UBC SAUDER SCHOOL OF BUSINESS

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Effects of High-Speed Rail Speed on Airline Demand and Price: Theoretical analysis and empirical evidence from a quasi-natural experiment *

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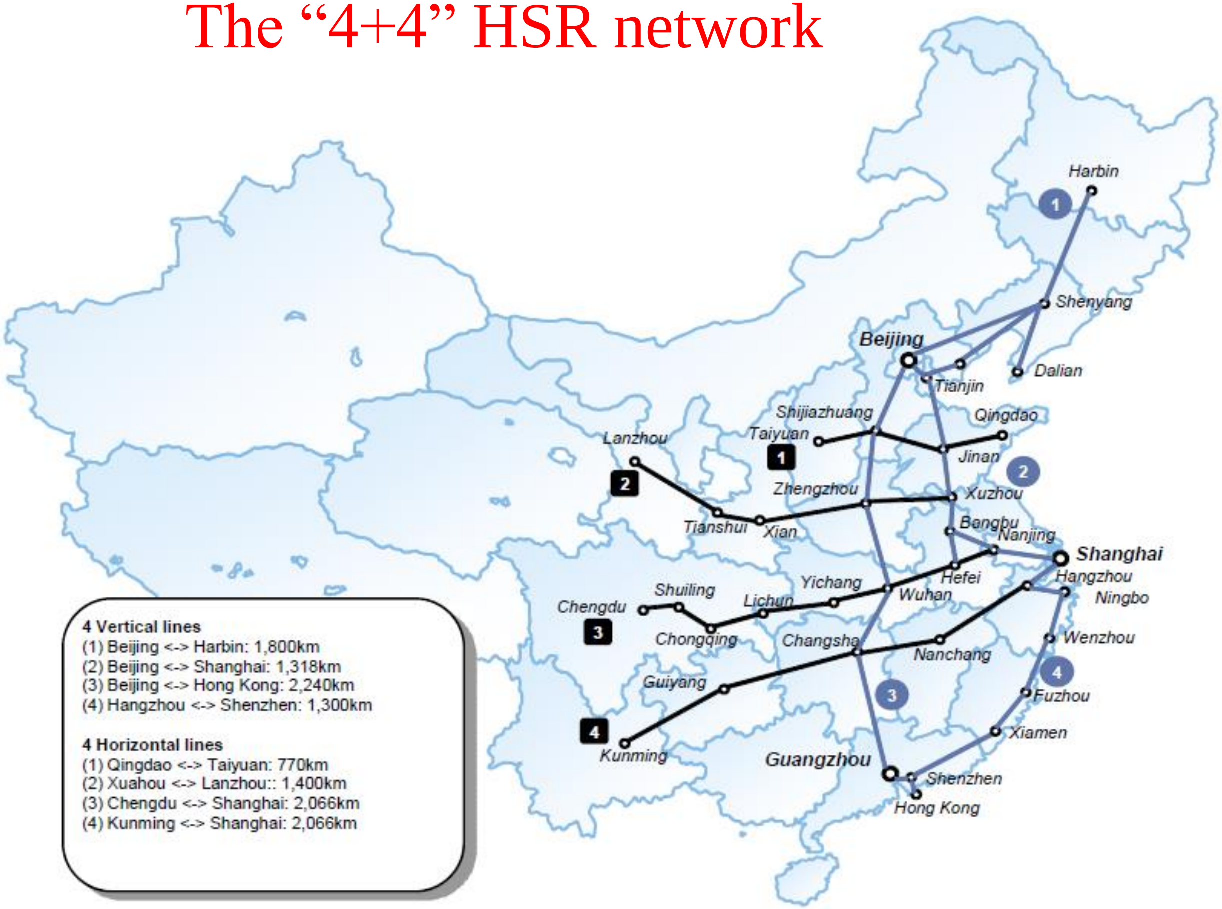
Sept 2017

1. Introduction

- High-speed rail (HSR) is developing fast around the world, especially in China.

- 2004: China laid out a blueprint of building a **4-vertical and 4-horizontal** corridors
  - **12,000 km** HSR network by 2020
  - Revised with acceleration in Oct 2008: 16,000 km by 2020

The “4+4” HSR network



Source: Ministry of Railways and Goldman Sachs

1. Introduction-(cont.)

- First HSR line: Beijing – Tianjin, Aug 1, 2008, 350 km/hr
- 23,914 km HSR in operation in 2017 (UIC, 2017): 200-350 km/hr
- This gives China the world's largest HSR network:
  - Japan (1964) 2,500 km
  - Europe (France's TGV, 1981; Spain, 1992) 5,764 km
  - Korea (2004) Seoul-Daejeon 155 km, -Busan 330 km (2009)
  - Taiwan (2007) Taipei-Kaohsiung 340 km
- … and greater than the rest of world combined

Operating statistics of China's high-speed rail

Year	Operational length (km)	Share of overall rail length (%)	Pax carried (million)	Share of overall rail pax (%)	Pax-km (billion)	Share of overall rail pax-km (%)
2008	672	0.8	7.34	0.5	1.56	0.2
2009	2,699	3.2	46.51	3.1	16.22	2.1
2010	5,133	5.6	133.23	8.0	46.32	5.3
2011	6,601	7.1	285.52	15.8	105.84	11.0
2012	9,356	9.6	388.15	20.5	144.61	14.7
2013	11,028	10.7	529.62	25.1	214.11	20.2
2014	16,456	14.7	703.78	30.5	282.5	25.1
2015	19,838	16.4	961.39	37.9	386.34	32.3

Source: China Statistical Yearbook, 2016

Huge HSR investment so far:

- In 2010, total railway investment amounted to 842 billion RMB (122 billion USD) (Zhao et al., 2015)

- 2011-2015, average yearly railway investment amounted to 716 billion RMB (103 billion USD); 2016: (est.) above 800 billion RMB (115 billion USD)

→ Total rail 2010-2016: 5.2 trillion RMB (752 billion USD)

→ Debt on HSR: (est.) over 3 trillion RMB (~ 400 billion USD)

“Mid-and-Long Term Railway Network Plan” July 2016

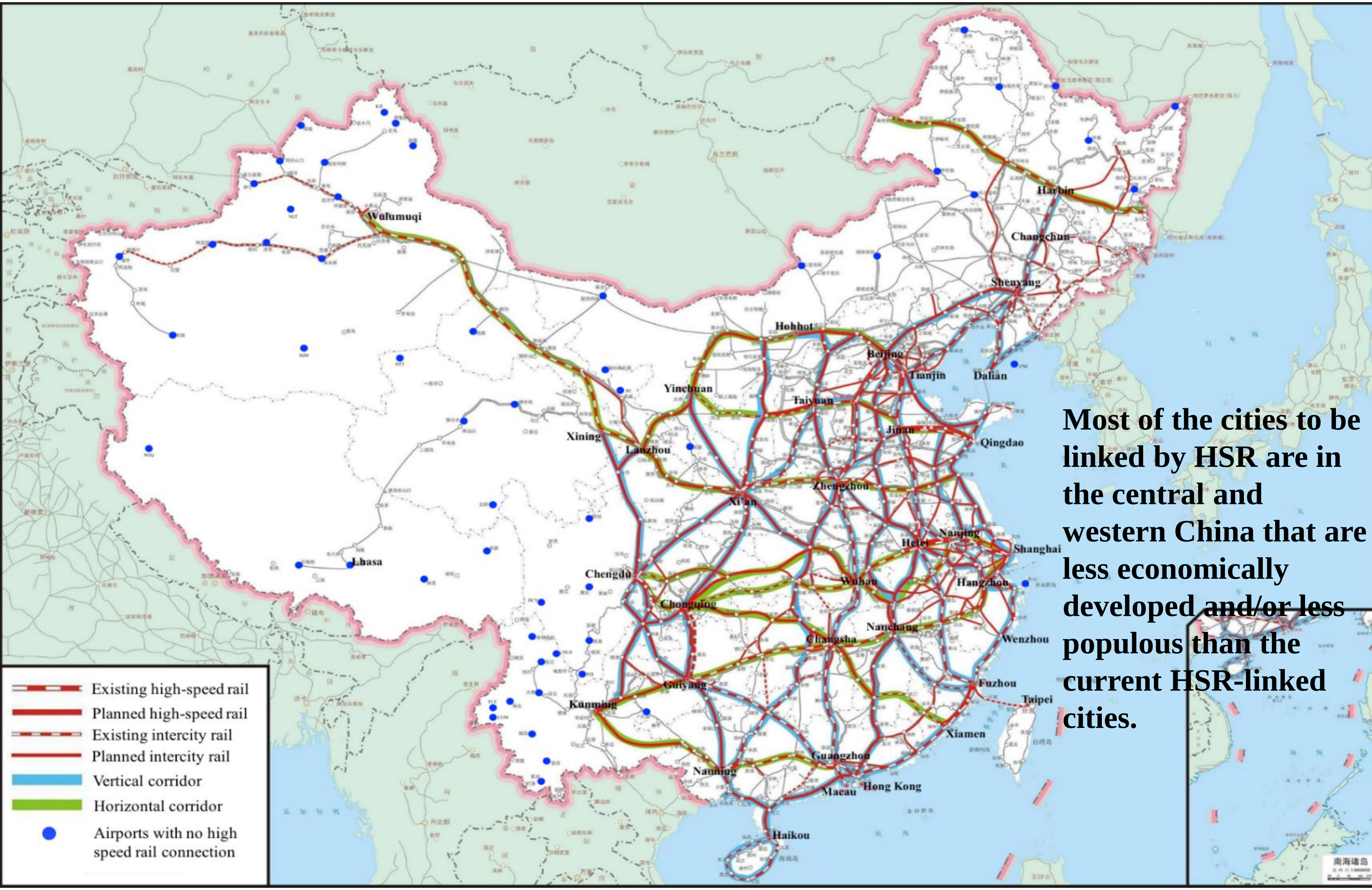
1) by 2020: 30,000 km HSR network in China

