Equilibrium and Market Power: An illustration from the Airline Industry

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Introduction

- The view that consumers gain from competition (through lower prices) relies on the assumption that the market is in equilibrium.
- Not clear if the market is in disequilibrium.
- We test whether competition reduces or not the likelihood of convergence toward an equilibrium.
- Our aim is twofold:
  - Construct a indicator that sheds light on whether or not a Nash equilibrium has been reached.
  - Identify factors that facilitate/complicate convergence in a specific market.
  - Based on a theoretical framework and tested with data.

Introduction

- In a Nash equilibrium firms are assumed to be capable of predicting correctly the behavior of their competitors.
- The rationalizability criterion enlarges the set of possible decisions: A firm may produce below the equilibrium because it expects the others to produce above the equilibrium.
- An equilibrium is more likely to arise if it is the unique rationalizable outcome (Guesnerie, 1992, which focuses on a competitive setting).
- Here firms enjoy a significant market power. The conditions of convergence toward a unique outcome need to be identified.
- We provide an empirical illustration using data from the U.S. airline industry over the period 2003-2013.
- Our empirical model suggests that around 10% of airline markets have not reached a Nash equilibrium over the period.

A Cournot setup

- One route is an origin-destination pair where airlines compete for carrying passengers.
- Airlines make different decisions in terms of # of slots/departures and aircraft capacities.
- Brander and Zhang, 1990, Brueckner, 2002, or Basso, 2008.
- Carrying q passengers using a type a aircraft costs $C_{af}(q)$ to firm f.
- f uses a given number n_{af} of type a aircrafts ($a \in \mathcal{A}_f$) (airport slots).
- In a static model without price differentiation, the profit of f is

$$\pi_f(\mathbf{q}_f; Q_{-f}) = \sum_{a \in \mathcal{A}_f} n_{af} \left[P\left(\sum_{z \in \mathcal{A}_f} n_{zf} q_{zf} + Q_{-f} \right) q_{af} - C_{af}(q_{af}) \right],$$

with $P(Q)$ is the demand function and Q_{-f} denotes the others' production.

A Cournot setup

- Profit maximization gives the number of passengers best-response to Q_{-f}

$$\sum_{a \in \mathcal{A}_f} n_{af} q_{af} \equiv q_f = \sum_{a \in \mathcal{A}_f} n_{af} R_{af}(Q_{-f}) \equiv R_f(Q_{-f}).$$

- The best-response R_f is decreasing in Q_{-f}.

Equilibrium benchmark

- A Nash equilibrium is a profile (q_f^*) such that

$$q_f^* = R_f\left(Q_{-f}^*\right) \text{ for all } f.$$

- In equilibrium every airline guesses the others' production correctly.

- Relax this assumption: assume instead that it is common knowledge that for every firm z, q_z belongs to some interval $[q_z^{\inf}(0), q_z^{\sup}(0)]$ that comprises q_z^* (but does not necessarily reduces to it).

Rationalizable outcomes

- Since R_f is decreasing, every firm f produces between

$$q_f^{\text{inf}}(1) = R_f\left(\sum_{z \neq f} q_z^{\text{sup}}(0)\right),$$

and

$$q_f^{\text{sup}}(1) = R_f\left(\sum_{z \neq f} q_z^{\text{inf}}(0)\right).$$

- Iterating yields a system whose Nash equilibria are fixed points.
- An equilibrium is more likely to arise if the system is contracting.

A condition for local contraction

Proposition 1. The Nash equilibrium is locally the unique rationalizable outcome if and only if

$$S \equiv -\sum_{f} \frac{R_f'(Q_{-f}^*)}{1 - R_f'(Q_{-f}^*)} < 1,$$

where, for all f,

$$R_f'\left(Q_{-f}^*\right) = \frac{\left[P''(Q^*)q_f^* + P'(Q^*)\right] \sum_{a \in \mathcal{A}_f} \frac{n_{af}}{C_{af}''(q_{af}^*)}}{1 - \left[P''(Q^*)q_f^* + 2P'(Q^*)\right] \sum_{a \in \mathcal{A}_f} \frac{n_{af}}{C_{af}''(q_{af}^*)}}.$$

- This results generalizes Desgranges and Gauthier (2016).

