Game Theory & Transportation Markets:

overcoming regulatory failure

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Motivation

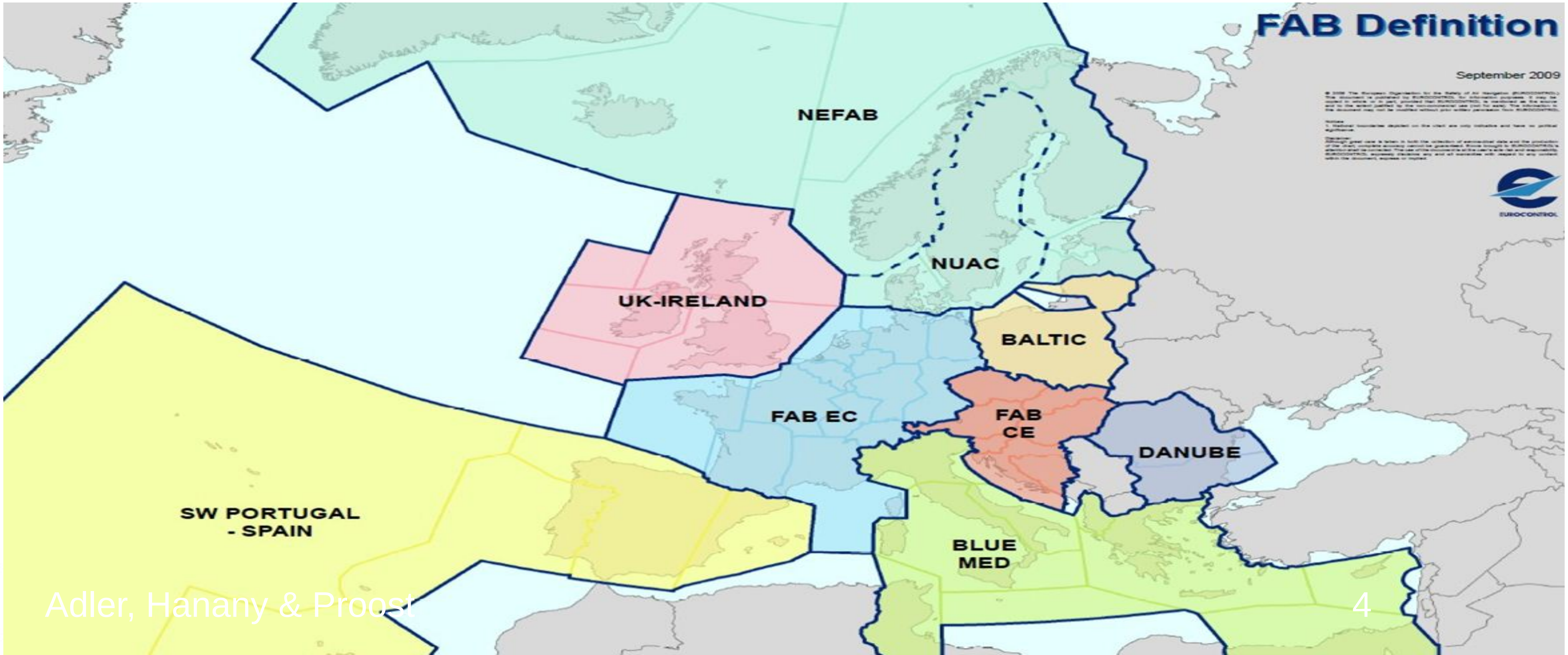
- present system in EU is composed of 37 national providers
  - compared to FAA, EU system is 34% more costly (2011)
- **barriers to cost efficiency:**
  - ownership form: governmental organizations
  - fragmentation: missing economies of scale
  - protectionism: power of Labor Unions & member states
  - weak regulation: failure to implement FABs or strict price-caps
- **barriers to increasing capacity:**
  - new technologies estimated cost: 30 billion euro
  - relatively low congestion currently
  - opposition to change / fear of technology

European Air Traffic Control System: weak regulators?