   - 24,000 km as of now

2) by 2025: **38,000 km**, connecting all the Provincial capitals with cities of 0.5 million (or more) people

   - Cities of 0.5 million (or more) people: 221

   - A much **larger “8+8” HSR network**



Most of the cities to be linked by HSR are in the central and western China that are less economically developed and/or less populous than the current HSR-linked cities.

Source: 2016 Mid-and-Long Term Railway Network Plan

Accelerated HSR investment, 2017-2025:

- ❑ At least a yearly investment of 800 billion RMB (**115 billion USD**) with current HSR construction cost is required to maintain the pace of HSR

→ Total HSR investment about 7.2 trillion RMB (1.04 trillion USD), which is about **10% of Chinese GDP in 2016**

As a result of **“high speed”** rail:

Air and rail modes now become effective **competitors** over a much longer range of distance:

Used to be: the air mode for medium-to-long distance travel
rail for short distance (slower speed)

→ The two services are much differentiated

Examples of air and HSR competition

Routes	Year of HSR entry	Distance	Impacts
Paris-Lyon	1981	427 km	Air share fell from 31% in 1981 to 7% in 1984.
Madrid-Seville	1992	472 km	Air share fell from 40% in 1991 to 13% in 1994.
London-Paris	1994	373 km	Airline lost 56% passengers.
Frankfurt-Cologne	2002	177 km	Air services were suspended.
Seoul-Busan	2004, 2009	330 km	Air share fell from 42% in 2004 to 17% in 2008.
Taipei-Kaohsiung	2007	345 km	All commercial flights were suspended in 2012.
Wuhan-Guangzhou	2009	1,069 km	Airlines' daily frequency was reduced from 32 to 17 in 2010.

Sources: European Commission (1998), Givoni and Dobruszkes (2013), Cheng (2010) and Fu et al. (2012)

1. Introduction (cont.)

- Many studies on air-HSR competition:
  - Theoretical: Adler et al. (2010), D'Alfonso et al. (2015), Jiang and Zhang (2014), Xia and Zhang (2016), Yang and Zhang (2012), etc.
  - Empirical: Albalate and Bel (2012), Behrens and Pels (2012), Fu et al. (2014), Givoni and Dobruszkes (2013), Park and Ha (2006), Wan et al. (2016), Zhang et al. (2017), etc.

- Research gaps: No studies on the effects of **HSR speed** on airline demand and prices, except **Yang and Zhang (2012, TRB), Xia and Zhang (2016, TRB), D'Alfonso et al. (2015, TRB)**

  - Theoretical:
    - The current literature have yet explicitly explored the interaction of multi-dimensional differentiation (**vertical vs. horizontal**) between airline and HSR services.
    - HSR speed change can bring two countervailing effects on the HSR service quality in terms of travel time and safety (**vertical differentiation**), while the airline and HSR services are closer substitutes on short-haul routes and with faster HSR speed (**horizontal differentiation**).
    - How do the **HSR speed effect** on airline demand and prices vary with airline and HSR substitutability ?
    - How **inter-airline competition market structure** affect the HSR speed effect on airlines ?

  - Empirical:
    - What are the magnitudes of the speed effects? (e.g., the elasticities of airline demand and price to HSR speed)
    - How do the HSR speed effects vary with airline and HSR substitutability?

- HSR speed has two countervailing effects on HSR service quality: **travel time vs. Safety**

- Multi-dimensional differentiation products (IO literature):

  - **Both vertical and horizontal differentiations.**

- Neven and Thisse (1990); Caplin and Nalebuff (1991); Anderson et al. (1992); Ferreria and Thisse (1995); Degryse (1996).

- **Ferreria and Thisse (1995)** finds that the effect of vertical (quality differentiation) can have larger impact on equilibrium price and profit when horizontal differentiation (substitutability) is higher.

Objectives of this study:

1. **Develop an analytical model** to:
   - Explore HSR speed effect on airlines through the vertical differentiation on **travel time and safety level**, while accounting for air-HSR substitutability (short-haul vs. medium-to-long haul; lower-speed vs. higher-speed HSR)
   - Examine how airline market structure moderates the HSR speed effect on airlines.

2. **Utilize China's HSR speed reduction as a quasi-natural experiment to:**
   - Empirically verify theoretical findings and quantify HSR speed effects on airlines;
   - Provide airline demand and price elasticities with respect to HSR speed for routes with different air-HSR substitutability (short-haul vs. medium-to-long haul; lower-speed vs. higher-speed HSR).

2. The HSR speed reduction in China

Timeline	Event
April, 2011	Ministry of Railway planned to reduce HSR operating speed due to safety concerns.
July 1, 2011	The maximum operating speed on Wuhan-Guangzhou, Zhengzhou-Xi'an, Shanghai-Nanjing HSR lines slowed from 350 km/hr to 300 km/hr. The Beijing-Shanghai HSR was inaugurated, running at a speed of 300 km/hr, despite the designed maximum speed at 380 km/hr.
July 23, 2011	"Yong-Wen" HSR accident.
August 28, 2011	Slowed HSR speed system-wide, affecting 498 pairs of trains belonging to 18 railway sub-bureaus.

- China's HSR speed reduction provides a **natural experiment** to study the effects of HSR speed on (competing) airlines' market demand and price.

- Potential **endogeneity** of HSR speed is **minimized** for empirical estimation, because:
  - It is **exogenous**, instead of a market competition outcome;
  - It is **implemented almost at the same time on all the HSR routes**, thus independent of route heterogeneous characteristics.

- However, we need to disentangle in the estimation:
  - the (attenuating) accident panic effect;
  - the (ongoing) speed reduction effect.

3. Analytical Model

Demand side

- Suppose a passenger obtains the following net utility from travelling by air and by HSR:

$$U\ (q_A, q_H) - P_A q_A - P_H q_H - \lambda\ (T_A\ q_A + T_H\ q_H) + g(s_H) q_H$$

- $U\ (q_A, q_H)$: gross utility;
- P_i and q_i: the price and quantity of mode *i*, *i* = A or H;
- T_i: the travel time by mode *i* (including access/egress);
- λ: value of time;
- s_H indicates HSR's speed with D_H denoting HSR travel distance, with $s_H = D_H/T_H$.
- g(s_H) is a function capturing disutility of less safety level with increasing HSR speed with g(s_H)<0 and g'(s_H)<0.

- Without loss of generality, normalize $T_A = 0$. Thus, on short-haul routes, $T_H < T_A = 0$, while, on medium-to-long haul routes, $T_H > T_A = 0$.

- Maximize net utility with respect to q_A, q_H gives the inverse demand function of travel mode *i*:

$$P_A = \rho_A(q_A, q_H)$$

$$P_H = \rho_H(q_A, q_H) - \lambda \frac{D_H}{s_H} + \mathrm{g}(s_H)$$

- $\rho_i(q_A, q_H) = \frac{\partial U(q_A, q_H)}{\partial q_i}$: the marginal utility of mode *i* (w.r.t. q_i);
- s_H is HSR speed and D_H is HSR travel distance;
- $\frac{D_H}{s_H} = T_H$ measures HSR travel time.

