Scheduling in Transportation Markets

Endogeneity of Desired Arrival Times

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Empirical part joint work with
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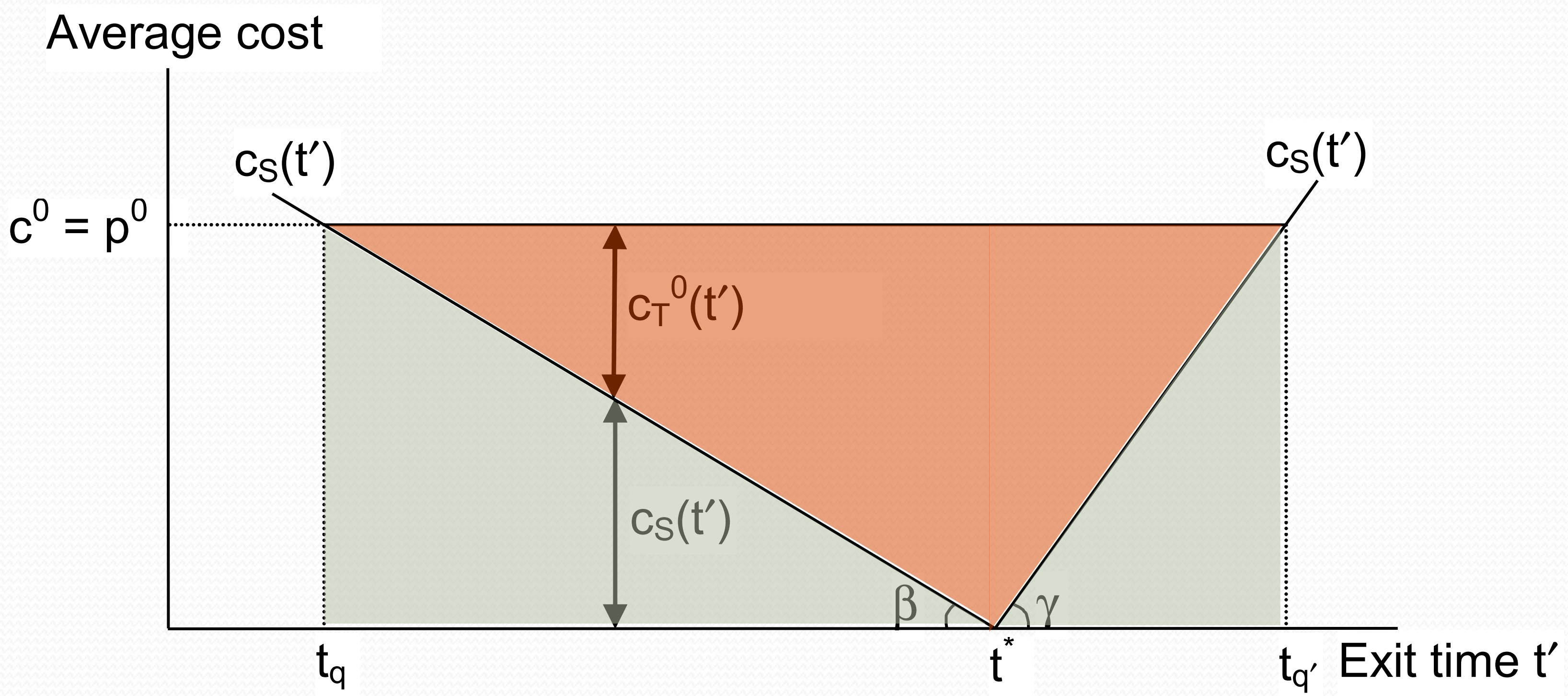
(IER, 2015)

Motivation

- VoT & VoSD: central concepts in transport research
- Good understanding of structure of consumer decision making is crucial to obtain the 'right' values
- This presentation:
  - Decompose scheduling decisions into long-run choices of routines, and short-run choices of departure times
  - Empirics
  - Theory & policy implications

Deterministic starting point

Vickrey 1968; Small 1982



SR vs LR: two dimensions

1. Different measures for preferred arrival time (PAT)
   - Long-run PAT (LRPAT): preferred arrival time if there were no congestion, ever
     - Interpretation in standard bottleneck model
   - Short-run PAT (SRPAT): preferred arrival time on a day given the expected pattern of travel times
     - Choice of 'routines' may make SRPAT deviate from LRPAT
     - With a LRPAT at 9:00, an SRPAT at 7:00, and a scheduled meeting at 7:30, an arrival time at 8:30 would bring cost of schedule delay late, not early
       - Evident: important to address in empirical modelling

