Traffic Congestion and Paradoxes of Transport Capacity: Recent Lessons from Laboratory Experiments

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Introduction and Goals (1): Road Traffic Congestion and Experimental Economics

- Congestion (road): Economic cost estimated to be between 0.5% from 2% of GDP (Koopmans, 2003 for a review),
- (Theoretically), Traffic Congestion is (now) essentially viewed as a coordination problem of users that interact strategically (See for instance Beckmann et al., 1956; Vickrey, 1969; Arnott et al., 1990; 1993).

- What this presentation mainly about:
  - How Experimental Economics (EE) as an empirical method helps us to better understand Users’ Behaviour that produce Traffic Congestion?
  - How EE enables us to assess potential impacts of several policies that aim at solving Traffic Congestion, e.g. Road Pricing, Traffic Information and Transport Capacity?
Introduction (2)

- Why is congestion a coordination problem?
Lawrence Peter "Yogi" Berra on why he no longer went to Ruggeri's, a St. Louis restaurant: "Nobody goes there anymore. It's too crowded!"

- The reward associated to a given decision may be contingent to the total number of identical decisions taken by other players,

- the question is whether independent choices made by different people will somehow generate the maximum amount of efficiency, i.e. minimizing total travel costs.
Introduction (4): Solving Congestion by Increasing Road Capacity?

- Congestion: Should this coordination failure be solved by increasing capacity?

  - *American Road and Transportation Builders Association* claims that "adding highway capacity is key to helping to reduce traffic congestion" ...

  - ... vs *American Public Transit Association* which claims that without new investment in public transit, highways will become so congested that they "will no longer work".
Introduction (5): Solving Congestion by Increasing Road Capacity?


- But almost impossible to isolate the causal effect of road capacity on traffic congestion, independently of other explanatory variables, simply by using field data,

- This becomes possible with Laboratory Experiments that enable the experimenter to control carefully major explanatory variables in order to isolate this causal effect.
Structure of this presentation

- What is Experimental Economics?
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- Experimental Economics and Traffic Congestion
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- Experimental Economics and Traffic Congestion
- Experimental Economics and Transport Capacity Paradoxes
Experimental Economics: What is it? (1/3)

- Vernon Smith, Nobel Prize 2002: "Economics has been widely considered a non-experimental science, relying on observation of real-world economies rather than controlled laboratory experiments. Nowadays, however, a growing body of research is devoted to modifying and testing basic economic assumptions; moreover, economic research relies increasingly on data collected in the lab rather than in the field."
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  - **Designing** markets & policies by using "laboratory as a wind tunnel" (V. Smith, 1988).

- Many experiments have challenged the assumption of a universally selfish and rational *homo economicus* (Falk & Heckman, 2009).
Experimental Economics: What is it? (2/3)

- The main principles are the following:
  - The experimenter fixes economic environment and economics institutions that rule individual behavior and choices during the experiment (endogenous variables),

  - Saliency principle implies real incentives, which makes EE different from other empirical methods that aim at observing behaviors (psychology, marketing - e.g. Choice Experiments).
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Experimental Economics: What is it? (3/3)

Figure: LABEX-EM (LABoratory for EXperiments in Economics and Management, University of Rennes, Department of Economics)
Experimental Economics and Traffic Congestion (1/7): A Market-Entry Game

- A very simple Game: 12 participants should choose to enter a given market or not
  - The payoff is either 1$ for staying out,
  - Whereas for entering, the payoff is ($m$ being the number of entrants):
    \[ \pi_e = 9 - m \]$ (1)

- What is the traffic equilibrium?
Experimental Economics and Traffic Congestion (2/7): A Market-Entry Game

- Nash-Wardrop Equilibrium (Game Theory) states that, assuming that players are perfectly rational and selfish, there is many equilibriums of such a game, but simply:
  - either \( m = 8 \) or \( m = 7 \) are possible equilibriums, that is entry rate should lie between \( 7/12 \) (58%) to \( 8/12 \) (66%),
  - The maximum efficiency would be reached if \( m = 4 \) (that is the total payoff for the group of 12 participants would be maximum), i.e. we have a social dilemma,
  - Very difficult coordination among participants since equilibriums are asymmetric, i.e. some participants should enter whereas other should not enter,
- What are the experimental results?
Experimental Economics and Traffic Congestion (3/7): A Market-Entry Game

- Participants are in groups of 12 (20 periods) or 24 (20 periods), and play this game during 2X20 periods (Denant-Boemont & Fortat, 2011):

- Kahneman (1988): ”It looks like magic!”
Experimental Economics and Traffic Congestion (4/7): A Market-Entry Game

- Behavioral insight: Participants succeed to coordinate around equilibrium.... But do not succeed to avoid congestion,
- What about Pricing? Is it useful to help them to coordinate better? (i.e. maximizing social welfare)

![Graph showing entry rates over rounds]

Source: Anderson et al., 2008
Experimental Economics and Traffic Congestion (5/7): A Market-Entry Game

▶ What about Information? Is it useful?

