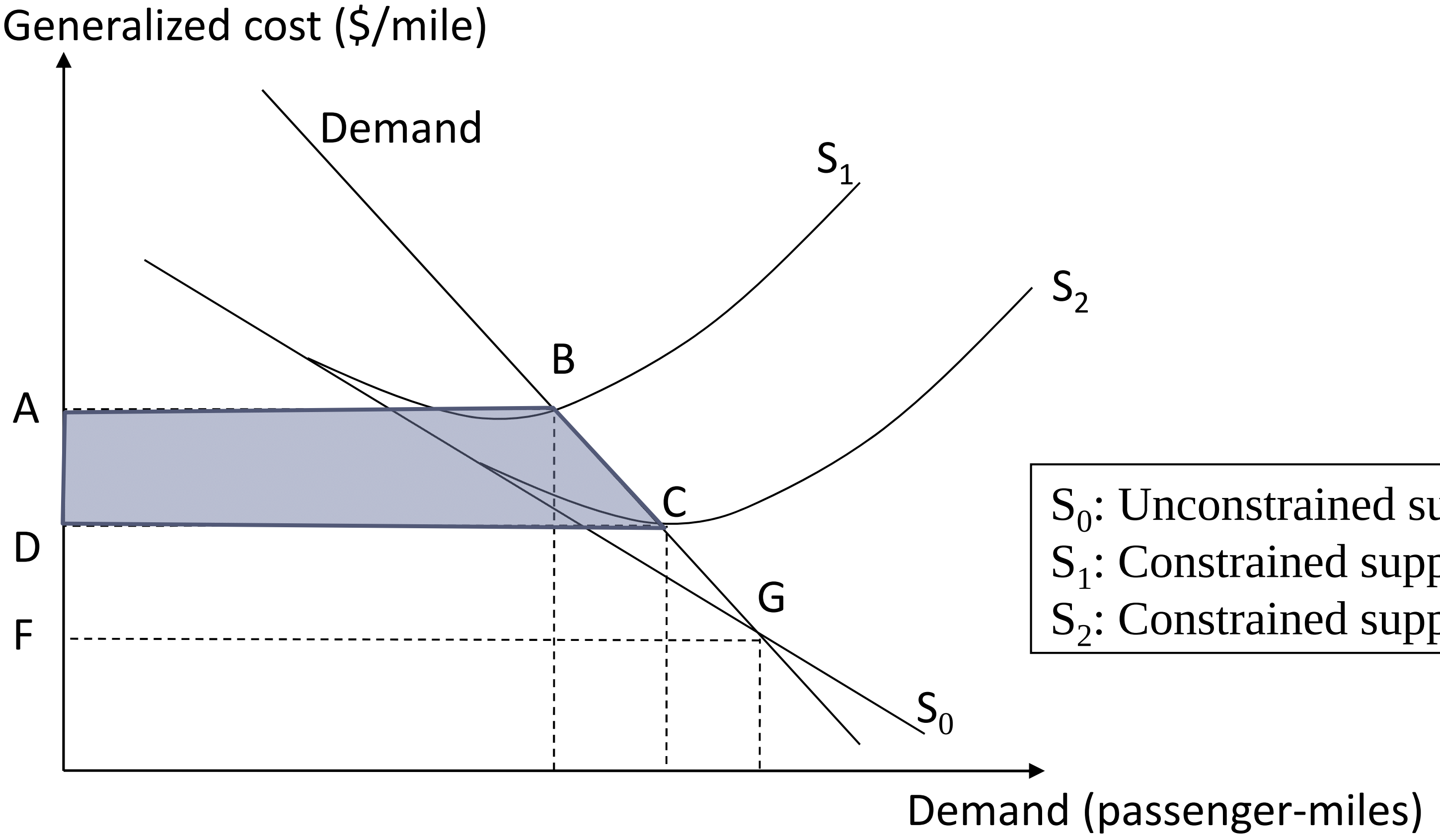
With congestion, the positive feedback loop is disrupted