- Totally differentiate the inverse demand functions with respect to s_H and solve for the partial derivatives of airline and HSR demand to the HSR travel speed:

$$\frac{\partial q_A}{\partial s_H} = \frac{(\overbrace{\lambda\frac{D_H}{{s_H}^2}}^{>0} + \overbrace{g'(s_H)}^{<0})\overbrace{\frac{\partial \rho_A}{\partial q_H}}^{<0}}{\underbrace{\frac{\partial \rho_H}{\partial q_H}\frac{\partial \rho_A}{\partial q_A} - \frac{\partial \rho_H}{\partial q_A}\frac{\partial \rho_A}{\partial q_H}}_{>0}}$$

$$\frac{\partial q_H}{\partial s_H} = \frac{-(\overbrace{\lambda\frac{D_H}{{s_H}^2}}^{>0} + \overbrace{g'(s_H)}^{<0})\overbrace{\frac{\partial \rho_A}{\partial q_A}}^{<0}}{\underbrace{\frac{\partial \rho_H}{\partial q_H}\frac{\partial \rho_A}{\partial q_A} - \frac{\partial \rho_H}{\partial q_A}\frac{\partial \rho_A}{\partial q_H}}_{>0}}$$

Note: $\left|\frac{\partial \rho_i}{\partial q_i}\right| > \left|\frac{\partial \rho_i}{\partial q_{-i}}\right|$

$\Downarrow$

$\left|\frac{\partial q_H}{\partial s_H}\right| > \left|\frac{\partial q_A}{\partial s_H}\right|$

- $\lambda\frac{D_H}{{s_H}^2}$ indicates the passenger's marginal utility gain with increasing HSR speed due to shorter travel time.
- $g'(s_H)$ stands for a passenger's marginal utility loss with increasing HSR speed due to higher risk of accident.
- When $\left|\lambda\frac{D_H}{s_H^2}\right| > |g'(s_H)|$, **"travel time" effect dominates**, giving $\lambda\frac{D_H}{s_H^2} + g'(s_H)>0$, i.e. $\frac{\partial q_A}{\partial s_H} < 0$ and $\frac{\partial q_H}{\partial s_H} > 0$.
- When $\left|\lambda\frac{D_H}{s_H^2}\right| < |g'(s_H)|$, "**safety" effect dominates**, giving $\lambda\frac{D_H}{s_H^2} + g'(s_H)<0$, i.e. $\frac{\partial q_A}{\partial s_H} > 0$ and $\frac{\partial q_H}{\partial s_H} < 0$.
- The HSR speed has **a larger impact** on HSR demand than on airline demand.

- Assume P_H is exogeneous, based on the fact that China's HSR price is strictly regulated (with a baseline price of 0.45 RMB/km).
- Since the HSR price P_H is fixed in Chinese market, the airline inverse demand function can be expressed as:

$$P_A = \rho_A\left(q_A, q_H(q_A, P_H + \lambda \frac{D_H}{s_H} + g(s_H))\right)$$

- We thus can derive the partial derivative of airline price to s_H:

$$\frac{\partial P_A}{\partial s_H} = \underbrace{\frac{\partial \rho_A}{\partial q_H}}_{<0} \frac{\partial q_H}{\partial s_H}$$

- The sign of $\frac{\partial P_A}{\partial s_H}$ follows the sign of $-\frac{\partial q_H}{\partial s_H}$, which again depends on $\lambda \frac{D_H}{s_H^2} + g'(s_H)$.
- When $\lambda \frac{D_H}{s_H^2} + g'(s_H) > 0$ (travel time effect dominates), $\frac{\partial q_H}{\partial s_H} > 0$, giving $\frac{\partial P_A}{\partial s_H} < 0$.
- When $\lambda \frac{D_H}{s_H^2} + g'(s_H) < 0$, $\frac{\partial q_H}{\partial s_H} < 0$ (safety effect dominates), giving $\frac{\partial P_A}{\partial s_H} > 0$.

3. Analytical Model-cont'd

Supply side

- Suppose an oligopoly airline market with N airlines.
- Airlines engage in Cournot competition.
- A single airline maximizes:

$$\underset{q_j^A}{\text{Max}}\ \pi_j^A = (P_A(q_A, s_H) - c)\ q_j^A$$

- $q_A = \sum_{j=1}^{N} q_j^A$: total air traffic;
- c: common constant marginal cost.

- First-order condition (FOC):

$$P_A - c + q_j^A \frac{\partial P_A}{\partial q_A}\left(1 + \frac{\partial q_{-j}^A}{\partial q_j^A}\right) = 0$$

- q_{-j}^A: the quantity of all the other airlines except airline j;
- $\delta = \frac{\partial q_h^A}{\partial q_j^A} \in [0, 1]$ with $h \neq j$ is the "conjectural variation" or "conduct parameter" (Brander and Zhang, 1990; 1993);
- $\delta = 0 \; or \; 1$ indicates Cournot and cartel airline competition, respectively;
- The larger the δ, the more collusion or less competition among the airlines.

- By symmetry, FOC can be rewritten as:

$$P_A - c + \frac{q_A}{N}\frac{\partial P_A}{\partial q_A}(1 + (N-1)\delta) = 0$$

- Total differentiate FOC with respect to s_H, and denote $M = \frac{1+(N-1)\delta}{N} > 0$.
- We have:

$$\frac{\partial q_A^*}{\partial s_H} = -\frac{\frac{\partial P_A}{\partial s_H} + M q_A \frac{\partial^2 P_A}{\partial q_A \partial s_H}}{\underbrace{\frac{\partial P_A}{\partial q_A} + M\left(\frac{\partial P_A}{\partial q_A} + q_A \frac{\partial^2 P_A}{\partial q_A^2}\right)}_{<0}}$$

- In case of non-linear demand, $\frac{\partial^2 P_A}{\partial q_A \partial s_H} = 0$.
- In case of non-linear demand, if $\frac{\partial^2 P_A}{\partial q_A \partial s_H}$ is small in magnitude, the sign of $\frac{\partial q_A^*}{\partial s_H}$ follows the sign of $\frac{\partial P_A}{\partial s_H}$.
- As a result, $\frac{\partial q_A^*}{\partial s_H} < (>) 0$ if $\lambda \frac{D_H}{s_H^2} + \mathrm{g}'(s_H) > (<) 0$.
- Therefore, the equilibrium airline traffic decreases (increases) with HSR speed when HSR "travel time" ("safety") effect is dominant.

- Rewrite FOC as: $(P_A - c)\frac{\partial q_A}{\partial P_A} + q_A M = 0$

- Total differentiate FOC with respect to s_H,

We have: $$\frac{\partial P_A^*}{\partial s_H} = -\frac{M\frac{\partial q_A}{\partial s_H} + (P_A - c)\frac{\partial^2 q_A}{\partial P_A \partial s_H}}{\underbrace{(1+M)\frac{\partial q_A}{\partial P_A} + (P_A - c)\frac{\partial^2 q_A}{\partial P_A^2}}_{<0}}$$

- In case of non-linear demand, $\frac{\partial^2 q_A}{\partial P_A \partial s_H} = 0$.
- In case of non-linear demand, if $\frac{\partial^2 q_A}{\partial P_A \partial s_H}$ is small in magnitude, the sign of $\frac{\partial P_A^*}{\partial s_H}$ follows the sign of $\frac{\partial q_A}{\partial s_H}$.
- As a result, $\frac{\partial q_A^*}{\partial s_H} < (>) 0$ if $\lambda \frac{D_H}{s_H^2} + g'(s_H) > (<) 0$.
- Therefore, the equilibrium airline price decreases (increases) with HSR speed when HSR “travel time” (“safety”) effect is dominant.

Proposition 1.

When HSR **"travel time"** effect dominates the **"safety"** effect ($\lambda \frac{D_H}{s_H^2} > -g'(s_H)$), the airline demand (conditional on airline and HSR prices), and equilibrium airline traffic and price **decrease** with HSR speed. However, when the **"safety"** effect dominates **"travel time"** effect ($\lambda \frac{D_H}{s_H^2} < -g'(s_H)$)), the airline demand, and equilibrium airline traffic and price increase with HSR speed.

- In order to investigate how the air-HSR substitutability (**horizontal differentiation**) can moderate the HSR speed effect (**vertical differentiation**) on airline demand, equilibrium airline traffic and price, a quadratic utility function is imposed on the gross utility function:
- The net utility from travelling by air and by HSR thus becomes:

$$\alpha_A q_A + \alpha_H q_H - \left(\frac{1}{2}{q_A}^2 + \frac{1}{2}{q_H}^2 + \gamma q_A q_H\right) - P_A q_A - P_H q_H - \lambda \frac{D_H}{s_H} q_H + \mathrm{g}(s_H) q_H$$

  - α_i: potential market size;
  - $\gamma \in (0,1)$: service substitutability between airline and HSR;
  - Airlines and HSR are closer substitutes on short-haul routes with faster HSR speed, i.e. a larger γ.

