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Incorporating Social Aspects in a Prospect Theory Model of Travel Choice

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אפקה המכללה האקדמית להנדסה בתל-אביב
הנדסה גבוהה

Outline

- Gain/Loss asymmetry, reference dependency and Prospect Theory (PT)
- Application to network modelling
- Extending PT framework to represent
  - (i) heterogeneity;
  - (ii) dynamic and social reference dependency
- Numeric example to illustrate the model
- Emergence of learning? (simulation)
- Discussion and Conclusions

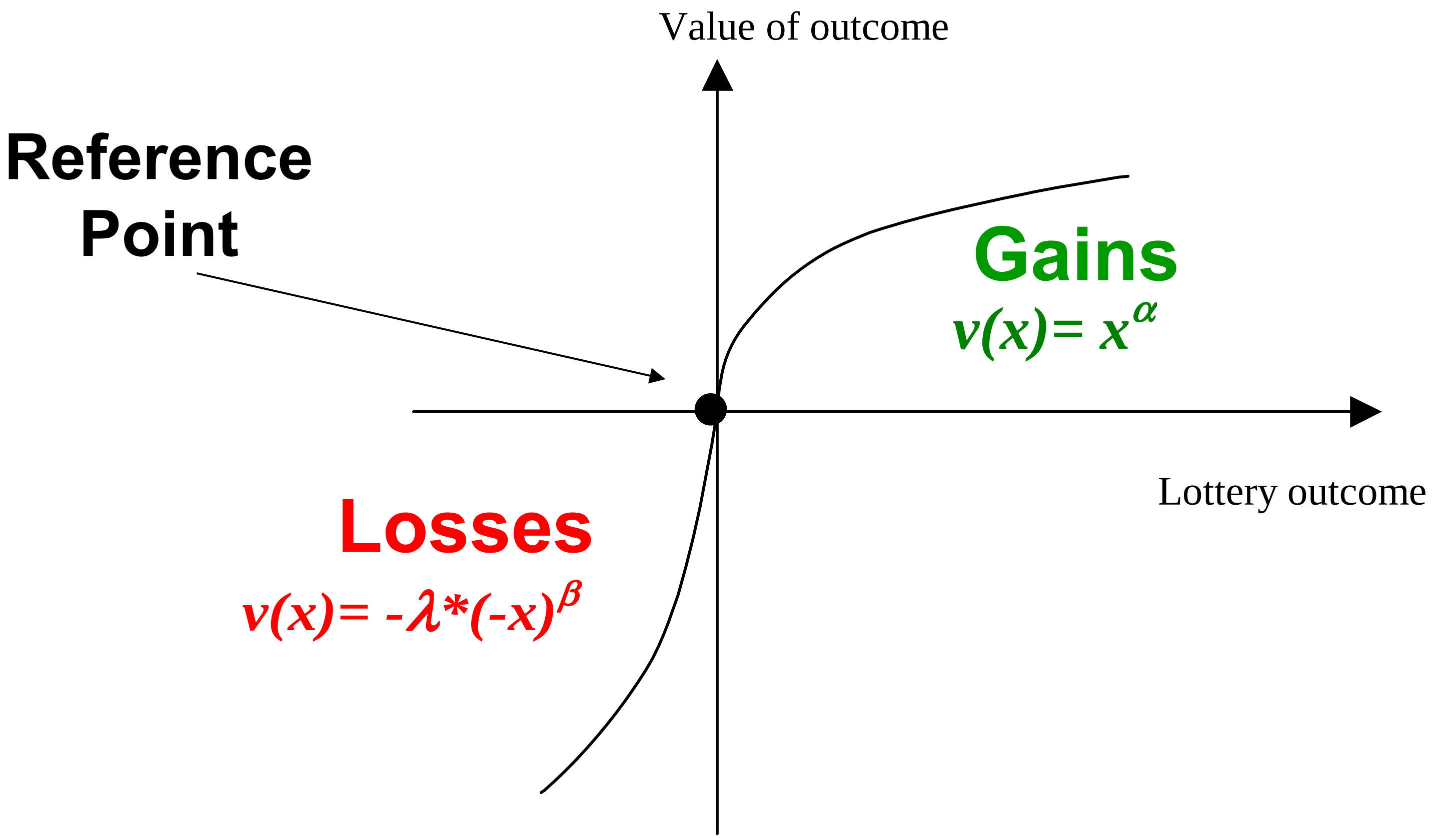
Loss Avoidance
Loss/Gain Asymmetry

- People are more sensitive to 'bad outcomes' than to 'good outcomes': The psychological effect of a loss is about twice than the psychological effect of a same-sized gain

- People tend to avoid losses more than they seek gains

- Gains and Losses are defined and measured against a "Reference Point" (Kahneman & Tversky, 1979; Thaler, 1985)

Prospect's Theory Value Function



λ Degree of loss aversion

α, β degree of diminishing sensitivity

Travel time – Gain or loss?

Loss!

travel as a derived demand

Travel time – Gain or loss?

But could be Gain!

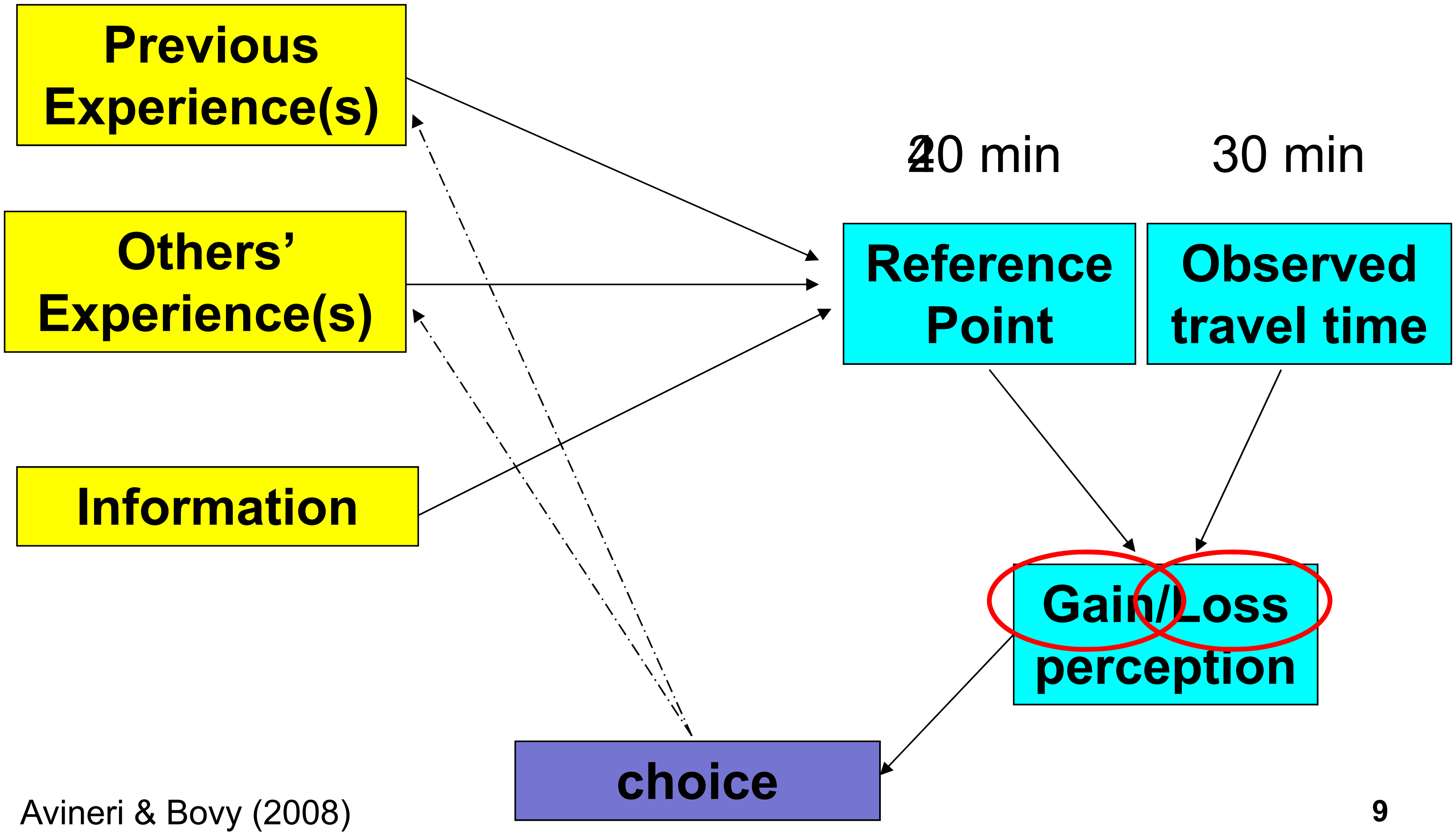
Positive utility of the commute (Mokhtarian & Redmond ,2001)
Ideal positively related to actual and to ‘liking and utility’ of the commute
“…it is possible to commute as little as well as too much…”

