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A Pricing Versus Slots Game in Airport Networks (Work in Progress)

Achim I. Czerny, Hong Kong Polytechnic University
Hao Lang, Hong Kong Polytechnic University

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Department of LOGISTICS & MARITIME STUDIES 物流及航運學系

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Acknowledgements

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A Pricing versus Slots Game

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Achim Czerny
Hong Kong Polytechnic University - Faculty of Business

Hao Lang
The Hong Kong Polytechnic University

Date Written: October 11, 2017

Abstract

We consider a three-city network of complementary airports, where local governments independently choose between pricing and slots policies to manage own congestion. Governments may value airport profits or attach a zero value to airport profits. Pricing policies are weakly dominant strategies in the first case, while slots are weakly dominant strategies in the second case. To compare pricing and slot policies we develop the notion of "inverse slot quantities" which represent the airport charges that would have to be used to implement a given slot quantity. We show that the equilibrium prices in the case of congestion pricing can be written as the sum of the equilibrium inverse slot quantities plus a weighted markup depending on the price elasticities of passenger demands. We further show that this means that the equilibrium prices are too high in the case of congestion pricing and that the equilibrium inverse slot quantities are too low both relative to the first-best prices. Numerical instances indicate that pricing policies are beneficial from the aggregate economy's viewpoint when time valuations are high, while slot policies are beneficial from this viewpoint when time valuations are low.

Keywords: Airports; slots; congestion pricing; local governments; dominant strategies

JEL Classification: L93; R41; R48

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Introduction

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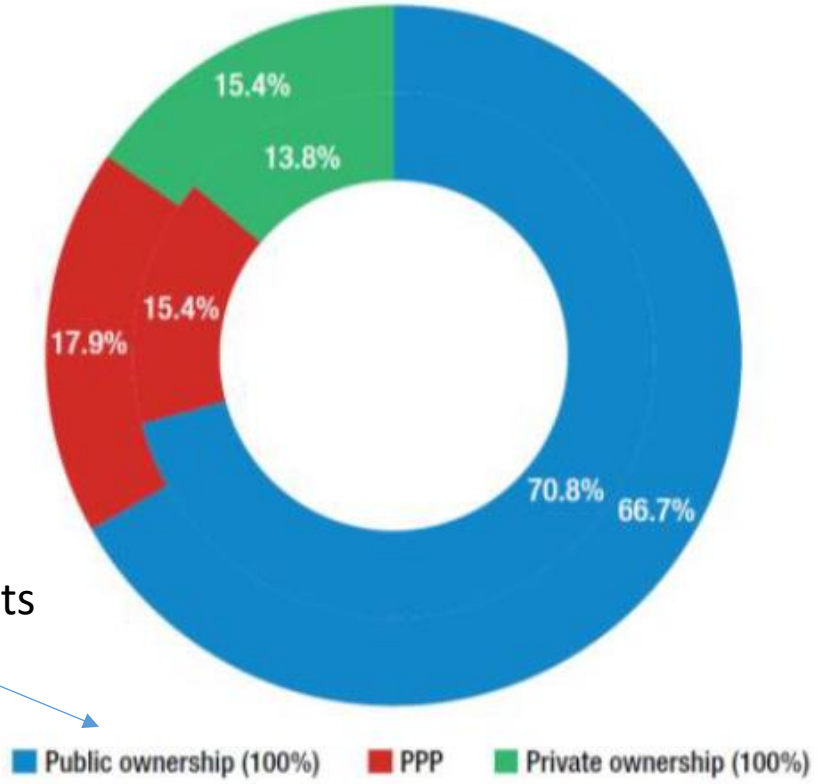
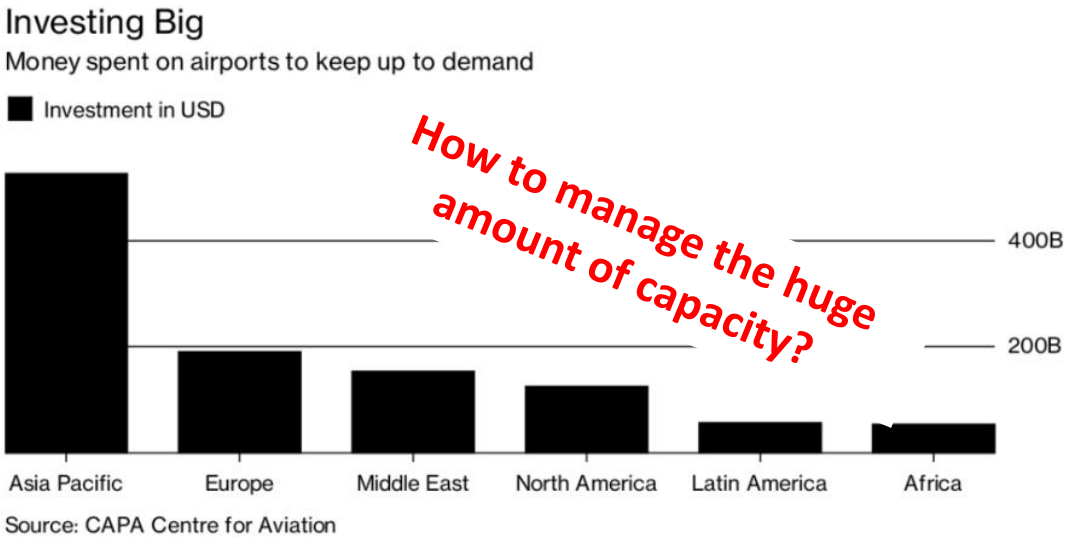
Graph 12: Proportion of airports (inside) and corresponding passenger traffic (outside) by ownership model (2013)



Regional governments involved!

***Source*: ACI** *(ACI Airport Economics Survey – 2014)*

quickly. It's hard to say the transfer market is going to be always yours."