Demand as a function of passengers generalized cost

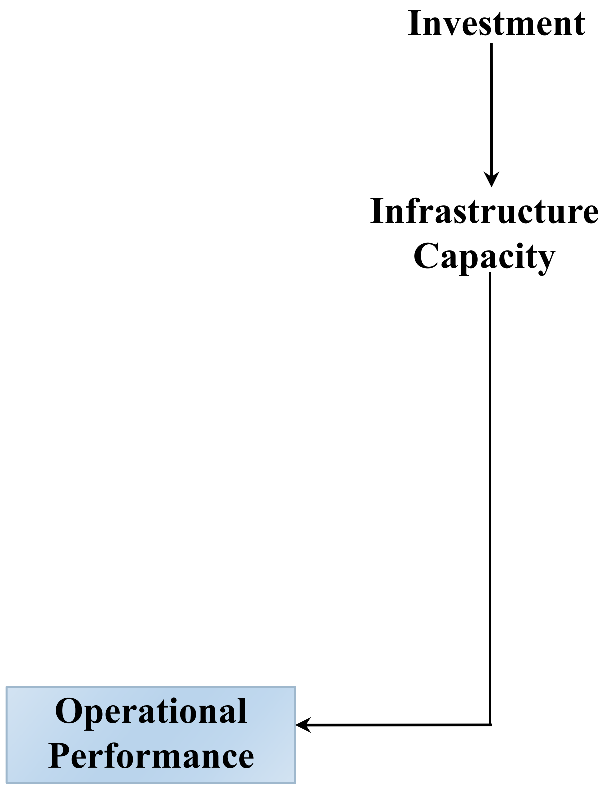


Capacity increase marks down the generalized cost



S_0: Unconstrained supply
S_1: Constrained supply 1
S_2: Constrained supply 2

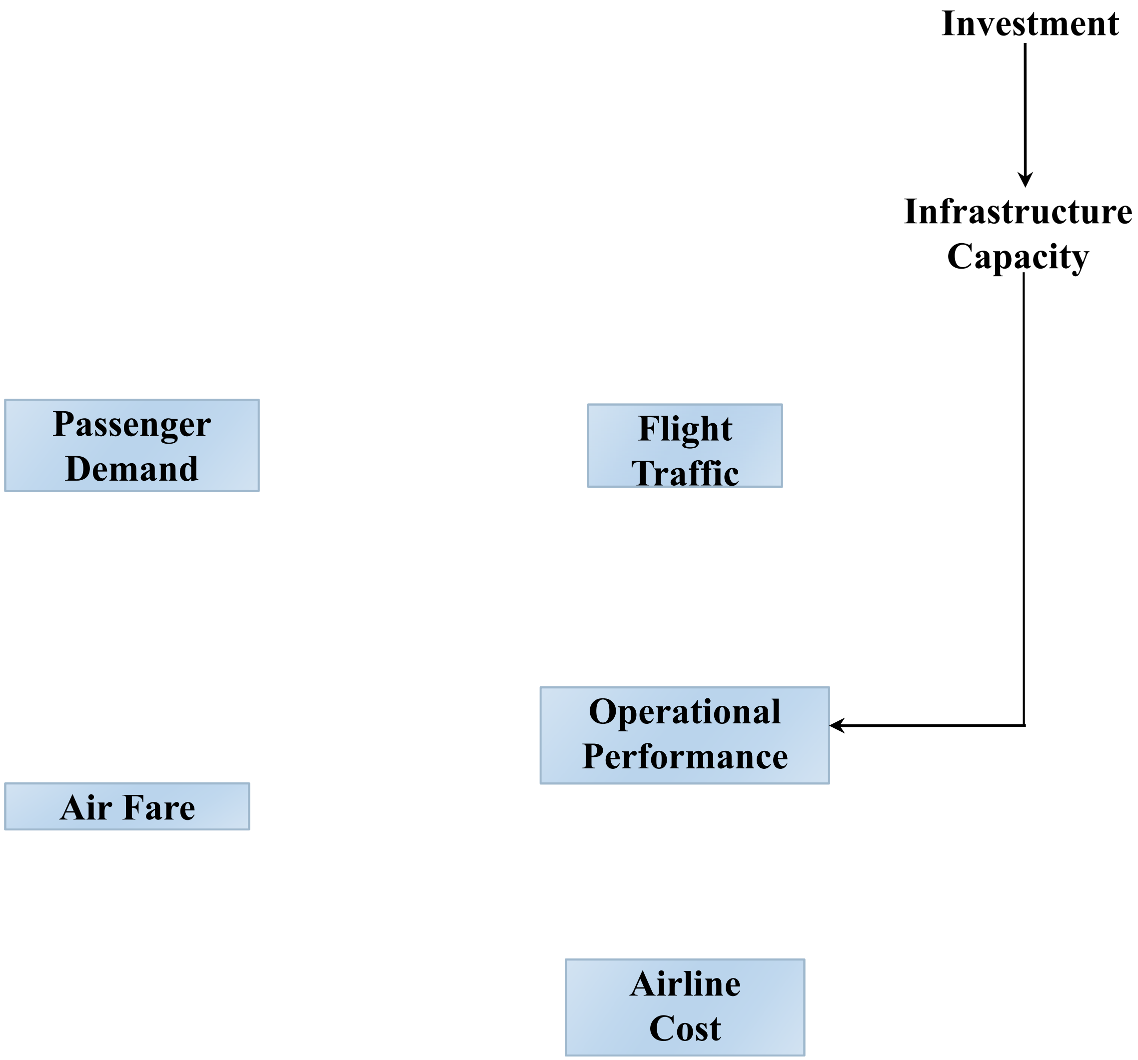
Proposed framework


Investment

Infrastructure Capacity

Operational Performance

Proposed framework



Investment

Infrastructure Capacity

Passenger Demand

Flight Traffic

Operational Performance

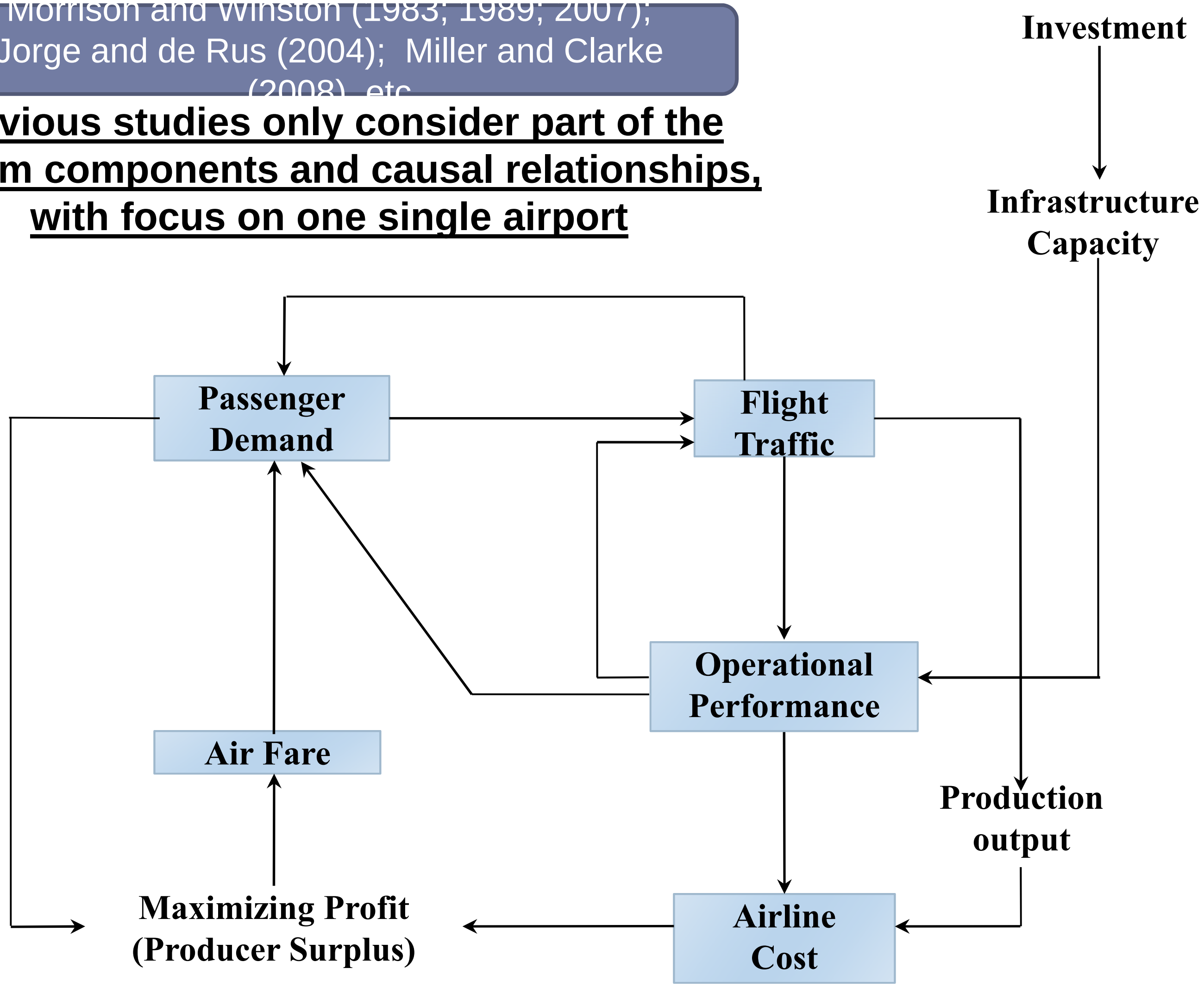
Air Fare

Airline Cost

Proposed framework

Morrison and Winston (1983; 1989; 2007); Jorge and de Rus (2004); Miller and Clarke (2008), etc.

Previous studies only consider part of the system components and causal relationships, with focus on one single airport



Investment

Infrastructure Capacity

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Air Fare

Production output

Maximizing Profit (Producer Surplus)