SR vs LR: two dimensions

2. Different values of time, schedule delay, depending on ‘degree of permanentness’
   - A structural one-minute travel time gain (‘one-minute shift of travel time distribution’) brings more benefits *per day* than an incidental minute brings on a random day
     - € 14.5 vs € 3 in earlier paper: Tseng Knockaert Verhoef, Trans Res C 2013
     - Intuition: the former allows better exploitation through adaption of routines
   - An unanticipated schedule delay brings a greater disutility than schedule delays that are anticipated when forming routines
     - Intuition: with longer notice, there is more time to adjust the plan for that day

Empirical hypotheses

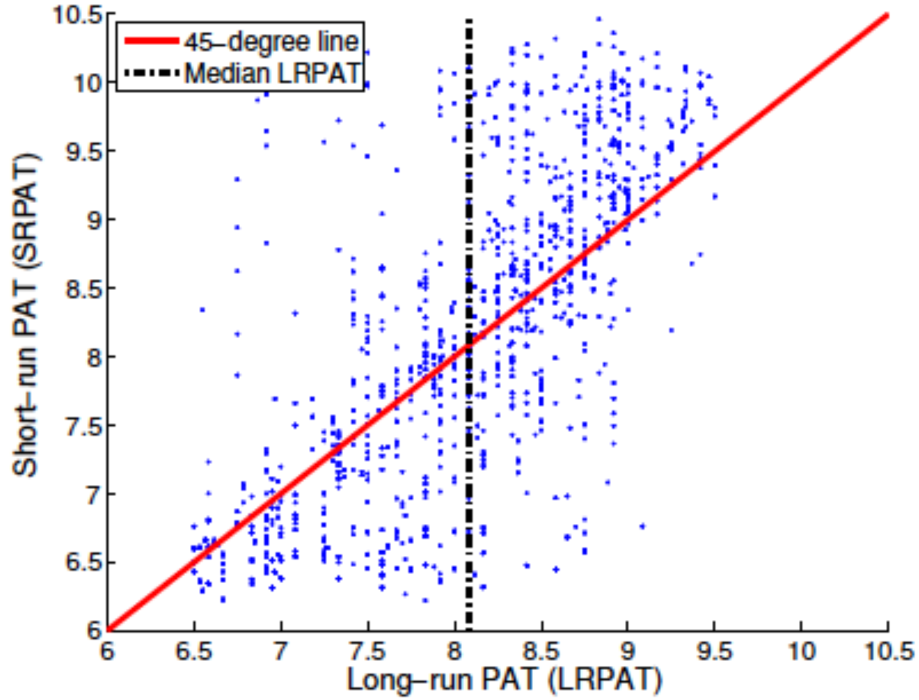
1. There is a difference in LRPAT and SRPAT
   - SRPAT can be explained from LRPAT, using measures for expected travel times and schedule delays relative to LRPAT
2. Departure time decisions are better explained using SRPAT than LRPAT
   - Specifically: a move away from SRPAT towards LRPAT *increases* schedule delay cost
3. Values of time and schedule delays vary with "degree of permanentness" of gains/losses
   - VoT: expect higher in LR than in SR choice model
   - VSD: expect lower in LR than in SR choice model

Data

- Modelling draws from SpitsMijden 2 project
  - Peak Avoidence through monetary reward stimulus
  - Some 2000 participants
  - Experiment: September – December 2009 (4 months)
  - Camera registration on A12
  - Expanded to door-to-door travel times using Geographically Weighted Regression technique (separate paper Peer *et al* 2012)
  - Questionnaire / SP study: only for LRPAT measure
    - "At what time would you like to arrive at work if there were for sure no time losses through congestion"

Relation between LRPAT and SRPAT

- Suggests a flattening of SRPAT relative to LRPAT
  - Drivers plan their routines to avoid congestion