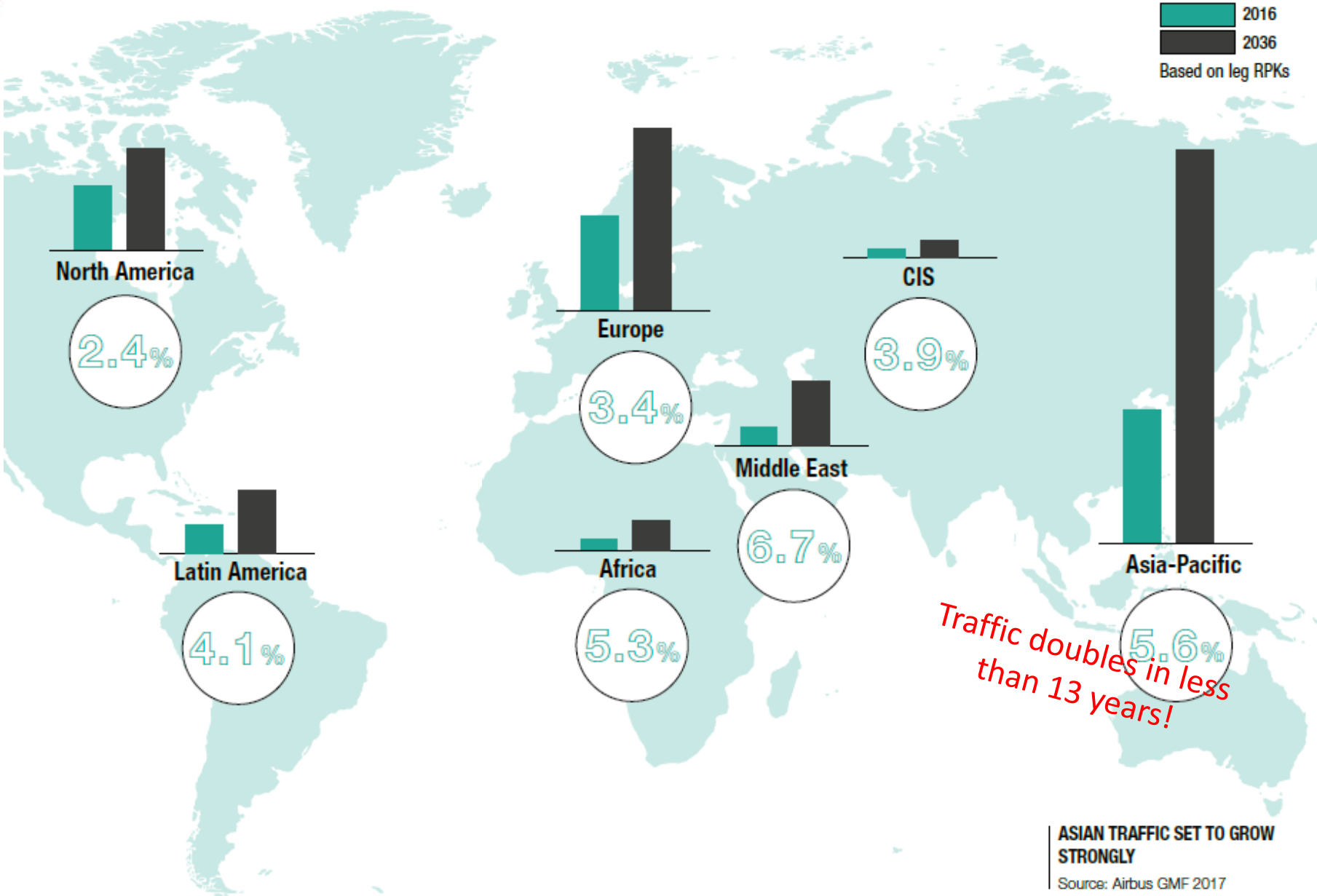
CAPA Centre for Aviation

In China, mainland carriers such as China Southern Airlines Co. are carrying so many first-time flyers each year that aviation authorities plan to create a mega-airport cluster almost within sight of Hong Kong. China Southern, Hainan Airlines Holding Co. and Chengdu Airlines Co. have opened new routes from second- and third-tier Chinese cities that go straight to the U.S. and Europe, bypassing Hong Kong.

"They have the potential to redraw the travel flows," Korn Ferry's Karlsson said.

China Southern, one of the nation's three largest state-run carriers, wants to turn its home base at Guangzhou Baiyun International Airport — less than 150 kilometers (94 miles) from Hong Kong — into China's primary transfer hub to Australia and Southeast Asia, it said in May.

Even closer to Hong Kong, the Civil Aviation Administration of China aims to build a



ASIAN TRAFFIC SET TO GROW STRONGLY

Source: Airbus GMF 2017

3

	A	B	C	D	E	F	G	H	I	J	
313	North Asia	Chinese Taipei	Taipei	TPE	3	3	3	service@aptcoord.org.tw		www.aptcoord.org.tw	
314	North Asia	Hong Kong (SAR), China	Hong Kong	HKG	3	3	3	hkgslot@cad.gov.hk		www.hkgslot.gov.hk	
315	North Asia	Macau (SAR), China	Macau	MFM	2	2	2	mfmslot@ada.com.mo			
316	**North Asia Level 2 Total**				2	2	2				
317	**North Asia Level 3 Total**				23	23	23				
318											
319	The Americas	Bermuda	Bermuda	BDA	2	2	2	rwithers@skyport.bm			
320	The Americas	Brazil	Aeroporto Internacional	BSB	2	2	2	slot@inframerica.aero	http://www2.anac.gov.br/slot/	www.anac.gov.br	
321	The Americas	Brazil	Aeroporto Internacional	VCP	2	2	2	slot@viracopos.com	http://www2.anac.gov.br/slot/	www.anac.gov.br	
322	The Americas	Brazil	Aeroporto Internacional	CNF	2	2	2	slot@bh-airport.com.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	
323	The Americas	Brazil	Belem	BEL	3	3		slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	Temporary level 3
324	The Americas	Brazil	Cuiaba	CGB	3	3		slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	Temporary level 3
325	The Americas	Brazil	Curitiba	CWB	3	3		slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	Temporary level 3
326	The Americas	Brazil	Florianopolis	FLN	3	3		slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	Temporary level 3
327	The Americas	Brazil	Fortaleza	FOR	3	3		slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	Temporary level 3
328	The Americas	Brazil	Foz do Iguacu	IGU	3	3		slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	Temporary level 3
329	The Americas	Brazil	Goiania	GYN	3	3		slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	Temporary level 3
330	The Americas	Brazil	Maceio	MCZ	3	3		slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	Temporary level 3
331	The Americas	Brazil	Manaus	MAO	3	3		slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	Temporary level 3
332	The Americas	Brazil	Porto Alegre	POA	3	3		slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	Temporary level 3
333	The Americas	Brazil	Recife	REC	3	3		slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	Temporary level 3
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335	The Americas	Brazil	Rio de Janeiro	SDU	3	3	3	slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	
336	The Americas	Brazil	Salvador	SSA	3	3		slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	Temporary level 3
337	The Americas	Brazil	Sao Paulo	GRU	3	3	3	slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	
338	The Americas	Brazil	Sao Paulo	CGH	3	3	3	slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	
339	The Americas	Brazil	Pampulha	PLU	3	3	3	slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	
340	The Americas	Brazil	Vitoria	VIX	3	3		slot@anac.gov.br	http://www2.anac.gov.br/slot/	www.anac.gov.br	Temporary level 3
341	The Americas	Canada	Calgary	YYC	2	2	2	yycflightschedule@yyc.com		www.calgaryairport.com	
342	The Americas	Canada	Montreal	YUL	2	2	2	horairedevol@admtl.com		www.admtl.com	
343	The Americas	Canada	Quebec	YQB	2	2	2	opsYQB@yqb.ca		www.aeroportdequebec.com	
344	The Americas	Canada	Toronto	YYZ	3	3	3	slots@gtaa.com; YXZTMCR@sita.amsmail.com			
345	The Americas	Canada	Vancouver	YVR	3	3	3	slot_coordination@yvr.ca			
346	The Americas	Colombia	Bogota	BOG	3	3	3	slot.fmu@aerocivil.gov.co			
347	The Americas	Colombia	Rionegro	MDE		3	3	slot.fmu@aerocivil.gov.co			Temporary level 3
348	The Americas	Cuba	Havana	HAV	3	3	3	slots@ecasa.avianet.cu			
349	The Americas	Cuba	Holguin	HOG	2	2	2	slots@ecasa.avianet.cu			
350	The Americas	Cuba	Santa Clara	SNU	2	2	2	slots@ecasa.avianet.cu			
351	The Americas	Cuba	Varadero	VRA	3	3	3	slots@ecasa.avianet.cu			
352	The Americas	Greenland	Ilulissat Airport	JAV	3	3	3	scr@airportcoordination.com		www.airportcoordination.com	
353	The Americas	Greenland	Kangerlussuaq Airport	SFJ	3	3	3	scr@airportcoordination.com		www.airportcoordination.com	
354	The Americas	Greenland	Nuuk Airport	GOH	3	3	3	scr@airportcoordination.com		www.airportcoordination.com	
355	The Americas	Mexico	Mexico City	MEX	3	3	3	lcalderon@aicm.com.mx			
356	The Americas	Turks & Caicos Islands	Providenciales Internatio	PLS	2	2	2	lavernskippings@tciairports.com		www.tciairports.com	
357	The Americas	United States	Chicago-O' Hare	ORD	2	2	2	FAA : 7-awa-slotadmin@faa.gov Gate Coordination: plark@igcinc.org			
358	The Americas	United States	Los Angeles	LAX	2	2	2	FAA : 7-awa-slotadmin@faa.gov Gate Coordination: laxiata@lawa.org			
359	The Americas	United States	New York-J.F. Kennedy	JFK	3	3	3	FAA : 7-awa-slotadmin@faa.gov Port Authority : JFKslots@panynj.gov			◦ Level 3 for runway
360	The Americas	United States	Newark	EWR	2	2	2	FAA: 7-awa-slotadmin@faa.gov Gate Facilitation: ewrslots@panynj.gov Port Authority: ewrslots@panynj.gov			
361	The Americas	United States	Orlando	MCO	2	2	2	MCOSchedules@goaa.org		www.orlandoairports.net	◦ Level 2 for internal
362	The Americas	United States	San Francisco	SFO	2	2	2	FAA : 7-awa-slotadmin@faa.gov Gate Coordination: scheduling@sfotec.com			
363	The Americas	United States	Seattle-Tacom Internati	SEA	2	2	2	SEAschedules@portseattle.org		www.portseattle.org	◦ Level 2 for internal
364	**The Americas Level 2 Total**				17	17	17				

