Airline and Passenger Responses to Novel Aircraft Technologies in China

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Peizhi (Peggy) Li, Khan Doyme, Lynnette Dray, Andreas W. Schäfer

Air Transportation Systems Lab

University College London

Introduction

- Achieving industry net-zero targets requires alternative fuels and disruptive technologies
- Challenges:
  - Scaling up drop-in alternative fuels
  - Range limitations of all-electric aircraft
  - Compatibility of hydrogen aircraft designs
  - Uncertainties in fuel cost, infrastructure, operating cost, etc.
  - Social acceptance

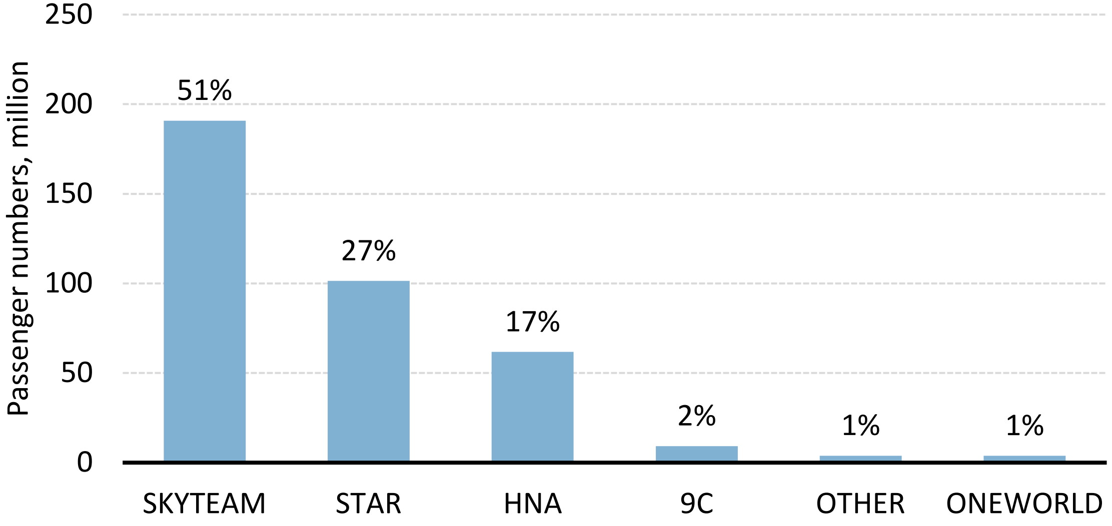
➢ **Under what Jet fuel and alternative fuel prices will airlines operate new aircraft profitably?**

➢ **How will consumer preference influence airline adoption and deployment of new technologies?**

- To investigate airline and passenger responses to novel aircraft technologies, the UCL Airline Behaviour Model (ABM) (Doyme et al. 2019) is adapted
- Domestic China selected as case study due to increasing air demand and rapid rise in CO_2 emissions

Data

- 78 major airports, 2176 city pairs in China
- Passenger movement, fare, and schedule data for 2015 used (Sabre, 2017)
- Direct network: 99% of total passenger numbers
- Global alliances



Aircraft Size Class	Example Aircraft	Seats Number	Max Range km
Class0	ATR72	70	3300
Class1	E190	96	3510
Class2	A319	120	4000
Class3	A320neo	175	4500
Class4	A321	189	5500
Class5	787	246	11960
Class6	A330	298	10150
Class7	777	342	13080
Class8	A380	615	10764

UCL Airline behaviour model (ABM)