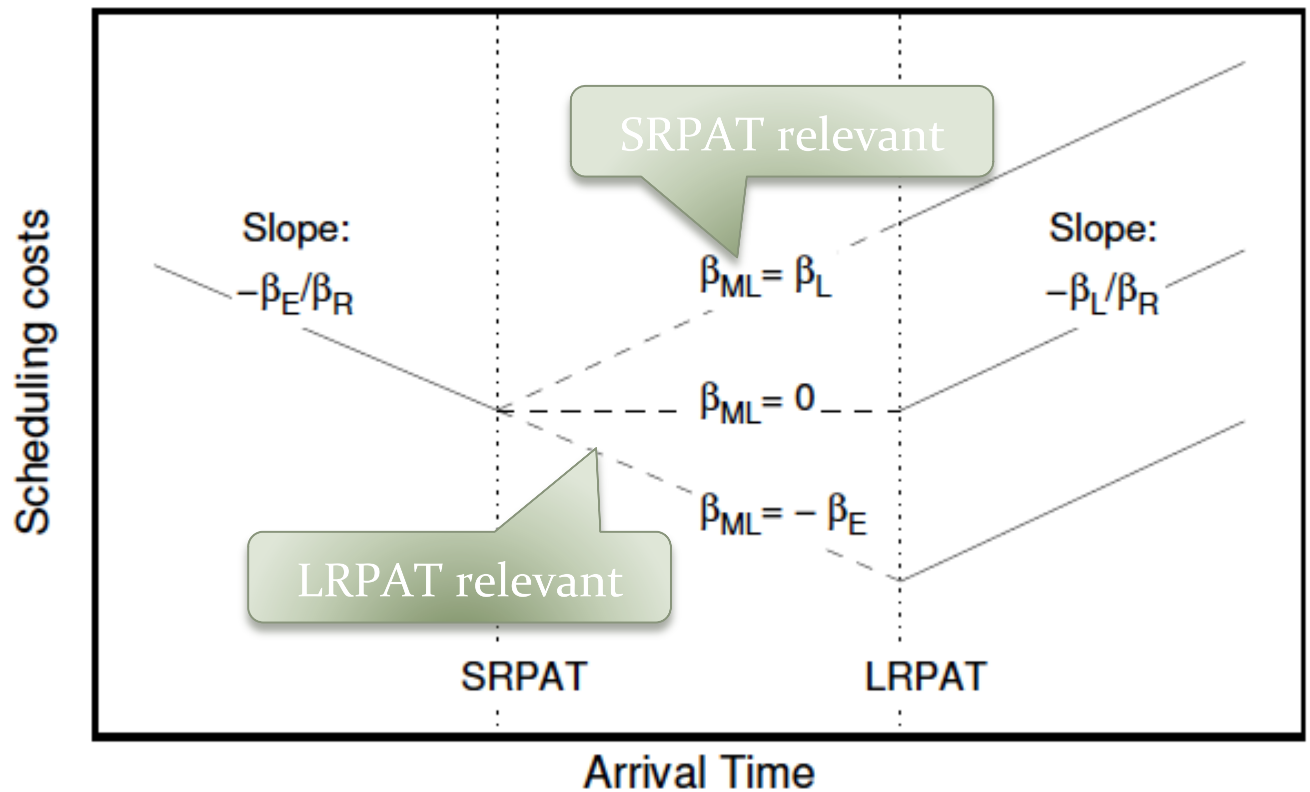


Estimation results main models

Coefficient	Long-Run Value	Long-Run t-Statistic	Short-Run Value	Short-Run t-Statistic
β_R	0.22	4.87	0.13	5.78
β_T	-6.56	-7.31	-0.69	-1.45
β_E	-2.03	-13.28	-2.89	-18.38
β_L	-1.57	-13.90	-2.70	-20.34
θ	–	–	0.43	6.25
VOT (Euro/h)	30.16		5.20	
VSDE (Euro/h)	9.34		21.62	
VSDL (Euro/h)	7.22		20.22	
Nr. Obs.	1158		5965	
LogLik.	-2681		-10550	
Pseudo R^2	0.17		0.36	

Departures anchored around SRPAT?

Figure I: Diagrammatic exposition: SRPAT $\leq$ LRPAT



Results confirm SRPAT

Coefficient	Long-Run		Short-Run		Short-run: 3 domains	
	Value	t-Statistic	Value	t-Statistic	Value	t-Statistic
β_R	0.22	4.87	0.13	5.78	0.17	6.75
β_T	-6.56	-7.31	-0.69	-1.45	-1.75	-3.09
β_E	-2.03	-13.28	-2.89	-18.38	-3.83	-14.52
β_L	-1.57	-13.90	-2.70	-20.34	-2.53	-20.80
β_{ME}	–	–	–	–	-1.45	-8.74
β_{ML}	–	–	–	–	-3.23	-9.88
θ	–	–	0.43	6.25	0.36	5.49
VOT (Euro/h)	30.16	4.14	5.20	1.31	10.56	2.55
VSDE (Euro/h)	9.34	4.70	21.62	5.47	23.16	5.90
VSDL (Euro/h)	7.22	4.72	20.22	5.52	15.27	6.22
VSDME (Euro/h)	–	–	–	–	8.76	5.22
VSDML (Euro/h)	–	–	–	–	19.54	5.57
Nr. Obs.	1158		5965		5965	
LogLik.	-2681		-10550		-10410	
Pseudo R^2	0.17		0.36		0.37	

Wrap-up

- H1: difference between LRPAT and SRPAT
  - SRPAT less clustered in time
- H2: SRPAT drives departure time decisions more strongly than LRPAT does
  - Scheduling disutility of moving away from SRPAT to LRPAT
- H3: Values of time and schedule delays vary with degree of permanentness of gains/losses
  - Travel time gains are worth more when permanent
  - Scheduling constraints more binding in the short run

Why bother?