▶ Information alone is useless!...

▶ ... But information coupled with pricing enables to reach optimal traffic level.

Source: Anderson et al., 2008
Experimental Economics and Traffic Congestion (6/7)

- A quick example based on Ziegelmeyer, Koessler, Boun My and Denant-Boemont (2008)
  - The aim was to implement lab experiments related to bottleneck model (Vickrey, 1969, Arnott et al., 1898,
  - In terms of policy and decision-making aid, how traffic information and road pricing could improve coordination failure among users?,

- Main principles of the 'basic' bottleneck model:
  - $N$ symmetric users should reach the same commuting trip and have the same goal (i.e. arrival time $t^*$), and one route/mode possible (no alternative),
  - The only choice is about Departure Time $t$, user time cost components are travel time, early arrival time or late arrival time
  - The route has a capacity $s$ which is less than $N$,
  - If $N$ users choose same departure time $t$, then travel time is $N/s$.  

Experimental Economics and Transport Economics? (7/7)

- Some experimental results: Is Public Information useful for improving congestion?
  - 2 treatments,
  - Information: All participants get the distribution of Departure Time chosen and actual Arrival Time,
  - No Information: Participants get just their individual outcome

![Graph showing distribution of departure times: Informed vs Non Informed]
Capacity Paradoxes (1)

- **Pigou-Knight-Downs Paradox** (Pigou, 1920; Knight, 1921; Downs, 1962): Increase in road capacity that *do not decrease* total travel times,
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Arnott & Small, 1994: All paradoxes assume that Wardrop traffic equilibrium occurs (Wardrop, 1952): Traffic equilibrium is reached when travel times are equivalent on all used routes and less or equal to travel times on any other route (Wardrop’s first principle),
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- Morgan et al. 2009, identify two basic principles to avoid paradoxes:
  - ”size principle” states that adding costless links reduces travel time if there are sufficiently many travelers (Braess)
  - ”least congestible route principle” states that the route/mode to be improved is the one which is the least sensible to traffic congestion (Pigou-Knight-Downs, Downs-Thomson)
Braess Paradox

- Alternative routes available in a given (road) network and TT which increases linearly with users number

![Diagram of the Braess Paradox](image)

**Figure:** The Braess Paradox (source: Morgan et al., 2009)

- In this example, as long as \( N \leq 120 \), the adverse strategic effect dominates the efficiency of the additional link, increasing consequently travel time.
Downs-Thomson Paradox

- 2 modes (a private and a public one), road travel time increases with traffic, decreases with traffic for public transit (Mohring, 1977; Small & Verhoef, 2007); Both travel times decrease with capacity.
Empirical evidence about Paradoxes

▶ Question: are these paradoxes more than intellectual curiosities? (Arnott & Small, 1994)

▶ Empirical evidence: Very few...
  ▶ DT: London (Mogridge, 1997); Sydney (Zeibots & Petocz, 2005)
  ▶ Mogridge, 1997:

<table>
<thead>
<tr>
<th>Sector and Mode</th>
<th>1962 (km/hr)</th>
<th>1971 (km/hr)</th>
<th>1981 (km/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 car</td>
<td>15.70</td>
<td>15.15</td>
<td>15.33</td>
</tr>
<tr>
<td>rail</td>
<td>15.29</td>
<td>14.84</td>
<td>13.54</td>
</tr>
<tr>
<td>2 car</td>
<td>18.49</td>
<td>16.76</td>
<td>15.67</td>
</tr>
<tr>
<td>rail</td>
<td>15.92</td>
<td>15.62</td>
<td>14.43</td>
</tr>
<tr>
<td>3 car</td>
<td>18.07</td>
<td>18.01</td>
<td>16.05</td>
</tr>
<tr>
<td>rail</td>
<td>16.15</td>
<td>16.44</td>
<td>14.64</td>
</tr>
<tr>
<td>4 car</td>
<td>17.80</td>
<td>17.81</td>
<td>17.09</td>
</tr>
<tr>
<td>rail</td>
<td>16.41</td>
<td>15.77</td>
<td>15.26</td>
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<tr>
<td>5 car</td>
<td>17.27</td>
<td>16.81</td>
<td>15.22</td>
</tr>
<tr>
<td>rail</td>
<td>15.87</td>
<td>15.71</td>
<td>14.30</td>
</tr>
<tr>
<td>6 car</td>
<td>16.55</td>
<td>16.16</td>
<td>15.10</td>
</tr>
<tr>
<td>Total car</td>
<td>17.19</td>
<td>16.89</td>
<td>15.66</td>
</tr>
<tr>
<td>rail</td>
<td>15.63</td>
<td>15.42</td>
<td>14.19</td>
</tr>
</tbody>
</table>
Laboratory Experiments about Paradoxes