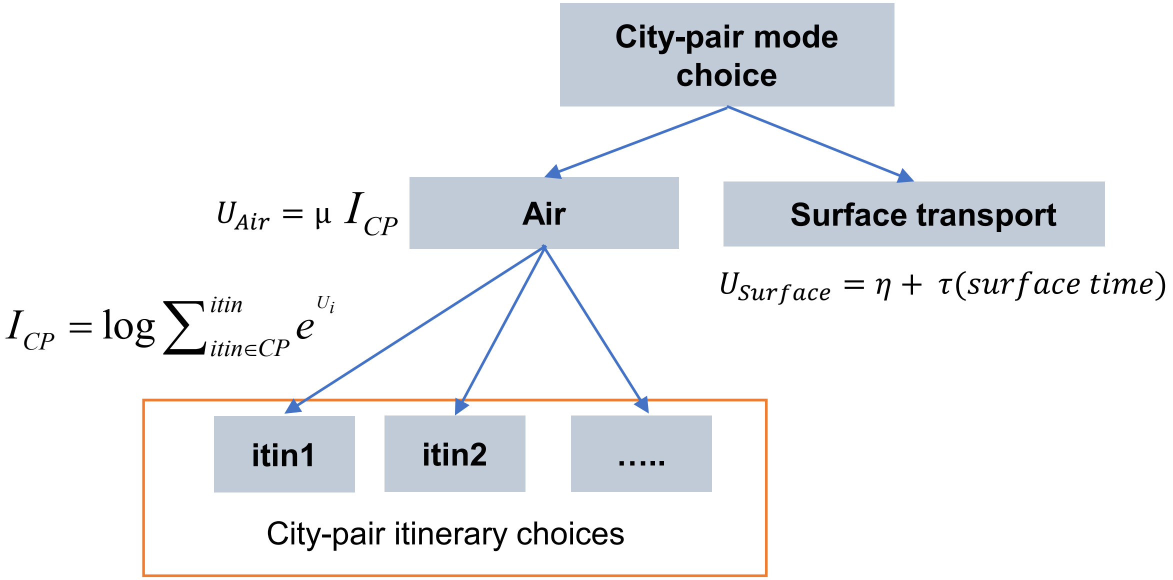
- Each airline is a player in an n-player noncooperative game
- Each airline A aims to maximise its profit
- Decision variables: airfare, flight frequency and type of aircraft across the network

$$P_A = \underbrace{\sum_{i \epsilon ITN_A} fare_i . pax_i + arev_A . pax_A}_{\text{Revenue}} - \underbrace{\sum_{j \epsilon SEG_A} \sum_{a \epsilon CRFT_j} opcost_{a,j} . freq_{a,j} - \sum_{j \epsilon SEG_A} \sum_{a \epsilon CRFT_j} paxcost_{a,j} . pax_{a,j}}_{\text{Operating cost: flight-related costs \& passenger-related costs}}$$

- Set of constraints (e.g., airport capacity) are imposed to reflect real limits on airline operations
- Airlines sequentially adjusting decision variables, iterate until profit equilibrium
- Doyme et al. (2019) and Dray et al. (2022) for more detail

Airline behaviour model adaptation for China

- Passenger itinerary choice and demand model estimated using Asia pacific data (9146 itineraries, 18334 city pairs)
- Demand model estimated based on a nested structure (Jamin et al, 2004)
- Fare endogeneity corrected using two-stage control function (Guevara & Ben-Akiva, 2006)
  - Hausman-type Instrumental Variable (IV)
  - Validity of IV tested using overidentification test proposed by Guevara (2018)



$$U_i = \beta_{fare} fare_i + \beta_{time} time_i + \beta_{\log\_fltfreq} \log\_fltfreq_i + \beta_{n\_stops} n\_stops_i + \beta_{airline} airline_i + airport_{ffx} + \varepsilon_i$$

$$D_{o_i d_i (Air)} = K \cdot (P_{o_i}, P_{d_i})^{\partial_1} (I_{o_i}, I_{d_i})^{\partial_2} e^{\partial_3 Spec} e^{\partial_4 \text{Business}} e^{\partial_5 Visa\_required} e^{\partial_6 Domestic} e^{\partial_7 Common\_language} e^{\partial_8 Island} e^{\partial_9 India} e^{\partial_{10} FracLH} e^{\partial_{11} Capital} e^{\partial_{12} \text{Modechoice\_logsum}} \cdot \frac{e^{\partial_{13} I_{cp}}}{e^{\partial_{13} I_{cp}} + e^{(\partial_{14} + \partial_{15} surfacetransport\_time)}}$$