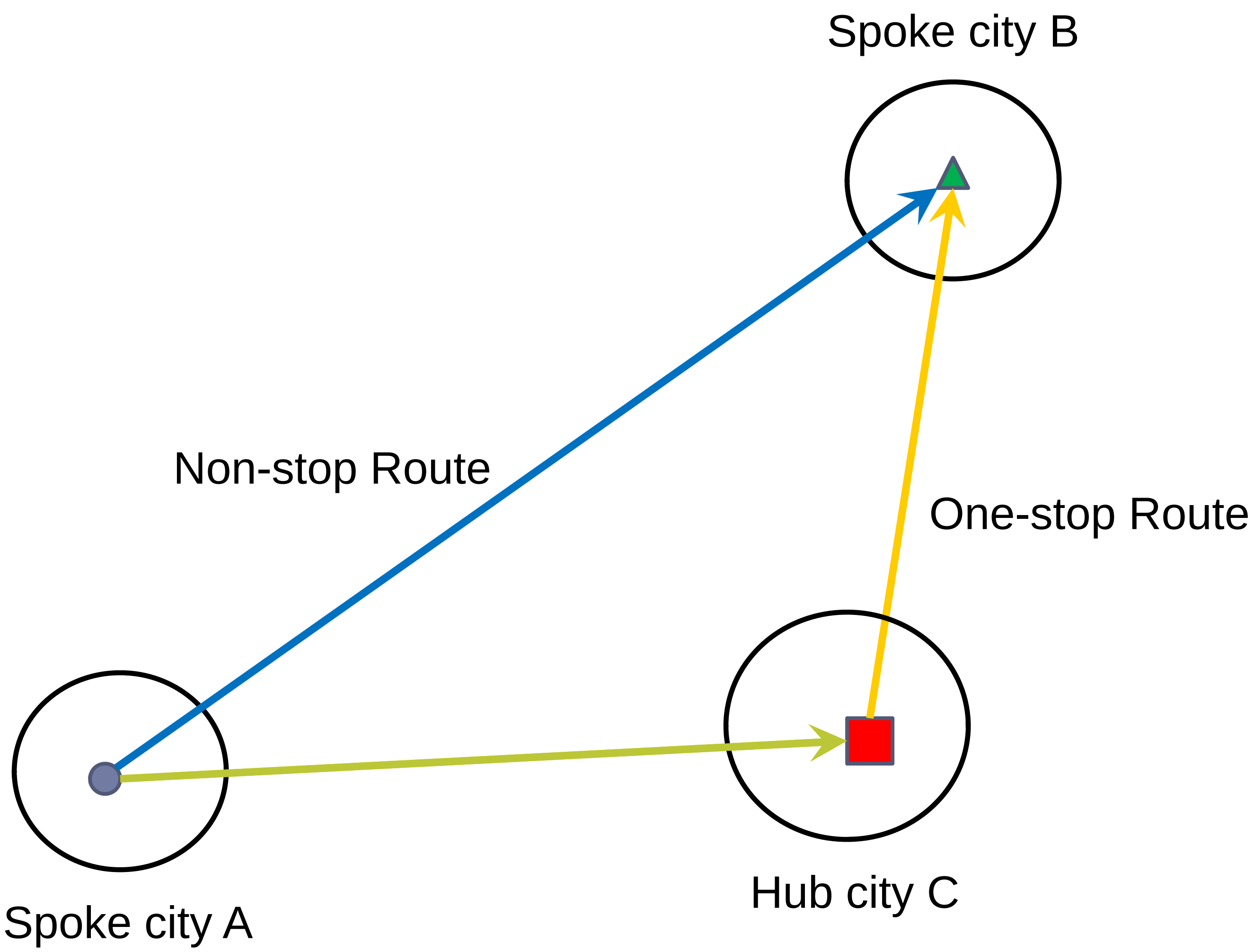
Airline Cost

Introduction of basic concepts

Route

Segment

Market



Spoke city B

Non-stop Route

One-stop Route

Spoke city A

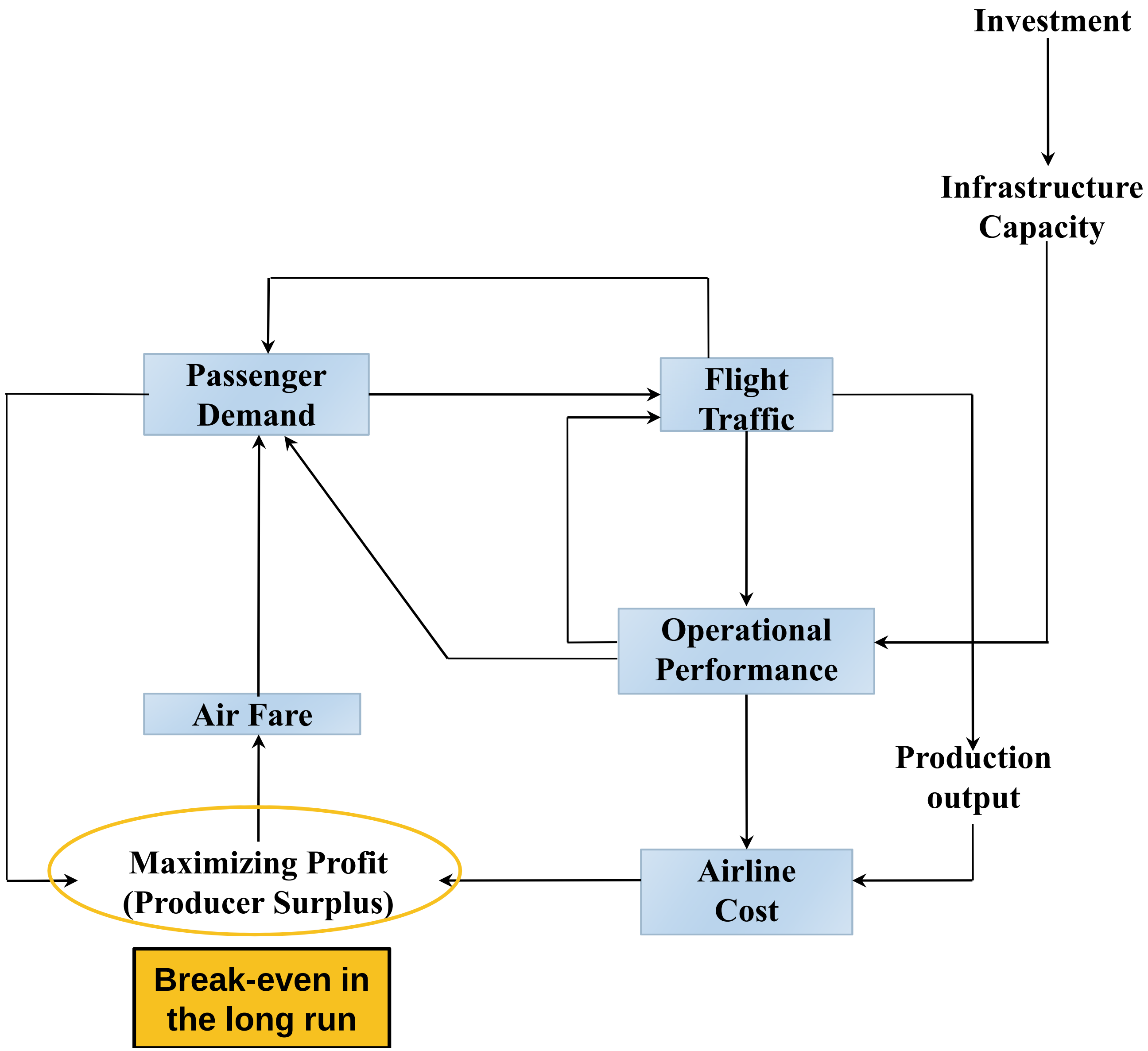
Hub city C

● Spoke airport A

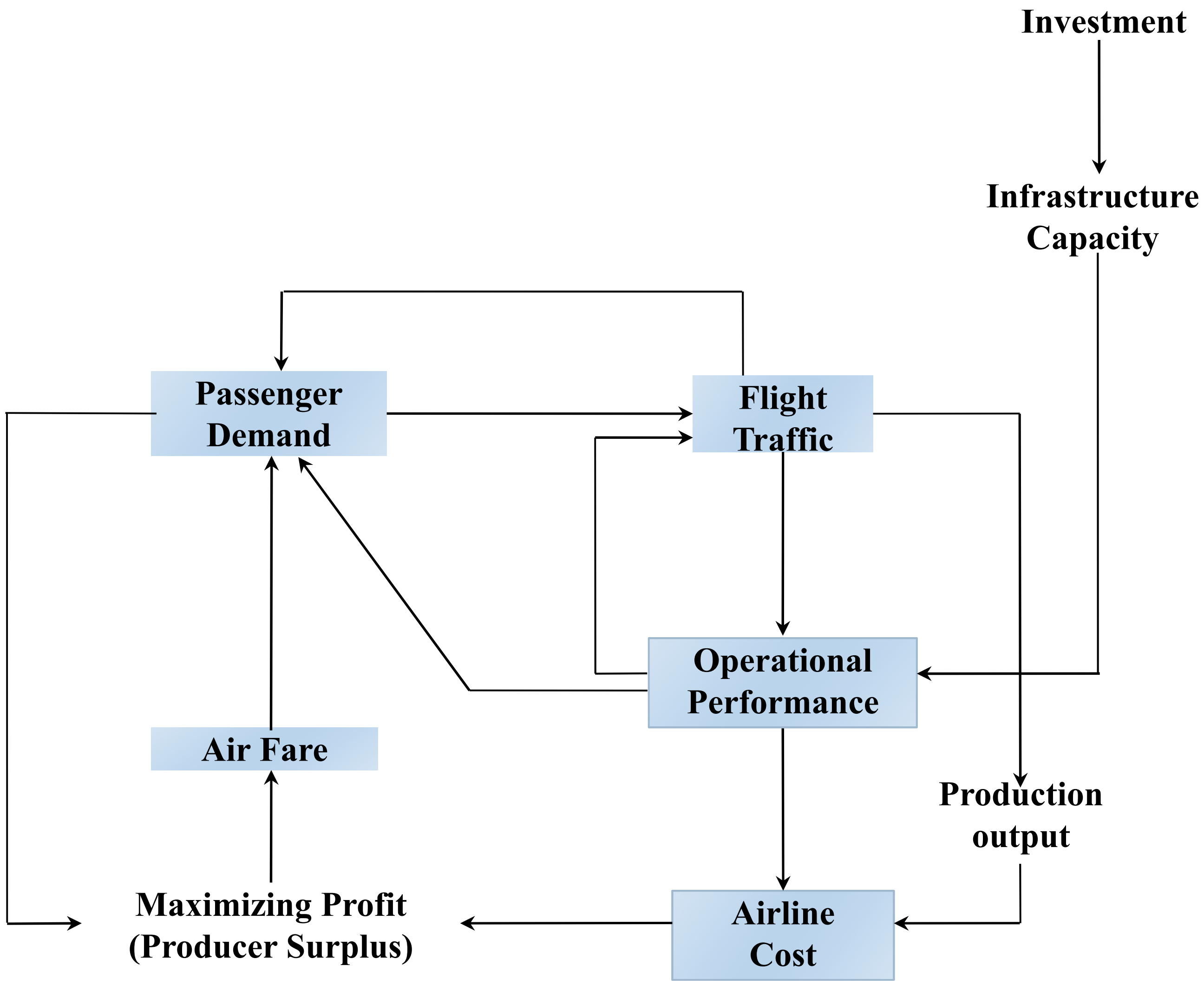
▲ Spoke airport B

🟥 Hub airport C

Proposed framework



Proposed framework



Component Estimation

Databases used

- DB1B Airline Origin Destination Survey Data
- T100 Flight Segment Traffic Data
- BTS Airline On-time Performance Data
- FAA Aviation System Performance Metric (ASPM) Data
- Bureau of Economic Analysis Regional Economic Accounts