“The gift of travel time” (Jain & Lyons, 2008)


YOUR TRAVEL TIME: 30 MI
DESIRED TIME: 20 MI
*** YOU LOST ! ***
9304
http://atom.smasher.org/highway/

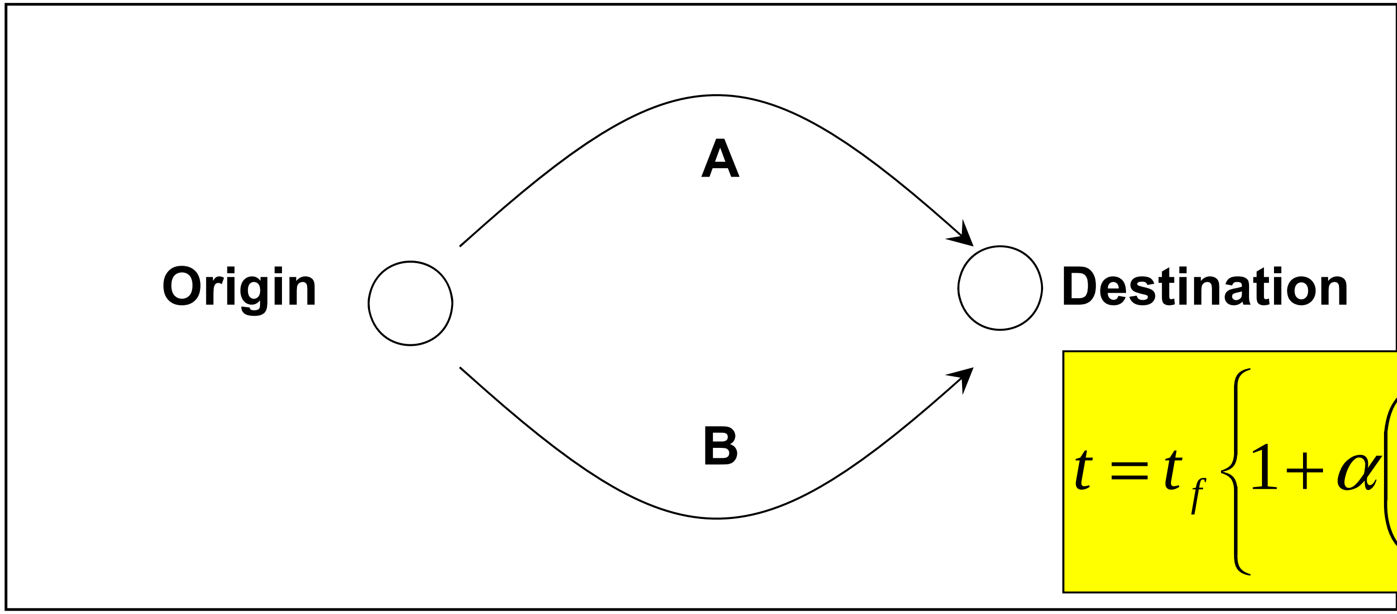

YOUR TRAVEL TIME: 30 MI
DESIRED TIME: 40 MIN
*** YOU WON ! ***
9304
http://atom.smasher.org/highway/

Reference Point: A travel choice context



Avineri & Bovy (2008)

Application of Prospect Theory to Network Modelling – Numeric (very simple!) example



$$t = t_f \left\{ 1 + \alpha \left(\frac{Q}{C} \right)^{\beta} \right\}$$

Travel time is calculated for each route based on the formulation by the Bureau of Public Roads (BPR)

- 10 drivers choose their routes independently
- On route A, t_f and C are *10* (minutes) and *10* (vehicles per hour). On route B t_f and C are *12* and *5*.
- α and β were set to *0.5* and *1.0*, for both routes

('Traditional') User Equilibrium

Wardrop's principle of user equilibrium:

Equilibrium under condition that no user can increase his/her route cost (time) by unilaterally switching routes

$$t = t_f \left\{ 1 + \alpha \left(\frac{Q}{C} \right)^{\beta} \right\} \qquad t_1 = 10 \left\{ 1 + 0.5 \left(\frac{Q_A}{10} \right)^{1} \right\} \quad t_2 = 12 \left\{ 1 + 0.5 \left(\frac{Q_B}{5} \right)^{1} \right\}$$

$$t_1 = t_2$$
$$Q_A + Q_B = 10$$

⇒

$$t_1 = t_2 = 14.1 \min$$
$$Q_A = 8.2$$
$$Q_B = 1.8$$

Application of Prospect Theory to Network Modelling

a user behaves as if s/he is a prospect maximizer;

assumed to know the distribution of travel time on each route.

Wardrop's principle of user equilibrium can be extended:

"Equilibrium under condition that no user can increase his/her route prospect value by unilaterally switching routes"

$$CWV_A^{Q_A} = CWV_B^{Q_B}$$

Equilibrium is reference-depended (Avineri 2006)

Application of Prospect Theory
(and other reference-dependence models)
to Network Modelling

• Avineri (2006) • Connors & Sumalee (2009) • Xu et al. (2011)	• Delle Site & Filippi (2011) • Tian et al. (2012) • Liu & Lam (2013)

- PT has been designed to capture individual ‘one-shot’ choices without feedback
- Homogeneity: All users share the same reference point
- Static: reference point(s) values are fixed over time

<u>This work introduces:</u>

- **Homogeneity → Heterogeneity** (random effects; individual experiences; social interactions – Festinger’s Theory of Social Comparisons)
- **Static → Dynamic** (imitation/learning processes)

Numeric Example

Behavioural assumptions of the model (1):

- **Gain/loss** (reference-dependency)

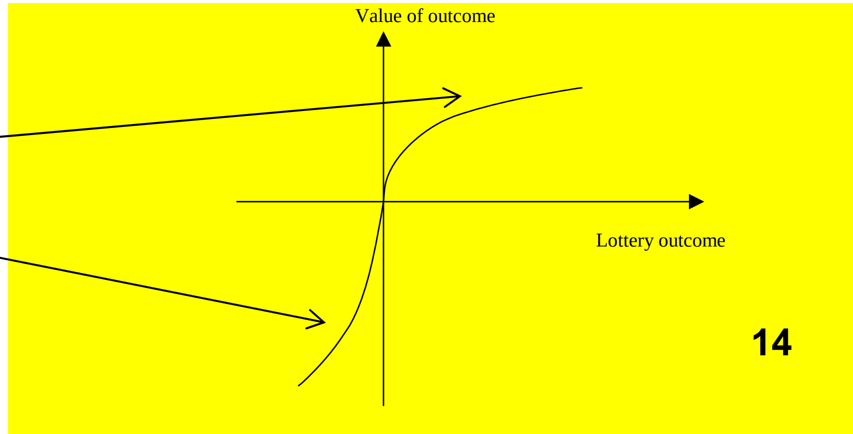
$$x_i = RP_i - T_i$$

- **Prospect-theoretic value** (following Tversky & Kahneman, 1979; *α=β=0.88, λ=2.25*)

λ – degree of loss aversion;

α, β – degree of diminishing sensitivity

$$v = CWV(x) = \begin{cases} x^{\alpha} & x \geq 0 \\ -\lambda(-x)^{\beta} & x < 0 \end{cases}$$



Numeric Example

Behavioural assumptions of the model (2):

- **Discrete choice rule**:

$$p(switching) = 0 < (-.025v + 0.5) < 1$$

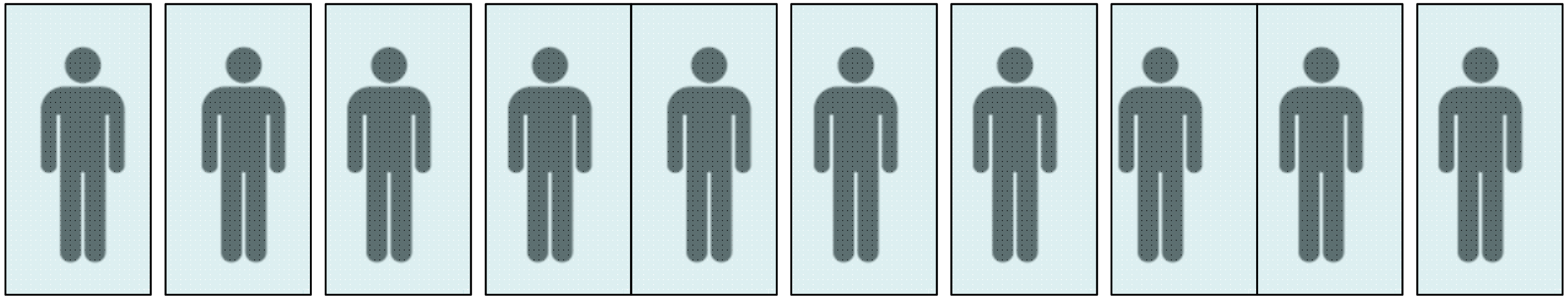
examples: *p(-15)=0.875,*
p(+15)=0.125,
p(0)=0.5