- Implications for CBA
  - VoT for measures that bring structural time gains higher than for those that reduce incidental time losses
  - Reverse for measures that affect schedule delay costs
- Implications for pricing
  - Is a separate regulation of choice of SRPAT desirable, above that of trip timing?

Henderson-Chu model

- Alternative to Vickrey – ADL bottleneck
  - Demand-side and scheduling behaviour identical
    - "α β γ" preferences
  - Congestion technology different
    - Vickrey: kinked performance function
    - Chu: smooth performance function
      - Delay is a function of outflow
      - E.g.: power function ("BPR")
  - Both have closed-form solutions
    - Also for equilibrium (time-independent) cost *c* and price *p*

Main ingredients

- N identical travellers with "$\alpha\ \beta\ \gamma$" preferences
  - LR VoSD fraction $g<1$ of SR VoSD
  - LR VoT: relative premium of $a>0$ added to SR VoT
- SRPAT ($t^{\#}$) endogenous, LRPAT (t^{*}) identical and 0
- To avoid degenerate problem, we need variation between the days
  - Otherwise: either all $t^{\#}=t^{*}$, or each individual's $t^{\#}=t'$
  - Stochastic capacity K: $K_0>K_1$
  - Probabilities: (1-π) on state 0; π on state 1
  - On the day itself, all travellers know the realization

