Optimal regulation of oligopolistic markets under discrete choice models of demand

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Outline

Regulated competitive markets in transportation

- Actors:
  - Demand: people as utility maximizers.
  - Supply: operators as profit maximizers.
  - Regulation: government as welfare maximizer.
- Issues:
  - Product differentiation
  - Fair treatment of market players
  - Externalities

Case study: intercity travel

Case study: alternatives

Alternative	0	1	2	3	4	5	6	7	8	9
Mode	Car	Air	Air	IC	HSR	HSR	HSR	HSR	HSR	HSR
Endogenous	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Operator	-	-	-	-	1	1	1	2	2	2
Dep	-	7:10	8:10	2:00	5:45	6:15	6:45	5:35	6:05	6:35
Arr	-	8:20	9:20	10:00	8:45	9:15	9:45	8:55	9:25	9:55
TT	6h	1h10'	1h10'	8h	3h	3h	3h	3h20'	3h20'	3h20'
WT	-	1h	1h	-	-	-	-	-	-	-
Access	-	30-60'	30-60'	0-60'	0-60'	0-60'	0-60'	0-60'	0-60'	0-60'
Egress	-	30-60'	30-60'	0-30'	0-30'	0-30'	0-30'	0-30'	0-30'	0-30'
Price	100 €	60 €	60 €	30 €	p_4	p_5	p_6	p_7	p_8	p_9

Table: Attributes of all scheduled services for problem instance 1.

Case study: alternatives

Alternative	0	1	2	3	4	5	6	7	8	9
Mode	Car	Air	Air	IC	HSR	HSR	HSR	HSR	HSR	HSR
Endogenous	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Operator	-	-	-	-	1	1	1	2	2	2
Dep	-	8:40	10:40	22:00	5:10	6:10	7:10	5:00	6:00	7:00
Arr	-	10:10	12:10	10:00	10:40	11:40	12:40	11:00	12:00	13:00
TT	**8h30'**	**1h30'**	**1h30'**	**12h**	**5h30'**	**5h30'**	**5h30'**	**6h**	**6h**	**6h**
WT	-	1h	1h	-	-	-	-	-	-	-
Access	-	30-60'	30-60'	0-60'	0-60'	0-60'	0-60'	0-60'	0-60'	0-60'
Egress	-	30-60'	30-60'	0-30'	0-30'	0-30'	0-30'	0-30'	0-30'	0-30'
Price	110 €	60 €	60 €	40 €	p_4	p_5	p_6	p_7	p_8	p_9

Table: Attributes of all scheduled services for problem instance 2.

Demand: discrete choice

- Discrete choice models allow to model choices of customers with different tastes and socioeconomic characteristics.
- Linearization: simulation is used to draw R times from the distribution of the error term of the utility function [Pacheco et al., 2017].

$$U_{inr} = V_{in} + \xi_{inr}.$$

- In each scenario, customers choose the alternative with the highest utility:

$$P_{inr} = \begin{cases} 1 & \text{if } U_{inr} = \max_{j \in I} U_{jnr}, \\ 0 & \text{otherwise.} \end{cases}$$

- Over R scenarios, the probability of customer n choosing alternative i is

$$P_{in} = \frac{\sum_{r \in R} P_{inr}}{R}.$$

Case study: demand

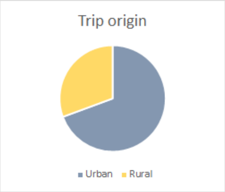
β	Business travelers			Other purpose travelers	
μ_{Air}	1.086			1.106	
μ_{HSR1}	1.190			1.333	
μ_{HSR2}	1.134			1.299	
Travel time (min)	-0.0133			-0.0054	
Access/egress time (min)	-0.00555			-0.0103	
Early schedule delay (min)	-0.00188			-0.00677	
Late schedule delay (min)	-0.0130			-0.00617	
Dummy male car (1/0)	1.400			0.550	
	Reimbursed	High income	Low income	High income	Low income
Cost car (euro)	-0.0222*	-0.0296*	-0.0527	-0.0228*	-0.0405
Cost Air (euro)	-0.0109	-0.0113*	-0.0201	-0.0109*	-0.0194
Cost IC (euro)	-0.0158	-0.0212*	-0.0377	-0.0097*	-0.0172
Cost HSR (euro)	-0.0120	-0.0160*	-0.0284	-0.0144*	-0.0256