- **Level of stability** of the network can be measured by the propensity of users to change route

$$\sum_{i}^{N} p_i(switching) \Big/ N$$

Numeric Example

Behavioural assumptions of the model (3):



Updating the reference point:

- Initial values of RP (minutes) are random – uniformly distributed (heterogeneity)

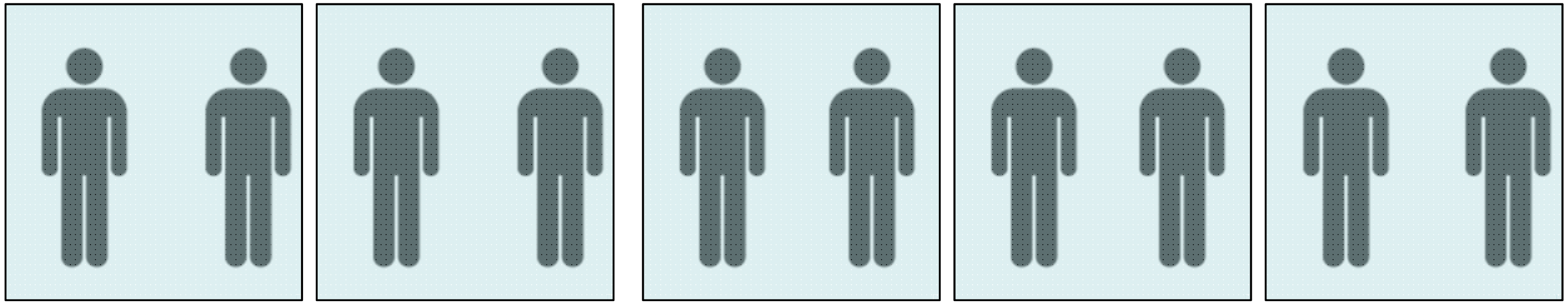
$$RP_i \in (10,35)$$

n=1 size of peer-group

$$RP_{i,t} = Average\{T_{i,t-1}, RP_{i,t-1}\}$$

Numeric Example

Behavioural assumptions of the model (4):



Updating the reference point:

- Social learning/imitation of reference values

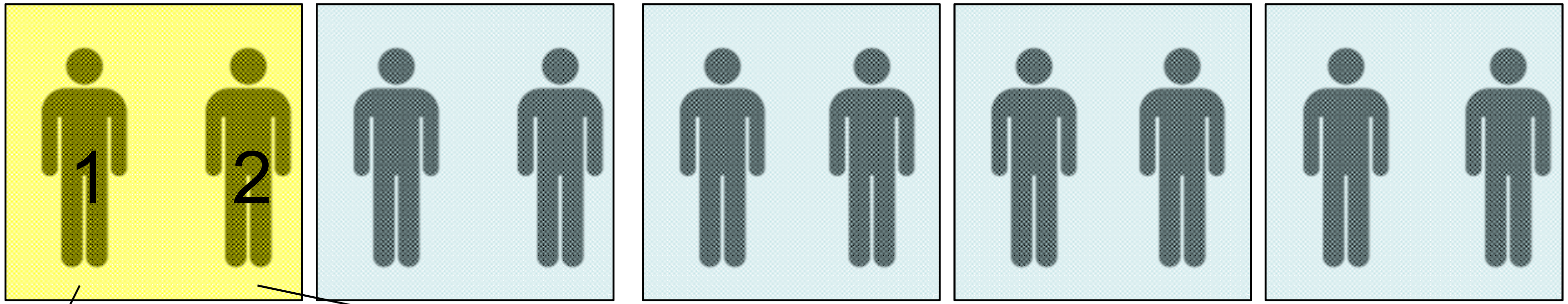
n=2 size of peer-group

$$x_j = \begin{cases} 1 & i = j \quad or\,(i,j) \in peer-group \\ 0\,otherwise & \end{cases}$$

$$RP_{i,t} = Average\left\{ T_{i,t-1}, \frac{\sum_{j=1}^{N} (RP_{j,t-1} x_{i,j})}{\sum_{j=1}^{N} x_{i,j}} \right\}$$

Numeric Example

Behavioural assumptions of the model (4):



$RP_{1,t-1}$=16,$T_{1,t-1}$=19

$RP_{2,t-1}$=18, $T_{1,t-1}$=23

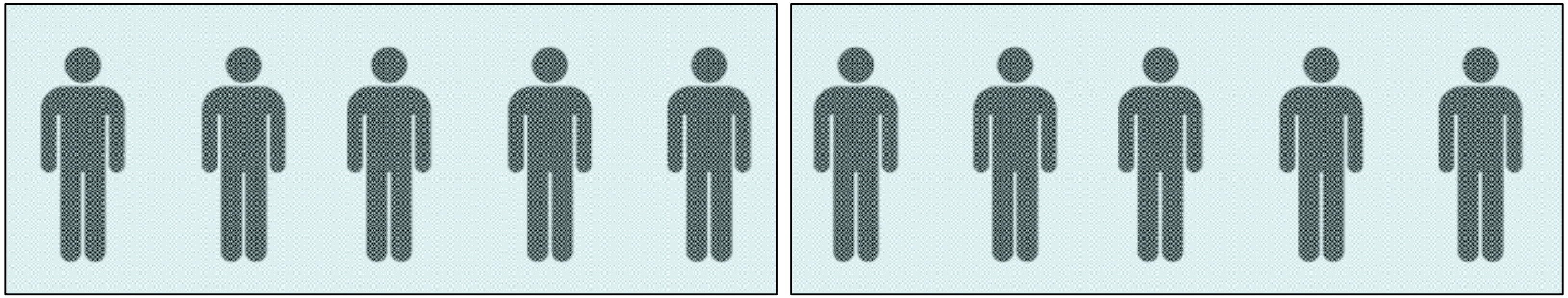
$RP_{1,t}$=Average{19,(16+18)/2}= 18

$RP_{2,t}$=Average{23,(16+18)/2}= 20

$$RP_{i,t} = Average\left\{ T_{i,t-1}, \frac{\sum_{j=1}^{N} (RP_{j,t-1} x_{i,j})}{\sum_{j=1}^{N} x_{i,j}} \right\}$$

Numeric Example

Behavioural assumptions of the model (5):



Updating the reference point:

- Social learning/imitation of reference values

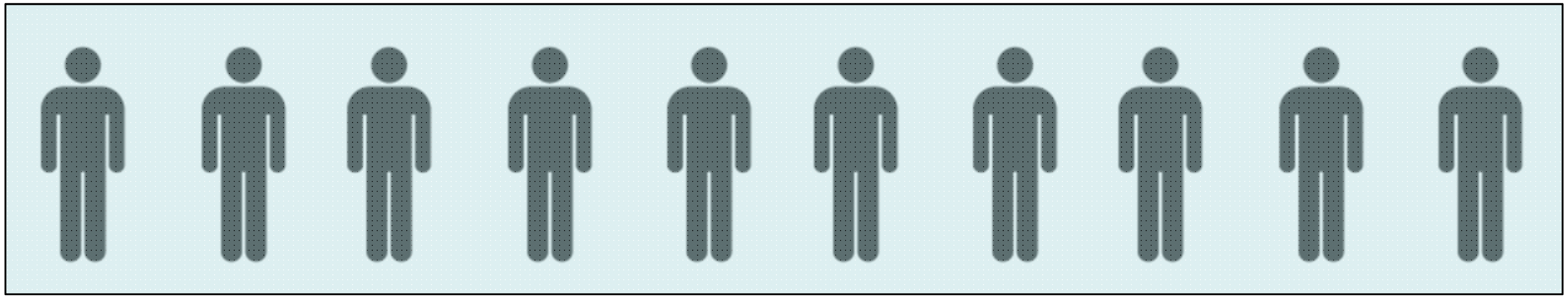
$$x_j = \begin{cases} 1 & i = j \quad or\,(i,j) \in peer-group \\ 0 & otherwise \end{cases}$$

n=5 size of peer-group

$$RP_{i,t} = Average\left\{ T_{i,t-1}, \frac{\sum_{j=1}^{N} (RP_{j,t-1} x_{i,j})}{\sum_{j=1}^{N} x_{i,j}} \right\}$$

Numeric Example

Behavioural assumptions of the model (6):



Updating the reference point:

- Social learning/imitation of reference values

n=10 size of peer-group

$$x_j = \begin{cases} 1 \quad i = j \quad or\,(i, j) \in peer - group \\ 0\, otherwise \end{cases}$$

$$RP_{i,t} = Average\left\{ T_{i,t-1}, \frac{\sum_{j=1}^{N} (RP_{j,t-1} x_{i,j})}{\sum_{j=1}^{N} x_{i,j}} \right\}$$

Research Questions

• SOCIAL/DYNAMIC RP mechanism (as described in the numeric example) – Emergence of (social) **Learning**?