- European Union:
  - – 2004 Law: cooperation between air traffic control providers through functional airspace blocks (FAB)
  - – 2009 Law: economic regulation passed from Member States to European Union
    - price cap replacing cost plus approach
    - data collected regularly since 2002 enabling benchmarking approach

European Air Traffic Control System: too many suppliers?

- European Union:
  - 2004 Law: cooperation between providers through functional airspace blocks (FAB)
  - Reduce suppliers from 37 to 9 FAB



how could cost efficiency and technology adoption be encouraged simultaneously?

- **changes in ownership form**
  - horizontal integration
  - vertical integration
  - commercialization / privatization
- **changes in pricing regulation**
  - strict individual price-caps
  - peak / off peak charges
  - hybrid price-caps
- **changes in capacity**
  - adopting new technologies

Outline of talk

- Literature search
- Model to analyse change in ownership form
  - 2-stage network congestion game with auctioning
    - 1st stage: air navigation service providers
    - 2nd stage: airlines
  - Numerical results for West European case study
- Conclusions & Future Research
  - Theoretical
    - sub-game perfect outcome different to Wardrop & potential game solutions
  - Case study
    - privatization or commercialization will reduce charge by around 50%
    - regulator still needs to set minimum capacities

Literature Search

- Air Traffic Control
  - On the US system:
    - Odoni (1987), Ball et al. (2001, 2003), Kim & Hansen (2013, 2015)
    - Morrison & Winston (2008), Nextor (2010)
  - On the European system:
    - Lulli & Odoni (2007)
    - Castelli, Labbe and Violin (2013), Jovanovic et al. (2014)
    - Button and Neiva (2014)
- Network congestion games
  - Network Equilibria:
    - Wardrop (1952)
    - Rosenthal (1973), Monderer & Shapley (1996)
  - Sub-game Perfect Nash Equilibria:
    - Selten (1975), Myerson (2013)

2 stage network congestion game

- **Stage 1: Providers set prices, labor & technology levels**
  - En-route providers set peak/off-peak charges
    - may be price capped according to regulatory rules
    - capacity = f(labor levels, technology investment, size of airspace)
  - Terminal providers limit flights in peak
    - form of slot allocation
- **Auction:**
  - sealed bid, lexicographic
    - 1st peak price; 2nd off-peak price; 3rd home bias; 4th capacity
  - complete information
  - combinatorial with inter-dependent valuations

Air navigation service provider objective function

- Business as Usual
  - government organization
  - set charges according to price caps
  - maximize labor
  - examples: DFS (Germany) and DSNA (France)
- Non-profit public companies
  - set charges to cover costs
  - maximize capacity according to company charter
  - airlines on Board of public company
  - example: NavCanada
- For-profit private companies
  - maximize profits
  - example: NATS (public-private partnership in UK)

Business as usual

- Objective function
  - Maximize labor rents

$$Max\ \ l_s$$

- Constraints
  - Production function

$$\zeta(l_s)^{\alpha}(t_s)^{\beta} = k_s$$

  - Zero profits

$$\sum_{b\in B^E} h_{sb}\left(\sum_{w} \tau_{sbw}F^{*}_{bw}\right) - c_s^{Sl}l_s - c_s^{St}t_s = 0$$

  - Price caps
  - Lower bounds on labor & technology

$$0 \leq \tau_{sb2} \leq \tau_{sb1} \leq \tau^{0}_{sb}\ \ \forall\ s, b$$

$$l_s \geq l', t'' \geq\ t_s \geq t'\ \ \forall\ s$$

For-profit auctions

- Objective function: maximize profit

$$Max - c_s^{Sl} l_s - c_s^{St} t_s$$

$$+ \sum_{b \in B^E} \begin{cases} \sum_w \tau_{sbw} \big(F_{bw}^* + max\{0, \varphi_{bw}^+ (F_{bw}^* - f_{bw}^0)\} - max\{0, \varphi_{bw}^- (f_{bw}^0 - F_{bw}^*)\} \big) & if\ Y_b = \{s\} \\ 0 & otherwise \end{cases}$$