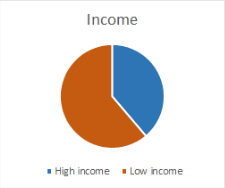
Value of Travel Time	Reimbursed	High income	Low income	High income	Low income
Car (euro/h)	35.88*	26.95*	15.14	14.24*	8.00
Air (euro/h)	73.21	70.67*	39.70	29.73*	16.70
IC (euro/h)	50.51	37.68*	21.17	33.54*	18.84
HSR (euro/h)	66.50	50.02*	28.10	22.53*	12.66

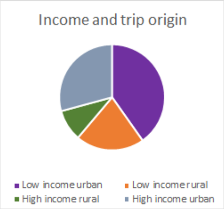
Table: Nested logit model parameters and VoTTs derived from Cascetta and Coppola [2012].

Case study: demand

- Origin
- Purpose
- Income
- Desired arrival time

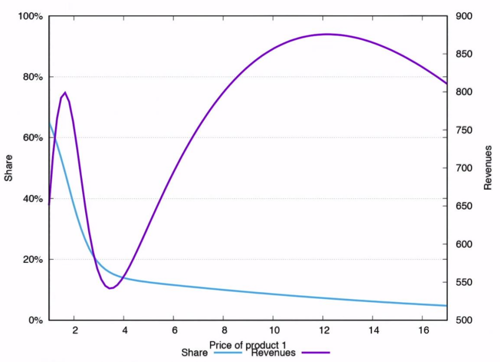






Supply: optimization

- Each supplier $k \in K$ chooses the strategy that maximizes its profits.
- Discrete choice models are embedded into the optimization problem of the suppliers.



From the MOOC Introduction to Discrete Choice Models (Michel Bierlaire and Virginie Lurkin)

Choice-based optimization: MILP model

$$\max_{s=(p,X)} \quad \pi_s = \frac{1}{|R|} \sum_{i \in I_k} \sum_{n \in N} \sum_{r \in R} p_{in} P_{inr} - c(X),$$

$$\begin{aligned}
s.t. \quad & U_{inr} = \beta_{p,in} p_{in} + \beta_{in} X_{in} + q_{in} + \xi_{inr} && \forall i \in I, \forall n \in N, \forall r \in R,\\
& U_{inr} \leq U_{nr} && \forall i \in I, \forall n \in N, \forall r \in R,\\
& U_{nr} \leq U_{inr} + M_{U_{nr}} (1 - P_{inr}) && \forall i \in I, \forall n \in N, \forall r \in R,\\
& \sum_{i \in I} P_{inr} = 1 && \forall n \in N, \forall r \in R,\\
& P_{inr} \in \{0, 1\} && \forall i \in I, \forall n \in N, \forall r \in R.
\end{aligned}$$

Regulation

- The utilities U_{inr} depend on the prices p_{in}.

$$p_{in} = r_{in} + t_{in} - s_{in},$$

  where

  - r_{in} is the revenue made by the supplier in case of purchase,
  - s_{in} is the subsidy given by the regulator to the consumer,
  - t_{in} is the tax imposed by the regulator to the consumer.

- In case of purchase we have that

  - the consumer pays $r_{in} + t_{in} - s_{in}$,
  - the supplier receives r_{in},
  - the regulator intervenes with $t_{in} - s_{in}$, i.e. it gives s_{in} to or receives t_{in} from the consumer, or does not intervene at all ($s_{in} = t_{in} = 0$).