System component estimation

Passenger Demand | **Flight Traffic** | **Air Fare** | **Operational Performance**

System component estimation

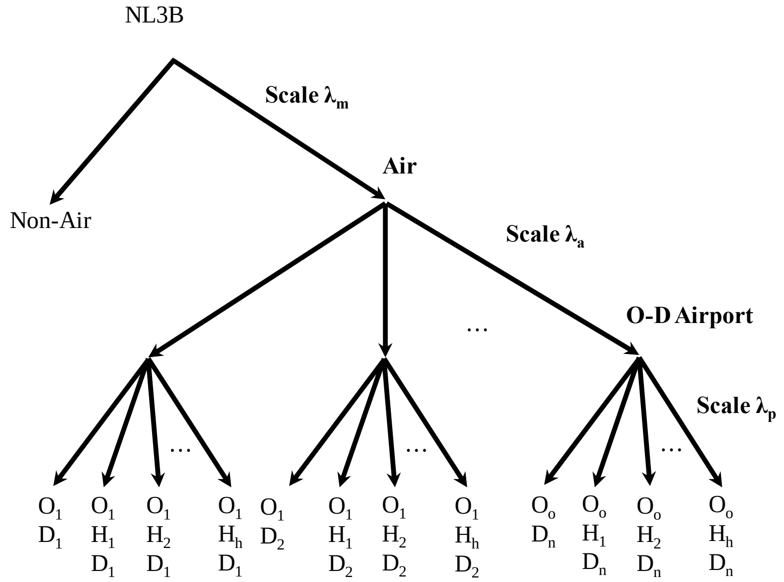
Passenger Demand | **Flight Traffic** | **Air Fare** | **Operational Performance**

3-Level NL (Hsiao and Hansen, 2011)
Dependent variable: route market share

Selected estimation results

Variable	Est.
Fare (hundreds of 2004 dollars)	-1.546^{***}
ln(Frequency)—Direct (flights per quarter)	1.240^{***}
ln(Max frequency of two segments)—Connecting (flights per quarter)	0.627^{***}
ln(Min frequency of two segments)—Connecting (flights per quarter)	0.957^{***}
Scheduled flight time—Direct (min)	-0.004^{*}
Scheduled flight time—Connecting (min)	-0.006^{***}
Positive hub arrival delay $_{t-1}$ (min/flight)	-0.006^{***}
Positive hub arrival delay $_{t-4}$ (min/flight)	-0.007^{***}

*** Significant at 1% level; * Significant at 10% level



System component estimation

Passenger Demand | **Flight Traffic** | **Air Fare** | **Operational Performance**

Log-log model
Dependent variable: segment frequency

System component estimation

Passenger Demand | **Flight Traffic** | Air Fare | Operational Performance

Log-log model
Dependent variable: segment frequency
2SLS

Selected estimation results

Variable	Est.	*p*-value
Segment passenger volume	0.6483	0.000
Segment distance	-0.3657	0.000
Segment Herfindahl Hirschman Index (HHI)	-0.3166	0.000
Origin airport HHI	-0.0383	0.000
Destination airport HHI	-0.0419	0.000
Origin delay (four quarters lag)	-0.0221	0.053
Destination delay (four quarters lag)	-0.0238	0.038
R^2		0.8947

Segment passenger volume: 0.65

Flight frequency increases at a slower rate than passenger volume

Origin/Destination delay: ~-0.02

10 percent increase in delay at one airport would decrease frequency by 0.2 percent

System component estimation

Passenger Demand	Flight Traffic	**Air Fare**	Operational Performance

Log-log model

Dependent variable: yield ($/passenger-mile)

System component estimation

Passenger Demand	Flight Traffic	**Air Fare**	Operational Performance

Log-log model
Dependent variable: yield ($/passenger-mile)
2SLS

Selected estimation results: Non-stop routes

Variable	Est.	*p*-value
Route passengers	-0.0194	0.014
Market distance	-0.6833	0.000
Origin delay (four quarters lag)	0.0499	0.000
Destination delay (four quarters lag)	0.0547	0.000
Route HHI	0.0438	0.009
Market HHI	0.0336	0.007
Origin airport HHI	0.0103	0.130
Destination airport HHI	0.0132	0.054
R^2		0.8512

Route passengers: -0.02

Cost effect from economies of density dominates over demand effect

Origin/Destination delay: ~0.05

10 percent increase in delay at origin/destination airport would increase yield by 0.5 percent

System component estimation

Passenger Demand | **Flight Traffic** | **Air Fare** | **Operational Performance**

Log-log model
Dependent variable: yield ($/passenger-mile)
2SLS

Selected estimation results: One-stop routes

Variable	Est.	*p*-value
Route passengers	0.0458	0.000
Sum of segment density	-0.0118	0.000
Circuity	-0.3154	0.000
Market distance	-0.6510	0.000
Origin delay (four quarters lag)	0.0219	0.000
Destination delay (four quarters lag)	0.0245	0.000
Hub delay (four quarters lag)	0.0221	0.000
R^2		0.5164

Sum of segment density: -0.012

Economies of density contribute to lower fare

Origin/Destination/Hub delay: ~0.02

10 percent increase in delay at origin/destination/connecting airport would increase yield by 0.2 percent

System component estimation

Passenger Demand | **Flight Traffic** | **Air Fare** | **Operational Performance**

Log-linear model

Dependent variable: average airport delay

System component estimation

Passenger Demand | **Flight Traffic** | **Air Fare** | **Operational Performance**

Log-linear model
Dependent variable: average airport delay

Selected estimation results

Variable	Est.	*p*-value
Proportion of time under IFR conditions (IFR)	1.1283	0.000
IFR^2	-0.7089	0.000
Average wind speed	0.0168	0.000
Traffic volume/airport capacity (VC)	1.0192	0.000
VC^2	1.1747	0.000
Traffic volume	-0.0017	0.000
Standard deviation of scheduled flights (peakedness)	0.1774	0.000
R^2		0.5064

VC: 1.0192; VC^2: 1.1747

Increase in VC ratio increases delay

Std. dev. of scheduled flights: 0.1774

Increase in schedule peakedness increases delay

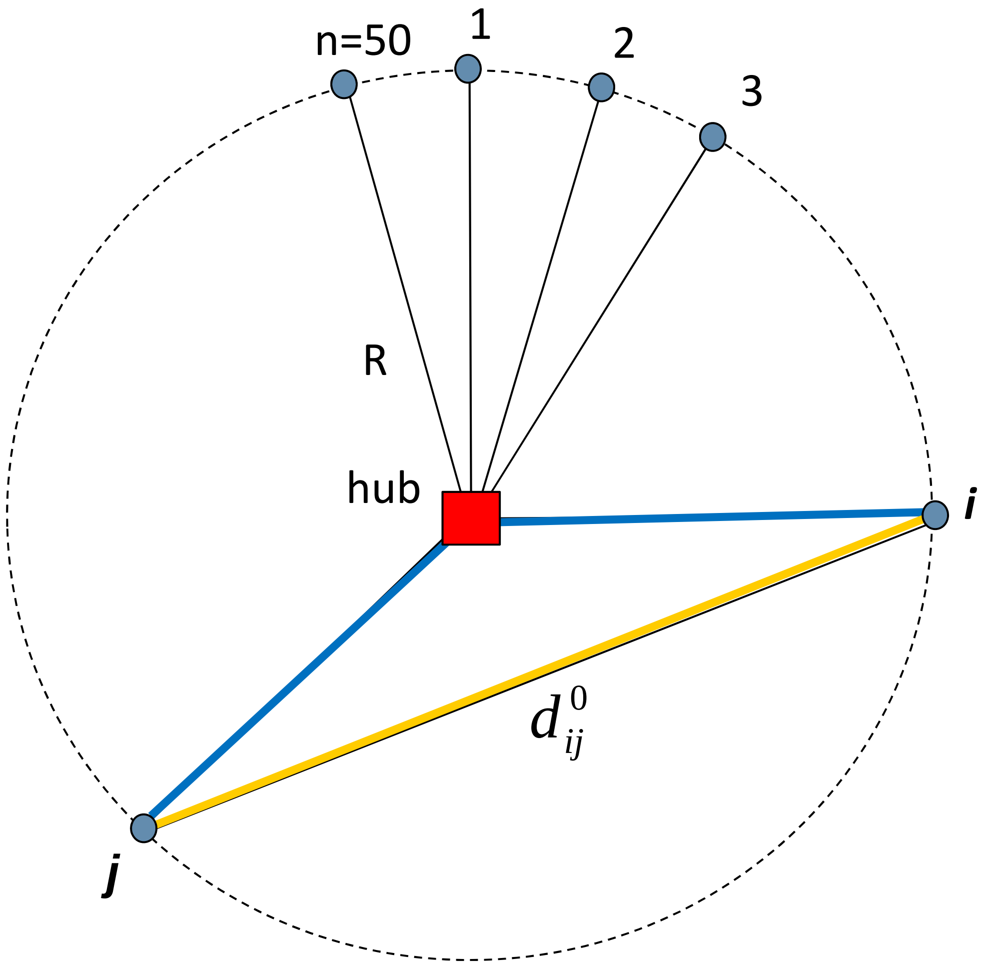
Summary of component model estimation

- All else being equal, higher delay leads to
  - Lower one-stop route demand (higher hub delay)
  - Lower total market demand
  - Lower flight frequency
  - Higher air fare