- Convergence of **perceived RP** towards a specific value

- Convergence of route choices and **travel times** towards a user equilibrium

- **Stability** - propensity of users to change route is to be reduced over time (less fluctuations)

• Effect of the size of the peer-group *(n=1,2,5,10)* ?

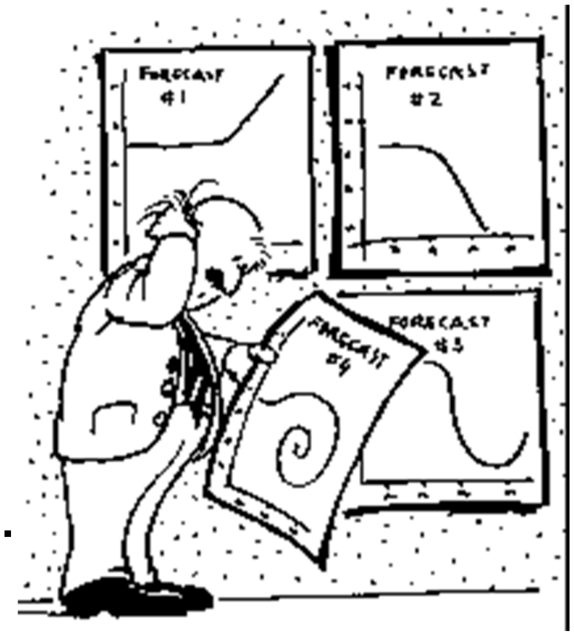
Methodology

• Simulation (20 runs) of perceived RPs and route choices of 10 agents over 12 rounds.

• Based on traffic assignment at the previous round, and previous values of travel times and reference points, values are updated for each agent.

• Repeated for different sizes of the peer-group (n=1,2,5,10).

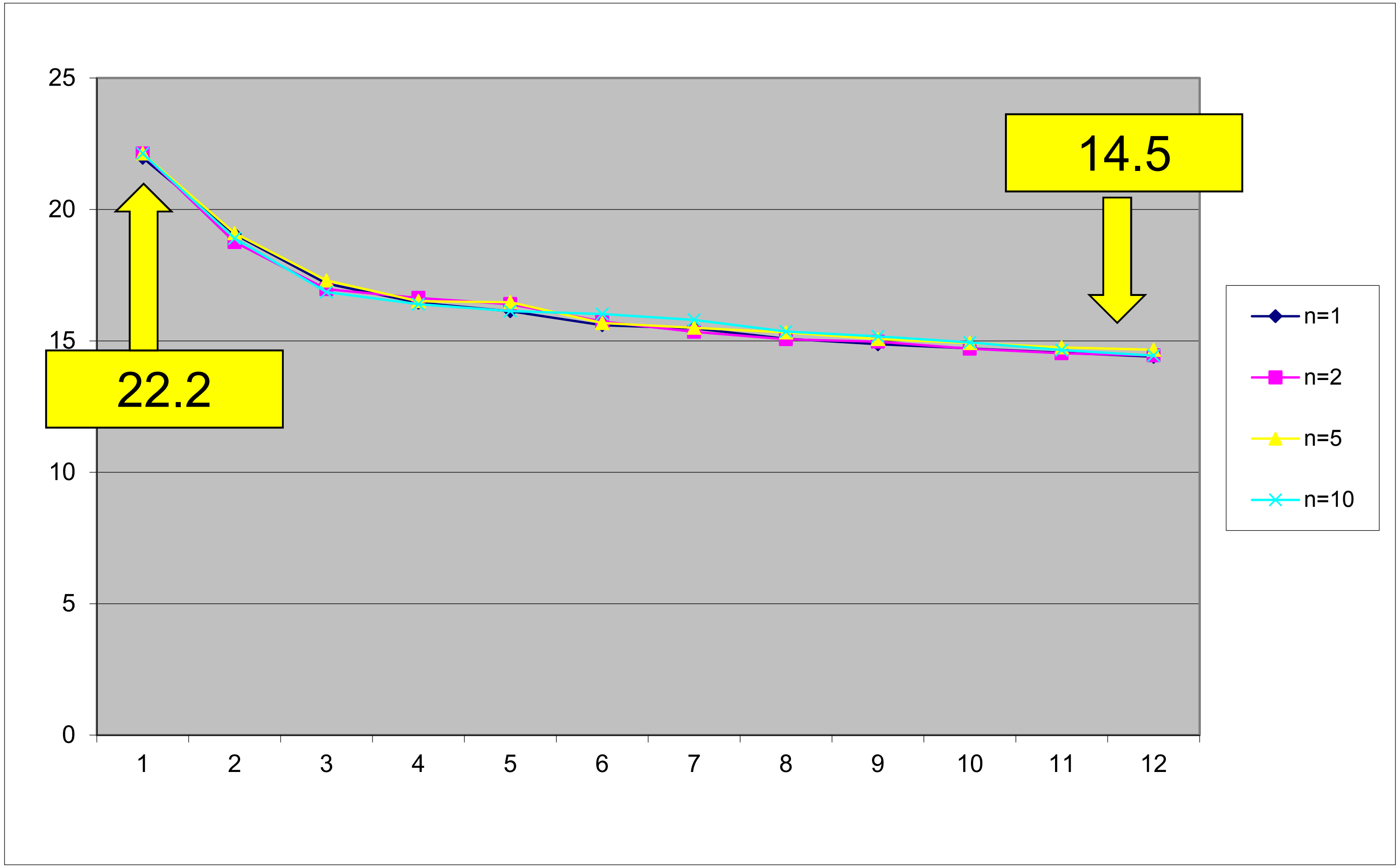
• Also – a model without loss aversion and diminishing sensitivity (*α=β=0, λ=0*), but with dynamic/social updating of reference points.