Airline behaviour model adaptation for China

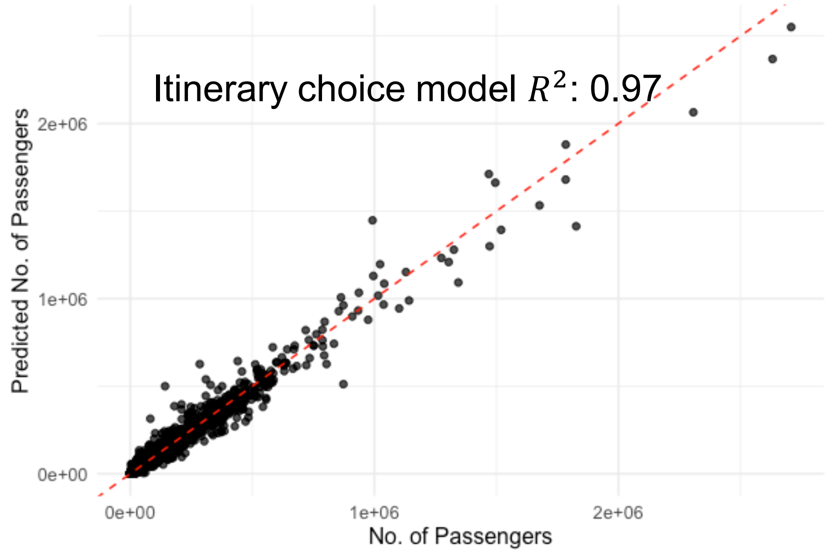
Itinerary choice model

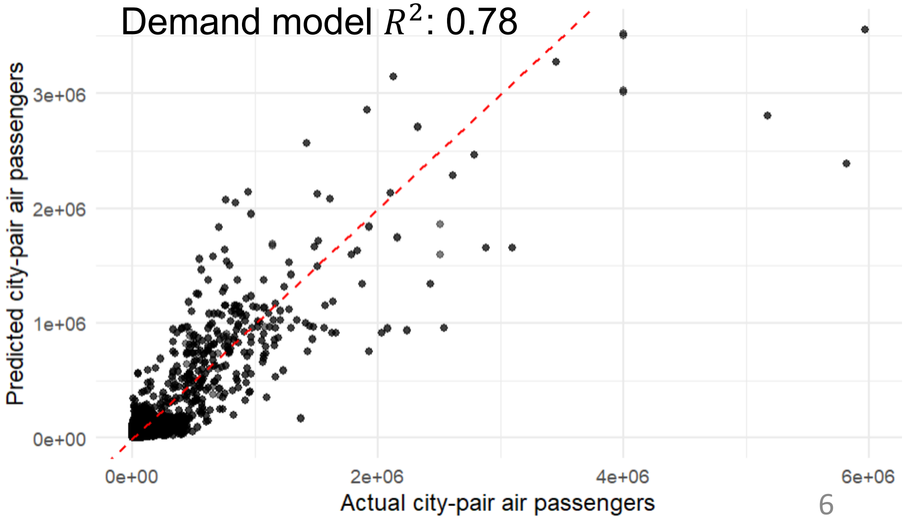
Variable	Estimate	t value
Fare	-0.0101	-10.30
Time	-0.0064	-4.02
Log (flight frequency)	0.965	114.03
Number of legs	-0.33529	-11.67
Residuals	0.00974	9.84
IndiGo (6E)	0.416	3.65
Spring (9C)	0.109	1.49
JetAirways (9W)	0.219	6.04
AirAsia (AK)	0.148	0.81
Hainan (HNA)	0.17	4.36
LionAir (JT)	0.188	1.56
ONEWORLD	0.172	5.51
OTHER	0.002	0.63
SpiceJet (SG)	0.409	2.78
SKYTEAM	-0.03278	-6.10
STAR	0.49781	2.67