System Operations Services

- ATO International
- Flight Service
- Performance Analysis
- ATO Security
- **Surface Operations**
- NAS Operations

FAA Home ▸ Offices ▸ Air Traffic Organization ▸ Service Units ▸ System Operations Services ▸ Surface Operations

Slot Administration

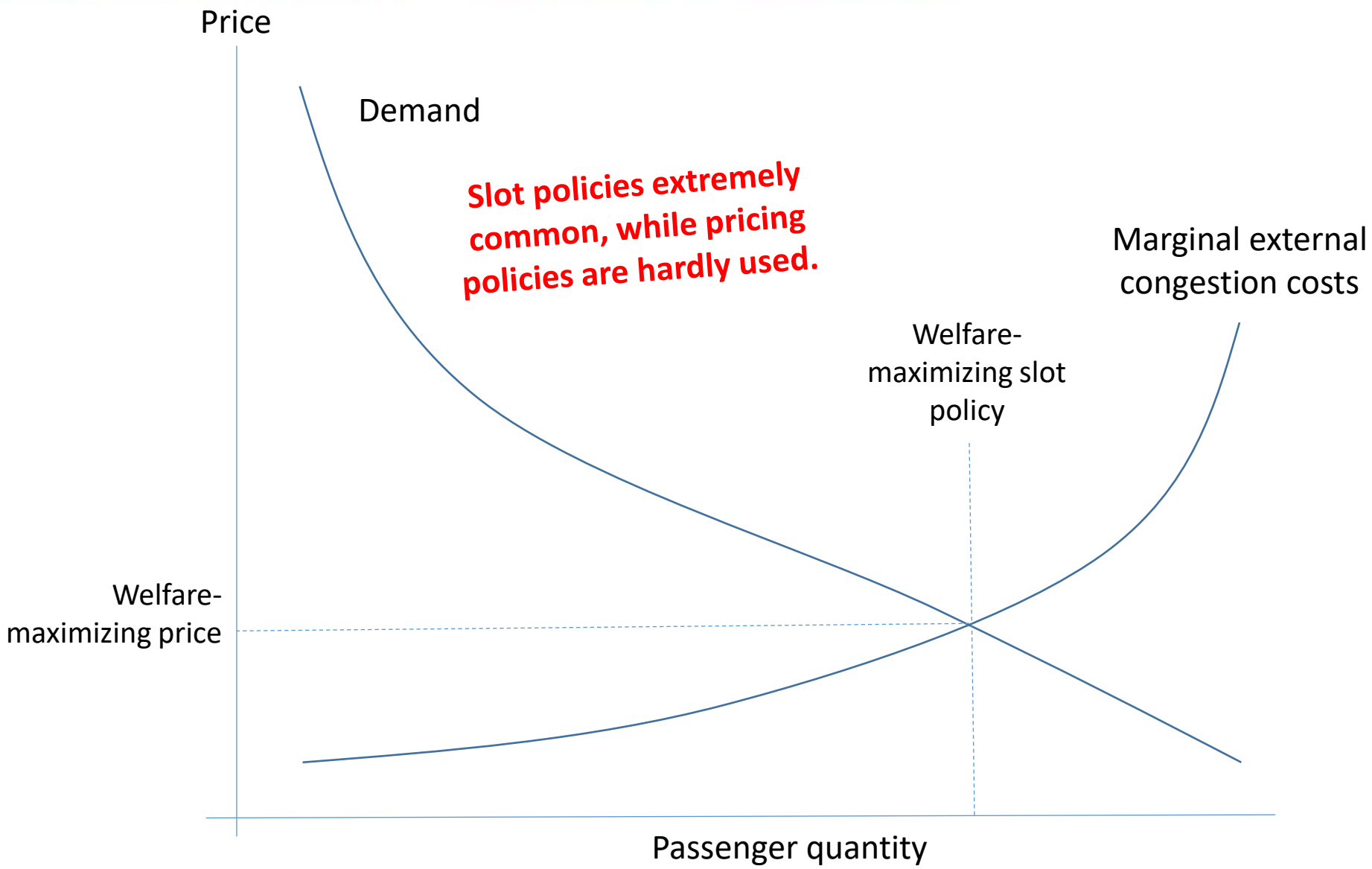
The Federal Aviation Administration (FAA) uses runway slots to limit scheduled air traffic at certain capacity constrained airports. In the U.S., those airports are John F. Kennedy International Airport (JFK) and LaGuardia Airport (LGA) in New York, and Ronald Reagan National Airport (DCA) in Virginia, outside Washington D.C. In addition, the FAA monitors scheduled air traffic demand at other airports and has a formal schedule review and approval process at several airports. Those airports are Chicago O'Hare International Airport (ORD), Los Angeles International Airport (LAX), Newark Liberty International Airport (EWR), and San Francisco International Airport (SFO).

At EWR, JFK, LAX, ORD, and SFO, the FAA generally follows the International Air Transport Association (IATA) Worldwide Slot Guides (WSG) to the extent they do not conflict with U.S. laws, rules, or procedures. See the current IATA Calendar of Coordination (PDF). [1]

Carriers may contact the Slot Administration Office in the Air Traffic Organization at the FAA for more information about operations at slot-controlled or schedule-facilitated airports: 7-awa-slotadmin@faa.gov.

What is a slot?

In the context of airport coordination, a slot is an authorization to either take-off or


Price
Demand
Slot policies extremely common, while pricing policies are hardly used.
Marginal external congestion costs
Welfare-maximizing slot policy
Welfare-maximizing price
Passenger quantity

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Literature

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Literature on Price vs Quantity Controls (Sample)

No network effects!
No distributional effects!

Environment

- Weitzman (1974): Prices vs. quantities.
- Stavins (1996): Correlated uncertainty.
- Brenck and Czerny (2002): Multiplicative errors.

Congestion

- Czerny (2008, 2010): Airports and uncertainty.
- Brueckner (2009): Airports and market power.
- Basso and Zhang (2010): Airport cost recovery.
- De Palma and Lindsey (2017): Additive, multiplicative errors among other things.

Market power

- Czerny (2007): Price vs. quantity standards.
- Basso, Figueroa, Vasquez (2017): Mechanism design.

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Grandfathering!

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What is a slot?

In the context of airport coordination, a slot is an authorization to either take-off or

Oman breaks Heathrow record with deal for slots

Dominic O'Connell and John Collingridge

February 14 2016, 12:01am,
The Sunday Times

Prices soar: Heathrow slots are in demand from the US to the Gulf (Daniel Nicholson)

OMAN AIR has set a record by paying $75m for a pair of take-off and landing slots at Heathrow.

The tiny Gulf carrier is understood to have bought the pair — which includes a highly prized early morning arrival — from Air France-KLM. The price beats the $60m (£40m) paid by American Airlines for a slot a year ago, bought from the Scandinavian carrier SAS.