- Demand functions can be derived from the net utility:

$$q_A = \frac{\alpha_A - P_A + (P_H - \alpha_H + T_H \lambda)\gamma}{1 - \gamma^2}$$

$$q_H = \frac{(P_A - \alpha_A)\gamma - (P_H - \alpha_H + T_H \lambda)}{1 - \gamma^2}$$

- The elasticity of airline demand q_A with respect to s_H, conditional on P_A and P_H is:

$$\varepsilon_{q_A,s_H} = \frac{\frac{\Delta q_A}{q_A}}{\frac{\Delta s_H}{s_H}} = \frac{\partial q_A}{\partial s_H}\frac{s_H}{q_A} = \frac{-\gamma s_H(\lambda \frac{D_H}{{s_H}^2} + g'(s_H))}{\underbrace{\left(P_H - \alpha_H + \lambda \frac{D_H}{s_H} - \mathrm{g}(s_H)\right)\gamma - (P_A - \alpha_A)}_{>0}}$$

- The sign of ε_{q_A,s_H} still depends on the relative dominance of the "travel time" effect and "speed" effect of HSR speed change.
- As a result, $\varepsilon_{q_A,s_H} < (>)0$ if $\lambda \frac{D_H}{s_H^2} + \mathrm{g}'(s_H) > (<)0$.

- How the magnitude of ε_{q_A,s_H} changes with substitutability γ?

$$\frac{\partial\left|\varepsilon_{q_A,s_H}\right|}{\partial\gamma}=\frac{s_H(\alpha_A-P_A)\left|\lambda\frac{D_H}{s_H^2}+g'(s_H)\right|}{\left(\alpha_A-P_A+\left(P_H-\alpha_H+\lambda\frac{D_H}{s_H}-g(s_H)\right)\gamma\right)^2}>0$$

- The magnitude of ε_{q_A,s_H} increases when airline and HSR services are more substitutable.
- Therefore, the air-HSR substitutability measured by γ reinforces the HSR speed effect (vertical differentiation), no matter which quality aspect ("travel time" or "safety") is dominant.

- N airlines engage in oligopoly competition.
- Equilibrium airline traffic and price can be derived:

$$q_{i,A}^{*} = \frac{-c + \alpha_A + (P_H - \alpha_H + \lambda \frac{D_H}{s_H} - \mathrm{g}(s_H))\gamma}{(1-\gamma^2)(1 + N + (N-1)\delta)}$$

$$q_A^{*} = N \frac{-c + \alpha_A + (P_H - \alpha_H + \lambda \frac{D_H}{s_H} - \mathrm{g}(s_H))\gamma}{(1-\gamma^2)(1 + N + (N-1)\delta)}$$

$$P_A^{*} = \frac{cN + ((N-1)\delta + 1)(\alpha_A + (P_H - \alpha_H + \lambda \frac{D_H}{s_H} - \mathrm{g}(s_H))\gamma\Big)}{1 + N + (N-1)\delta}$$

- $q_{i,A}^{*}$: equilibrium individual airline traffic;
- q_A^{*}: equilibrium total airline traffic.
- P_A^{*}: equilibrium airline price.

- We next derive how equilibrium changes with HSR speed s_H.

$$\frac{\partial q_{i,A}^*}{\partial s_H} = -\frac{(\lambda \frac{D_H}{s_H^2} + \mathrm{g}'(s_H))\gamma}{(1-\gamma^2)(1+N+(N-1)\delta)}$$

$$\frac{\partial q_A^*}{\partial s_H} = -\frac{N(\lambda \frac{D_H}{s_H^2} + \mathrm{g}'(s_H))\gamma}{(1-\gamma^2)(1+N+(N-1)\delta)}$$

$$\frac{\partial P_A^*}{\partial s_H} = -\frac{((N-1)\delta+1)(\lambda \frac{D_H}{s_H^2} + \mathrm{g}'(s_H))\gamma}{1+N+(N-1)\delta}$$

- The signs again depend on the relative dominance of "travel time" effect and "speed" effect, i.e. $\lambda \frac{D_H}{s_H^2} + \mathrm{g}'(s_H)$.
- When the "travel time" ("safety") effect dominates, equilibrium airline traffic and price decrease (increase) with HSR speed.

- Comparative statics of the equilibrium results with respect to the inter-airlines competition, measured by N or δ, are given:

$$\frac{\partial q_A^*}{\partial N} > 0, \frac{\partial P_A^*}{\partial N} < 0, \frac{\partial q_{i,A}^*}{\partial N} < 0$$

$$\frac{\partial q_A^*}{\partial \delta} < 0, \frac{\partial P_A^*}{\partial \delta} > 0, \frac{\partial q_{i,A}^*}{\partial \delta} > 0$$

  - Total airline equilibrium traffic **decrease** when airlines are **more collusive** or **the number of airlines is smaller**.
  - But the airline equilibrium price and individual airline equilibrium traffic **increase** when airlines are **more collusive** or **the number of airlines is smaller**.

- The elasticity of equilibrium total airline traffic q_A^* or $q_{i,A}^*$ with respect to s_H is:

$$\varepsilon_{q_A^*,s_H} = \varepsilon_{q_{i,A}^*,s_H} = \frac{\partial q_A^*}{\partial s_H}\frac{s_H}{q_A^*} = \frac{-s_H\gamma(\lambda\frac{D_H}{s_H^2} + \mathrm{g}'(s_H))}{\underbrace{-c + \alpha_A + (P_H - \alpha_H + \lambda\frac{D_H}{s_H} - g(s_H))\gamma}_{>0}}$$

- The elasticity of equilibrium airline price with respect to s_H is:

$$\varepsilon_{P_A^*,s_H} = \frac{\partial P_A^*}{\partial s_H}\frac{s_H}{P_A^*} = \frac{-s_H\gamma(1 + (N-1)\delta)(\lambda\frac{D_H}{s_H^2} + \mathrm{g}'(s_H))}{cN + (1 + (N-1)\delta)(\alpha_A + \gamma(P_H - \alpha_H + \frac{D_H}{s_H}\lambda - g(s_H))\Big)}$$

The signs of $\varepsilon_{q_A^*,s_H}$, $\varepsilon_{q_{i,A}^*,s_H}$ and $\varepsilon_{P_A^*,s_H}$ depends on the sign of $\lambda\frac{D_H}{s_H^2} + \mathrm{g}'(s_H)$.

- Comparing the magnitude of elasticities, we have:

$$\left|\varepsilon_{q_A^*,s_H}\right| = \left|\varepsilon_{q_{i,A}^*,s_H}\right| > \left|\varepsilon_{P_A^*,s_H}\right|$$

Proposition 2.

The magnitude of elasticity of equilibrium airline traffic to HSR speed is **larger** than that of equilibrium airline price, i.e., $|\varepsilon_{q_A^*, s_H}| > |\varepsilon_{P_A^*, s_H}|$.

- How the magnitudes of $\varepsilon_{q_A^*,T_H}$ and $\varepsilon_{P_A^*,T_H}$ change with the substitutability parameter γ?

$$\frac{\partial\left|\varepsilon_{q_A^*,s_H}\right|}{\partial\gamma}=\frac{s_H\left|\lambda\frac{D_H}{s_H^2}+\mathrm{g}'(s_H)\right|(-c+\alpha_A)}{\left(-c+\alpha_A+(P_H-\alpha_H+\lambda\frac{D_H}{s_H}-g(s_H))\gamma\right)^2}>0$$

$$\frac{\partial\left|\varepsilon_{P_A^*,s_H}\right|}{\partial\gamma}=\frac{s_H(1+(N-1)\delta)(cN+\alpha_A(1+(N-1)\delta))\left|\lambda\frac{D_H}{s_H^2}+g'(s_H)\right|}{\left(cN+(1+(N-1)\delta)(\alpha_A+\gamma(P_H-\alpha_H+\lambda\frac{D_H}{s_H}-g(s_H)))\right)^2}>0$$

- Comparing the magnitude of elasticities, we have:

$$\frac{\partial\left|\varepsilon_{q_A^*,s_H}\right|}{\partial\gamma}>\frac{\partial\left|\varepsilon_{P_A^*,s_H}\right|}{\partial\gamma}$$

Proposition 3.

The elasticities of airline demand ε_{q_A,s_H}, equilibrium airline traffic $\varepsilon_{q_A^*,s_H}$, and price $\varepsilon_{P_A^*,s_H}$ to HSR travel speed increase with the air-HSR service substitutability γ.