Value of Time: 38$/h

Demand model

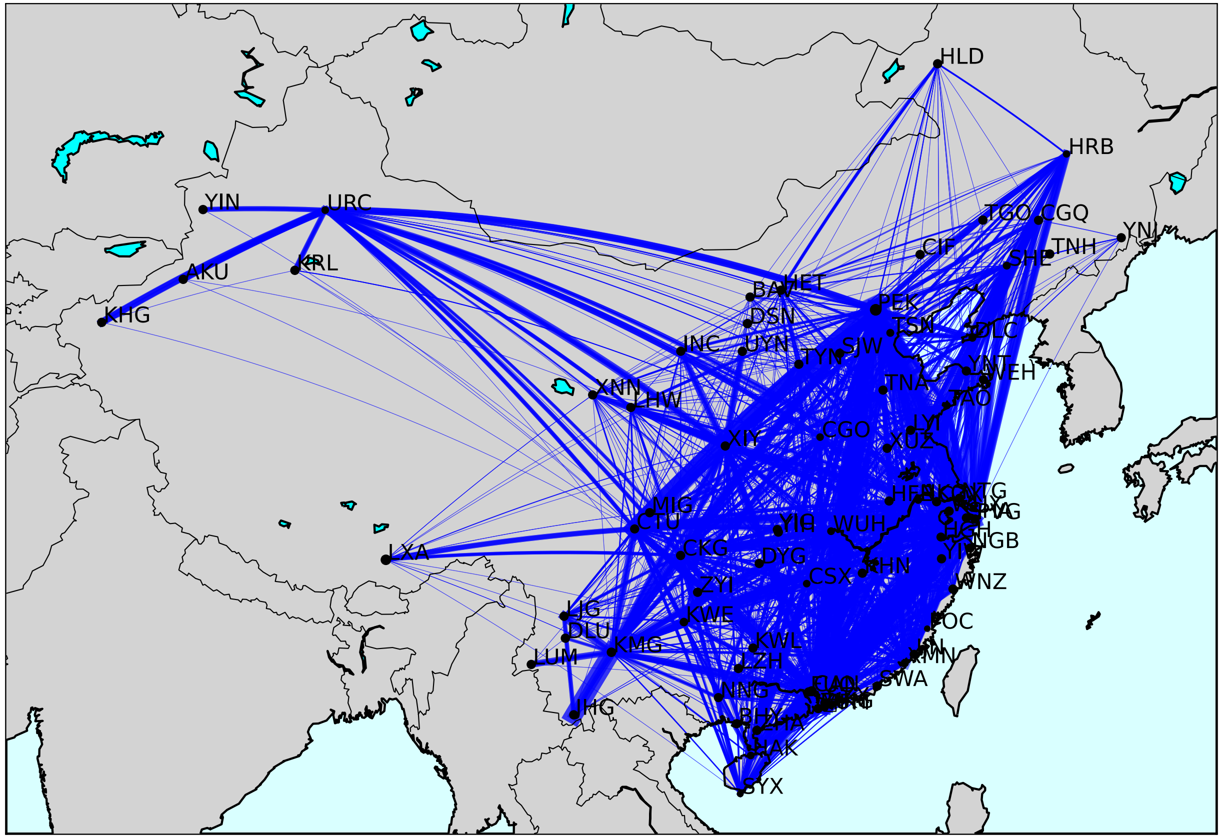
Variable	Estimate	t value
(Intercept)	1.243	10.852
Population	0.219	79.381
Income	0.179	57.484
Air logsum	0.771	17.688
Business_route	1.513	78.805
Domestic route	0.803	31.655
Capital city	0.246	21.374
FracLH	0.884	37.332
Common_lanuage	0.482	20.109
Visa_required	-0.156	-6.39
Tourist city	0.592	53.921
Tourist city_or	0.256	14.097
Island	0.128	11.554
India	-0.172	-8.646
Mode choice logsum	0.55	16.042
Surface transport time	-0.0036	-34.593
Surface transport intercept	1.842	7.583



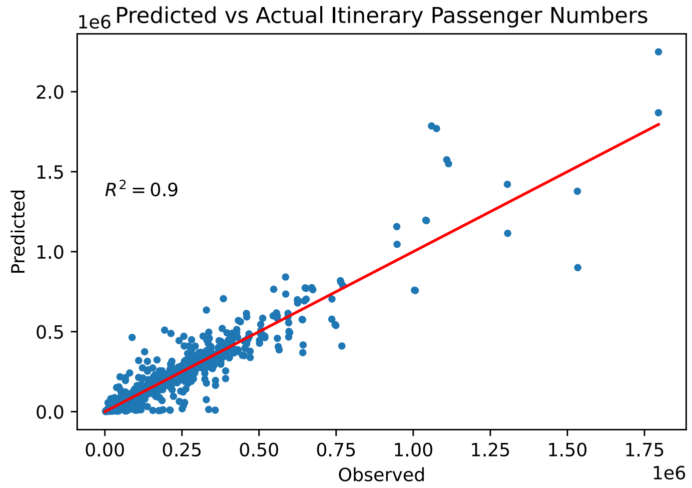


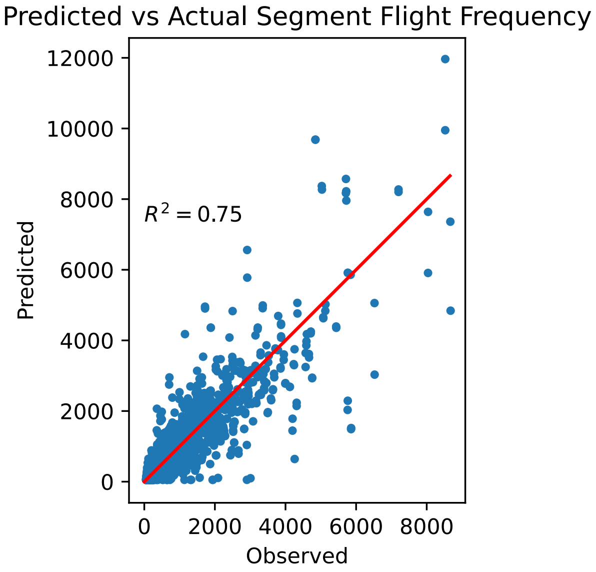
Airline behaviour model validation for China