- Constraints
  - Maximum # auctions
  - Production function
  - Lower bounds on labor & technology

$$\sum_{b \in B^E} X_{sb} \leq \upsilon^E \ \ \forall s$$

$$\zeta (l_s)^{\alpha} (t_s)^{\beta} \Big(\sum_{b | Y_b = \{s\}} d_b \Big)^{\gamma} = K_S^e$$

$$0 \leq \tau_{sb2} \leq \tau_{sb1} \leq \tau_{sb}^0 \ \ \forall s, b$$

$$l_s \geq l', t'' \geq \ t_s \geq t' \ \ \forall s$$

Non-profit auctions

- Objective function: goal program

$$Max\ K_s^e - \xi \left| \sum_{b \in B^E} \sum_w \left(\tau_{sbw} F_{bw}^* - c_s^{Sl} l_s - c_s^{St} t_s \right) \right|$$

- Constraints
  - Maximum # auctions

$$\sum_{b \in B^E} X_{sb} \le \upsilon^E \quad \forall\ s$$

  - Production function

$$\zeta (l_s)^\alpha (t_s)^\beta \left(\sum_{b | Y_b = \{s\}} d_b \right)^\gamma = K_s^e$$

  - Lower bounds on labor & technology

$$0 \le \tau_{sb2} \le \tau_{sb1} \le \tau_{sb}^0 \quad \forall\ s, b$$

$$l_s \ge l', t'' \ge\ t_s \ge t' \quad \forall\ s$$

2 stage network congestion game

- **Stage 2 - Airlines choose flight paths given schedules**
  - minimize only self-inflicted delays
  - cost components:
    - operational
    - congestion
    - air traffic control en-route charges
    - + revenue loss because flying off-peak lowers airfares
  - option to ‘not fly’ necessary for demand elasticity
  - Note:
    - Congestion is non-linear
    - Closer to capacity: the higher the delays

Savings from adoption of new technology

2nd stage airline cost minimization:

non-linear in congestion

- Objective function: non-linear cost minimization

$$\Psi_l \equiv \sum_w \sum_{b\in B^E} \sum_{a\in A_b} \begin{bmatrix} C^O_{la}\left(1-\max\left\{\eta\left(\frac{K^e_{Y_b}}{k^0_b}-1\right),0\right\}\right)+C^R_{law} \\ +C^G_{lbw}\left(1-\max\left\{\varsigma\left(\frac{K^e_{Y_b}}{k^0_b}-1\right),0\right\}\right)\left(\sum_{l'od} f_{l'odaw}\right) \\ +\tau_{sbw} \end{bmatrix} \vartheta_a \sum_{od} f_{lodaw} + \sum_{od} C^H_{od} f^H_{lod}$$

