Marginal congestion costs with multi-class traffic: Some tentative estimates for the Paris Region

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INTRODUCTION
Urban road congestion and urban freight

- Urban areas are characterized by « push and pull » forces: desirable advantages emerge from the density of activities and households. But they also give rise to plenty of negative externalities including road congestion.

- Road congestion has been studied extensively for passenger transportation. Comparatively, the literature on the subject of road congestion caused by freight vehicles is less developed.
BACKGROUND OF THE STUDY
Traffic data and congestion in the Paris Region

- Our case study is the Paris Region, Ile-de-France. It is considered as one of the most congested urban area in Europe: motorists spend on average 70 hours per year in traffic (London is behind with only 52 hours); 80% of the congestion in France is concentrated in the Paris Region.

- Public traffic data for freight vehicles is scarce in the Paris Region => only available for the main highways, distinguishing Heavy Trucks from personal vehicles. This causes another problem: 60% of goods movements in the Paris Region are done with Light Goods Vehicles (LGV).

- We use two databases to measure congestion: the 2010 Enquête Globale Transport (EGT, Ile-de-France’s Household Mobility Survey) and the 2010 Urban Freight Survey (UFS) for delivery-drivers.
AIM OF THE STUDY
Measuring congestion using OD matrices and survey data

In this paper:

- We suggest a theoretical framework in order to model multi-class traffic congestion

- We confront data on passenger transportation (the Household Mobility survey), both for individual trips and for a general level of traffic in the form of an OD matrix; and data on freight transportation: the driver-survey (for individual trips), and results from the Freturb model (for the OD matrix)

- We propose an econometric analysis of travel times for passenger and freight vehicles and we make them depend on the magnitude of similar/dissimilar traffic flows

- We calculate marginal congestion costs (work in progress)
Theoretical Framework

Travel-time flow relationships in the literature

- The relationship between travel-time and traffic flows can be analyzed using a travel-time flow function developed by the BPR (Bureau of Public Road). It is expressed as:

\[ D = D^0 \left( 1 + \alpha \left( \frac{F}{K} \right)^\beta \right) \]  

(1)

- One important limitation of equation (1) is that it does not account for multi-class traffic. For this reason, Yun et al (2005) suggested the following modifications:

\[ D = D^0 \left[ 1 + \alpha \left( \frac{F_i}{K} \right)^\beta \left( 1 + \frac{F_j}{F} \right)^\delta \right] \]  

(2)

\( D \) is the time necessary to travel 1 kilometer
\( D^0 \) is the “empty road” travel time (using maximal authorized speeds)
\( F \) is the hourly vehicle flows per kilometer of road; \( F_i \) is the hourly vehicle flows/km of class \( i \) vehicles and \( F_j \) is the hourly vehicle flows/km of class \( j \) vehicles
\( K \) is the theoretical road capacity (vehicle/hour/km)
In equation (2) \( \beta \) describes the travel-time road usage relationship for class \( i \) vehicles and \( \delta \) the travel-time road usage relationship for class \( j \) vehicles; the \( \alpha \) parameter depends on the type of infrastructure.
THEORETICAL FRAMEWORK
Empirical specifications of our model

Given the availability of data, and limitations of equation (2), we focus on individual trips over large geographical areas (ODs, rather than specific road segments). For an individual of class $i$ vehicles on OD $k$ during period $t$, travel time is:

$$D_{ikt} = \alpha_1 D_{ik}^0 + \alpha_2 \frac{F_{ikt}}{K_k} + \alpha_3 \frac{F_{jkt}}{F_{kt}} + \alpha_4 T_i + \alpha_5 X_{ik} + \varepsilon_i$$  \hspace{1cm} (3)

$D_{ik}^0$ is the minimal travel time to make the trip on OD $k$ if the road is empty, found by crossing the average maximal speeds with the distance travelled by the vehicle.

$\frac{F_{ikt}}{K_k}$ describes the similar class $i$ flow to capacity ratio.

$\frac{F_{jkt}}{F_{kt}}$ describes the dissimilar class $j$ flow within the total traffic.

Vector $X_{ik}$ includes some control variables, suspected to influence travel duration.

The dummy variable $T_i$ is $1$ is class $i$ is a truck, $0$ otherwise.

$\alpha_2$ and $\alpha_3$ are our main parameters of interest: they represent the impact of traffic flows $i$ and $j$ on travel time.

In equation (3) we focus on the impact of traffic flows on travel time. It assumes that these impacts are homogeneous across vehicle classes. Equation (4) relaxes this assumption:

$$D_{ikt} = \alpha_1 D_{ik}^0 + \alpha_2 \frac{F_{ikt}}{K_k} + \alpha_3 \frac{F_{jkt}}{F_{kt}} + (\alpha_1^* D_{ik}^0 + \alpha_2^* \frac{F_{ikt}}{K_k} + \alpha_3^* \frac{F_{jkt}}{F_{kt}}) T_i + \alpha_5 X_{ik} + \varepsilon_i$$  \hspace{1cm} (4)

$\alpha_1^*, \alpha_2^*$ and $\alpha_3^*$ can be considered as “sensitivity premiums”.