A condition for local contraction

- Cost efficiency and capacity are positively correlated

Proposition 2. *Consider the transfer of an additional type a aircraft to some airlines f. This transfer locally destabilizes the Nash equilibrium, i.e., it increases $S(\mathbf{q}^*)$.*

Proposition 3. *Consider the transfer of a type a aircraft from airlines f to airlines f'. This transfer locally stabilizes the Nash equilibrium, i.e., it reduces $S(\mathbf{q}^*)$, if and only if f enjoys the lowest capacity (is the least efficient).*

Stability on sub-markets: Test for the relevant market

- The threshold for the stability index $S(\mathbf{q}^*)$ above which the equilibrium is unstable should be adjusted downwards if stability is assessed from a sub-market of the relevant one.
- A transport service is a composite good that comprises differentiated items (non-stop direct versus indirect flights).
- Neglecting part of the relevant market implies an underestimated overall capacity.
- We examine a variant with two substitutable items thought of as direct and indirect flights in a given route.
- The demand for item m $(m = 1, 2)$ is $P^m(Q^m, Q^{-m})$.
- A best-response can be written as $q_f = R_f^m\left(Q_{-f}^m, Q^{-m}\right)$.
- The iterated process of elimination of dominated strategies is now driven by the partial derivatives

$$R'_{f1}(\mathbf{q}^*) = \frac{\partial R_f^m}{\partial Q_{-f}^m}\left(Q_{-f}^*, Q^*\right), \quad \text{and } R'_{f2}(\mathbf{q}^*) = \frac{\partial R_f^m}{\partial Q^{-m}}\left(Q_{-f}^*, Q^*\right)$$

Stability on sub-markets

- **Proposition 4.** *A symmetric Nash equilibrium is locally the unique rationalizable outcome if and only if*

$$\sum_{f \leq F} \frac{R'_{f1}(\mathbf{q}^*) + R'_{f2}(\mathbf{q}^*)}{R'_{f1}(\mathbf{q}^*) - 1} < \frac{1}{2}.$$

- If the demand in the other market is assumed to be exogenously fixed, $R'_{f2}(\mathbf{q}^*) = 0$, and the stability condition reduces to $S(\mathbf{q}^*) < 1/2$.
- The threshold for the stability index $S(\mathbf{q}^*)$ is adjusted downwards if missing data on other services.
- The observation of a significant difference between the theoretical Nash equilibrium and the observed number of passengers while $S(\mathbf{q}^*)$ is below 1 in a route may signal that the route is only a part of the relevant market.
- Test for assessing the size of the relevant market which does not require estimating cross-price elasticities.

A roadmap of the structural analysis

- Estimate the demand P and the cost C_{af} functions.
- Compute the Nash equilibrium (q^*_{af}) given by the FOC,

$$n_{af} P'(Q^*) q^*_{af} + P(Q^*) - C'_{af}(q^*_{af}) = 0$$

for all $a \in \mathcal{A}_f$ and all f, and

$$Q^* = \sum_{af} q^*_{af}$$

- Compute $R'_f \left(Q^*_{-f}\right)$ for every firm and get the index S.
- Relate S to the spread between actual and (computed) Nash production.

Data

- U.S. domestic market over the period 2003-2013.
- Several databases which are published by the Bureau of Transportation statistics:
  - Air Carrier Financial Reports. Companies' costs, including input prices such as the wage bill or fuel prices. Quarterly data.
  - Air Carrier Statistics (T100). Origin and destination points, the number of passengers carried, the flight frequency, and the route length.
  - Airline Origin and Destination Survey (DB1B). 10% sample which gathers statistics on ticket prices and other characteristics.
- We have cost data per firm $\times$ quarter $\times$ aircraft type. Market $=$ segment $\Rightarrow$ we estimate demand for direct flights only (involving one segment). Indirect flights are not taken into account.
- Select markets where the share of indirect services is low.