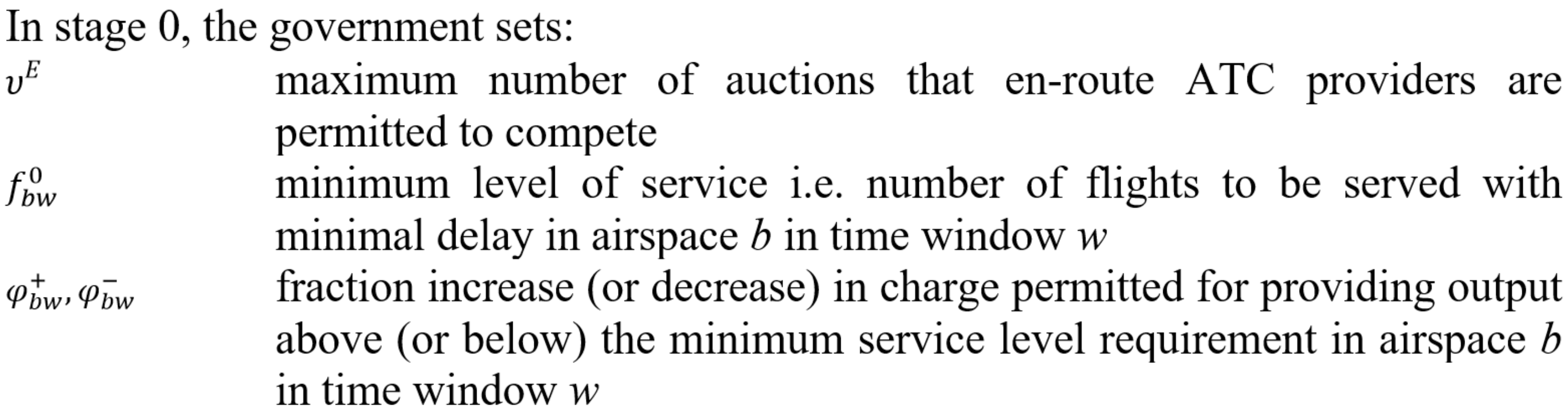
- Constraints
  - Meet demand at source, sink & transshipment nodes $\quad \sum_{od} f_{lodaw} \leq K_{law} \quad , \forall l \in L, \forall a \in A, \forall w \in W$
  - Limited capacity (by 1st stage analysis)

$$\sum_w \left[\sum_{j|(o,j)\in A} f_{lod(o,j)w} - \sum_{j|(j,o)\in A} f_{lod(o,j)w}\right] + f^T_{lod} = D_{lod}\ , \quad \forall l \in L, \forall o,d$$

$$\sum_w \left[\sum_{j|(j,d)\in A} f_{lod(d,j)w} - \sum_{j|(d,j)\in A} f_{lod(d,j)w}\right] + f^T_{lod} = D_{lod}\ , \quad \forall l \in L, \forall o,d$$

$$\sum_{j|(j,i)\in A} f_{lod(j,i)w} - \sum_{j|(i,j)\in A} f_{lod(i,j)w} = 0, \forall l \in L, w \in W, \forall o,d,i \in N\ (i \neq o,d)$$