Market equilibrium

- We look for ε-equilibrium solutions: stationary states of the system in which no competitor has an incentive to change its decision to increase profit by more than ε%.
- Fixed-point iteration algorithm
- Fixed-point MIP model

Fixed-point MIP model for the regulator

$$\max \quad \frac{1}{|N||R|}\sum_{i\in I_s}\sum_{n\in N}\sum_{r\in R} P_{inr}{'}$$

s.t. Equilibrium constraints:

$$\pi_k^{''} \leq (1+\varepsilon)\pi_k^{'} \qquad \forall k \in K,$$

Regulator constraints:

$$\sum_{n\in N}\sum_{r\in R}\sum_{i\in I} P_{inr}{'}(s_{in} - t_{in}) \leq B,$$

$$s_{in} = s_{jn} \qquad \forall i,j \in I_s, \forall n \in N,$$

$$s_{in} = 0 \qquad \forall i \in I \setminus I_s, \forall n \in N,$$

$$t_{in} = t_{jn} \qquad \forall i,j \in I_t, \forall n \in N,$$

$$t_{in} = 0 \qquad \forall i \in I \setminus I_t, \forall n \in N,$$

Supplier and consumer constraints:

...

Algorithmic approach

1. Identify candidate equilibrium regions efficiently.
2. Use exact method on restricted strategy sets derived from step 1 to find a subgame equilibrium: fixed-point MIP model.
3. Verify if best-response conditions are satisfied for the initial problem:

$$\pi_k^{BR} \leq (1+\varepsilon)\pi_k^{FP} \qquad \forall k \in K.$$

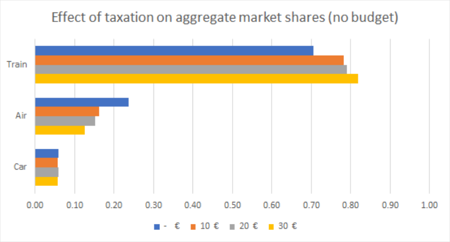
   If they are not, modify the restricted problem (add/remove strategies) and go to step 2.

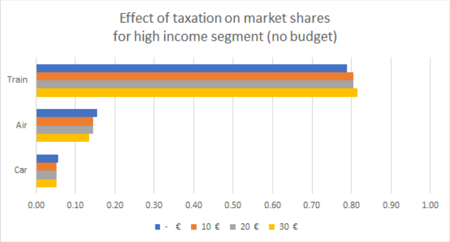
- Do multiple runs to search for different ε-equilibrium solutions.

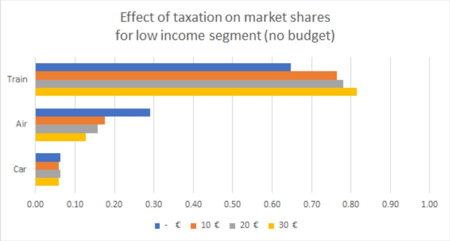
Regulation of an intercity travel market

- The regulator wants to promote low-emission mobility.
- Subsidies or tax must satisfy some constraints.
- What are the optimal levels?
  - Competition analysis, e.g. how do supply pricing strategies change?
  - Demand analysis, e.g. what is the effect on choices and utilities on specific segments of the population?
  - Environmental analysis, e.g. what are the marginal abatement costs in different budget scenarios?

Preliminary tests: 3h-3h30' train travel time

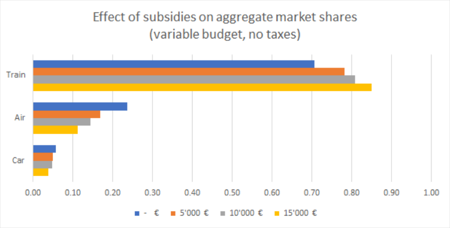


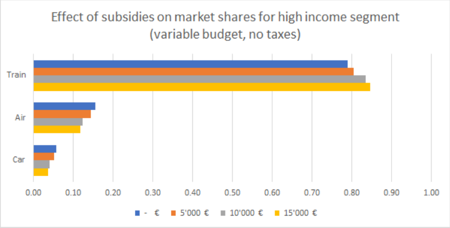


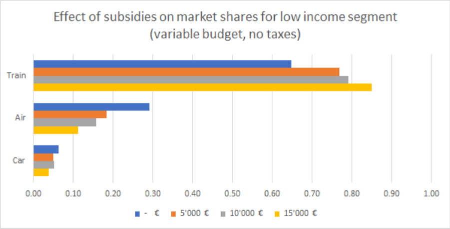


- Train subsidies are financed through taxation on air travel.
- More low income travellers are priced out of flying.