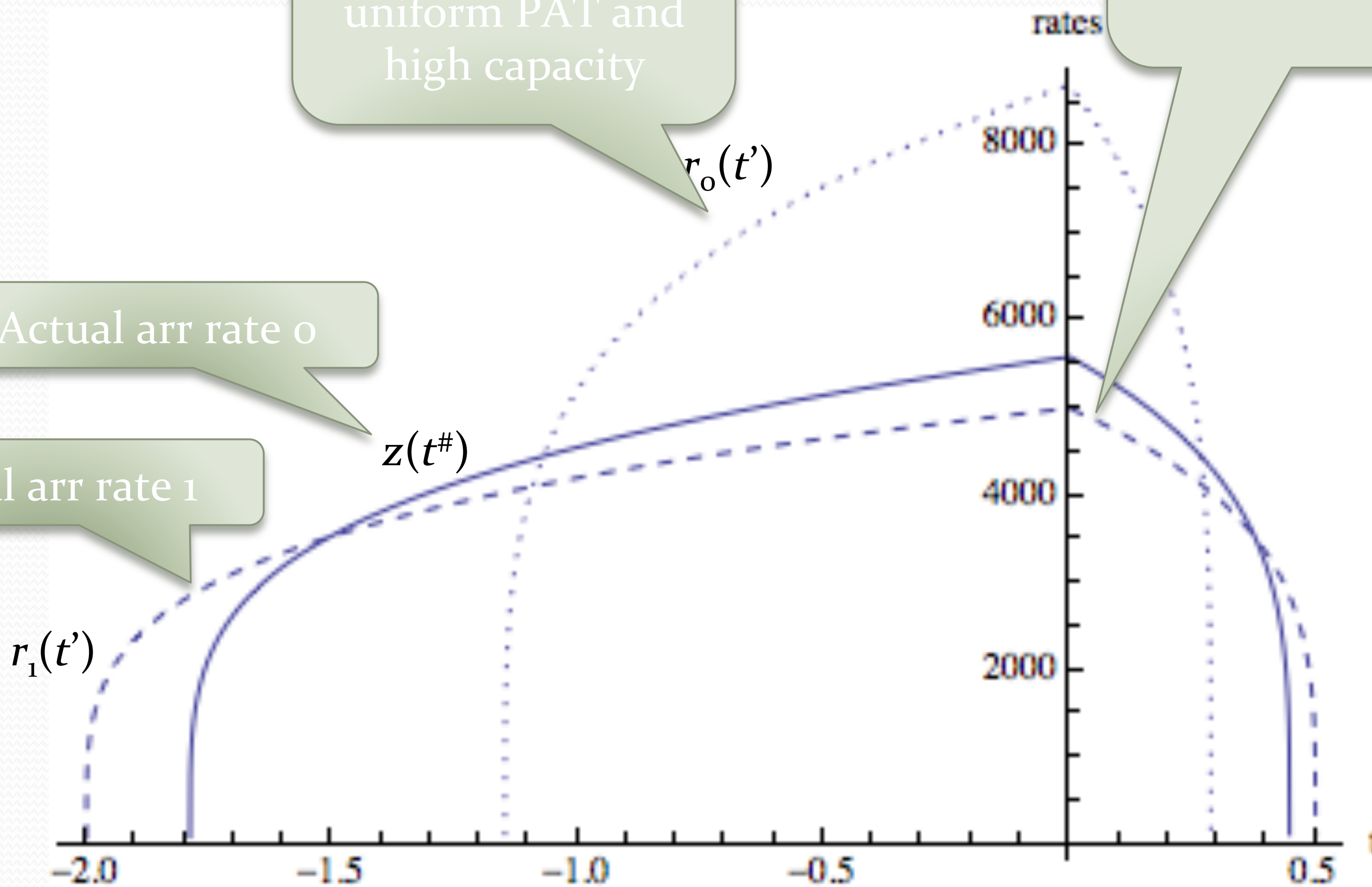
Main ingredients con'd

- BPR travel time function
  - Ignore free-flow travel time
  - Delay: $(r\,(t')/K)^{\chi}$
- Equilibria
  1. Short-run: equilibrium distribution of arrival times $r(t')$
     - ... given the distribution of desired arrival times $z(t^{\#})$ and given the realization of K
  2. Long-run: equilibrium distribution of SRPATs $z(t^{\#})$
     - ... given that short-run equilibria as above will apply