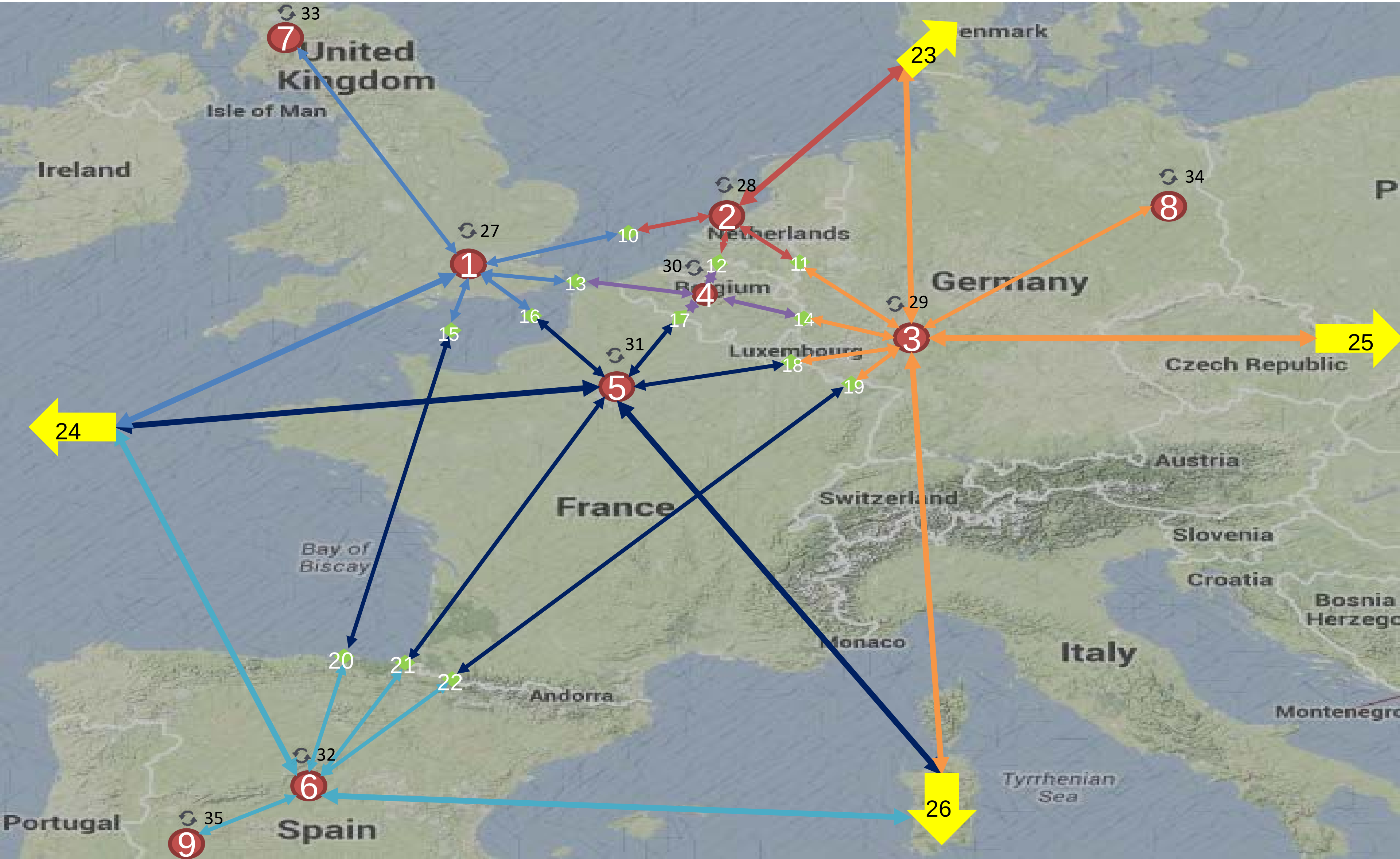
Government Auction Decisions



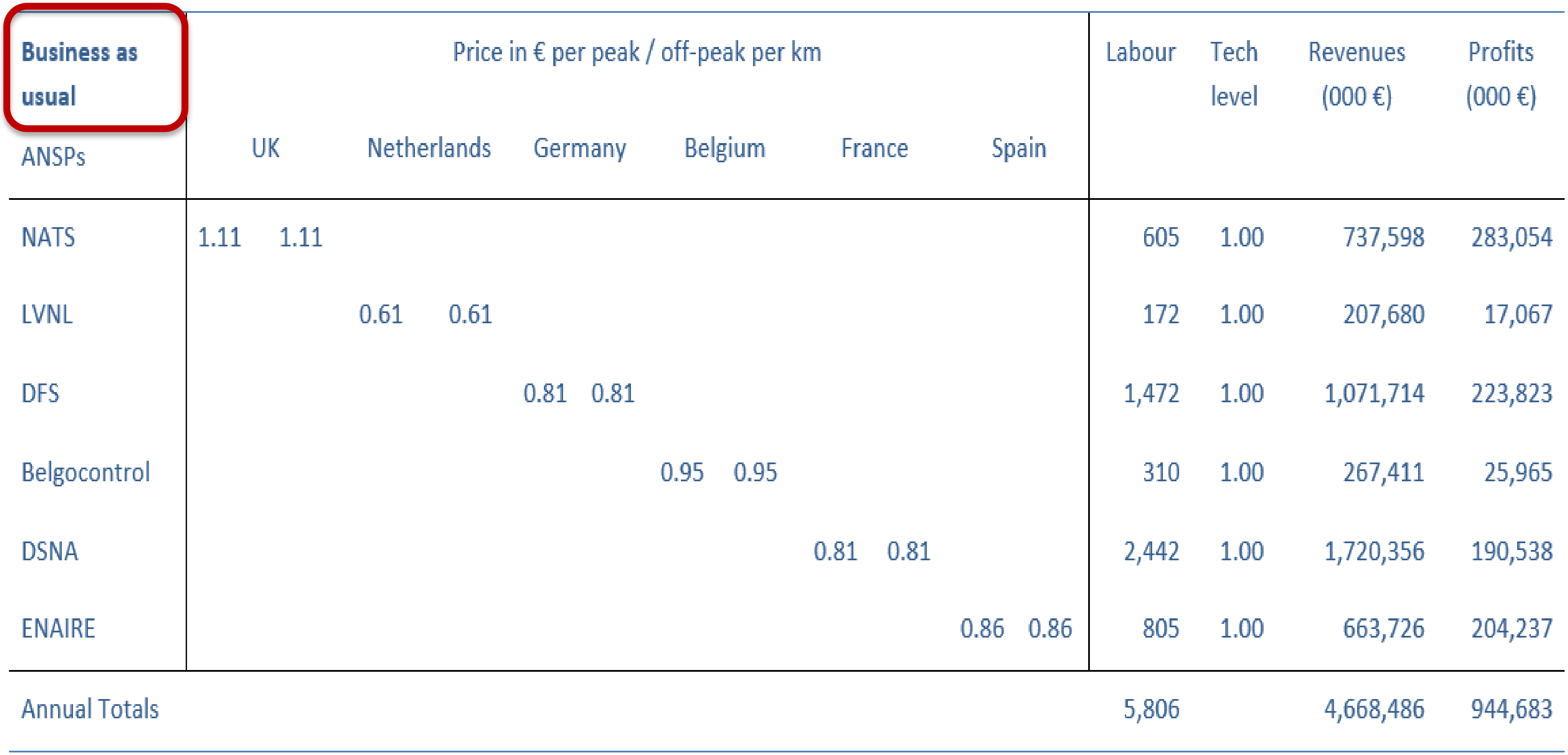
In stage 0, the government sets:

υ^E	maximum number of auctions that en-route ATC providers are permitted to compete
f_{bw}^0	minimum level of service i.e. number of flights to be served with minimal delay in airspace b in time window w