Air France also sold a slot for a lower price to Emirates, giving the Gulf airline six

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Basic Model

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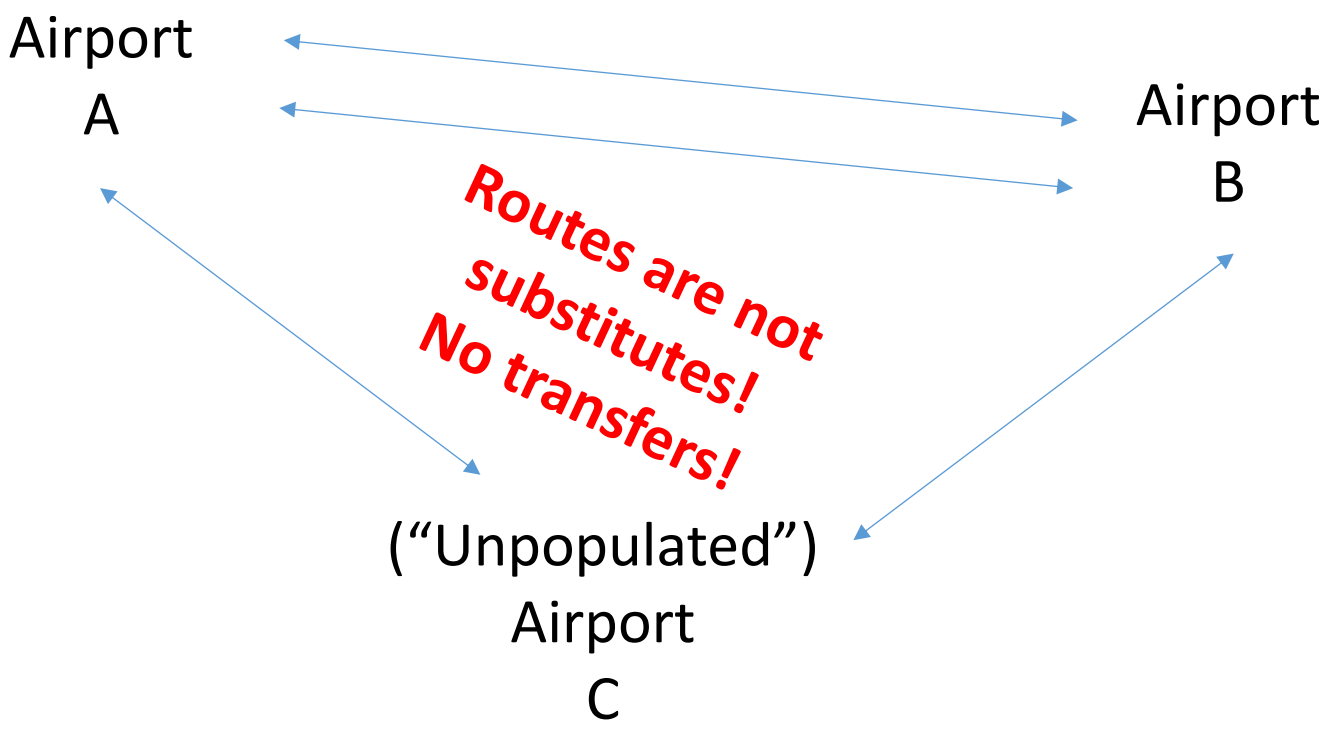
Airport Network



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Equilibrium Policies

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Consumer Surplus

$$CS_i(q_{ij}, q_{iC}, r_A(\phi_A), r_B(\phi_B), \phi_A, \phi_B)$$

$$= B_i(q_{ij}, q_{iC}) - q_{ij} \cdot (R_A(r_A(\phi_A), \phi_A) + R_B(r_B(\phi_B), \phi_B)) - q_{iC} \cdot R_i(r_i(\phi_i), \phi_i). \quad (1)$$

Can be written as:

$$CS_i(q_{ij}, q_{iC}, r_i(S), r_j(\phi_j), S, \phi_j) = CS_i(q_{ij}, q_{iC}, r_i(P), r_j(\phi_j), P, \phi_j) + (q_{ij} + q_{iC}) \cdot r_i(P). \quad (2)$$

Profit

$$\pi_i(Q_i, r_i(\phi_i), \phi_i) = Q_i \cdot R_i(r_i(\phi_i), \phi_i), \quad (3)$$

Welfare

$$W_i(q_{ij}, q_{iC}, q_{ji}, r_i(P), r_j(\phi_j), P, \phi_j) = W_i(q_{ij}, q_{iC}, q_{ji}, r_i(S), r_j(\phi_j), S, \phi_j) + q_{ji} \cdot r_i(P), \quad (5)$$

Equilibrium policies in terms of policy variables ϕ_i can be summarized as:

Proposition 1 *If airport profits do not matter, slot policies $\phi_A = \phi_B = S$ form an equilibrium in (weakly) dominant strategies, while pricing policies $\phi_A = \phi_B = P$ form an equilibrium in (weakly) dominant strategies if airport profits matter. Whether the policy choices in terms of the policy variables ϕ_i are determined by dominant or weakly dominant strategies depends on whether $r_i(P) > 0$ or $r_i(P) = 0$, respectively.*

This justifies the consideration of both pricing and slot policies!

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Equilibrium Prices vs Quantities (No Congestion)

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Demands

Total demand

$$D_i(r_A, r_B) = D_{AB}(r_A, r_B) + D_{BA}(r_A, r_B) + D_{iC}(r_i), \tag{8}$$

with

Lemma 1 *Demands are decreasing in airport prices r_i in the sense that*

$$(i)\ \frac{\partial D_{ij}(r_A, r_B)}{\partial r_i} = \frac{\partial D_{ij}(r_A, r_B)}{\partial r_j} < 0 \ \text{and}\ (ii)\ \frac{\partial D_{iC}(r_i)}{\partial r_i} < \frac{\partial D_{jC}(r_j)}{\partial r_i} = 0. \tag{7}$$

No congestion!

Inverse Slot Quantities

Inverse slot quantities $r_i(S)$ are implicitly determined by

$$\overline{Q}_i - D_i(r_A(S), r_B(S)) = 0. \tag{9}$$

Applying Cramer's rule to the system of equations in (9) yields:

Lemma 2 *(i) There is a unique pair of inverse slot quantities matched with each pair of slot quantities. (ii) Inverse slot quantities are decreasing in own slot quantities $\overline{Q}_i$ and increasing in the other airport's slot quantities:*

$$\frac{\partial r_i(S)}{\partial \overline{Q}_i} = \frac{\partial D_j / \partial rj}{\Phi(r_A, r_B)} < 0 < \frac{\partial r_j(S)}{\partial \overline{Q}_i} = -\frac{\partial D_j / \partial r_i}{\Phi(r_A, r_B)} < \left| \frac{\partial r_i(S)}{\partial \overline{Q}_i} \right| \tag{10}$$

with

$$\Phi(r_A, r_B) = \frac{\partial D_A}{\partial r_A}\frac{\partial D_B}{\partial r_B} - \frac{\partial D_B}{\partial r_A}\frac{\partial D_A}{\partial r_B} > 0. \tag{11}$$

Instrument and Distribution Effects

To formally separate distribution and instrument effects, a third policy regime indicated by $\phi_i = SP$ is introduced. This regime involves the choice of inverse slot quantities, thus, prices when airport revenues are zero by assumption. The total welfare effect of a move from pricing to slot policies is given by the difference $W_i(S) - W_i(P)$. Adding and deducting welfares when airports use inverse slot quantities as the decision variables given by $W_i(SP)$ leads to,

$$W_i(S) - W_i(P) = \underbrace{W_i(S) - W_i(SP)}_{= \text{instrument effect}} + \underbrace{W_i(SP) - W_i(P)}_{= \text{distribution effect}}, \tag{9}$$

which shows that the total change in equilibrium welfare can be written as the sum of the instrument and distribution effects.