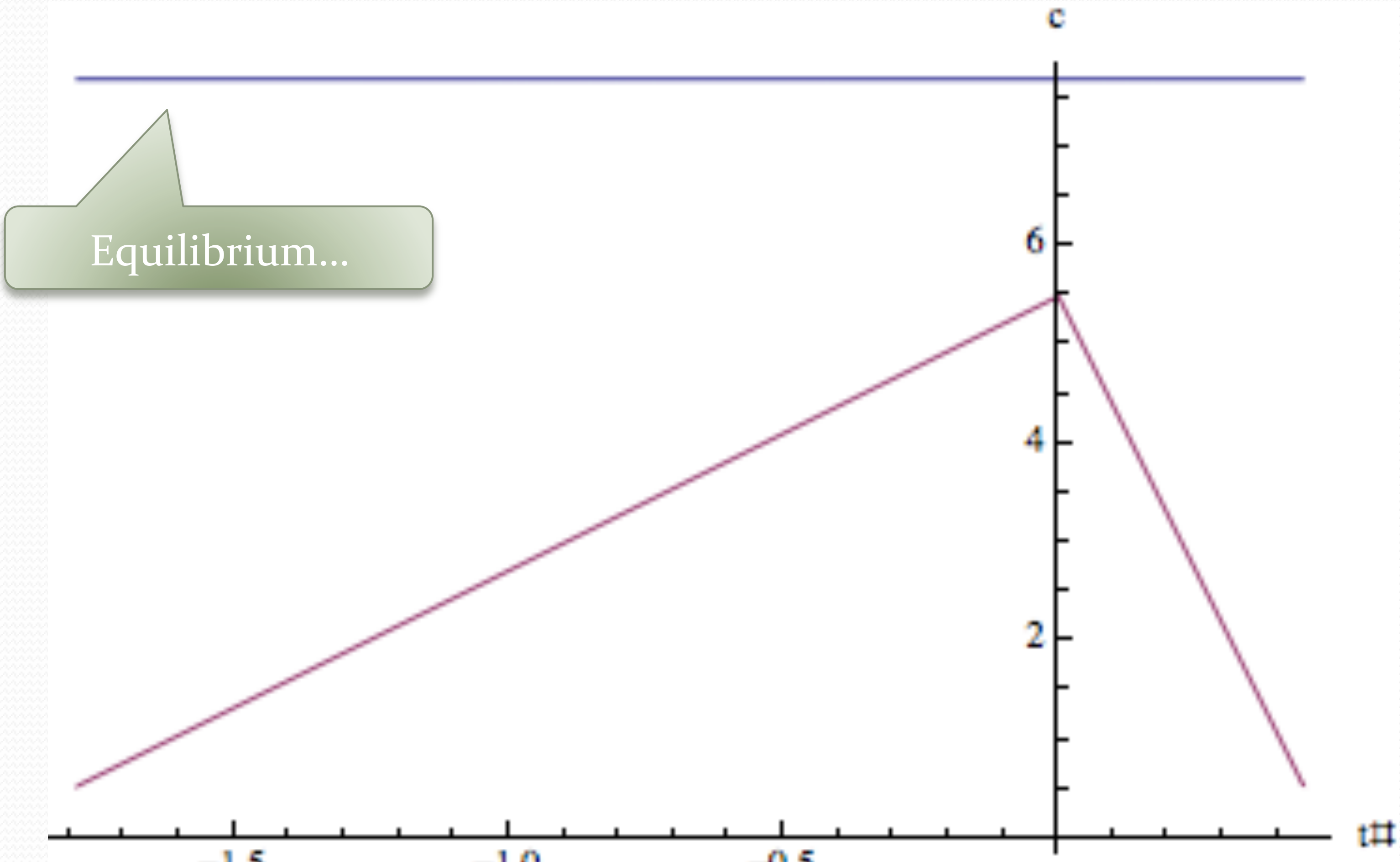
LR equilibrium

- Then there are three candidate types of LR equilibria
  - "Always Dispersed" (AD): density of $z(t^{\#})$ is chosen so low that all drivers arrive at $t^{\#}$ in both states
  - "Sometimes Dispersed" (SD): density of $z(t^{\#})$ is chosen such that all drivers arrive at $t^{\#}$ only in state 0
  - "Never Dispersed" (ND): density of $z(t^{\#})$ is chosen so high that in drivers never arrive at $t^{\#}$
    - (except for the one at t^{*})
- ND is no equilibrium: it always pays off to widen $z(t^{\#})$ to save SR SDC and accept increased LR SDC (g<1)

Example


This *would* be equilibrium with uniform PAT and high capacity
And this with low capacity
Actual arr rate 0
Actual arr rate 1
rates
$r_0(t')$
$z(t^\#)$
$r_1(t')$
8000
6000
4000
2000
−2.0
−1.5
−1.0
−0.5
0.5
t

Expected SR cost and LR cost



Are long-run tolls needed? AD

$$c^{LR}(t^{\#}) = \alpha \cdot \left(1 + a\right) \cdot \left((1-\pi) \cdot \left(\frac{z(t^{\#})}{K_0} \right)^{\chi} + \pi \cdot \left(\frac{z(t^{\#})}{K_1} \right)^{\chi} \right) + \begin{cases} -\beta \cdot g \cdot t^{\#} \\ \gamma \cdot g \cdot t^{\#} \end{cases}$$

$$p^{LR}(t^{\#}) = c^{LR}(t^{\#}) + (1-\pi) \cdot \tau_0^{SR}(t^{\#}) + \pi \cdot \tau_1^{SR}(t^{\#}) + \tau^{LR}(t^{\#})$$

$$mc^{LR}(t^{\#}) = c^{LR}(t^{\#}) + z(t^{\#}) \cdot \left(1 + a\right) \cdot \alpha \cdot \left(\left(1-\pi\right) \cdot \frac{\partial T_0(z(t^{\#}))}{\partial z(t^{\#})} + \pi \cdot \frac{\partial T_1(z(t^{\#}))}{\partial z(t^{\#})} \right)$$

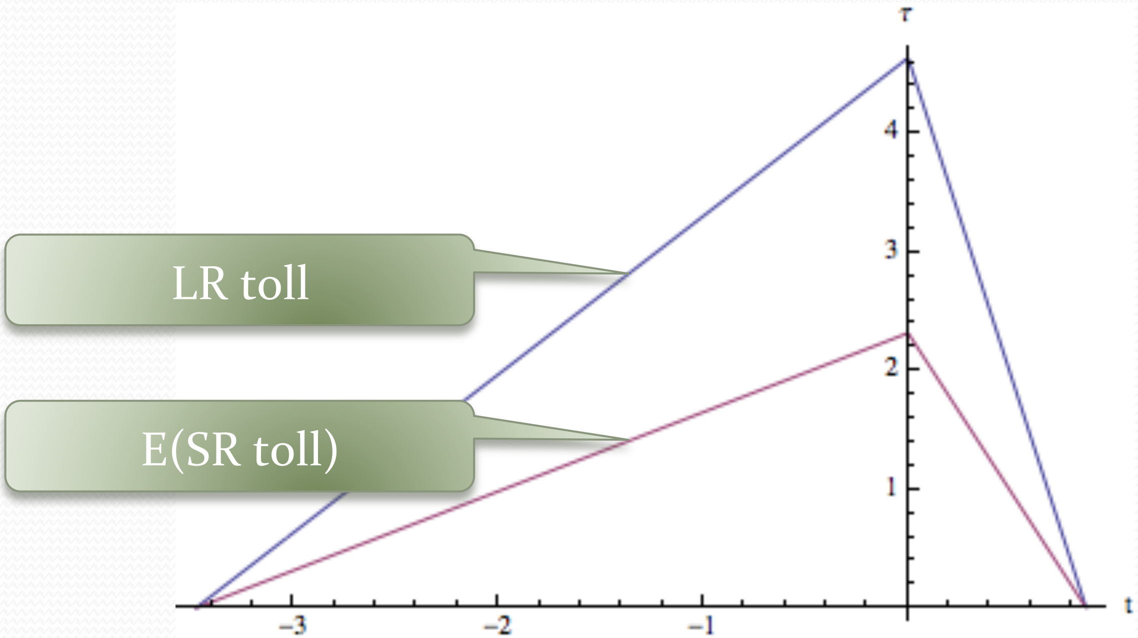
$$\tau_0^{SR}(t^{\#}) = z(t^{\#}) \cdot \alpha \cdot \frac{\partial T_0(z(t^{\#}))}{\partial z(t^{\#})} \qquad \tau_1^{SR}(t^{\#}) = z(t^{\#}) \cdot \alpha \cdot \frac{\partial T_1(z(t^{\#}))}{\partial z(t^{\#})}$$