$\varphi_{bw}^+, \varphi_{bw}^-$	fraction increase (or decrease) in charge permitted for providing output above (or below) the minimum service level requirement in airspace b in time window w

Case Study of Western Europe



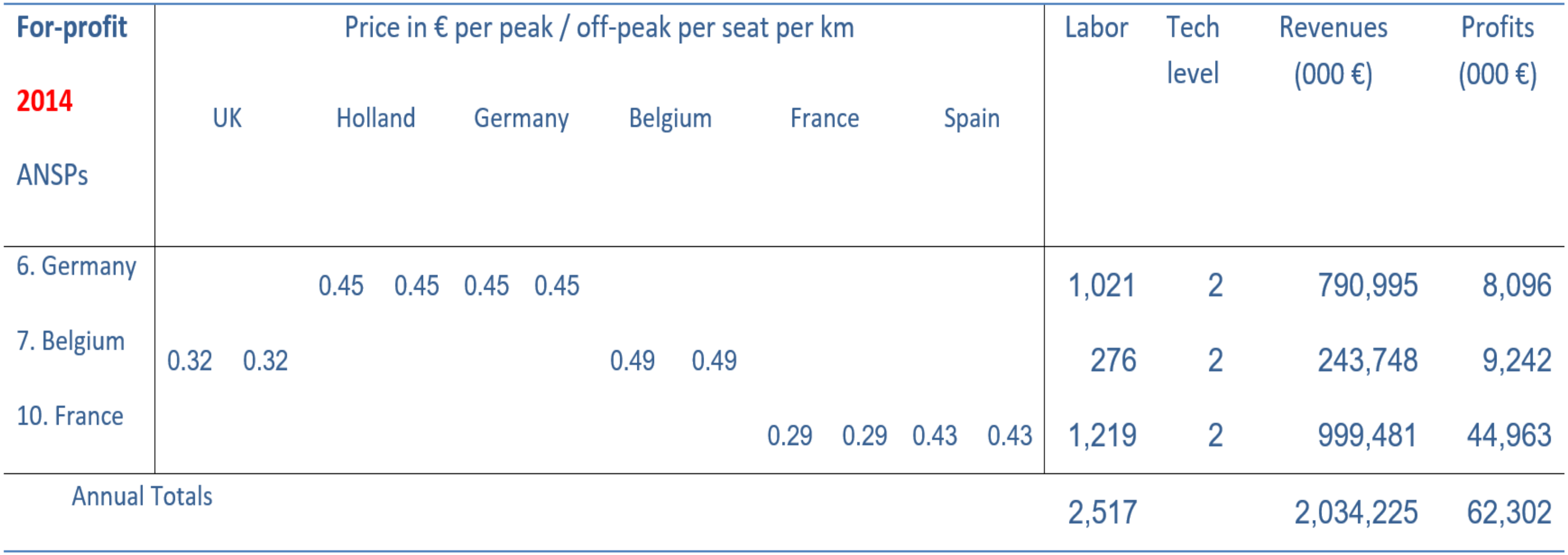
Results: no tender (1/3)