Costs

- Start from firm f's quadratic cost $c_{afs} = \sigma_{afs} q^2$ for any afs.
- Decompose σ_{afs} into firm, segment and aircraft characteristics:

$$\sigma_{afs} = \beta_0 \theta_f \, \theta_s \theta_a.$$

- Our data reports aggregate cost only:

$$C_{af} = \sum_s n_{afs} c_{afs} = \beta_0 \theta_f \theta_a \sum_s \theta_s n_{afs} q_{afs}^2.$$

- Introducing time the model to be estimated is

$$\ln C_{aft} = \ln \beta_0 + \ln \theta_{ft} + \ln \theta_a + \ln \left(\sum_s \theta_s n_{afst} q_{afst}^2 \right) + \varepsilon_{aft},$$

  where

$$\ln \theta_{ft} = \alpha \ln \text{Wage}_{ft} + (1 - \alpha) \ln \text{PFuel}_{ft} + \text{Airline}_f + \text{Time}_t$$

- Since a firm serves around 200 segments on average,

$$\theta_s = \gamma_0 + \gamma_1 \, \text{Dist}_s + \gamma_2 \, \text{Temperature}_s.$$

Estimation results: Costs

	(1)	(2)	(3)
Log (Salary)	0.281***	0.520***	0.490***
	0.082	0.058	0.054
γ_0	0.0068***	0.0029***	0.0074***
	0.0027	0.0006	0.0027
Dist	-0.0014***	0.0016***	0.0012***
	0.0006	0.0007	0.0004
Temp	-0.034**		-0.041**
	0.017		0.021
Q_2	-0.176***	-0.156***	-0.164***
	0.012	0.011	0.010
Q_3	-0.227***	-0.191***	-0.206***
	0.012	0.010	0.011
Q_4	-0.127***	-0.092***	-0.098***
	0.0135	0.0090	0.0086
Aircraft type f.e.	No	Yes	Yes
carrier f.e.	Yes	Yes	Yes
Year f.e.	Yes	Yes	Yes
# of Obs.	3,034	3,034	3,034
R^2	0.99	0.99	0.99
Log-Likelihood	-891.09	-411.58	-351.40

Demand

- We estimate a linear demand function

$$Q_{st} = \gamma_{st}^0 + \gamma_{st} P_{st} + \nu_{st},$$

with

$$\gamma_{st}^0 = \alpha_0 + \alpha_1 \text{PopOrigin}_{st} + \alpha_2 \text{PopDest}_{st} + \phi_s + \phi_t,$$

and

$$\gamma_{st} = \alpha_3 + \alpha_4 \text{Dist}_s + \alpha_5 \text{PopOrigin}_{st} + \alpha_6 \text{PopDest}_{st} + \phi_Q.$$

- The lagged price and input prices are used as an instrument.

Estimation results: Demand

Passengers number	MD1	MD2
Price IV	-0.591***	-0.673***
	0.024	0.057
Pop1	24.512***	24.164***
	2.901	2.918
Pop2	32.278***	33.826***
	3.738	4.223
PriceIV* Dist		0.210***
		0.036
PriceIV* Pop1		-0.018***
		0.004
PriceIV* Pop2		-0.070***
		0.014
Cons	83.493***	102.118***
	19.846***	20.352***
Year f.e.	Yes	Yes
Quarter f.e.	Yes	Yes
R^2	0.166	0.147
Number of obs.	19632	19632

Stability index

Mean	0.667
Std.Dev.	0.224
Percentiles	
1%	0.312
5%	0.395
10%	0.436
25%	0.509
50%	0.607
75%	0.797
90%	0.979
95%	1.088
99%	1.391
Obs.	6697

Large competitive routes have higher stability indexes

Variable	Mean	Mean	Std.Dev.	Min	Max
Number of competitors	SI>1	4.90	0.92	4	8
	SI<0.7	2.53	0.67	2	5
Passengers per route, in 1000	SI>1	716.22	435.06	133.65	2780.08
	SI<0.7	215.88	154.35	22.12	1095.02
Average fuel price per 1000 gallons, in 1000 U.S. dollars *	SI>1	2.36	0.71	0.75	3.77
	SI<0.7	2.10	0.79	0.71	4.32
Average salary level, per quarter in 1000 U.S. dollars*	SI>1	21.49	2.63	14.78	27.72
	SI<0.7	20.77	3.21	11.69	30.14
Distance, in 1000 km	SI>1	0.98	0.61	0.23	2.58
	SI<0.7	0.97	0.62	0.14	2.70
Obs.	SI>1	598			
	SI<0.7	4179			