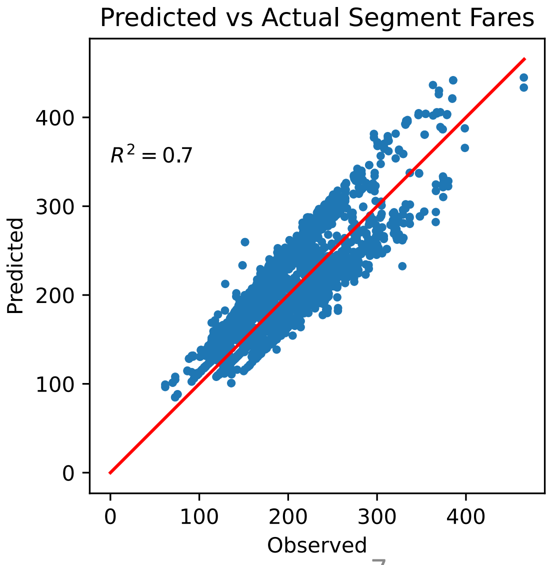
- Base year 2015
- Model calibrated and validated against base year value



Modeled 2015 Chinese domestic aviation network, thicker lines represent higher flight frequency





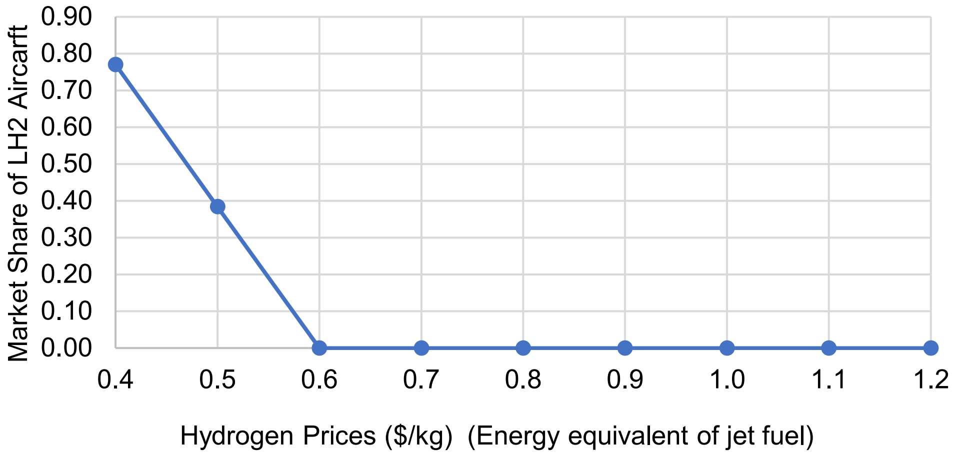


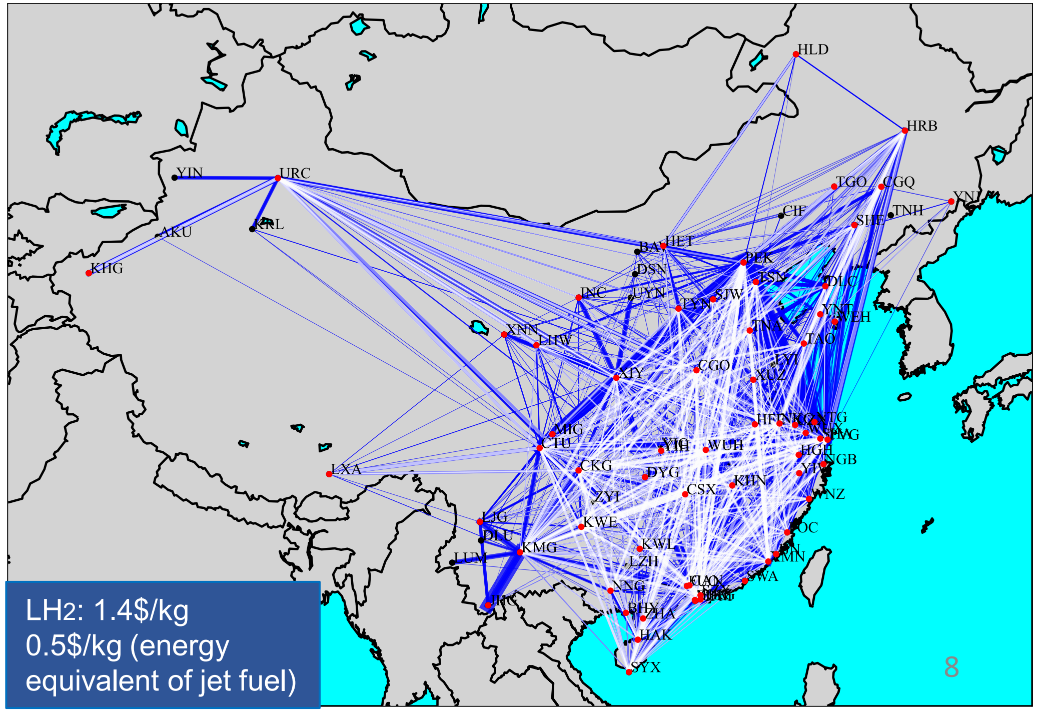
Airline Responses to New Technology – Liquid Hydrogen (LH_2) Aircraft