γ has larger impact on the elasticity of equilibrium airline traffic to HSR speed $\varepsilon_{q_A^*,s_H}$ than the elasticity of equilibrium airline price to HSR speed $\varepsilon_{P_A^*,s_H}$.

- By taking derivative of $\varepsilon_{P_A^*,T_H}$ with respect to N, we obtain:

$$\frac{\partial\left|\varepsilon_{P_A^*,s_H}\right|}{\partial N} = \frac{-c|s_H|\gamma(1-\delta)\left|\lambda\frac{D_H}{s_H^2} + g'(s_H)\right|}{\left(cN + (1 + (N-1)\delta)(\alpha_A + \gamma(P_H - \alpha_H + \lambda\frac{D_H}{s_H} - g(s_H)))\right)^2} < 0$$

Proposition 4.

The elasticity of equilibrium airline price to HSR speed $\varepsilon_{P_A^*,s_H}$

decreases with the level of inter-airlines competition (larger N).

- Implication: HSR speed effect on equilibrium airline price can be negatively moderated by the inter-airlines competition.

4. DID (Difference-in-differences) Econometric Model and identification strategy

- **Treatment group:** the airline routes with HSR presence;
- **Control group:** the airline routes without HSR presence;
- **DID:** we compare the changes of airline demand and price between the "treatment" and "control" groups both before and after the treatment – "HSR speed reduction".
- The **fixed effects** are controlled: including route specific, HSR-competing route specific, time specific fixed effects.

- A log-form airline demand equation is specified as,

$$\ln q_{it} = \eta_0 + \eta_1 \ln P_{it} + \eta_2 \frac{s_{it}}{D_i} HSR_{it} + \eta_3 \frac{HSR_{it}}{Post\_accident_{it}} + \eta_4 \ln Dist\_Air_i + \eta_5 \ln Pop_{it}$$

$$+\eta_6 \ln Income_{it} + \eta_7 Tourism_i + \eta_8 Spring_t + \eta_9 Summer_t + \eta_{10} Autumn_t$$

$$+\eta_{11} Year_t + \eta_{12} HSR_{it} + \phi_i + \sigma_{it}$$

- q_{it} is is the number of airline passengers on the airline route i at time t;
- HSR_{it} is a dummy variable: 1=HSR present on route i at time t, 0=otherwise;
- s_{it} is the HSR speed on route i at time t;
- D_i is the HSR route distance on route i;
- $Post\_Accident_{it}$ is the number of quarters (when using quarterly data) or the number of days (when using daily data) after the 7.23 rear-ending accident.

- $\eta_2 \frac{s_{it}}{D_i} HSR_{it}$ captures HSR speed effect on airline demand for those routes competing with airlines;
- $\frac{HSR_{it}}{Post\_accident_{it}}$ captures HSR accident effect, which attenuates over time.

- For the treated routes ($HSR_{it} = 1$), the airline demand elasticity w.r.t. HSR speed ε_{q_A,s_H} is,

$$\varepsilon_{q_A,s_H} = \frac{\partial lnq_{it}}{\partial lns_{it}} = \frac{\partial lnq_{it}}{\partial s_{it}} \times s_{it} = \eta_2 \frac{s_{it}}{D_i}$$

- With this specification, the sign of ε_{q_A,s_H} is determined by η_2.
- If $\eta_2 < 0$, we have $\varepsilon_{q_A,s_H} < 0$, which indicates that the HSR "travel time" effect dominates.
- If $\eta_2 > 0$, we have $\varepsilon_{q_A,s_H} > 0$, which indicates that the HSR "safety" effect dominates.
- This specification is consistent with Proposition 3 in than when HSR is faster (larger s_{it}) or when airline and HSR service are more substitutable (smaller D_i), the magnitude of ε_{q_A,s_H} is larger.

- The overall HSR competition effect (with vs. without HSR presence) on airline demand can be estimated as $e^{\frac{\eta_2}{D_i} s_{it}} - 1$.

- The reduced-form equilibrium airline traffic equation is specified as,

$$\ln q^*_{it} = \pi_0 + \pi_1 \frac{s_{it}}{D_i} HSR_{it} + \pi_2 \frac{HSR_{it}}{Post\_accident_{it}} + \pi_3 \ln Dist\_Air_i + \pi_4 \ln HHI_{it}$$
$$+ \pi_5 \ln Pop_{it} + \pi_6 \ln Income_{it} + \pi_7 LCC_{it} + \pi_8 Tourism_i + \pi_9 Spring_t + \pi_{10} Summer_t$$
$$+ \pi_{11} Autumn_t + \pi_{12} Year_t + \pi_{13} HSR_{it} + \psi_i + \xi_{it}$$

  - q^*_{it} is equilibrium airline traffic on the route i at time t.

- Note that airline price is excluded because this is a reduced-form equation, while we include HHI index and the presence of LCCs, which capture the supply-side impacts on equilibrium airline traffic.

- The elasticity of equilibrium airline traffic to HSR speed $\varepsilon_{q^*_A, s_H}$:

$$\varepsilon_{q^*_A, s_H} = \frac{\partial \ln q^*_{it}}{\partial \ln s_{it}} = \frac{\partial \ln q^*_{it}}{\partial s_{it}} \times s_{it} = \pi_1 \frac{s_{it}}{D_i}$$

The sign of $\varepsilon_{q^*_A, s_H}$ depends on parameter π_1.

- The reduced-form equilibrium airline price equation is specified as,

$$\ln P_{it}^{*} = \alpha_0 + \alpha_1 \frac{s_{it}}{D_i} HSR_{it} + \alpha_2 \frac{HSR_{it}}{Post\_accident_{it}} + \alpha_3 \ln Dist\_Air_i + \alpha_4 \ln HHI_{it}$$

$$+ \alpha_5 \ln Pop_{it} + \alpha_6 \ln Income_{it} + \alpha_7 \, LCC_{it} + \alpha_8 Tourism_i + \alpha_9 Spring_t + \alpha_{10} Summer_t$$

$$+ \alpha_{11} Autumn_t + \alpha_{12} Year_t + \alpha_{13} HSR_{it} + \tau_i + \nu_{it}$$

- P_{it}^{*} is equilibrium airline average yield on the route i at time t. Airline yield is calculated by dividing airfare by the flying distance of the route i;

- The elasticity of equilibrium airline price to HSR speed $\varepsilon_{p_A^*, s_H}$:

$$\varepsilon_{p_A^*, s_H} = \frac{\partial \ln p_{it}^{*}}{\partial \ln s_{it}} = \frac{\partial \ln p_{it}^{*}}{\partial s_{it}} \times s_{it} = \alpha_1 \frac{s_{it}}{D_i}$$

The sign of $\varepsilon_{p_A^*, s_H}$ depends on parameter α_1.

- Our econometric set-up follows analytical model:
  - Suggested by **Proposition 1**, if $\pi_1 < 0$ and $\alpha_1 < 0$, we can verify that the HSR "travel time" effect dominates the "safety" effect;
  - Suggested by **Proposition 2**, we expect $|\pi_1| > |\alpha_1|$;
  - Suggested by **Proposition 3**, the magnitudes of ε_{q_A,s_H}, $\varepsilon_{q_A^*,s_H}$, $\varepsilon_{P_A^*,s_H}$ are expected to increase with air-HSR substitutability (i.e., shorter distance or faster HSR speed);
  - Suggested by **Proposition 4**, an interaction of HHI and the term $\frac{s_{it}}{D_i} HSR_{it}$ is included in the airline reduced-form price equation to verify the moderation effect of inter-airlines competition.