$$\tau^{LR}(t^{\#}) = z(t^{\#}) \cdot a \cdot \alpha \cdot \left(\left(1-\pi\right) \cdot \frac{\partial T_0(z(t^{\#}))}{\partial z(t^{\#})} + \pi \cdot \frac{\partial T_1(z(t^{\#}))}{\partial z(t^{\#})} \right)$$

Intuition

- To establish short-run optimum in both states, short-run tolls must be based on short-run "α β γ"
  - Through Pigouvian form, α in particular
- But long-run expected travel times are proportional (probability-weighted) with short-run travel times
  - Same internalization argument applies
  - Must be a long-run toll in order not to distort short-run optima
- Value of long-run toll is simply a times the expected value of short-run tolls

Numerical illustration (a = 2)



- Still, modest cost reduction compared to QFB
  - QFB realizes 82% of FB cost reduction
  - Absence of LR toll makes SR tolls higher; E peaks near 4

Long-run tolls are less strongly needed in SD

$$c^{LR}(t^{\#}) = (1-\pi)\cdot\alpha\cdot(1+a)\cdot\left(\frac{z(t^{\#})}{K_0}\right)^{\chi} + \pi\cdot\left(c_1^{SR} + a\cdot\alpha\cdot\left(\frac{r_1(t'(t^{\#}))}{K_0}\right)^{\chi}\right) + \begin{cases} \beta\cdot(g-\pi)\cdot -t^{\#} \\ \gamma\cdot(g-\pi)\cdot t^{\#} \end{cases}$$

$$p^{LR}(t^{\#}) = \tau^{LR} + (1-\pi)\cdot\left(\tau_0^{SR} + \alpha\cdot(1+a)\cdot\left(\frac{z(t^{\#})}{K_0}\right)^{\chi}\right) + \pi\cdot\left(p_1^{SR} + a\cdot\alpha\cdot\left(\frac{r_1(t'(t^{\#}))}{K_0}\right)^{\chi}\right) + \begin{cases} \beta\cdot(g-\pi)\cdot -t^{\#} \\ \gamma\cdot(g-\pi)\cdot t^{\#} \end{cases}$$

$$p^{LR}(t^{\#}) - mc^{LR}(t^{\#}) = \tau^{LR} + (1-\pi)\cdot\left(\tau_0^{SR} - (1+a)\cdot\alpha\cdot\frac{\partial T_0(z(t^{\#}))}{\partial z(t^{\#})}\right) + \pi\cdot\left(p_1^{SR} - mc_1^{SR} + a\cdot\alpha\cdot T_1(t'(t^{\#}))\right)$$