Business as usual ANSPs	Price in € per peak / off-peak per km UK		Netherlands		Germany		Belgium		France		Spain		Labour	Tech level	Revenues (000 €)	Profits (000 €)
NATS	1.11	1.11											605	1.00	737,598	283,054
LVNL			0.61	0.61									172	1.00	207,680	17,067
DFS					0.81	0.81							1,472	1.00	1,071,714	223,823
Belgocontrol							0.95	0.95					310	1.00	267,411	25,965
DSNA									0.81	0.81			2,442	1.00	1,720,356	190,538
ENAIRE											0.86	0.86	805	1.00	663,726	204,237
Annual Totals													5,806		4,668,486	944,683

- Labor rent seekers
  - Labor levels higher than the 5,000 currently employed; std. technology level
  - Profits approx. 20% as occurs today
- Prices set at price cap

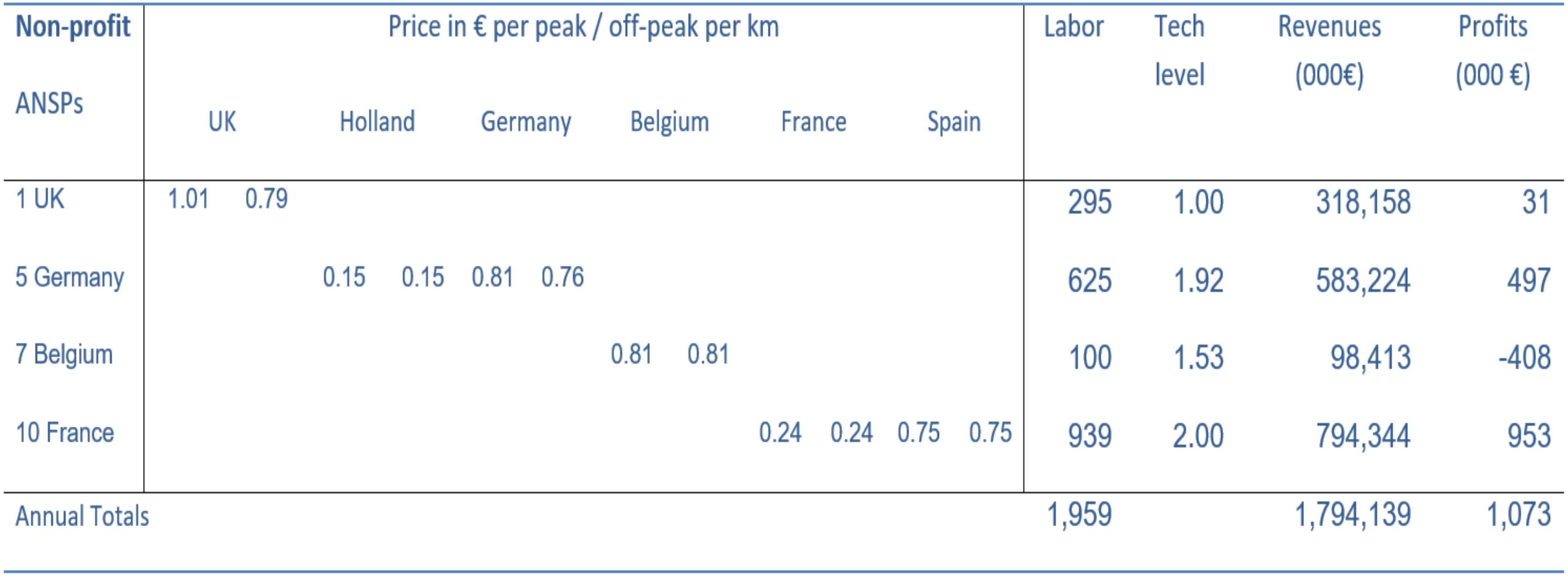
Results: with tender (2/5)
For Profit en-route providers