- Delay effect on fare and frequency not substantial – demand will be the main driver in equilibrium

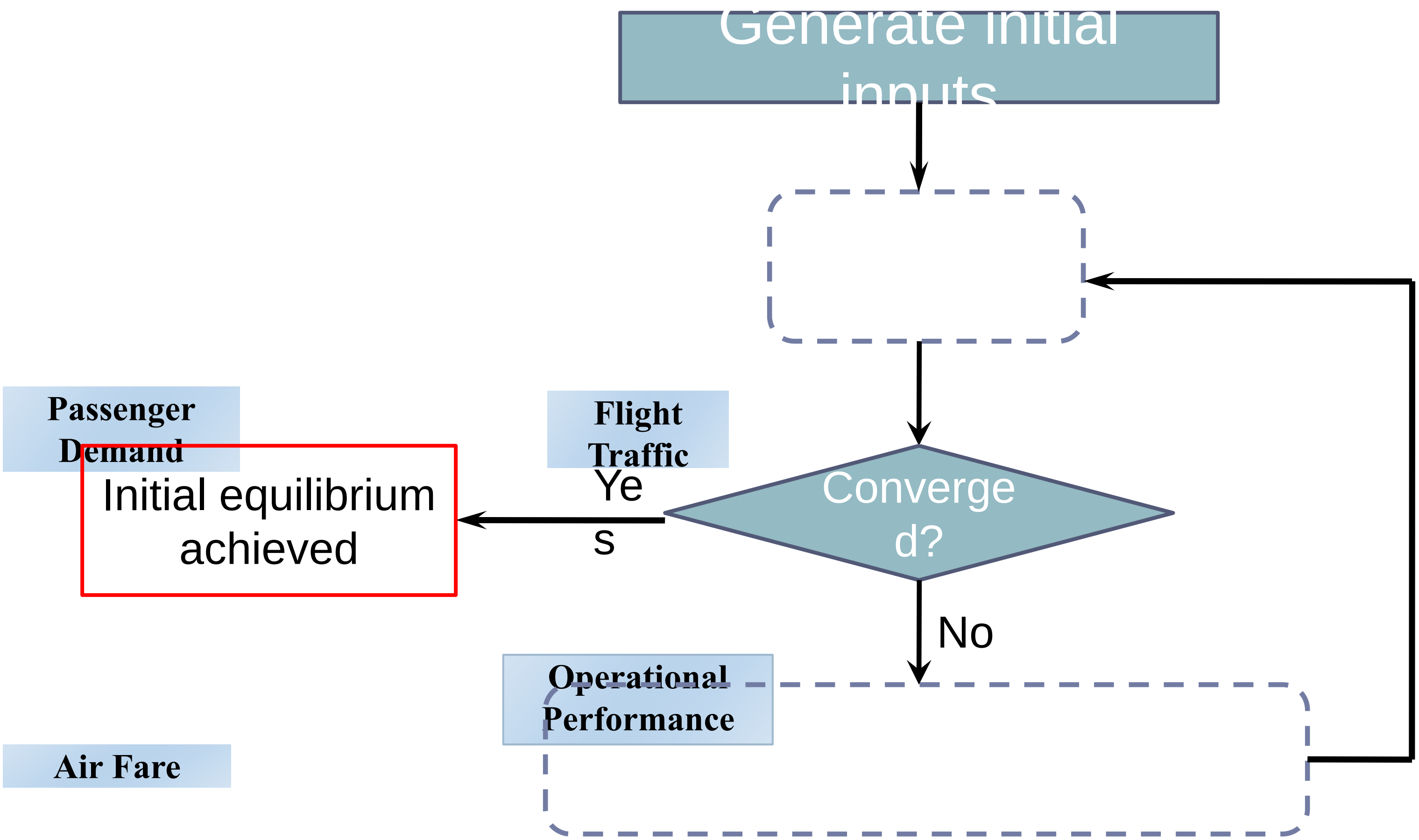
System Integration

Network topologies



- 50 spoke cities uniformly located on the circle
- Hub city at the center
- R=400 miles
- Each city has one airport
- Air service provided between any two airports
- Population
  - 10m for the hub city
  - 2m for spoke cities

Proposed framework



Generate initial inputs

Passenger Demand

Flight Traffic

Initial equilibrium achieved

Yes

Converged?