*(2*4 conditions) * (20 simulation runs) * (12 rounds) * (10 agents)*

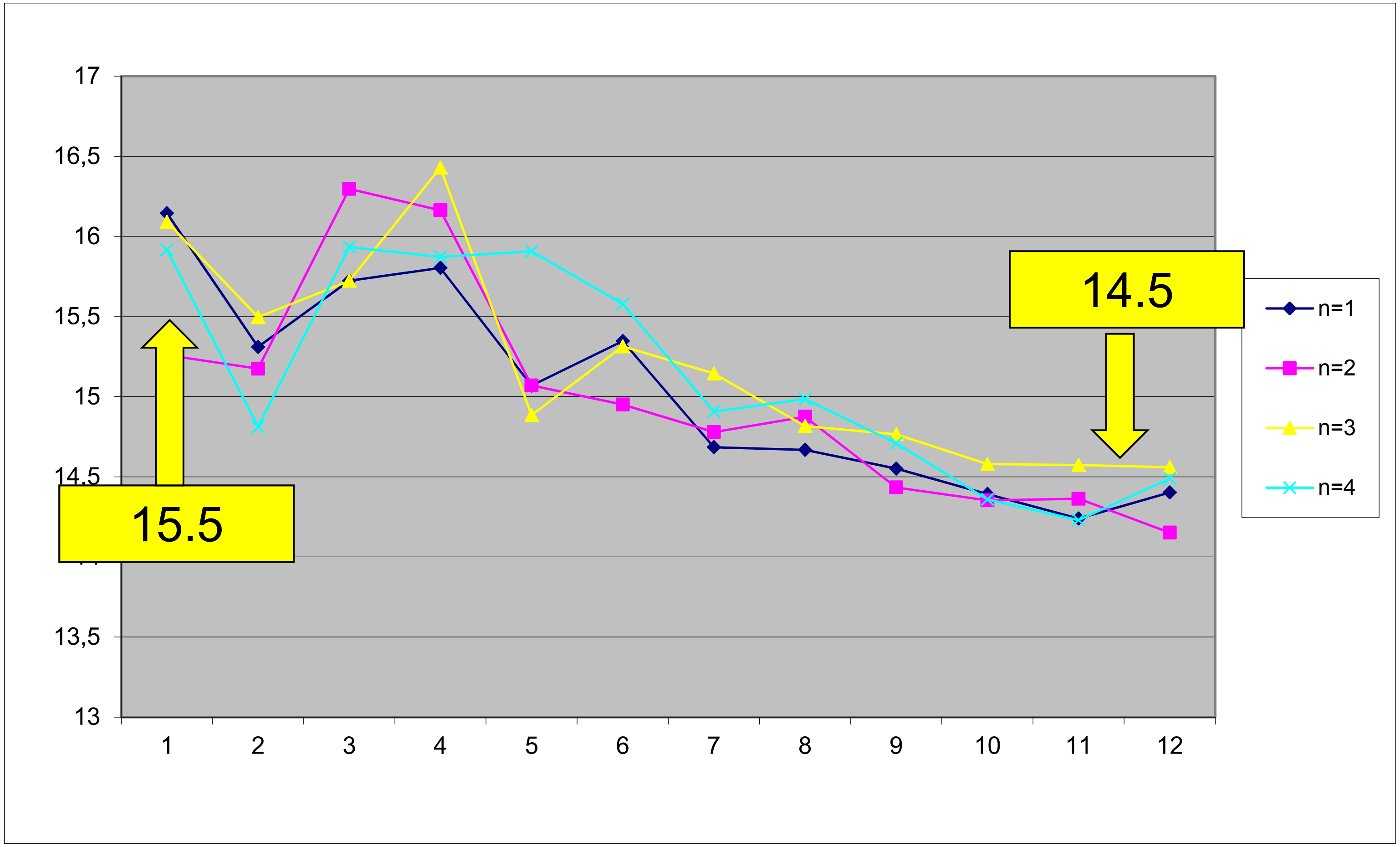
Results (1)
Reference point values

(20 runs, 10 agents, for each round, for each peer-group size)

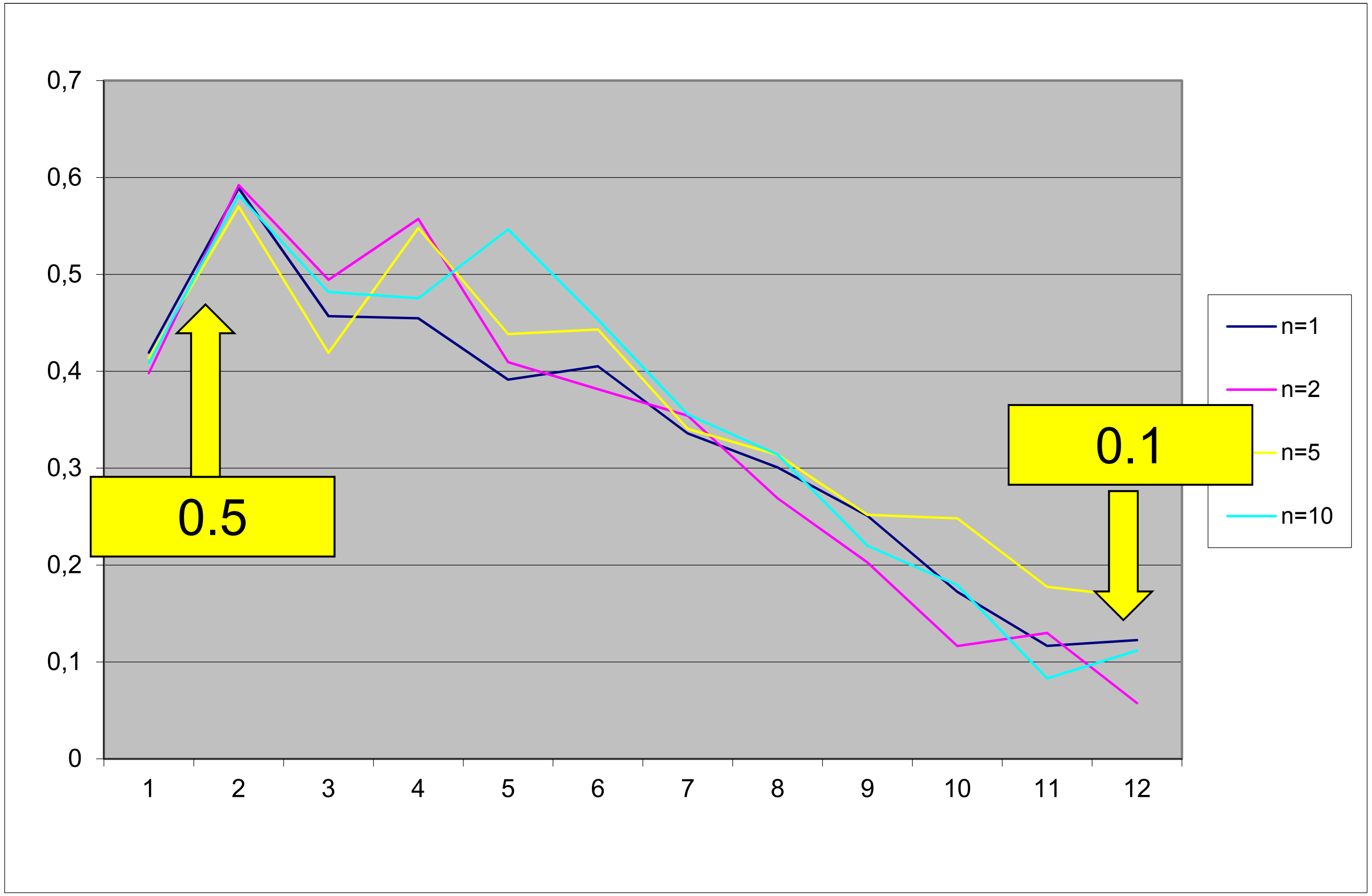


Results (2)
Travel times

(20 runs, 10 agents, for each round, for each peer-group size)



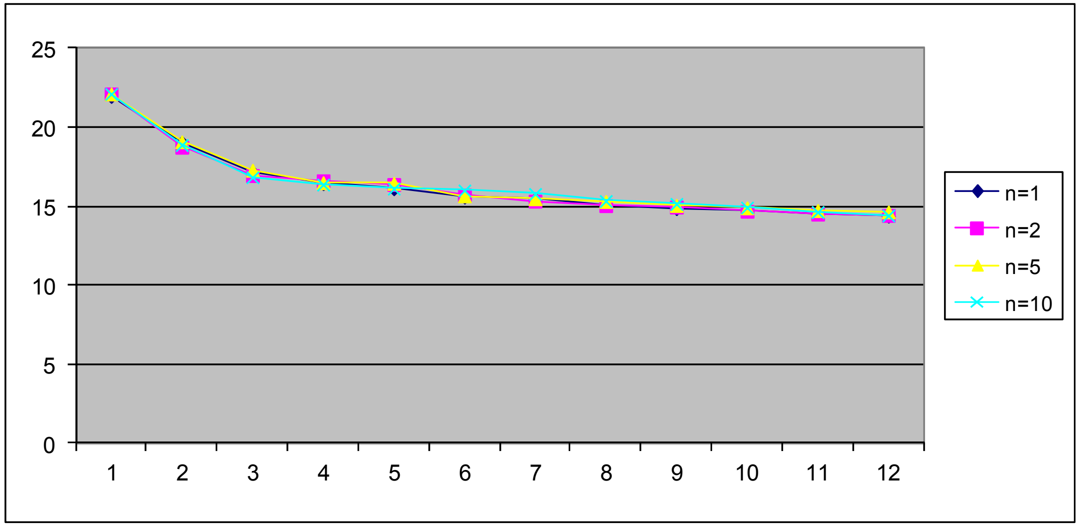
Results (3)
Stability (propensity to change route)
(20 runs, 10 agents, for each round, for each peer-group size)