For-profit **2014** ANSPs	Price in € per peak / off-peak per seat per km												Labor	Tech level	Revenues (000 €)	Profits (000 €)
	UK		Holland		Germany		Belgium		France		Spain					
6. Germany			0.45	0.45	0.45	0.45							1,021	2	790,995	8,096
7. Belgium	0.32	0.32					0.49	0.49					276	2	243,748	9,242
10. France									0.29	0.29	0.43	0.43	1,219	2	999,481	44,963
Annual Totals													2,517		2,034,225	62,302

- 3 companies remain
  - Germany/Holland; UK/Belgium; France/Spain
- New technologies adopted in full
- Revenues halved compared to current equilibria outcome
- Profits around 5%

Results: with tender (3/3)
Non-profit en-route providers



Non-profit ANSPs	Price in € per peak / off-peak per km						Labor	Tech level	Revenues (000€)	Profits (000 €)
	UK	Holland	Germany	Belgium	France	Spain				
1 UK	1.01 0.79						295	1.00	318,158	31
5 Germany		0.15 0.15	0.81 0.76				625	1.92	583,224	497
7 Belgium				0.81 0.81			100	1.53	98,413	-408
10 France					0.24 0.24	0.75 0.75	939	2.00	794,344	953
Annual Totals							1,959		1,794,139	1,073

- 4 companies survive
  - UK; Germany/Holland; Belgium; France/Spain
- Charges
  - external regions more expensive, competitive regions cheaper than for-profit outcome
  - but overall revenues lower and not sustainable in longer term
- Mixed pattern of technology adoption & fewer controllers than for-profit (i.e. lower capacity)

General conclusions

- Modeling ATC via 2-stage game enables cost-benefit analysis including distributional effects across stakeholders
- Single European Skies Initiative:
  - Lower costs
    - defragmentation via FABS
    - price regulation
  - Increased capacity
    - SESAR
- How to achieve these goals? auction ATC provision en-route
  - similar to that of airport terminal provision in Spain, Sweden, UK…
  - leads to defragmentation of European airspace
    - around 5 companies will survive if market share cap of 20%
  - charges as much as halved
    - potentially removes need for price regulation

Specific Conclusions

- Auction Rules:
  - Very important: multiple bidders
  - Pressures on capacity thus need to set minimum levels
  - Should permit charges to increase/decrease as function of service levels
- Regulation:
  - Safety regulators (EASA, NSA…) need to continue
  - Data collection (STATFOR) would need to continue to check capacity levels
  - Economic regulator (PRB) may be less necessary
- Ownership form:
  - For Profits: most effective solution
  - Non-Profits: provides a solution between current equilibria outcome and for-profit potential solution