Equilibrium Slots

First-order condition for best responses in terms of slots:

$$\left(r_j(S) \cdot \frac{\partial D_{ij}}{\partial r_i} + r_i(S) \cdot \frac{\partial \left(D_{ij} + D_{iC} \right)}{\partial r_i} \right) \cdot \frac{\partial r_i(S)}{\partial \overline{Q}_i} = 0. \tag{13}$$

Implying:

Proposition 2 *If airport profits do not matter, the unique equilibrium implies that inverse slot quantities are equal to first-best prices independent of whether slot quantities or inverse slot quantities are considered as instruments.*

Corollary 2 *If airport profits do not matter, the instrument effect is zero, that is,* $W_i(S) - W_i(SP) = 0$.

Equilibrium Prices

First-order condition for best responses in terms of prices implies:

$$r_i(P) = -\frac{D_{ji}}{\partial D_i / \partial r_i} \tag{15}$$

Implying:

Proposition 3 *If airport profits matter, the unique pricing equilibrium implies that airport charges strictly exceed first-best prices.*

There may be a prisoner's dilemma situation, which depends on the level of asymmetry between airports!

Corollary 4 *If airport profits matter, the distribution effect is strictly positive, that is,* $W_i(SP) - W_i(P) > 0$.

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Congestion

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Model Extensions

Total congestion costs of own customers:

$$TC_i(q_{ij}, q_{iC}, Q_A, Q_B) = v\left(q_{ij}\left(C_A(Q_A) + C_B(Q_B)\right) + q_{iC}C_i(Q_i)\right).$$

This implies:

$$CS_i = B_i - q_{ij}\left(R_A(r_A(\phi_A), \phi_A) + R_B(r_B(\phi_B), \phi_B)\right) - q_{iC}R_i(r_i(\phi_i), \phi_i) - TC_i \tag{17}$$

$$W_i = B_i + q_{ji}R_i(r_i(\phi_i), \phi_i) - q_{ij}R_j(r_j(\phi_j), \phi_j) - TC_i. \tag{18}$$

Lemma 3 *In the presence of congestion and under symmetry, a marginal increase in price r_i changes demands as follows:*

$$(i)\ \frac{\partial D_{ji}}{\partial r_i} = \frac{\partial D_{ij}}{\partial r_i} < 0 \quad and \quad (ii)\ \frac{\partial D_{iC}}{\partial r_i} < 0 < \frac{\partial D_{jC}}{\partial r_i} < \left|\frac{\partial D_{iC}}{\partial r_i}\right|. \tag{21}$$

Congestion!

Equilibrium Slots

First-order condition for best responses in terms of slots:

$$r_i(S)\left(\frac{\partial D_i}{\partial r_i}\frac{\partial r_i}{\partial \overline{Q}_i}+\frac{\partial D_i}{\partial r_j}\frac{\partial r_j}{\partial \overline{Q}_i}\right)-\left(D_{ij}+D_{iC}\right)vC_i'=0. \tag{23}$$

Implying:

$$r_i(S)=\left(D_{ij}+D_{iC}\right)vC_i', \tag{25}$$

And:

Proposition 5 *If airport profits do not matter and in the case of networks of symmetric congested airports, the unique equilibrium in slot quantities implies that airports imperfectly internalize the marginal external congestion costs, $D_i vC_i'$, relative to first-best prices.*

Equilibrium "Inverse Slots"

First-order condition for best responses in terms of "inverse slots" imply:

$$r_i(SP) = \left(D_{ij} \cdot \frac{\frac{\partial (D_i + D_j)}{\partial r_i}}{\frac{\partial D_i}{\partial r_i}} + D_{iC} \right) vC_i' \tag{31}$$

And:

Proposition 6 *If airport profits do not matter and in the case of networks of symmetric congested airports, the unique equilibrium in inverse slot quantities implies that airports imperfectly internalize the marginal external congestion costs, $D_i vC_i'$, relative to first-best prices although internalization is stronger than in the case where slot quantities are considered as instruments.*

Equilibrium Prices

First-order condition for best responses in terms of prices implies:

$$r_i(P) = r_i(SP) + \left| \frac{D_{ij}}{\partial D_i / \partial r_i} \right|. \tag{43}$$

Implying that equilibrium prices strictly exceed first-best prices.

Proposition 7 *If airport profits do matter and in the case of networks of symmetric congested airports, the unique equilibrium in prices overinternalizes the marginal external congestion costs, $D_i v C_i'$, relative to first-best prices.*