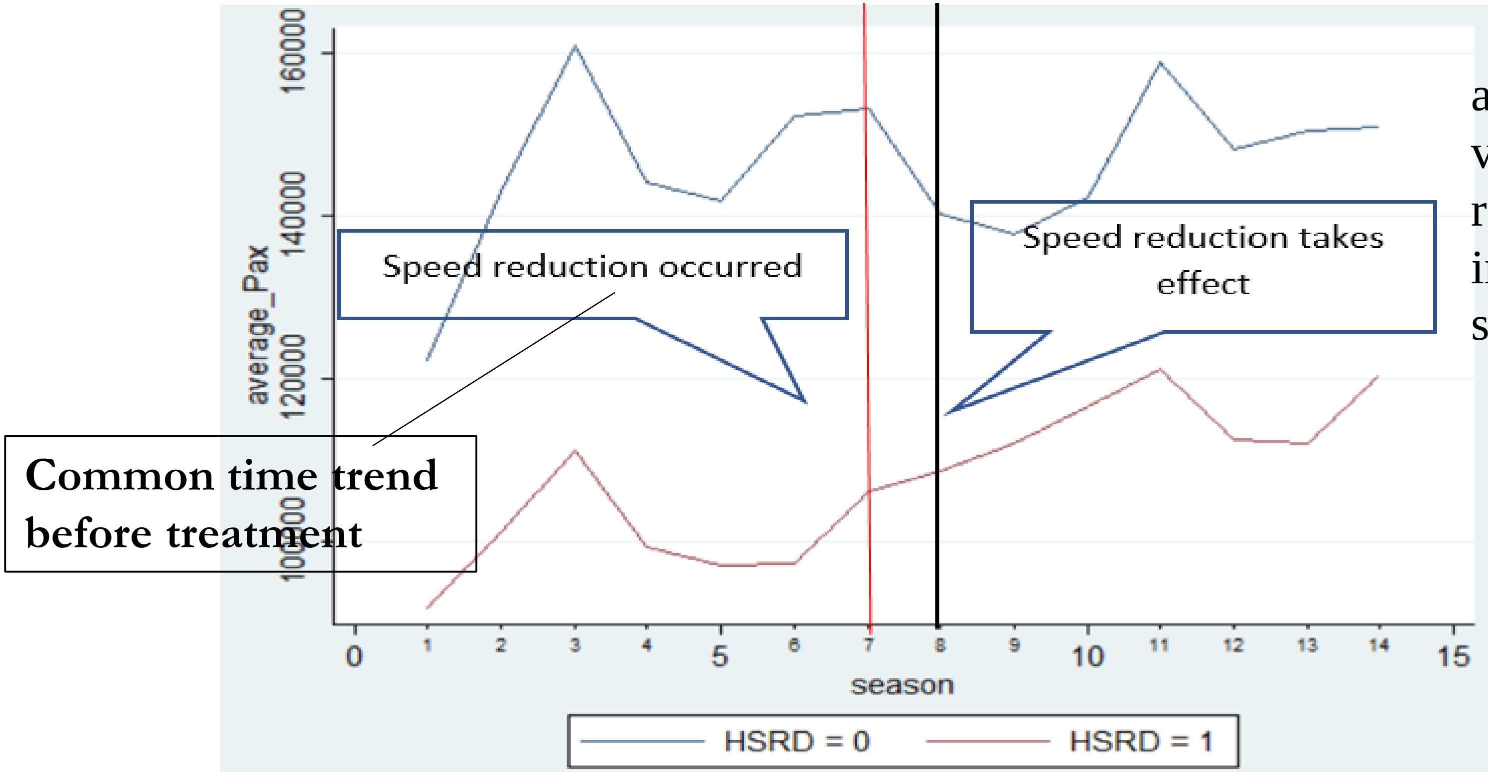
5. Data Description and Empirical Estimation

- Route level airline price and traffic for the “Big Three”
- Study period: **Jan 2010 to June 2013**
- A total of **74** routes, including the ones linking Beijing, Shanghai and Guangzhou to all provincial capital cities
- HSR is present on **9** routes, and reduced speed
- The **9** routes form our **treated group**, with the other **65** routes being the **control group**

Summary of the routes with HSR competition before and after the HSR speed reduction

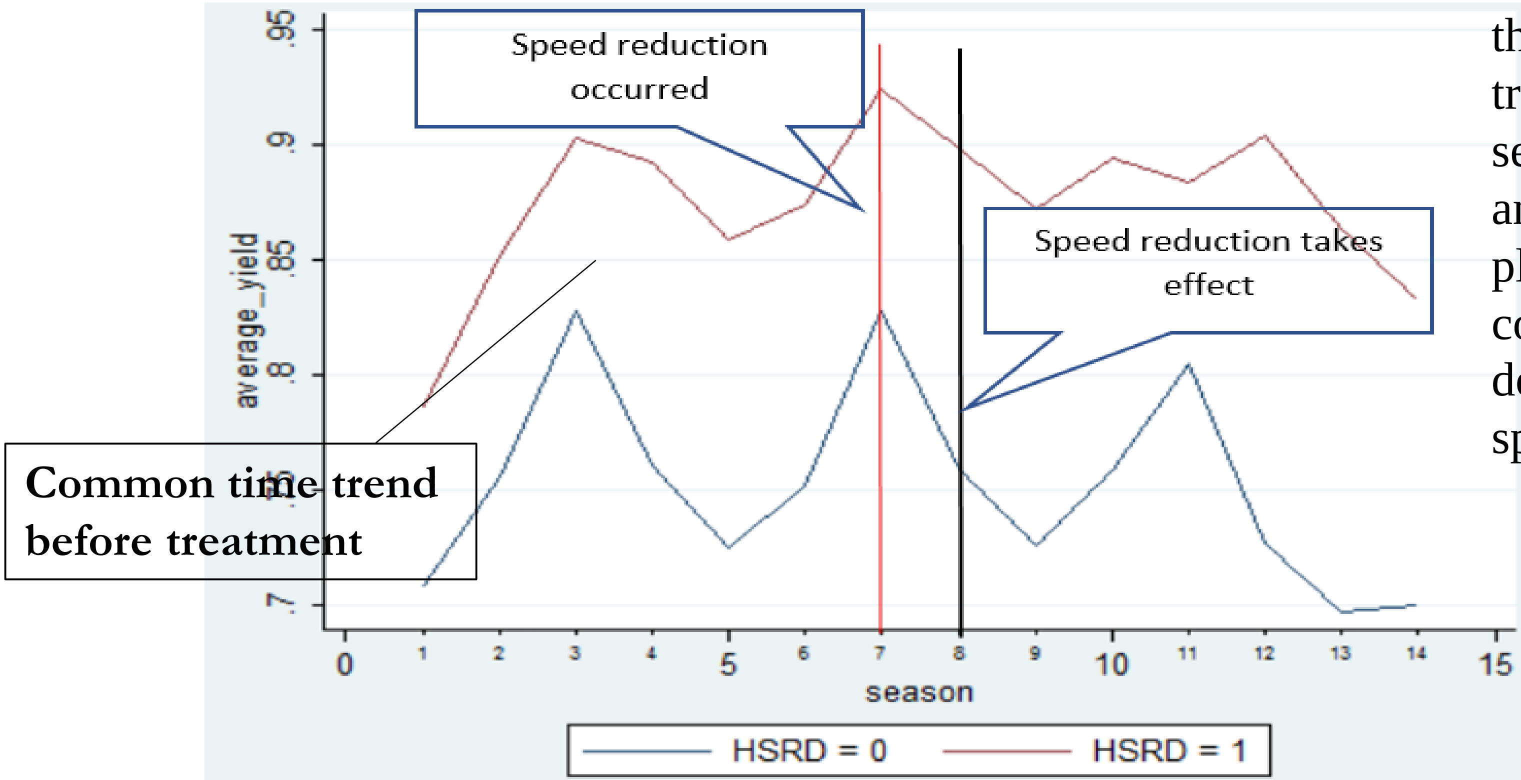
Route	Distance (km)	Date of speed reduction	Speed before reduction	Speed after reduction
Shanghai-Hefei	456	28-Aug, 2011	233	186
Beijing-Taiyuan	513	28-Aug,2011	250	200
Shanghai-Zhengzhou	651	28-Aug,2011	250	200
Guangzhou-Changsha	726	01-Jul,2011	350	300
Shanghai-Wuhan	826	28-Aug,2011	240	192
Shanghai-Fuzhou	883	28-Aug,2011	250	200
Guangzhou-Wuhan	995	01-Jul,2011	350	300
Shanghai-Xiamen	1109	28-Aug,2011	250	200
Guangzhou-Hefei	1427	01-Jul,2011	325	275

Note: The Shanghai-Hefei HSR line passes through Shanghai-Nanjing intercity railway segment (with design speed of 250 km/hr before the speed reduction) and Nanjing-Hefei passenger-railway segment (with design speed of 200 km/hr before the speed reduction). The HSR speed on the Shanghai-Hefei line is calculated by taking a weighted average based on distance of the two segments. The same applies to the lines of Shanghai-Wuhan and Guangzhou-Hefei.