- Choice and demand model parameters kept at base model value
- Assume unchanged airport capacities and available infrastructure
- Assume fleet turnover has taken place
- LH_2 aircraft modeled with A321 fuel burn (energy equivalent) similar operating cost to A321

Aircraft Size Class	Example Aircraft	Seats Number	Max Range km
Class3	A320neo	175	4500
Class4	A321	189	5500
Class8	A321hydro	175	4500

- Simulated LH_2 uptake with jet fuel price at $0.7/kg and varying hydrogen prices (hypothetically introducing LH_2 aircraft into the 2015 system)



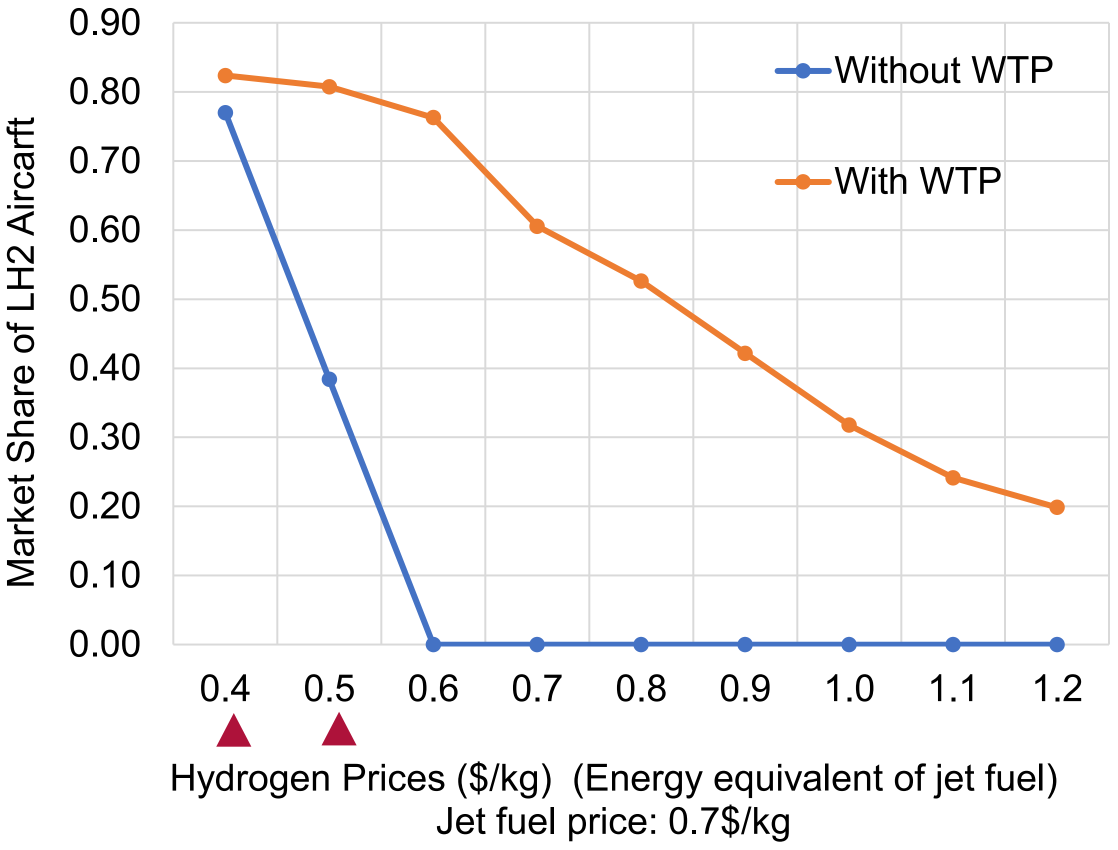


Airline and Passenger Responses to New Technology- Liquid Hydrogen (LH_2) Aircraft