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Numerical Instances

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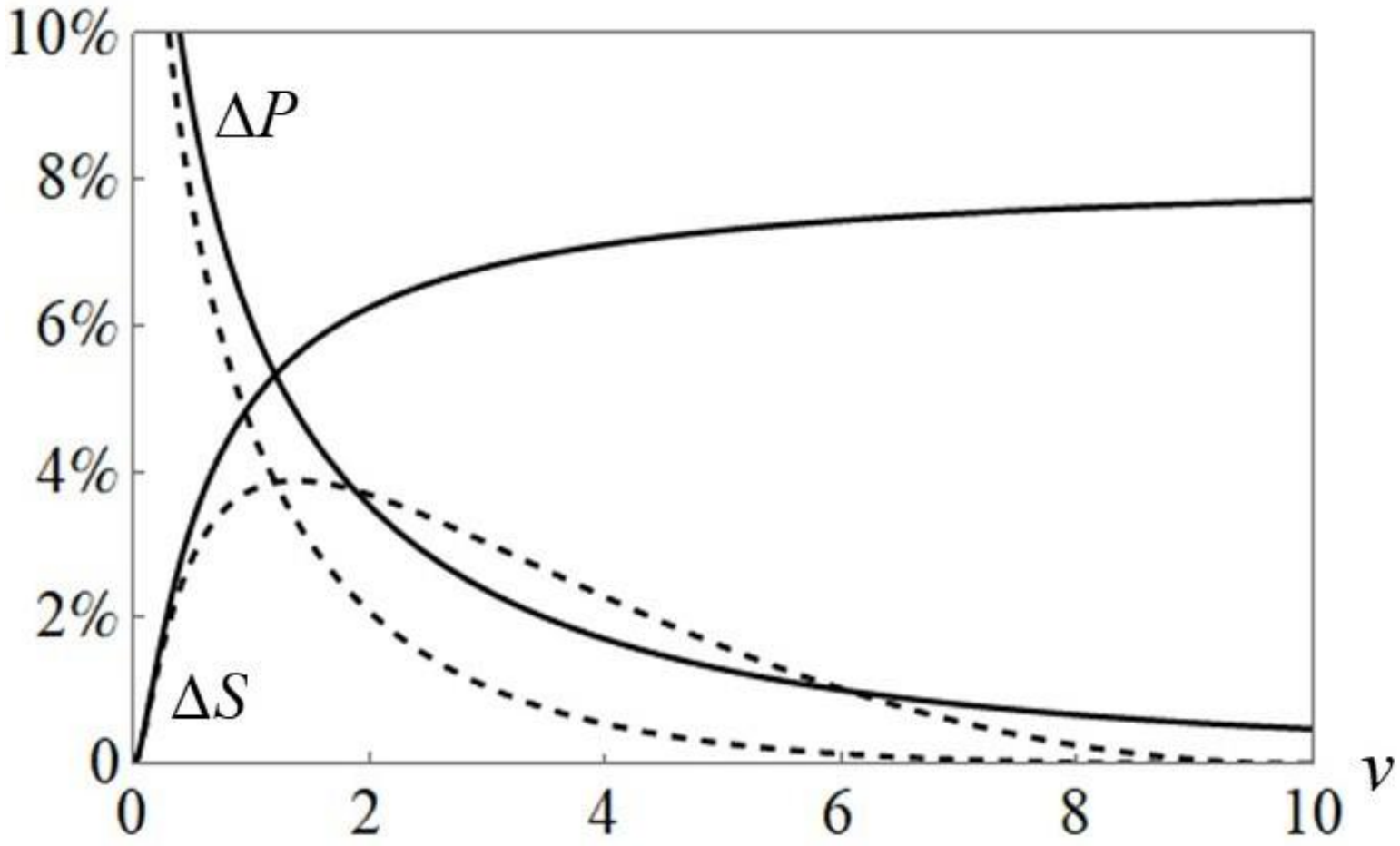
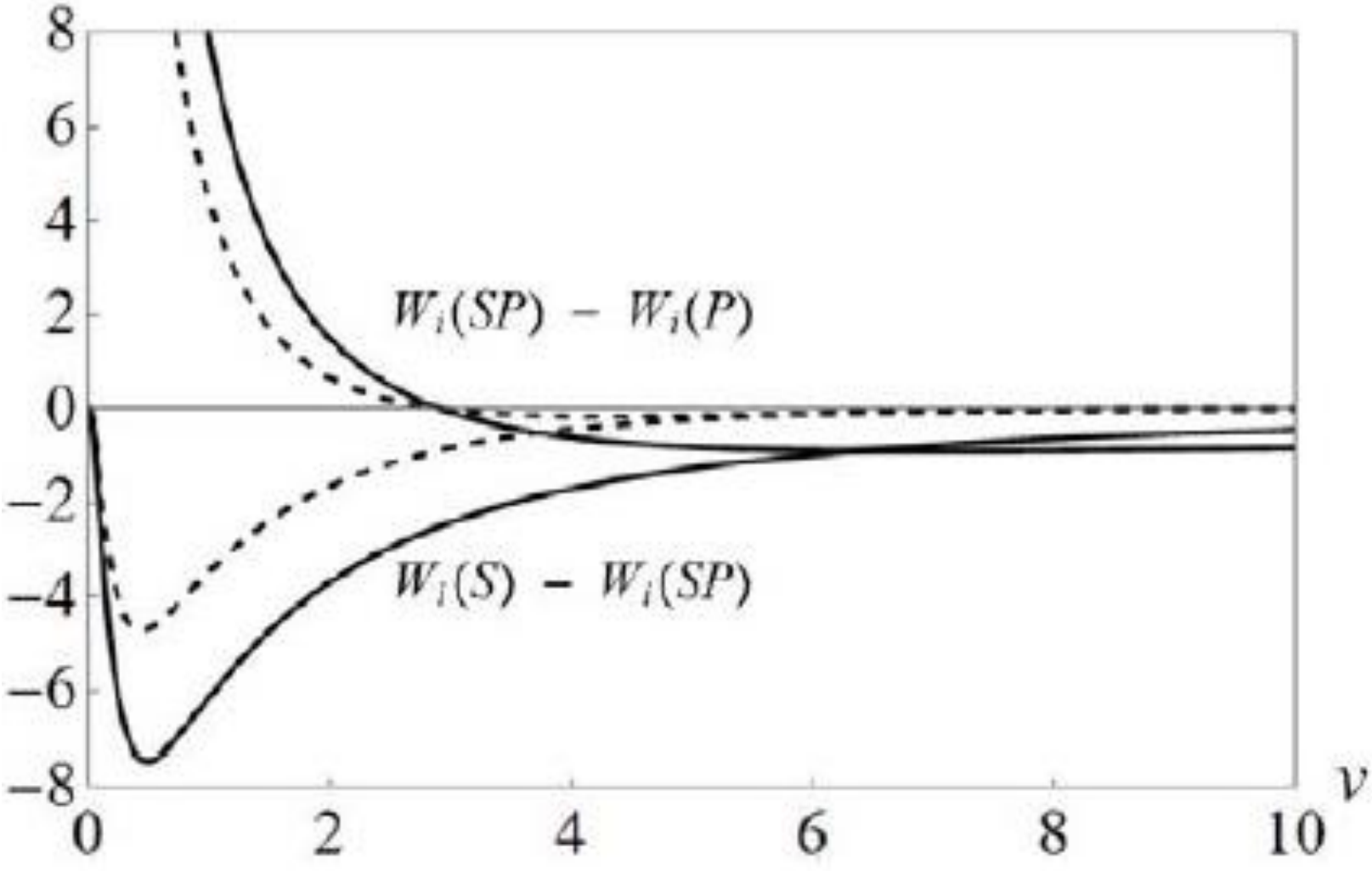
Welfare loss
relative to first-best