Results (4)
Reference point values

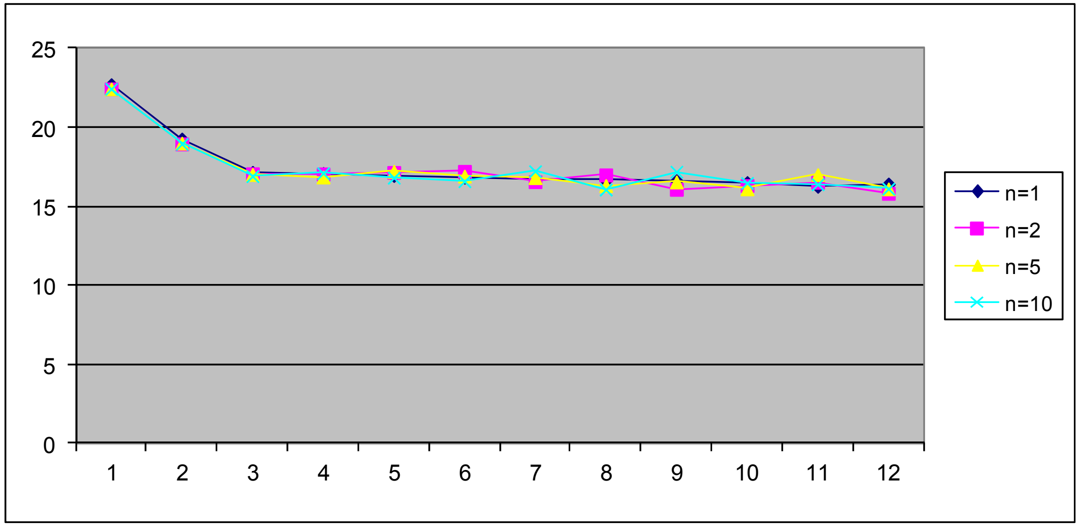
(20 runs, 10 agents, for each round, for each peer-group size)

Prospect Theory
α=β=0.88, λ=2.25



RP→14.5

'Traditional' Utility model
α=β=0, λ=0

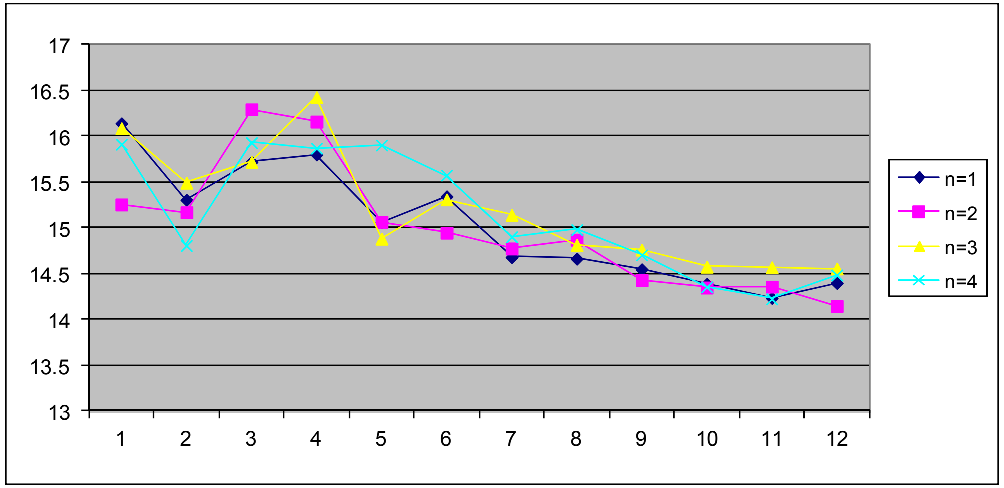


RP→16.0

Results (5)
Travel times

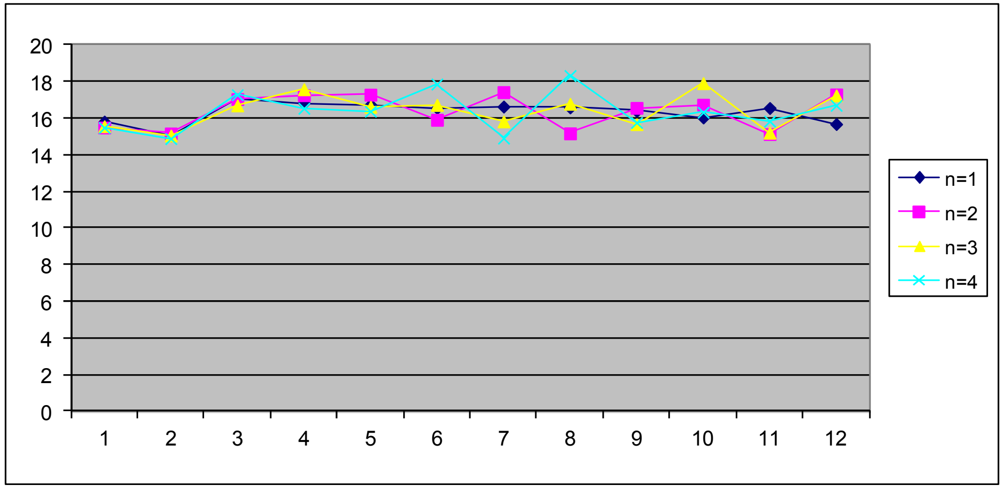
(20 runs, 10 agents, for each round, for each peer-group size)

Prospect Theory
α=β=0.88, λ=2.25



T→14.5

'Traditional' Utility model
α=β=0, λ=0

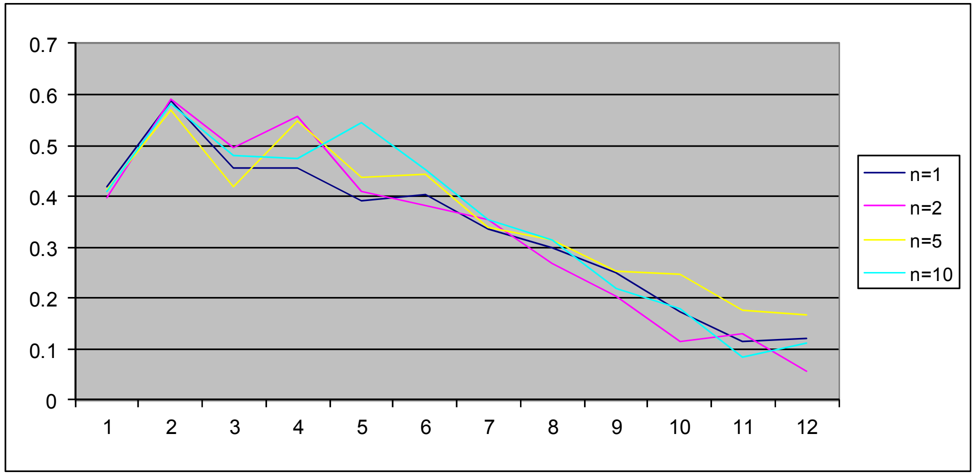


T→**?**17.0
(UE=14)

Results (6)
Stability (propensity to change route)

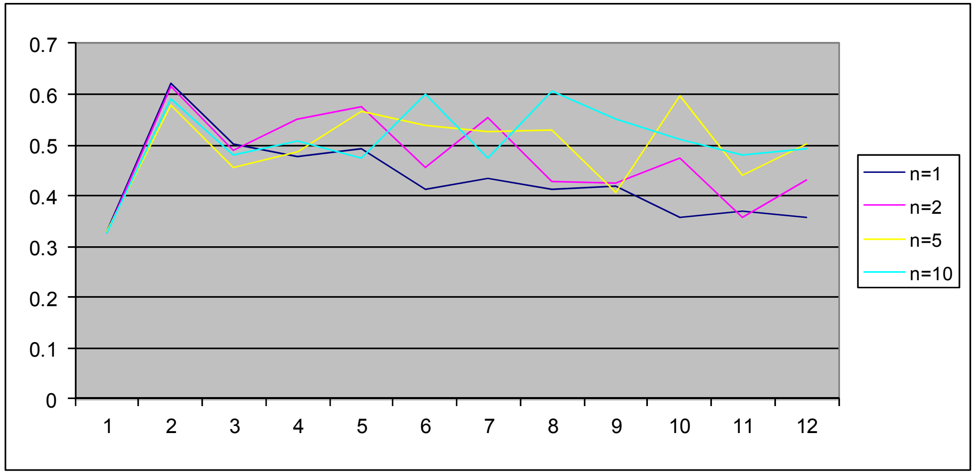
(20 runs, 10 agents, for each round, for each peer-group size)

Prospect Theory
α=β=0.88,
λ=2.25



p: 0.5→0.1

'Traditional' Utility model
α=β=0,
λ=0



p: 0.5→**?**0.5

Discussion (1)

- Can the SOCIAL/DYNAMIC RP mechanism (as described in the numeric example) be associated with learning?

Prospect Theory | 'Traditional' Utility model

✓ - Convergence of **perceived RP** towards a specific value — RP→14.5

✓ - Convergence of route choices and **travel times** towards a user equilibrium — T→14.5

✓ - **Stability** - propensity of users to change route is to be reduced over time (less fluctuations) — p: 0.5→0.1

Discussion (2)

- Can the SOCIAL/DYNAMIC RP mechanism (as described in the numeric example) be associated with learning?