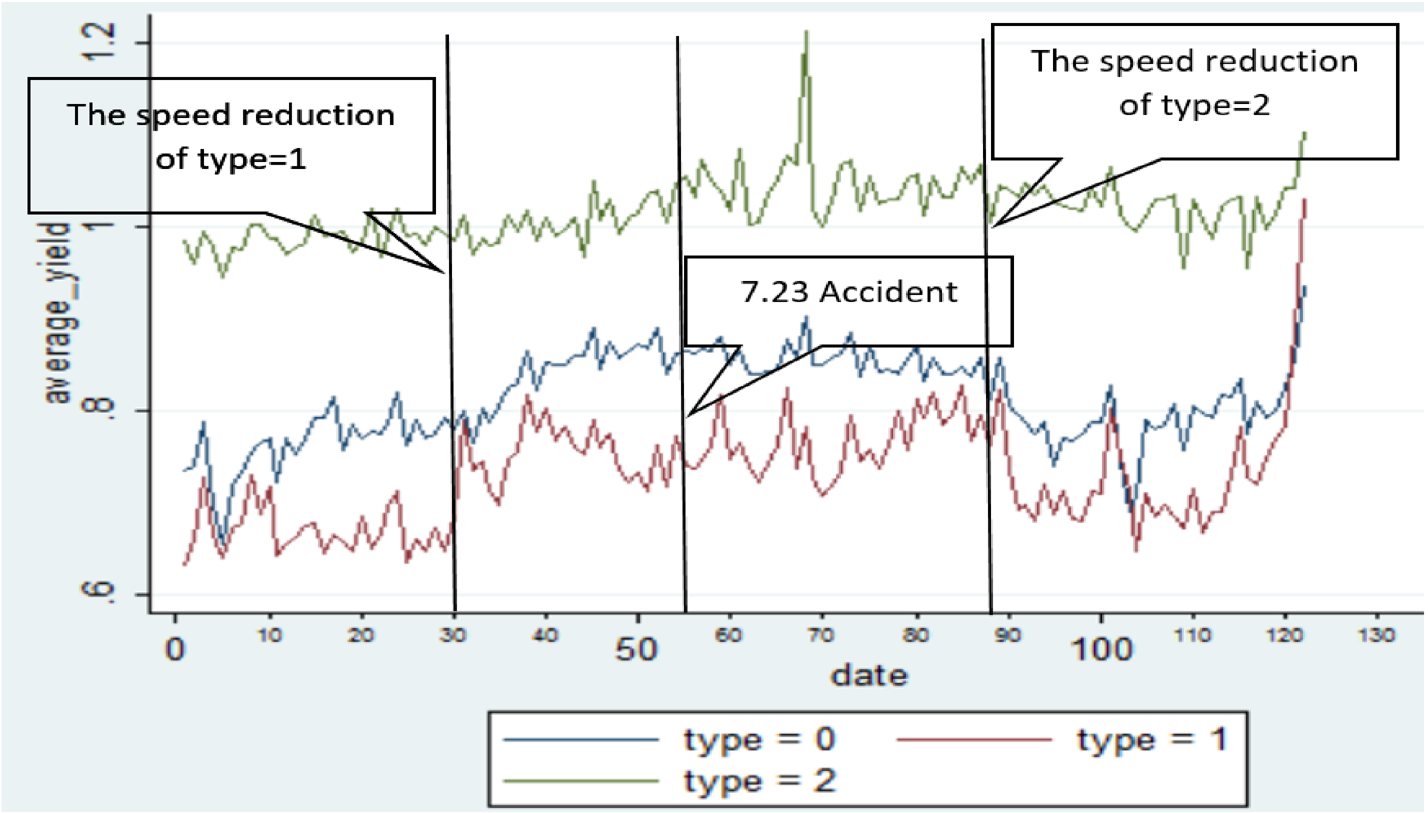
airline passenger volume on treated routes significantly increased after the speed reduction

Evolution of average passenger volume for the HSR and non-HSR routes (quarterly data from 1st quarter of 2010 to 3rd quarter of 2013)



the yield on the treated routes seems less volatile and does not plummet as the control group does after the speed reduction

Evolution of airline yield for the HSR competing and non-HSR competing routes (quarterly data from 1st quarter of 2010 to 3rd quarter of 2013)



Evolution of airline yield for the HSR competing and non-HSR competing routes (daily data from 1 June 2011 to 30 September 2011)

Note: Type=0 is for the non-HSR competing routes; Type=1 is for the HSR competing routes with speed reduction on July 1st 2011; Type=2 is for the HSR competing routes with speed reduction on August 28th 2011.

-**Airline Demand equation (2SLS)**

Airline Demand	Model 1	Model 2
Airline yield	-0.911**	-0.840*
	(0.480)	(0.457)
η_2	-2.398***	-2.354***
	(0.572)	(0.564)
η_3	5.042	4.840
	(3.661)	(3.647)
Population	0.049	-0.119
	(0.807)	(0.801)
Income	-0.358**	-0.360**
	(0.142)	(0.147)
LCC	-0.0003	0.001
	(0.069)	(0.070)
Tourist	0.020	0.011
	(0.046)	(0.047)
Spring	-0.179***	-0.180***
	(0.043)	(0.044)
Summer	-0.090**	-0.091***
	(0.026)	(0.026)
Autumn	0.141**	0.138**
	(0.061)	(0.058)
Year2011	0.117***	0.122***
	(0.021)	(0.023)
Year2012	0.185***	0.190***
	(0.035)	(0.035)
Year2013	0.211***	0.223***
	(0.063)	(0.062)
Constant	13.901***	15.043***
	(5.415)	(5.338)
Time trend fixed effect	✓	✓
HSR route fixed effect	✓	✓
Individual route fixed effect	✓	✓
No. of Observations	1,036	962

Note: Quarterly dummy variables have been suppressed. Standard errors are reported in parentheses. ***, ** and * stands for the significant level at the 1%, 5% and 10% respectively.

- Model 1 uses all quarters' data;
- Model 2 excludes the data of 3rd quarter of 2011;
- The airline demand elasticity to airline price is η_3: **-0.911** (Model 1) and **-0.840** (Model 2);
- $\hat{\eta}_2 < 0$, verifies that the "travel time" effect dominates the "safety" effect (**Proposition 1**);
- **Airline demand elasticity** to the HSR speed is $\varepsilon_{q_A,s_H} = \frac{\eta_2}{D_i} s_{it} < 0$, the magnitude of which increases with air-HSR substitutability, **in line with Proposition 3;**
- The accident effect (parameter η_3) is insignificant using quarterly data.

-Reduced-form airline traffic equation

Airline traffic	Model 3	Model 4
π_1	-1.793***	-1.899***
	(0.416)	(0.437)
π_2	-0.027	-0.001
	(0.079)	(0.101)
HHI Index	-0.083**	-0.092**
	(0.043)	(0.044)
Population	-0.809	-0.876
	(0.634)	(0.664)
Income	-0.360***	-0.352***
	(0.122)	(0.130)
LCC	-0.021	-0.027
	(0.061)	(0.064)
Tourist	0.020	0.018
	(0.041)	(0.043)
Spring	-0.239***	-0.237***
	(0.042)	(0.044)
Summer	0.229	0.198
	(0.158)	(0.163)
Autumn	-0.635***	-0.609***
	(0.156)	(0.160)
Year2011	0.766***	0.153***
	(0.156)	(0.029)
Year2012	0.865***	0.840***
	(0.157)	(0.162)
Year2013	-0.085	0.356***
	(0.161)	(0.041)
Constant	20.608	21.099***
	(4.026)	(4.207)
Time trend fixed effect	✓	✓
HSR route fixed effect	✓	✓
Individual route fixed effect	✓	✓
No. of Observations	1,036	962

- Model 3 uses all quarters' data;
- Model 4 excludes the data of 3rd quarter of 2011;
- $\hat{\pi}_1 < 0$, which verifies that the "travel time" effect dominates the "safety" effect (**Proposition 1**);
- **Airline equilibrium traffic elasticity** to the HSR speed is $\varepsilon_{q_A^*, s_H} = \frac{\pi_1}{D_i} s_{it} < 0$, the magnitude of which increases with air-HSR substitutability, **confirming Proposition 3**;
- The accident effect (parameter π_2) is insignificant using quarterly data.