8
6
4
2
0
−2
−4
−6
−8
0
2
4
6
8
10
v
$W_i(SP) - W_i(P)$
$W_i(S) - W_i(SP)$

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Substitutes

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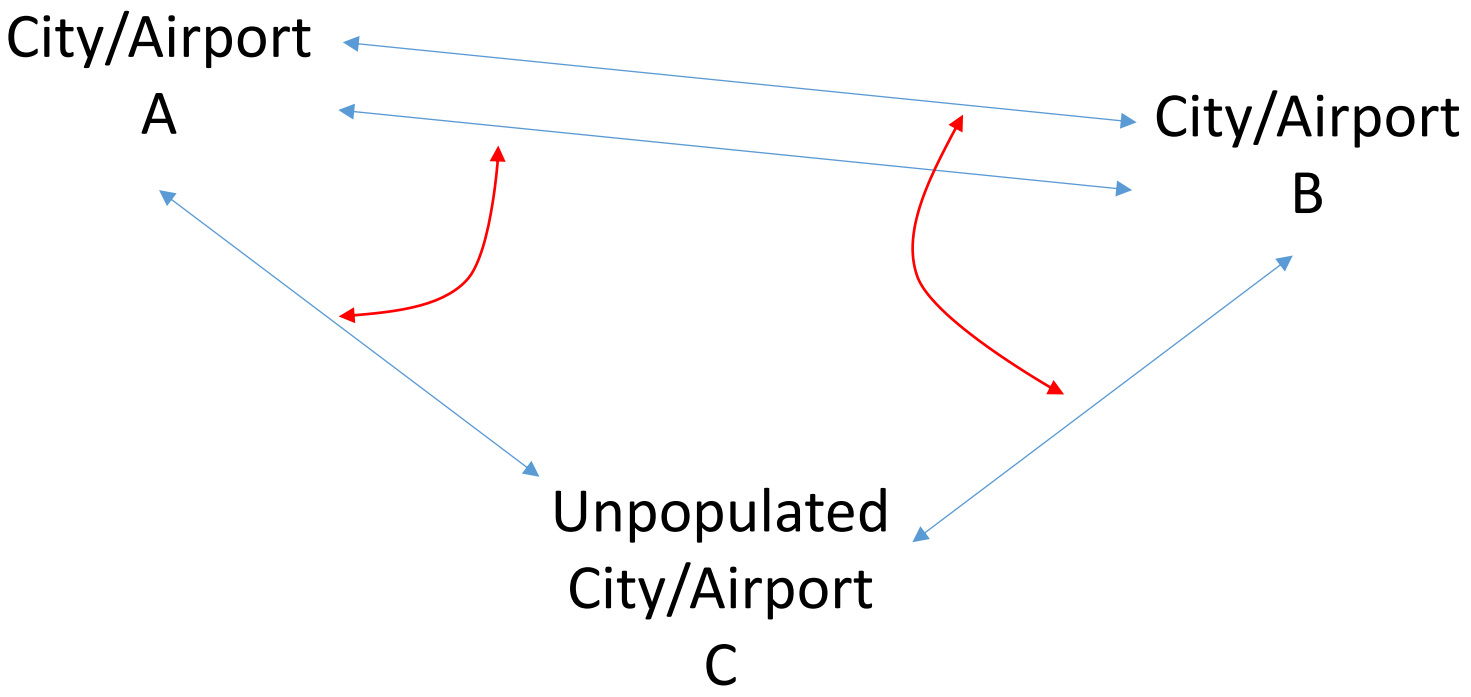
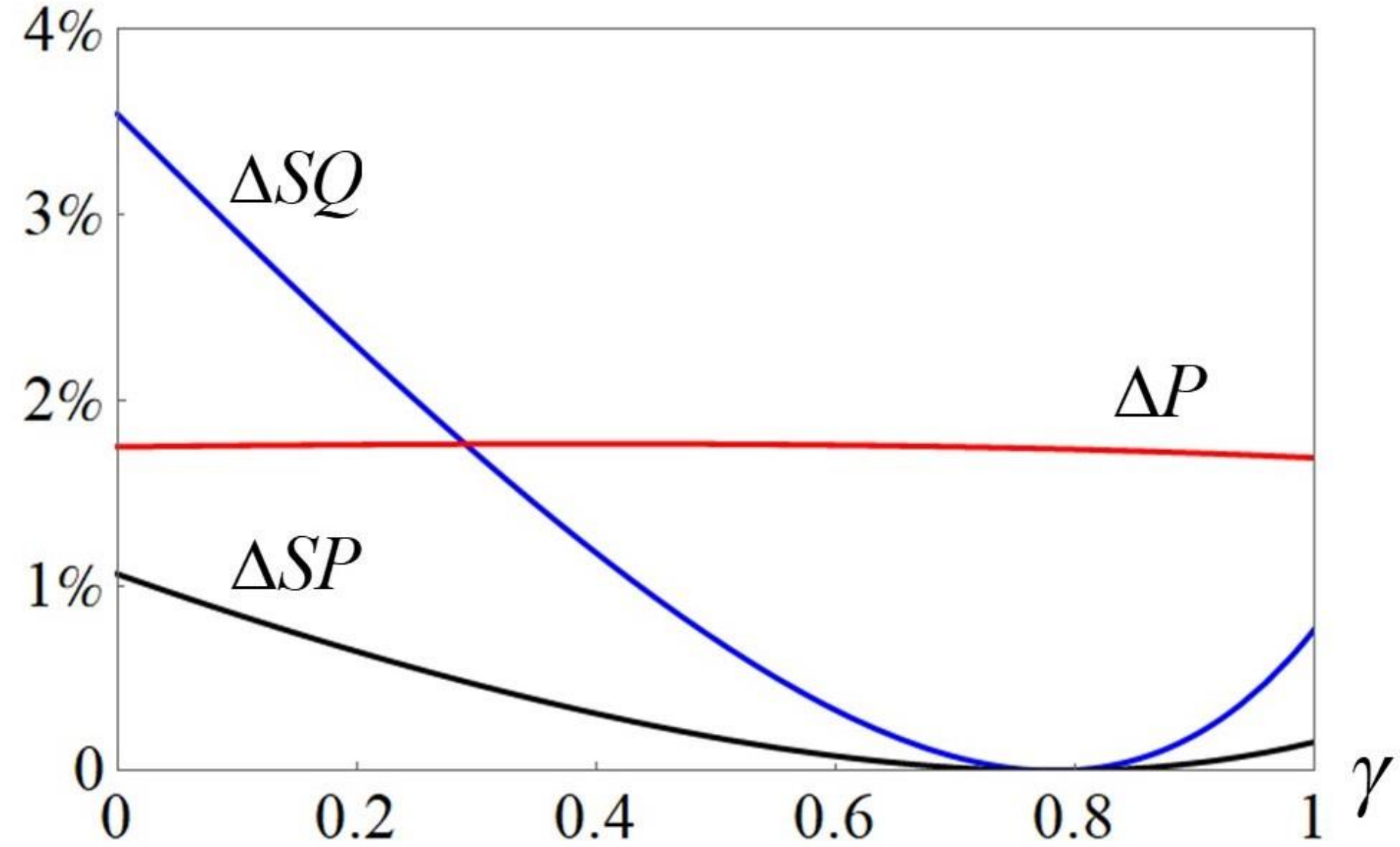
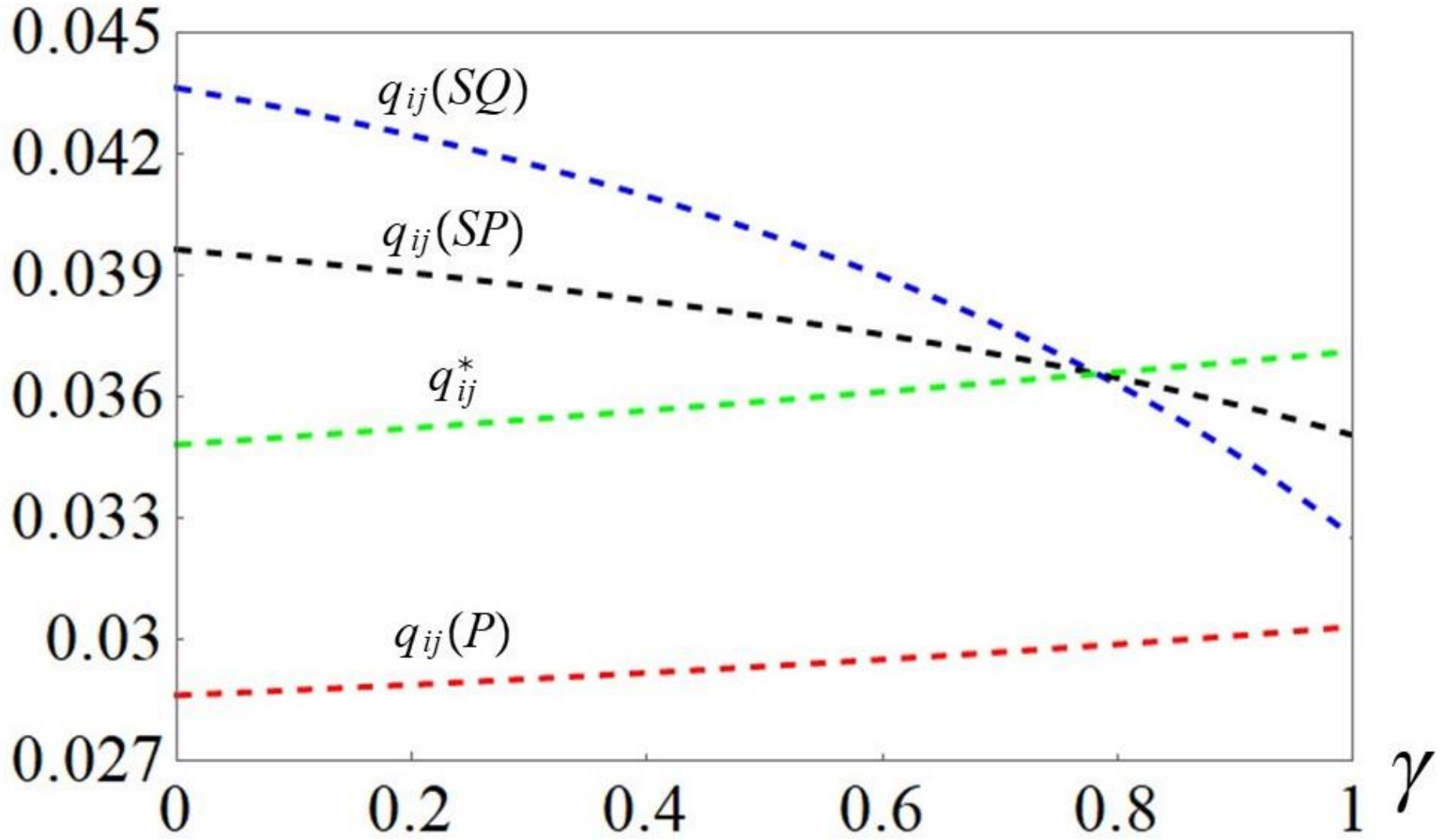
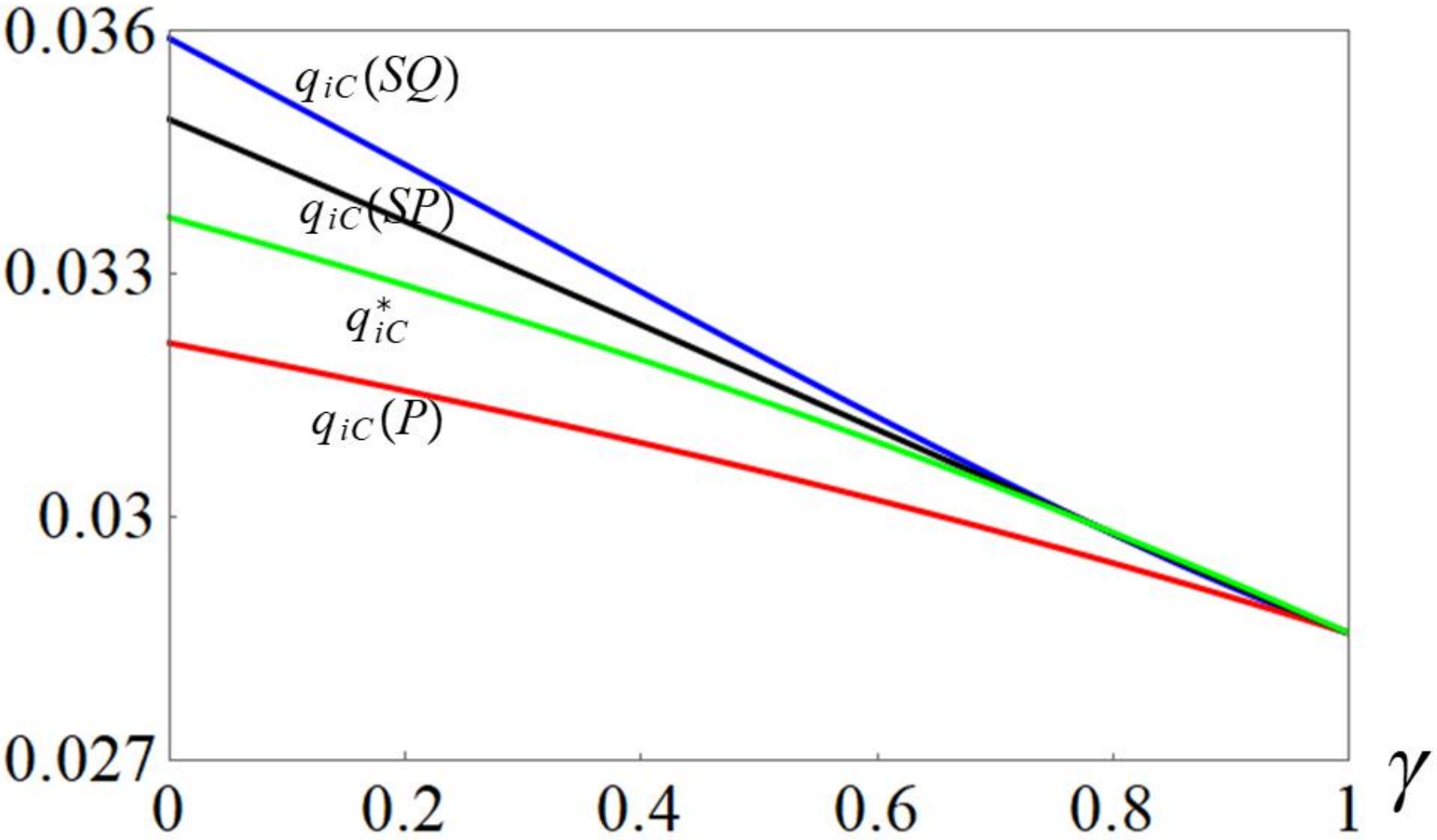
Routes Substitutes