No

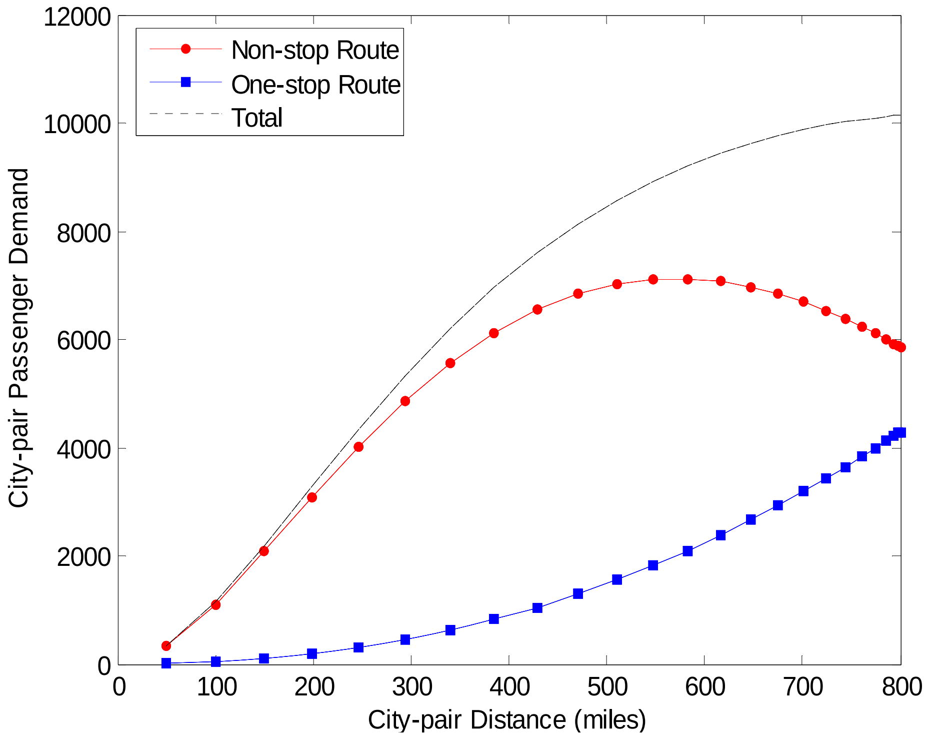
Operational Performance

Air Fare

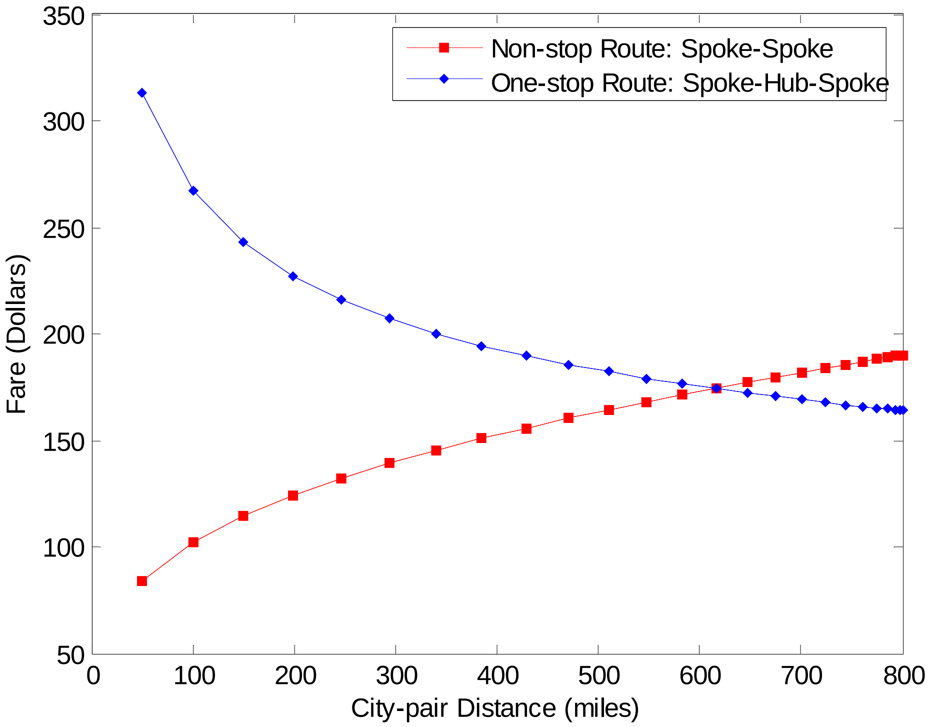
- Existence: Brouwer’s fixed point theorem guarantees at least one solution exists
- Uniqueness & convergence: different starting values converge to the same equilibrium

Initial equilibrium: results (I)

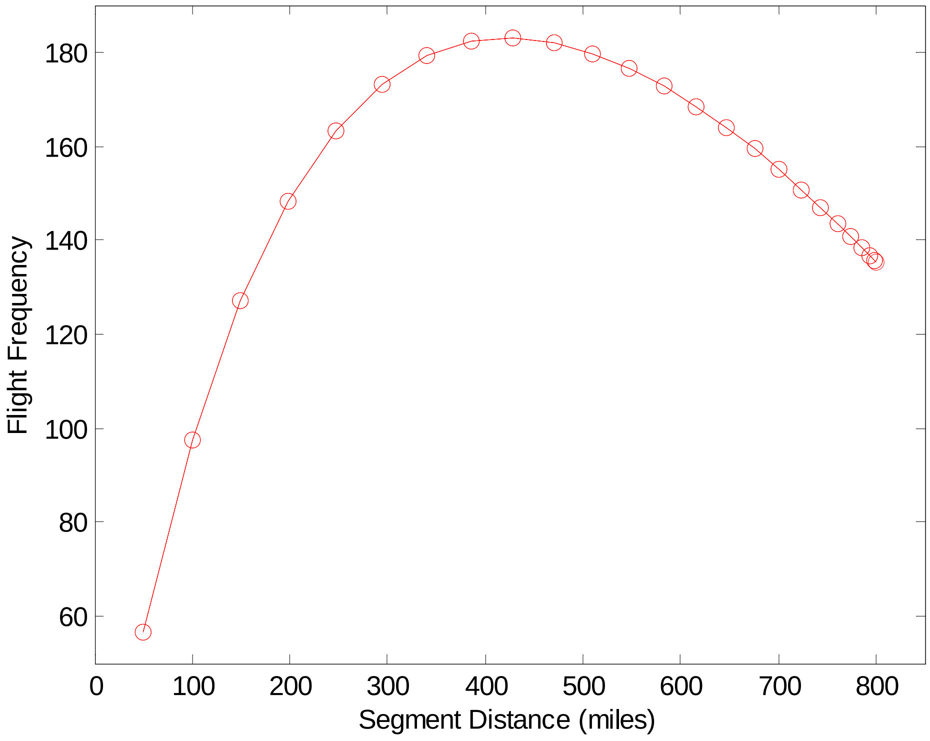
Demand



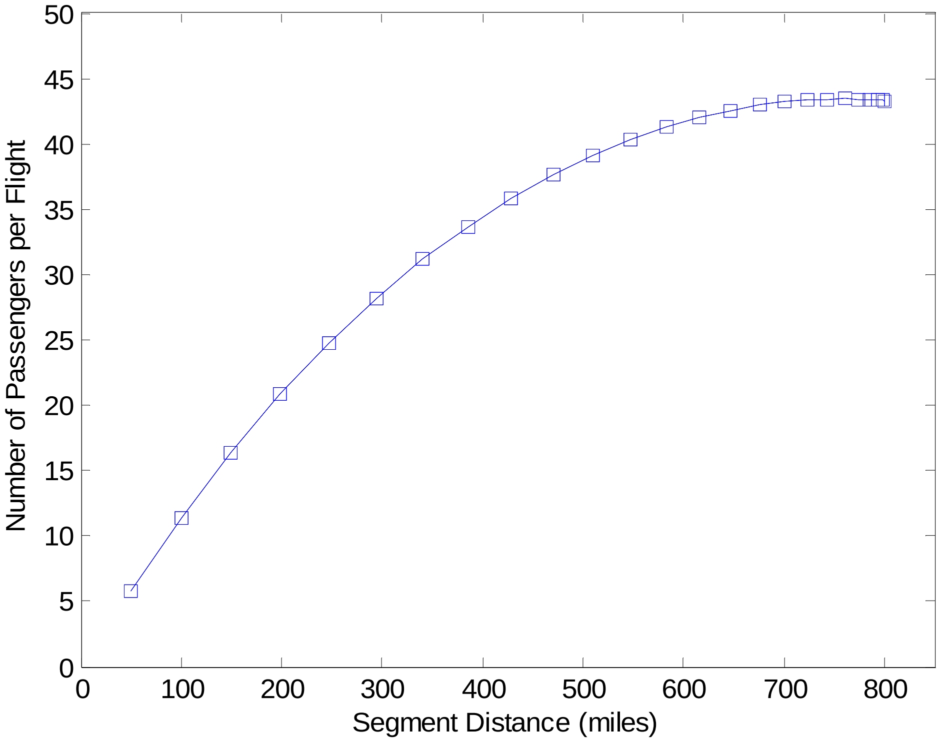
Air Fare



Initial equilibrium: results (II)



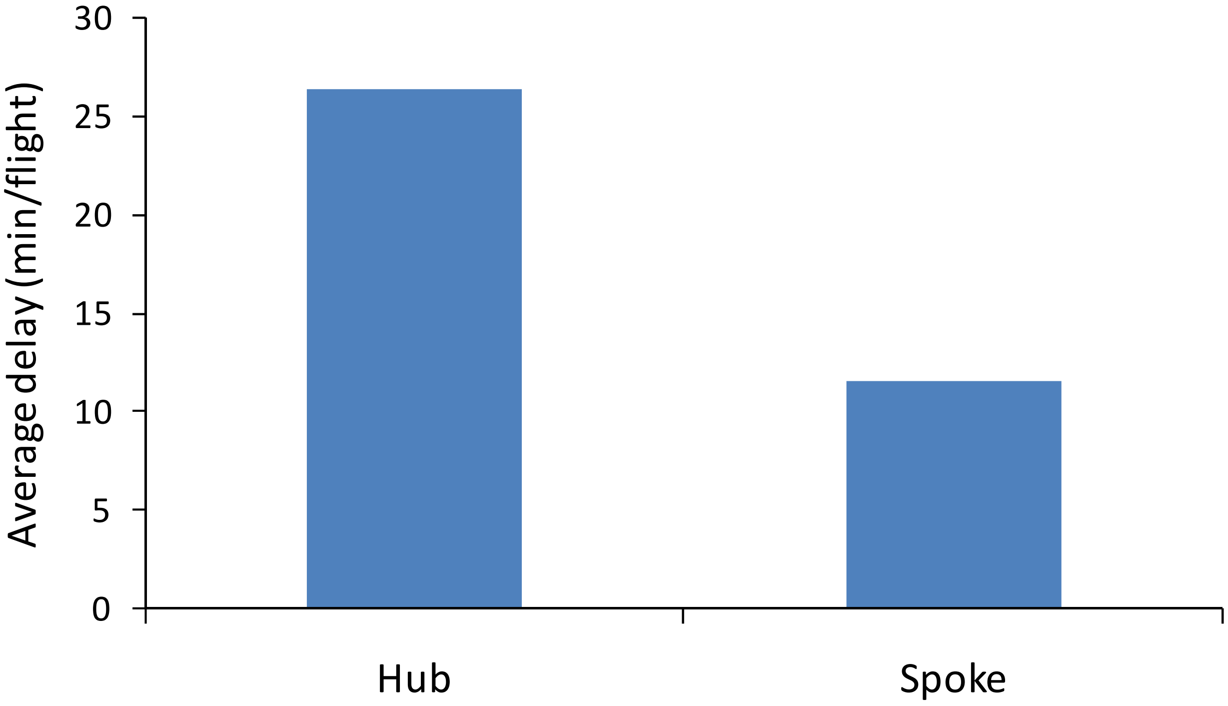
Flight frequency



Number of passengers per flight

Initial equilibrium: results (III)