- Consumer Willingness-to-Pay (WTP) for flying on LH_2 aircraft: $41 (Li P et al, 2023)
- Itinerary choice model modified to combine Revealed Preference (RP) and Stated Preference (SP) data

$$U_{i_{scaled\_RP}} = b_{fare} fare_i + b_{time}\, time_i + \frac{freq_{hydro}}{freq_i}\, b_{fare} * WTP_{hydro} + b_{fltfreq} \log(freq_i) + \gamma_i$$

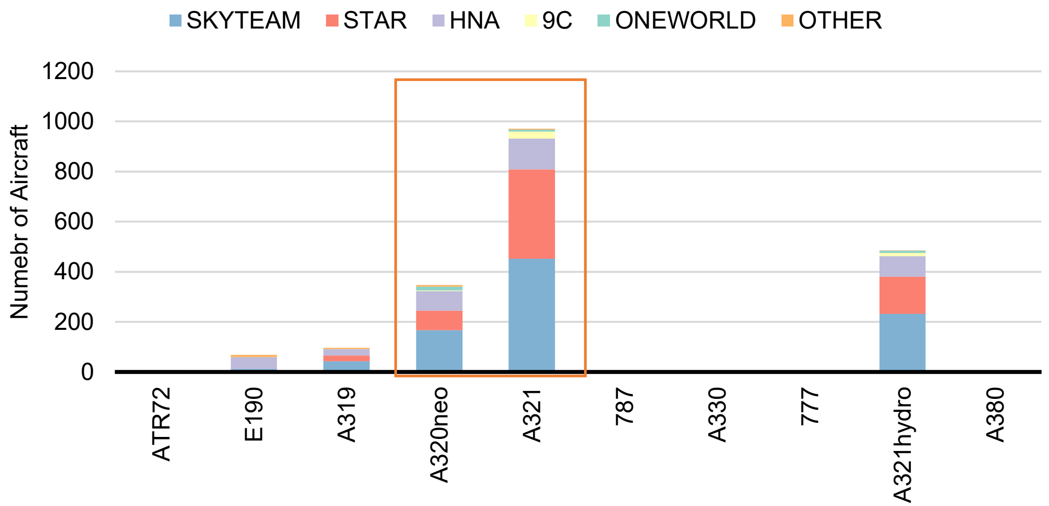
- Higher market share for LH_2 with consumer WTP
- LH_2 price at $0.4/kg and $0.5/kg: 8% increase in total passenger numbers and 6% increase in total flight frequency with consumer WTP



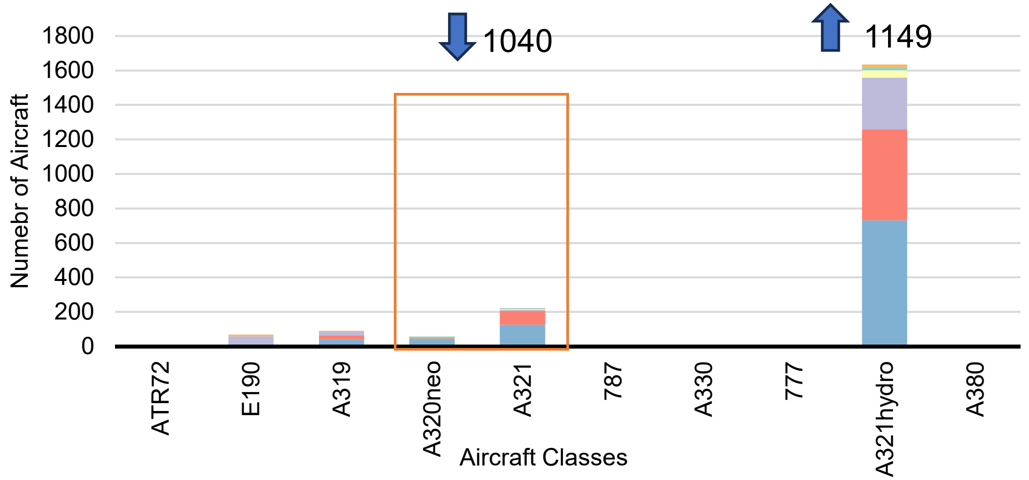
Airline and Passenger Responses to New Technology- Liquid Hydrogen (LH2) Aircraft

Jet fuel: **0.7$/kg**
LH2: 1.4 $/kg, **0.5$/kg** (energy equivalent of jet fuel)