1. Braess Paradox: Rapoport et al., 2006, 2009; Morgan et al., 2009; Meinhold & Pickhardt, 2009
Lab Experiments about Paradoxes

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3. DT Paradox: Denant-Boemont & Hammiche, 2009; Datta & Razzolini, 2009,
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Such paradoxes occur quite frequently in the lab (more than "intellectual curiosities").
A Laboratory Experiment about DT Paradox

- 1 Public Transit operator (A) and 14 participants as transport users,
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- sequential game: Operator chooses first capacity for Public Transit, users are informed about her choice, and then users choose between X (road) and Y (PT) without outside option,
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- Payoff for road are to decrease with the number of Road Users whereas payoff for Public Transit is to increase with Road Traffic (see Mohring, 1977).
- In this theoretical model, any increase in road capacity by shifting users’ equilibrium will decrease total travel times level (DT paradox) and vice versa (that is decreasing road capacity should increase total travel times).
Experimental Design

- PT operator A chooses $c_2 \in [1, \ldots, 11]$
- For users B, payoffs are:

$$H_i(\delta) = \begin{cases} 
6 + (c_1 - m_1) & \text{if } \delta^i = X \\
0.25 + (c_2 + m_2) & \text{if } \delta^i = Y
\end{cases}$$

(2)
Experimental design on DT Paradox

- Groups of 15 players, 1 A and 14 B, partners design,
- Each participant A should choose a level for capacity $c_2$ in the first step,
- Each participant B, being aware of $c_2$ level chosen by A, have to choose the market she enters in step 2,
- 2 experimental treatments: LOW Capacity and HIGH capacity,
- 2 experimental conditions (sessions): ADD (road capacity increase over time, i.e. LOW + HIGH) or DEL (road capacity decrease over time, i.e. HIGH + LOW),
- For each condition, 40 periods of interaction (2 X 20).
- 16 sessions (8 in ADD condition, 8 in DEL condition) held in LABEX, University of Rennes 1, i.e. 240 participants.
Given our calibration, Traffic Equilibriums are characterized by:

<table>
<thead>
<tr>
<th>treatment</th>
<th>$c_2$</th>
<th>$m_1$</th>
<th>$m_2$</th>
<th>$\pi^i_A$</th>
<th>$\pi^i_B (X)$</th>
<th>$\pi^i_B (Y)$</th>
<th>$W_{Nash}$</th>
<th>$W_{Max}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW c.</td>
<td>1</td>
<td>6</td>
<td>8</td>
<td>7</td>
<td>3</td>
<td>2.25</td>
<td>43</td>
<td>90.5</td>
</tr>
<tr>
<td>HIGH c.</td>
<td>1</td>
<td>10</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1.25</td>
<td>28</td>
<td>91</td>
</tr>
</tbody>
</table>
Experimental Results on DT Paradox: Entry rate on road

- entry rate on road increases significantly with road capacity:

**ADD condition**

![Graph showing increase in entry rate with road capacity in ADD condition]

**DEL condition**

![Graph showing increase in entry rate with road capacity in DEL condition]

Figure: Average Entry Rate on Road per Period
DT Paradox: Experimental Welfare Levels (1)

- Theoretical model: Doubling road capacity decreases welfare level (group’s payoff) from 35%,
  - On average, group payoff decreased from 12% between LOW and HIGH treatment,
  - But in ADD condition, such a difference is significant (DT Paradox), whereas it is not for DEL condition.
DT Paradox: Experimental Welfare Levels (2)

- Two opposite effects: (1) Learning with repetition (Operators and Users) and (2) "treatment" effect (LOW vs HIGH),
DT Paradox: Experimental Welfare Levels (2)

- Two opposite effects: (1) Learning with repetition (Operators and Users) and (2) ”treatment” effect (LOW vs HIGH),

- When road capacity rises, learning effect magnifies the treatment effect, whereas when capacity is to be decreased, learning opposites itself to the treatment effect,
Concluding comments

- Laboratory Experiments show that coordination on 'congestion' equilibrium is often reached (but with huge variations among time)...
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- that is in terms of public policies, it is fair to be skeptical about the positive effect of increasing road capacity (Mogridge, 1997; Duranton & Turner, 2009)... 

- But, from the efficiency point of view -e.g. fighting urban congestion-, planners have also to be cautious about cuts in road capacities (Goodwin et al., 1998).
Thanks for your attention! Questions, comments?

"Human guinea pigs...I find that insulting!"

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