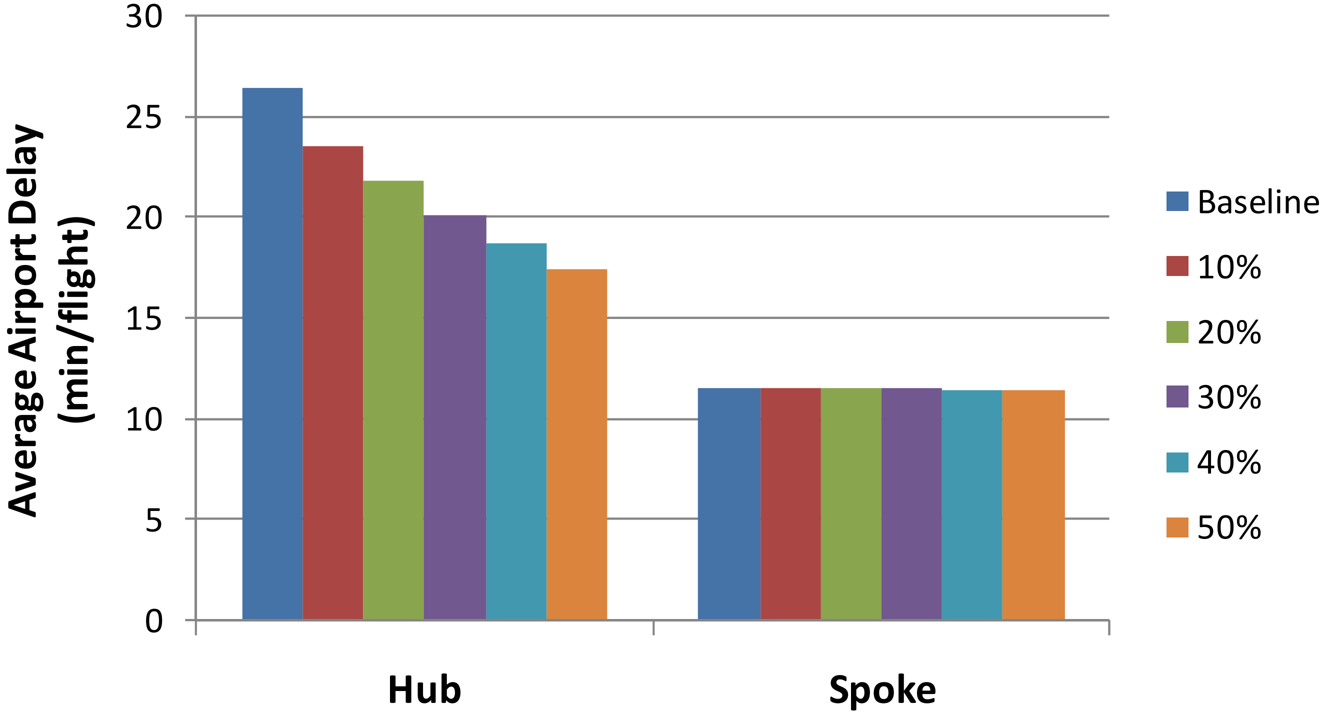
Airport delays



Equilibrium shift due to capacity increase

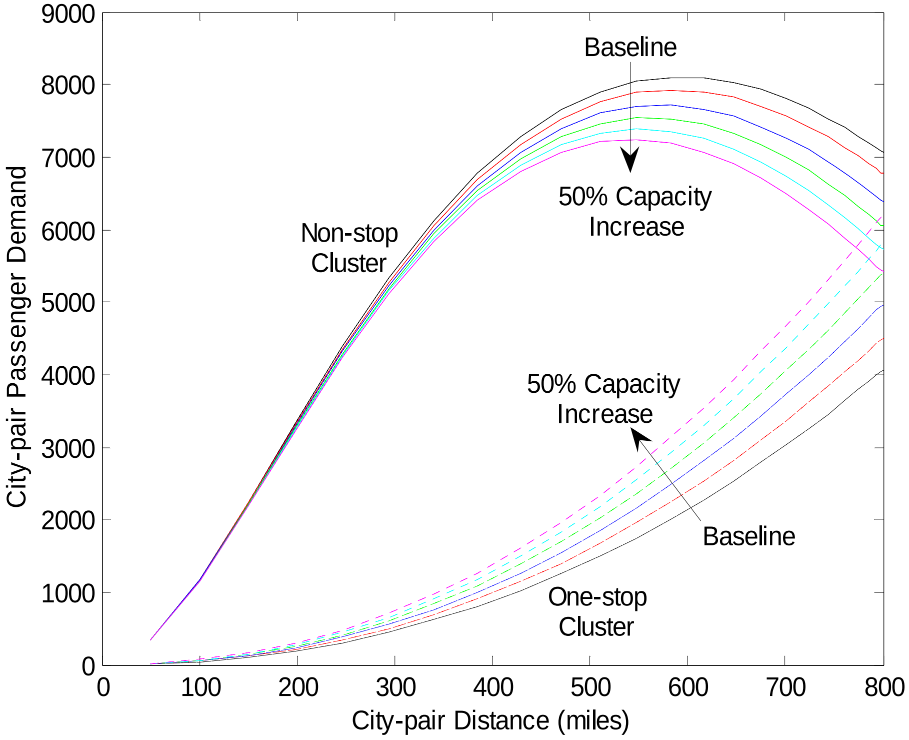
- Five scenarios: increase hub capacity by 10, 20, 30, 40, 50%
- Compute new equilibrium under each scenario