Airlines Interactions Across Segments

- On each route, we construct a vector of zeros and ones. The *fth* entry $= 1$ if firm f is present, 0 otherwise.
- We cluster the *closest* routes into a single hypothetical market to shed light on airlines' behavior.
- Ex: 5 airlines, 3 routes, and 2 clusters:

Route 1	1	0	0	1	0
Route 2	0	1	1	0	0
Route 3	1	0	0	0	1

- Distance between route 1 and route 2 is
$(1-0)^2 + (0-1)^2 + (0-1)^2 + (1-0)^2 + 0 = 4$.
- Distance between route 1 and route 3 is 2.
- Distance between route 2 and route 3 is 4.

$\Longrightarrow$ Routes 1 and 3 are clustered into the same hypothetical market, while route 2 stays alone.

Airlines Interactions Across Segments

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
WN	100	65	0	0	100
DL	5	6	34	72	23
AA	100	0	100	0	0
UA	53	100	34	4	0
nb of routes	871	946	696	1,284	1,391
Average stability index	0.810	0.760	0.710	0.560	0.600

Nash versus observed quantities

- Let $\mathcal{F}_{st}$ be the set of airlines active in segment s during period t. The spread between the theoretical Nash and the actual number of transported passengers is measured by

$$\|\mathbf{q}_{st} - \mathbf{q}_{st}^*\| = \sqrt{\sum_{f \in \mathcal{F}_{st}} \left(q_{fst} - q_{fst}^*\right)^2}.$$

- Since this measure tends to be higher in segments with intense traffic, we normalize by

$$\|\mathbf{q}_{st}^*\| = \sqrt{\sum_{f \in \mathcal{F}_{st}} q_{fst}^{*2}}.$$

- Our normalized measured for the spread between Nash and actual production (at the segment $\times$ period level) is

$$\Delta_{st} = \frac{\|\mathbf{q}_{st} - \mathbf{q}_{st}^*\|}{\|\mathbf{q}_{st}^*\|}.$$

- We run the regression

$$\log \Delta_{st} = \delta_0 + \delta \log S_{st} + \mathrm{Cluster}_s + \mathrm{Period}_t + \varepsilon_{st}$$

Stability index and departure from Nash

	log Δst	
	(1)	(2)
Stability index	0.203***	0.242***
	(0.025)	(0.028)
Cluster 2		−0.079***
		(0.027)
Cluster 3		0.026
		(0.029)
Cluster 4		0.124***
		(0.027)
Cluster 5		−0.137***
		(0.026)
Constant	−0.925***	−0.889***
	(0.055)	(0.056)
Observations	5,188	5,188
R^2	0.033	0.056
Adjusted R^2	0.024	0.047
Residual Std. Error	0.572 (df = 5143)	0.566 (df = 5139)
F Statistic	3.940*** (df = 44; 5143)	6.331*** (df = 48; 5139)

Other determinants

	stabindex
log(distance)	0.048***
	(0.003)
Market size	
log(maxpop)	−0.012***
	(0.002)
log(minpop)	0.040***
	(0.001)
Direct competition	
nairlines	0.125***
	(0.003)
herfindhal	−0.523***
	(0.023)
Relevant market	
sharedirect	0.640***
	(0.024)
h.distance	0.014***
	(0.001)
Airlines interactions	
Cluster 2	−0.014***
	(0.004)
Cluster 3	−0.021***
	(0.004)
Cluster 4	−0.022***
	(0.004)
Cluster 5	−0.026***
	(0.004)
Constant	−0.793***
	(0.053)
Observations	5,188
Adjusted R^2	0.871

Concluding comments

1. Some consistent evidence that market power may help firms to form accurate predictions about the behavior of their competitors $\rightarrow$ increase the likelihood that a (Nash) equilibrium be eventually reached.
2. However the spread between actual and Nash outcomes remains significant on ‘stable’ routes.
3. Several features are absent from the theoretical model: dynamics, price discrimination, network, active airports.
4. Empirical side restricted to segments (demand for direct flights).