4%
3%
2%
1%
0
ΔSQ
ΔP
ΔSP
0
0.2
0.4
0.6
0.8
1
γ

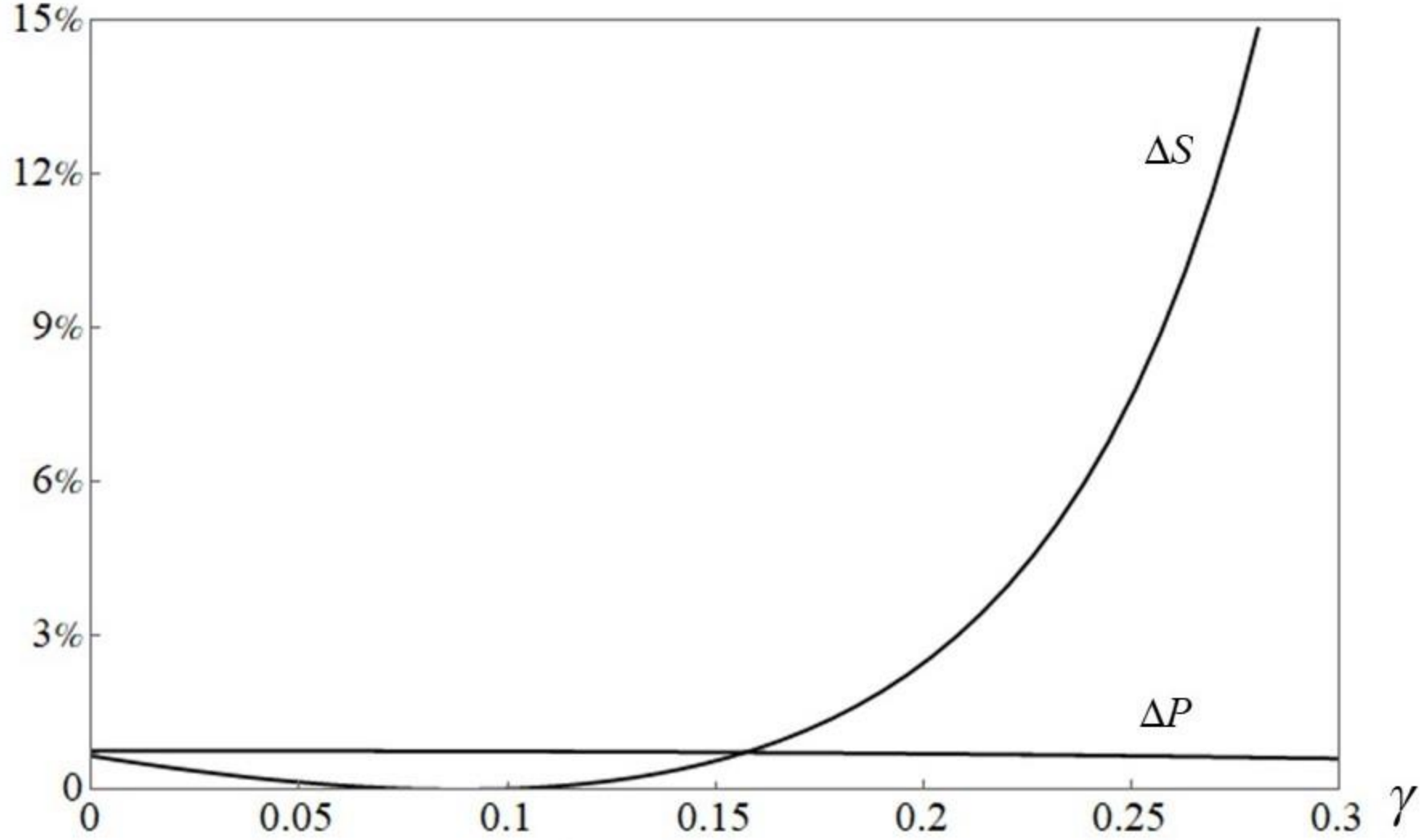

0.045
0.042
0.039
0.036
0.033
0.03
0.027
$q_{ij}(SQ)$
$q_{ij}(SP)$
q_{ij}^{*}
$q_{ij}(P)$
0
0.2
0.4
0.6
0.8
1
γ


0.036
0.033
0.03
0.027
0
0.2
0.4
0.6
0.8
1
γ
$q_{iC}(SQ)$
$q_{iC}(SP)$
q_{iC}^{*}
$q_{iC}(P)$

Conclusions

- Network effects matter
- A change from pricing to slots matters because of distributional and instrument effects, which can be separately evaluated and shown to move into the same directions when congestion is present and routes aren't substitutes (or complements)
- Demand structures matter as well (next paper…)


Vielen
Dank



$$\gamma^* = \frac{(3-\sqrt{7})}{4}$$