Airport delays

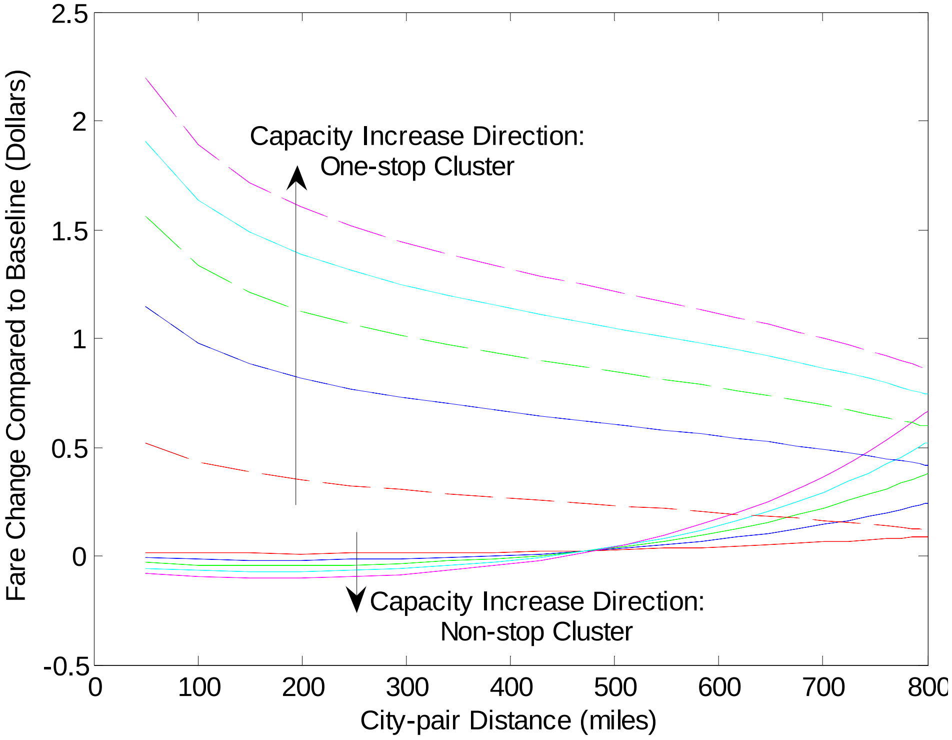


Equilibrium shift: demand and fare

Demand



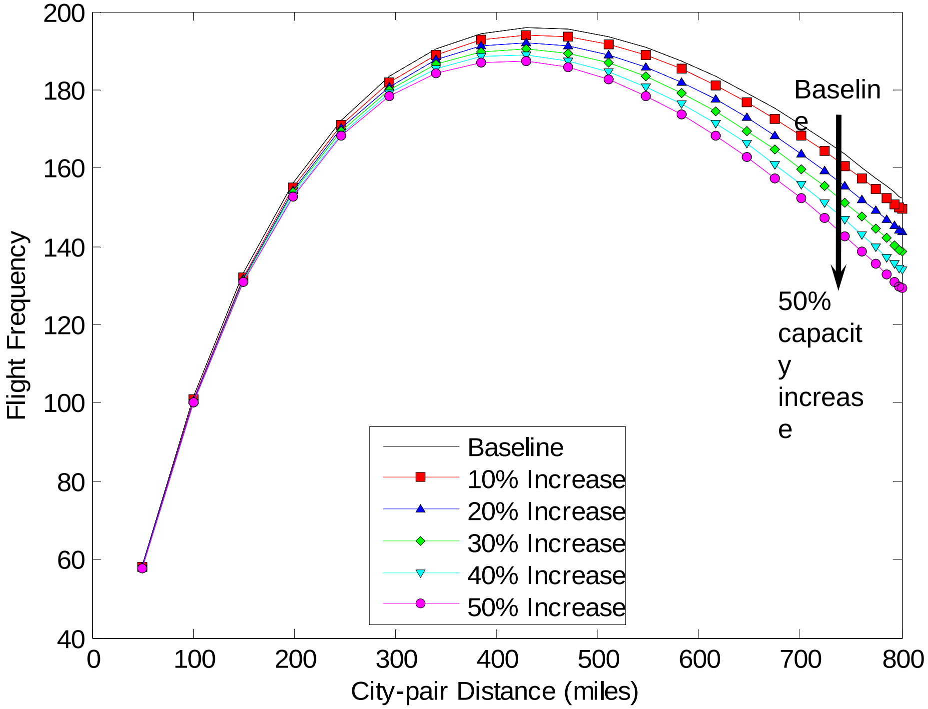
Air Fare Change

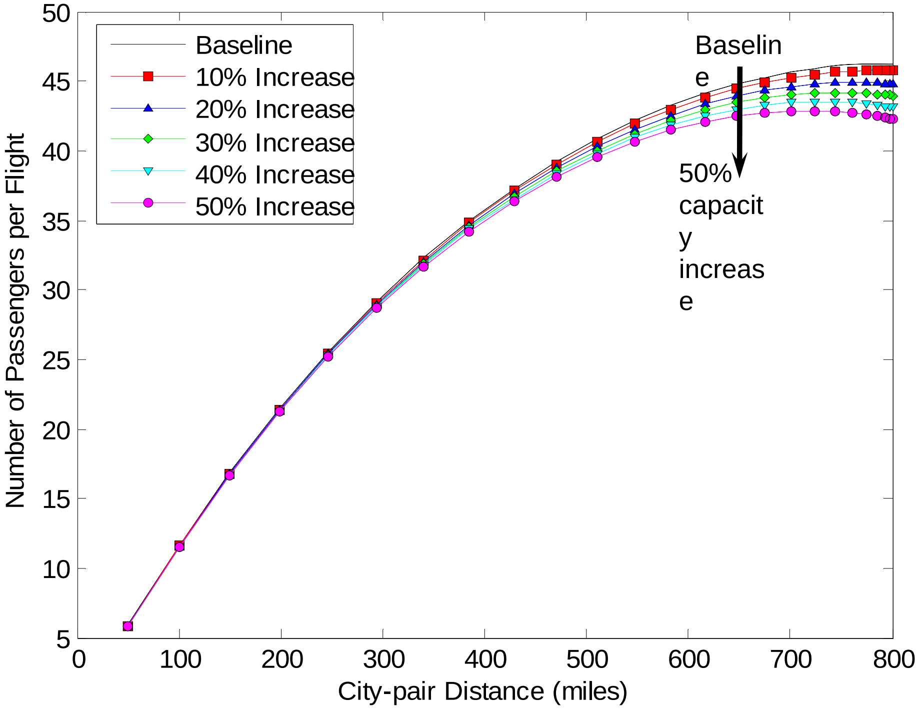


Equilibrium shift: frequency and number of passengers per flight

Flight frequency

Number of passengers per flight





Equilibrium shift: consumer benefits

System-wide consumer benefit gains (million$/qtr)

capacity increase percentage	Logsum measure	Rule of half: same proportional route price change	Rule of half: same absolute route price change
10%	51.8	55.2	55.3
20%	96.7	104.2	104.4
30%	139.8	150.9	151.3
40%	180.2	194.7	195.3
50%	218.4	236.1	236.9

Sensitivity analysis: consumer benefit gains

Baseline capacity

Capacity increment

	90000	110000	130000	150000
8000	46.2	38.1	33.0	29.0
16000	40.2	36.5	31.6	27.9
24000	38.9	33.6	30.1	26.3
32000	36.8	32.5	28.5	24.9
40000	35.0	31.2	27.0	23.6
48000	33.3	29.2	25.6	22.4

Diminishing return to baseline capacity and capacity investment

Comparison with conventional method: passenger benefits

Baseline hub capacity: 1000 ops/day; increase by 50%

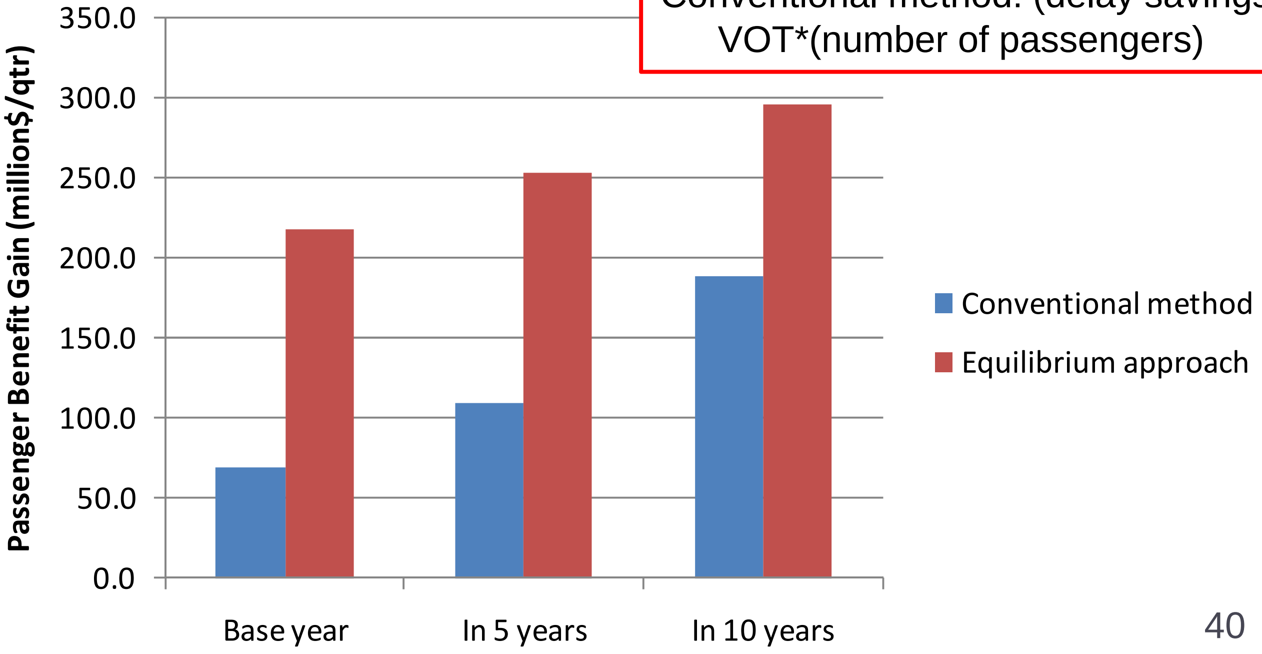
Assumptions about growth

Time	Income per capita	Population	Flight traffic
Year 5	10%	5%	10%
Year 10	21%	11%	22%

Equilibrium approach: Logsum

Conventional method: (delay savings)* VOT*(number of passengers)

Conventional method underestimates consumer benefit gain



Conclusions

- This research proposes an equilibrium framework to assess benefits from aviation infrastructure investment

- Major findings
  - Capacity change engenders system equilibrium shift, leading to adjustment in passenger demand, air fare, flight frequency, number of passengers per flight, and delay
  - The effect of delay on fare and frequency is limited; demand is the main driver in system equilibrium shift
  - Equilibrium approach is able to capture benefits beyond delay reduction

Thanks you!

Question?