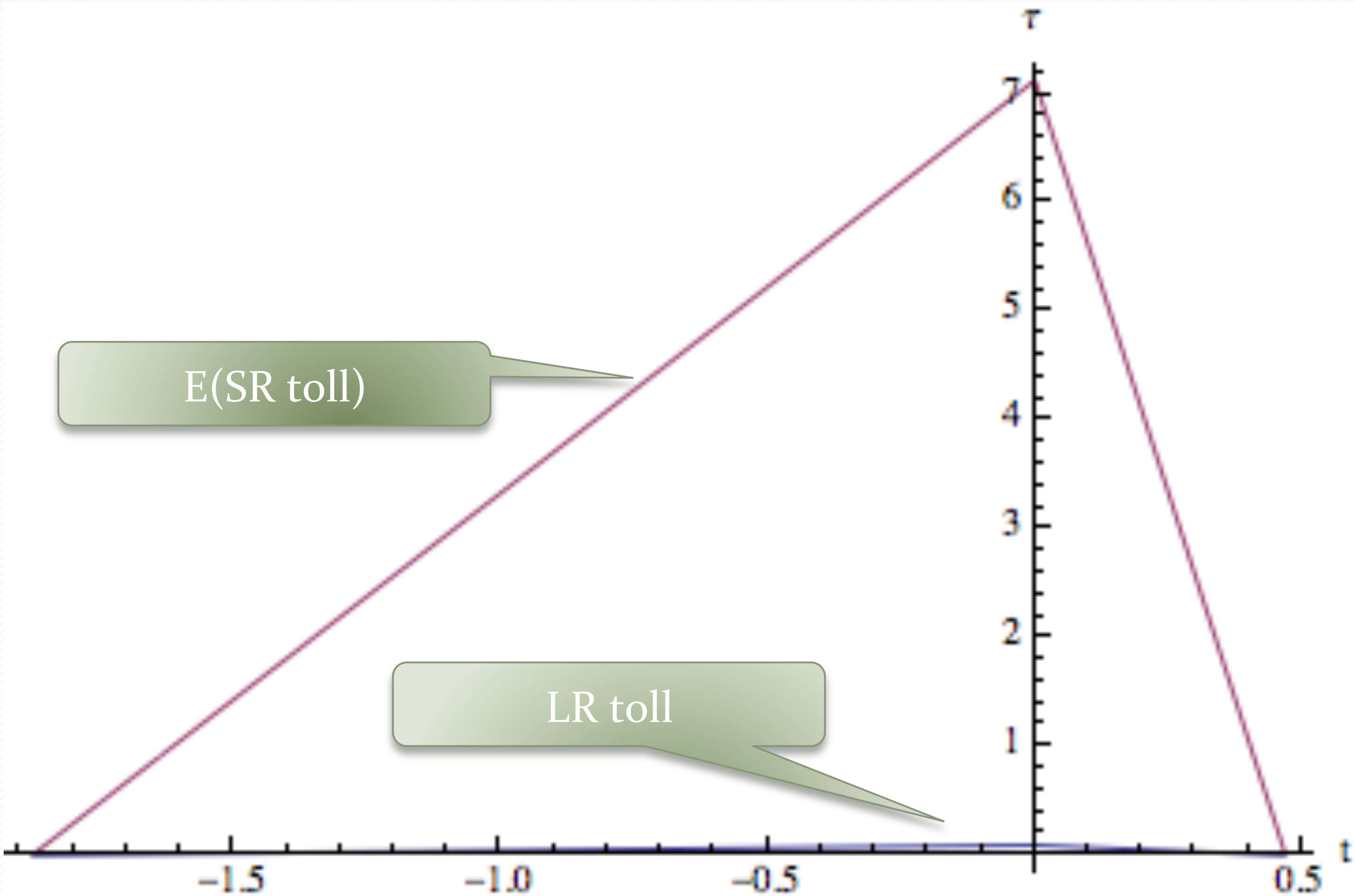
$$\tau_0^{SR}(t^{\#}) = z(t^{\#})\cdot\alpha\cdot\frac{\partial T_0(z(t^{\#}))}{\partial z(t^{\#})} \qquad \tau_1^{SR}(t') = r_1(t')\cdot\alpha\cdot\frac{\partial T_1(r_1(t'))}{\partial r_1(t')}$$

$$\tau^{LR}(t^{\#}) = (1-\pi)\cdot z(t^{\#})\cdot a\cdot\alpha\cdot\frac{\partial T_0(z(t^{\#}))}{\partial z(t^{\#})} - \pi\cdot a\cdot\alpha\cdot T_1(t'(t^{\#}))$$

Intuition

- For state 0, things work as in previous (AD) case
  - LR toll contains a factor $(1-\pi)\times a$ times SR toll in state 0
- But for state 1, the congestion externality is dropped
  - Marginal changes in $z(t^{\#})$ will not change traffic conditions in state 1: it is a condensed equilibrium
  - So no externality of that type enters the LR toll rule
- Instead, what is subtracted from the LR toll rule is the factor $\pi\times a\times$(travel delay in state 1)
  - It is part of the generalized price, but not of the marginal cost for $z(t^{\#})$
  - A marginal change in $z(t^{\#})$ does not change these costs

Numerical illustration



Wrap-up

- Long-run toll is needed when short-run and long-run valuations of time diverge
  - Surprisingly, the need is larger for instances of light congestion
  - Reason: in a condensed equilibrium, arrival pattern becomes insensitive to marginal changes in desired arrival times
    - LR toll is not capable of affecting the time losses
    - LR-toll may be close to zero, and even negative

Conclusion

- LR vs SR scheduling seems a plausible assumption on behaviour
- Empirical study suggested that this indeed occurs
  - VoT relatively high in the long run, VoSD's relatively low
  - SRPATS more dispersed than LRPATS
- Modelling study suggested that this may have policy implications
  - For pricing
  - But presumably for other instruments as well
  - E.g. self-financing will break down with SR tolls only…