Preliminary tests: 3h-3h30' train travel time

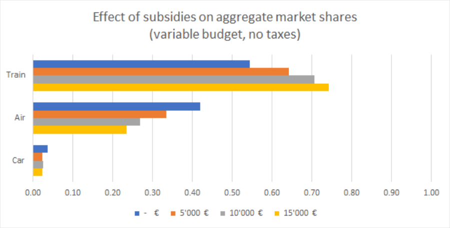


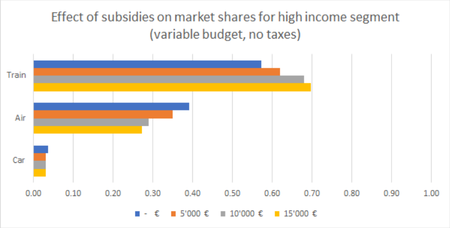


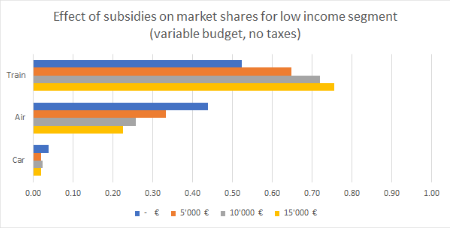


- Train subsidies are financed with a fixed budget.
- Higher modal shift.
- Cost-benefit analysis needed to compare with monetized benefits.

Preliminary tests: 5h30'-6h train travel time



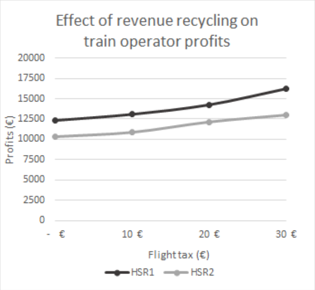


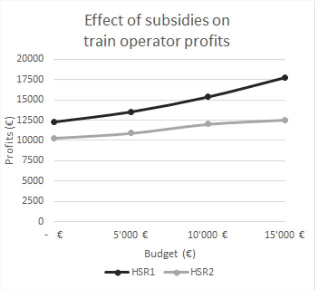


- Flying gives higher travel time savings.
- Higher initial modal share.
- Money "better spent" than in previous case.

Preliminary tests: 5h30’-6h train travel time

- Part of the subsidies is cashed in by the train operators...
- ...but we are currently neglecting the competitive behaviour of airlines.





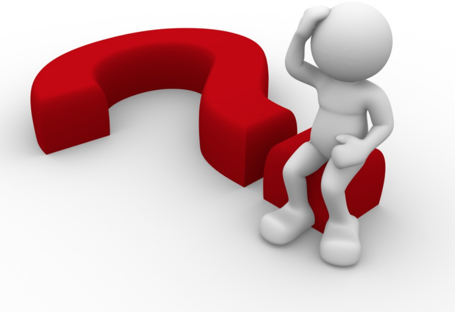
Summary

- Discrete choice models are embedded in the optimization problems of the suppliers.
- We use an algorithmic approach to find market ε-equilibrium solutions.
- Subsidies or taxes are set by the regulator to maximize welfare or achieve other targets, subject to budget or market-specific constraints.
- The application to a realistic case study shows potential for various types of analysis.
- The framework is very general and can accommodate many complex discrete choice models.

Next steps

- Improve models and try to reduce computational times.
- Allow targeted measures on the regulator side.
- Do more experiments and refine case studies.

Questions and discussion time



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