-**Reduced-form airline price equation** using quarterly data

Airline price	Model 5	Model 6
α_1	-0.666***	-0.656***
	(0.170)	(0.169)
α_2	0.035	-0.019
	(0.032)	(0.032)
HHI Index	0.103***	0.111***
	(0.017)	(0.017)
Population	0.614**	0.551**
	(0.259)	(0.261)
Income	0.103**	0.108**
	(0.050)	0.051
LCC	0.003	0.004
	(0.025)	(0.025)
Tourist	0.001	-0.001
	(0.016)	(0.017)
Spring	-0.032*	-0.031*
	(0.017)	(0.017)
Summer	0.183***	0.184***
	(0.064)	(0.064)
Autumn	-0.202***	-0.198***
	(0.064)	(0.063)
Year2011	0.290***	-0.038
	(0.064)	(0.011)
Year2012	0.248***	0.245
	(0.064)	(0.064)
Year2013	-0.303***	-0.048
	(0.066)	(0.016)
Constant	-5.951	-5.649
	(1.648)	(1.659)
Time trend fixed effect	✓	✓
HSR route fixed effect	✓	✓
Individual route fixed effect	✓	✓
No. of Observations	1,036	962

- Model 5 uses all quarters' data;
- Model 6 excludes the data of 3rd quarter of 2011;
- $\hat{\alpha}_1 < 0$, verifies that "travel time" effect dominates the "safety" effect (**Proposition 1**);
- **Airline price elasticity** to the HSR speed is $\varepsilon_{P_A^*,s_H} = \frac{\alpha_1}{D_i} s_i < 0$, the magnitude of which increases with air-HSR substitutability, **confirming Proposition 3**;
- $|\hat{\pi}_1| > |\hat{\alpha}_1|$, or equivalently $\varepsilon_{q_A^*,s_H} > \varepsilon_{P_A^*,s_H}$, **confirms Proposition 2**.

The estimated elasticities of airline equilibrium price and demand to HSR speed reduction and HSR competition

(a). for the 250 km/hr speed HSR lines

Items	Markets	Estimated value
Airline demand elasticity to HSR speed	short-haul (500 km)	-1.20
	medium-to-long haul (1,000 km)	-0.60
Airline equilibrium traffic elasticity to HSR speed	short-haul (500 km)	-0.896
	medium-to-long haul (1,000 km)	-0.448
Airline equilibrium price elasticity to HSR speed	short-haul (500 km)	-0.33
	medium-to-long haul (1,000 km)	-0.17
Airline demand (%) increase due to HSR speed reduction	short-haul (500 km)	24.0%
	medium-to-long haul (1,000 km)	12.0%
Airline equilibrium traffic increase (%) with HSR speed reduction	short-haul (500 km)	17.9%
	medium-to-long haul (1,000 km)	8.9%
Airline equilibrium price increase (%) with HSR speed reduction	short-haul (500 km)	6.60%
	medium-to-long haul (1,000 km)	3.34%
Airline demand decrease (%) with HSR entry	short-haul (500 km)	-69.9%
	medium-to-long haul (1,000 km)	-45.2%
Airline equilibrium traffic decrease (%) with HSR entry	short-haul (500 km)	-59.2%
	medium-to-long haul (1,000 km)	36.1%
Airline equilibrium price decrease (%) with HSR entry	short-haul (500 km)	-28.3%
	medium-to-long haul (1,000 km)	-15.4%

(b). for the 350 km/hr speed HSR lines

Items	Markets	Estimated value
Airline demand elasticity to HSR speed	short-haul (500 km)	-1.68
	medium-to-long haul (1,000 km)	-0.86
Airline equilibrium traffic elasticity to HSR speed	short-haul (500 km)	-1.253
	medium-to-long haul (1,000 km)	-0.640
Airline equilibrium price elasticity to HSR speed	short-haul (500 km)	-0.47
	medium-to-long haul (1,000 km)	-0.35
Airline demand (%) increase due to HSR speed reduction	short-haul (500 km)	24.0%
	medium-to-long haul (1,000 km)	12.7%
Airline equilibrium traffic increase (%) with HSR speed reduction	short-haul (500 km)	17.9%
	medium-to-long haul (1,000 km)	9.1%
Airline equilibrium price increase (%) with HSR speed reduction	short-haul (500 km)	6.72%
	medium-to-long haul (1,000 km)	5.00%
Airline demand decrease (%) with HSR entry	short-haul (500 km)	-81.4%
	medium-to-long haul (1,000 km)	-57.7%
Airline equilibrium traffic decrease (%) with HSR entry	short-haul (500 km)	-71.4%
	medium-to-long haul (1,000 km)	47.3%
Airline equilibrium price decrease (%) with HSR entry	short-haul (500 km)	-37.5%
	medium-to-long haul (1,000 km)	-29.5%

- Using the **daily data** to identify the accident effect:

	Airline traffic		Airline price
π_1	-1.120***	α_1	-0.416***
	(0.078)		(0.092)
π_2	0.110***	α_2	0.066***
	(0.009)		(0.011)
Constant	7.393***	Constant	-0.234***
	(0.008)		(0.003)
Time dummy fixed effect	✓	Time dummy fixed effect	✓
HSR route fixed effect	✓	HSR route fixed effect	✓
Individual route fixed effect	✓	Individual route fixed effect	✓
No. of Observations	8,963	No. of Observations	8,963

Accident effect

- Presume accident started one week (half a month) post the July 23;
- It suggests a 6.6% increase in airline equilibrium price and a 11% increase in airline equilibrium traffic in the first period after the accident;
- This estimated magnitude of accident effect is smaller than Wei et al. (2016) because we use the tickets for passengers actually flew on particular day, not the ticket booking information on that day.

- We include an **interaction term** in the airline price equation to test the **moderation effect** of inter-airlines competition on HSR speed effect.

$$\ln P_{it}^{*} = \alpha_0 + \gamma \frac{S_{it}}{D_i} \times HSR_{it} + \theta \frac{S_{it}}{D_i} \times \ln HHI_{it} \times HSR_{it} + \alpha_2 \frac{HSR_{it}}{Post\_accident_{it}}$$

$$+\beta_1 \ln Dist\_Air_i + \beta_2 \ln HHI_{it} + \beta_3 \ln Pop_{it} + \beta_4 \ln Income_{it} + \beta_5 LCC_{it}$$

$$+ \beta_8 Tourism_i + \beta_9 Spring_t + \beta_{10} Summer_t + \beta_{11} Autumn_t + \beta_{12} Year_t + \tau_i + \nu_{it}$$

- This interaction term $\theta \frac{S_{it}}{D_i} \times \ln HHI_{it}$ measures the airline HHI's moderation on the HSR competition and travel time impact.
- The direction of the HHI moderation can be implied by the sign of θ.
- When the "travel time" effect is dominant, θ should be negative, as the less level of inter-airlines competition will reinforce the "travel time" effect.
- When "safety" effect is dominant, θ should be positive.

	Model 7	Model 8
α_1	1.836	1.957
	(1.656)	(1.672)
θ	-0.275*	-0.287*
	(0.181)	(0.183)
HHI Index	0.110***	0.119***
	(0.018)	(0.018)
Time trend fixed effect	✓	✓
HSR route fixed effect	✓	✓
Individual route fixed effect	✓	✓
No. of Observations	1,036	962

Moderation effect

The parameter $\boldsymbol{\theta}$ of the interaction term is estimated to be **negative**, suggesting that the HSR speed effect is, on average, **negatively moderated** by the **inter-airlines competition**.

7. Conclusion

- This study **analytically investigates and empirically tests** the HSR speed effects on airline demand, equilibrium airline traffic and price.
- Our theoretical results suggest that **when "travel time" effect dominates the "safety" effect**, airline demand, and equilibrium airline traffic and price **decrease** with HSR speed, while the opposite is true when the "safety" effect dominates.
- The **elasticities** of airline demand, equilibrium traffic and price to HSR speed **increase with higher substitutability** between airline and HSR services.

7. Conclusion – cont'd

- The air-HSR service **substitutability has larger impact** on the elasticity of equilibrium airline traffic to HSR speed than the elasticity of equilibrium airline price to HSR speed.
- In addition, the elasticity of equilibrium airline traffic to HSR speed is **larger in magnitude** than the elasticity of equilibrium airline price.
- Inter-airlines competition can **reduce** the elasticity of equilibrium airline price to HSR speed.

7. Conclusion – cont'd

- Our empirical findings **verify** that **"travel time" effect** due to HSR change **dominates** the **"safety" effect**, leading to a negative HSR speed effect on airlines.
- The elasticities of the airline demand, and equilibrium airline traffic and price with respect to HSR speed are **larger in magnitude** on short-haul routes than on medium-to-long-haul routes.
- The entry of HSR on short-haul routes has **larger negative impacts** on airline demand and equilibrium airline traffic and price than on medium-to-long-haul routes.
- We identified a positive and statistically significant **accident effect** with **daily data**, but this accident effect is small in magnitude.

7. Conclusion – cont'd

Future research:

- As the HSR price is constant in China, the **supply side** of HSR is not well modeled. Future study is thus called for those markets with HSR free to decide price, such that the full impact of airline-HSR intermodal competition can be identified.
- We did not considered the **airline and HSR frequencies adjustment** in this study due to data unavailability. Since frequencies have important impact on passengers' schedule delays, future study is called for to incorporate frequency adjustments by airlines and HSR.

THANK YOU