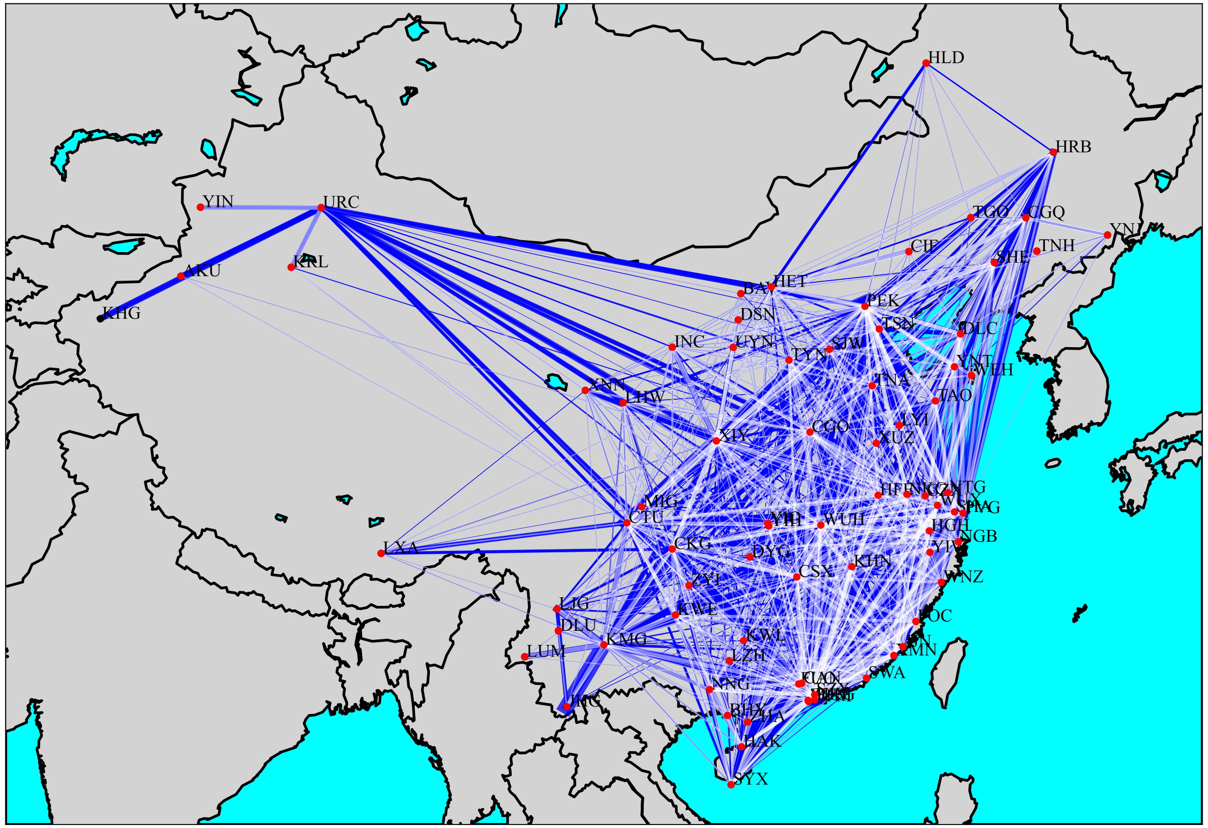
Number of Aircraft Used per Airline **without WTP**



Number of Aircraft Used per Airline **with WTP**



Jet fuel: **0.7$/kg**
LH2: 3.3$/kg,**1.2$/kg** (energy equivalent of jet fuel)
LH2 : **20%** of the market (in PKM)



Conclusions

- **LH2 Adoption without consumer WTP**: \$0.2/kg cheaper than jet fuel (energy-equivalent basis)
- **Social Acceptance**: critical for introducing new technology
  - When LH2 costs are high (>0.5\$/kg JetA equivalent), consumer WTP increases LH2 market share considerably.
  - 20% market share achievable with hydrogen priced at \$1.2/kg JetA equivalent, with consumer WTP
- **Induced Demand**: Consumer WTP leads to an increase in total passengers and flight frequency
- **Limitations**:

  I. Based on 2015 airline operations
  II. Assumptions for LH2 aircraft and inputs
- **Future Work**:

  I. Evaluate LH2 uptake in future years
  II. Assess different levels of WTP impact on market share
  III. Use ABM to assess the feasibility and market impact of all-electric aircraft and SAF

Thank you

More information:

UCL ATSLab http://www.atslab.org/