Prospect Theory	'Traditional' Utility model

✓✓ - Convergence of **perceived RP** towards a specific value

RP→14.5	RP→16.0

✓✗ - Convergence of route choices and **travel times** towards a user equilibrium

T→14.5	T→**?**17.0 (UE=14)

✓✗ - **Stability** - propensity of users to change route is to be reduced over time (less fluctuations)

p: 0.5→0.1	p: 0.5→**?**0.5

Discussion (3)

- Loss aversion - an important element of (social) learning and system stability?

  Evolutionary Psychology –
  Loss aversion can represent an optimal strategy for a person evolved to maximize his prospects for survival in environments that vary between abundance and scarcity over time (McDermott et al., 2008).

- Effect of the size of the peer-group (*n=1,2,5,10*)?
  - No significant size effect was observed
  - Might be associated with the size and complexity of the network?

Further Research

• **Further theoretical and empirical investigation** of the behavioural assumptions

- Calibration of model parameters
- Validation of assumptions and results
- Applied context
- Social dilemmas
- Large and complex networks

• **Application areas**

- Modelling
- Behavioural change
- Connected vehicles
- Social Networks

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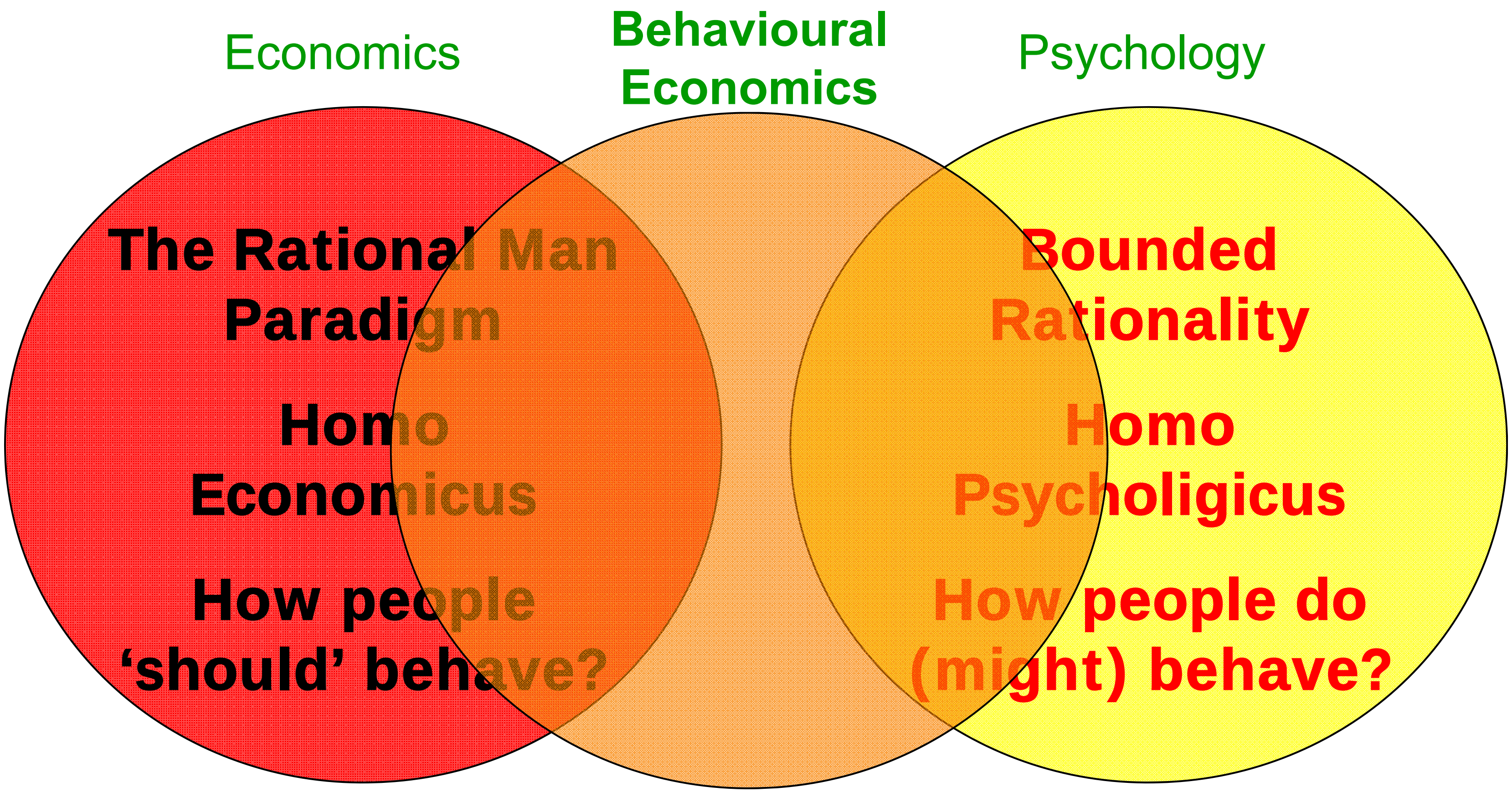
Two Paradigms of Human Behaviour



Behavioural Economics study the effects of social, cognitive, and emotional factors on economic decisions

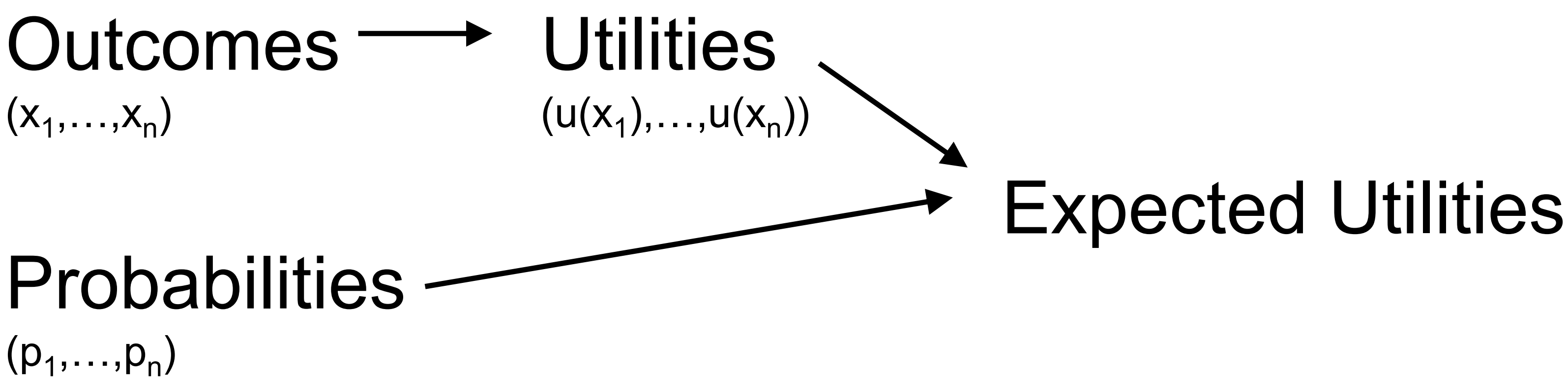
"Cognitive Anomalies"

(McFadden, 1999)

Effect	Description
CONTEXT	
Anchoring	Judgments are influenced by quantitative cues contained in the statement of the decision task
Context	History and presentation of the decision task influence perception and motivation
Framing	Equivalent lotteries, presented differently, are evaluated differently
Prominence	The format in which a decision task is stated influences the weight given to different aspects
Saliency	Subjects are inconsistent in selecting and weighting the information judged salient to a decision task
REFERENCE POINT	
Asymmetry	Subjects show risk aversion for gains, risk preference for losses, and weigh losses more heavily
Reference point	Choices are evaluated in terms of changes from an endowment or status quo point
Status Quo Endowment	Current status and history are favored relative to alternatives not experienced
AVAILABILITY	
Availability	Responses rely too heavily on readily retrieved information, and too little on background information
Certainty	Sure outcomes are given more weight than uncertain outcomes
Focal	Quantitative information is retrieved or reported categorically
Isolation	The elements of a multiple-part or multi-stage lottery are evaluated separately
Primacy and Recency	Initial and recently experienced events are the most easily recalled
Regression	Idiosyncratic causes are attached to past fluctuations, and regression to the mean is underestimated
Representativeness	High conditional probabilities induce overestimates of unconditional probabilities
Segregation	Lotteries are decomposed into a sure outcome and a gamble relative to this sure outcome
SUPERSTITION	
Credulity	Evidence that supports patterns and causal explanations for coincidences is accepted too readily
Disjunctive	Consumers fail to reason through or accept the logical consequences of actions
Superstition	Causal structures are attached to coincidences, and "quasi-magical" powers to opponents
Suspicion	Consumers mistrust offers and question the motives of opponents, particularly in unfamiliar situations
PROCESS	
Rule-Driven	Behavior is guided by principles, analogies, and exemplars rather than utilitarian calculus
Process	Evaluation of outcomes is sensitive to process and change
Temporal	Time discounting is temporally inconsistent, with short delays discounted too sharply relative to long delays
PROJECTION	
Misrepresentation	Subjects may misrepresent judgments for real or perceived strategic advantage
Projection	Judgments are altered to reinforce internally or project to others a self-image

Expected Utility Theory (EUT)

(Von Neuman & Morgenstern, 1944)

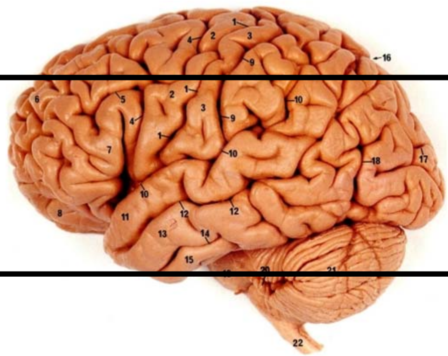


Expected Utility: $p_1u(x_1) + p_2u(x_2)+\ldots$

Prospect Theory

a descriptive model of decision making under risk and uncertainty

Kahneman & Tversky (1979) Prospect Theory
Tversky & Kahneman (1992) Cumulative Prospect Theory



Outcomes $(x_1,\dots,x_n)$ → Values $(v(x_1),\dots,v(x_n))$

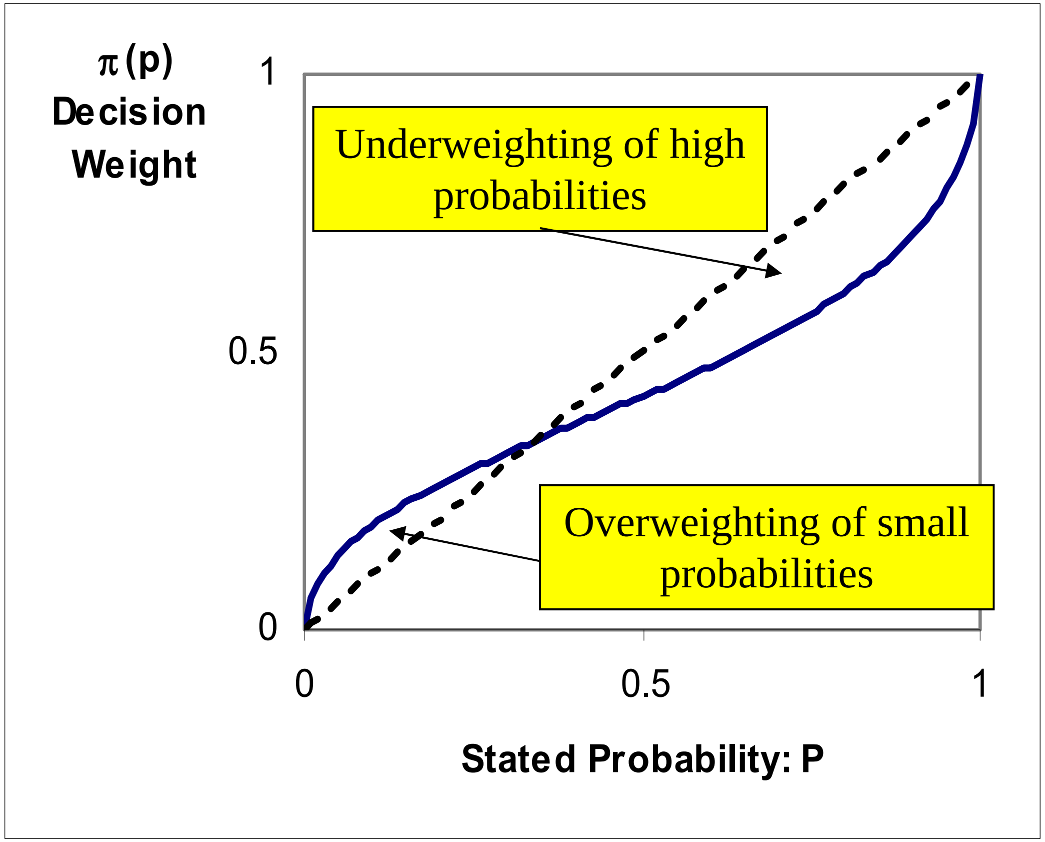
Probabilities $(p_1,\dots,p_n)$ → Weights $(\pi(p_1),\dots,\pi(p_n))$

Values, Weights → Prospects

Prospect: $\pi(p_1)v(x_1) + \pi(p_2)v(x_2)+\dots$

Weighting function (π) — Value function (v)

Prospect's Theory Weighting Function



• risk aversion when outcomes are framed as gains
• risk seeking when outcomes are framed as losses

$$w^{+}(p) = p^{\gamma} / [(p^{\gamma} + (1-p)^{\gamma}]^{1/\gamma}$$

$$w^{-}(p) = p^{\delta} / [(p^{\delta} + (1-p)^{\delta}]^{1/\delta}$$

CPT formulation

Tversky & Kahneman (1992)

$$CWV = v(f^{+}) + v(f^{-})$$

$$v(f^{+}) = \sum_{i=0}^{n} \pi_i^{+} v(x_i)$$

$$v(f^{-}) = \sum_{i=-m}^{0} \pi_i^{-} v(x_i)$$

$$\pi^{+}_{n} = w^{+}(p_n)$$

$$\pi^{-}_{-m} = w^{-}(p_{-m})$$

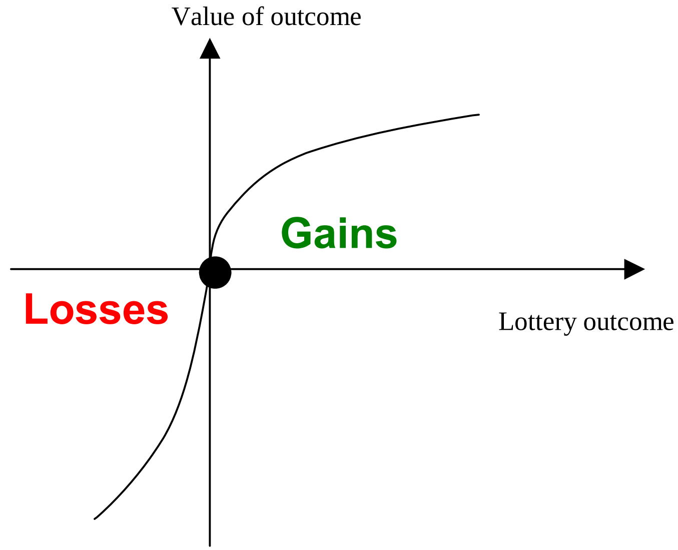
$$\pi^{+}_{i} = w^{+}(p_i + \ldots + p_n) - w^{+}(p_{i+1} + \ldots + p_n) \qquad 0 \le i \le n\text{-}1$$

$$\pi^{-}_{i} = w^{-}(p_{-m} + \ldots + p_i) - w^{-}(p_{-m} + \ldots + p_{i-1}) \qquad 1\text{-}m \le i \le 0$$

$$\pi^{+}(0) = w^{-}(0) = 0$$

$$\pi^{+}(1) = w^{-}(1) = 1$$

Setting a value to the reference point



- Money can be pooled / stored
- Time can not be stored

- 0 is the common reference point for gains / losses
- What is the reference point in the context of travel choice?

Violations of EUT in route-choice situations

preferences revealed in some problems violate the EUT assumptions (Avineri & Prashker, 2004)

These violations of EUT assumptions are **not** based on a specific shape of the utility function

a particular pattern of risk attitude is captured:
risk aversion when lotteries are framed as gains
risk seeking when lotteries are framed as losses

Robustness of Kahneman's & Tversky's results

Applications of Prospect Theory to Travel Choice Modelling

- Avineri & Prashker (2003, 2004, 2005)
- Senbil & Kitamura (2004)
- Avineri (2004, 2006)
- Viti et al. (2005)
- Han et al. (2005)
- Michea & Polak (2006)
- Chen & Mahmassani (2006)
- Zhao & Zhang (2006)
- Dell'Orco et al. (2007)
- Polak, Hess, & Liu (2008)
- Schwanen & Ettema (2009)
- van de Kaa (2010)
- EJTIR Special Issue (2010)
- Gao, Frejinger, Ben-Akiva (2010)
- …

- SP
- Small databases
- Static situations
- Not all features of PT incorporated/explored