If individual $i$ is driving a truck ($T_i = 1$), the impact of minimal travel time, similar class vehicles and dissimilar class vehicles will be respectively $(\alpha_1 + \alpha_1^*)$, $(\alpha_2 + \alpha_2^*)$ and $(\alpha_3 + \alpha_3^*)$. If $i$ is a small vehicle, then impacts will simply be $\alpha_1$, $\alpha_2$ and $\alpha_3$. 

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Flows and individual observations of passenger vehicles in 2010 are using the EGT. During the survey, over 43,000 persons and 143,000 trips were surveyed. It gives us the origin and destination, time of day, duration and length of trip. The observations were weighted, which allowed us to create OD matrices.

Individual observations of freight vehicles are using the 2010 Urban Freight Survey for delivery drivers. It gives us the type of vehicle, the origin and destination, time of day, duration and length of trip. 345 freight tours were surveyed and were divided into 2,000 freight trips.

Flows of freight vehicles were obtained using the Freturb model. For more details about the methodology, see Routhier & Toilier, 2007. It gives us flows of different types of freight vehicles (small and large) at different time periods.
PRESENTATION OF DATA
Description of data

- All observations are for week-days, three time periods: morning peak-hours (6-9 am), afternoon peak-hours (4-7pm) and rest of the day.

- Ile-de-France is divided into three macroscopic zones: Paris (dense center of the agglomeration), the inner suburbs (less dense) and the outer suburbs (even less dense).

- Road infrastructure data is obtained with “BD TOPO”, a GIS from the IGN (National Geographical Institute). It gives us the length, width (nb of lanes) and speed limits of the network. We select to use only the most important parts of the road network.
The table shows the hourly vehicle flow depending on the type of vehicles and the OD (cars + vans = small vehicles).

A large majority of urban traffic is generated by passenger vehicles. Average freight flows represent between 3 and 7% of total flows, depending on the OD.

Heavy goods vehicles represent between 38 and 45% of total freight flows, depending on the OD, and between 1 and 3% of total traffic.
## Presentation of data

Descriptive statistics of variable used in equation (3) and (4)

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>St. Dev</th>
<th>Min</th>
<th>Max</th>
<th>Obs</th>
</tr>
</thead>
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<td>Travel time</td>
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<td>29.80</td>
<td>1</td>
<td>198</td>
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<tr>
<td>Distance</td>
<td>18.78</td>
<td>18.62</td>
<td>0.078</td>
<td>162</td>
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<tr>
<td>Max speed</td>
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<td>3.41</td>
<td>65.07</td>
<td>81.52</td>
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<td>$D_{ik}^0$</td>
<td>14.06</td>
<td>13.78</td>
<td>0.06</td>
<td>120.23</td>
<td>49,822</td>
</tr>
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<td>$F_{ikt}$</td>
<td>644.76</td>
<td>456.50</td>
<td>3.26</td>
<td>1,823.398</td>
<td>49,822</td>
</tr>
<tr>
<td>$F_{jkt}$</td>
<td>25.85</td>
<td>112.25</td>
<td>3.26</td>
<td>1,823.398</td>
<td>49,822</td>
</tr>
<tr>
<td>$K_k$</td>
<td>9,061.45</td>
<td>2,862.94</td>
<td>4,605.81</td>
<td>12,150.11</td>
<td>49,822</td>
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<tr>
<td>$F_{ikt}/K_k$</td>
<td>0.08</td>
<td>0.07</td>
<td>0.0004</td>
<td>0.34</td>
<td>49,822</td>
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<tr>
<td>$F_{jkt}/F_{ikt}$</td>
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<td>0.02</td>
<td>0.0004</td>
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<td>Trucks</td>
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<td>0.15</td>
<td>0</td>
<td>1</td>
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<td>Goods</td>
<td>0.05</td>
<td>0.22</td>
<td>0</td>
<td>1</td>
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<tr>
<td>Area</td>
<td>8.60</td>
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<td>0.10</td>
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<tr>
<td>Paris</td>
<td>0.44</td>
<td>0.50</td>
<td>0</td>
<td>1</td>
<td>49,822</td>
</tr>
</tbody>
</table>

- Note the we use three control variables
  - Is the individual trip goods transportation? (dummy variable = 0 or 1)
  - The surface of the OD pair (in km$^2$)
  - Is the individual trip leaving or going to Paris? (dummy variable = 0 or 1)
## Econometric Analysis

Estimates of equations (3) and (4)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Lin-Lin</th>
<th>Lin-Lin</th>
<th>Log-Log</th>
<th>Log-Log</th>
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</thead>
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<tr>
<td>$D_{ikt}$</td>
<td>1.38***</td>
<td>1.38***</td>
<td>0.63***</td>
<td>0.63***</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
</tr>
<tr>
<td>$D_{ik}$</td>
<td>18.40***</td>
<td>18.67***</td>
<td>0.19***</td>
<td>0.21***</td>
</tr>
<tr>
<td></td>
<td>(1.35)</td>
<td>(1.35)</td>
<td>(0.01)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>$F_{ikt} / K_k$</td>
<td>9.66***</td>
<td>9.54***</td>
<td>67.75***</td>
<td>70.08***</td>
</tr>
<tr>
<td></td>
<td>(0.29)</td>
<td>(0.29)</td>
<td>(0.53)</td>
<td>(0.54)</td>
</tr>
<tr>
<td>$T_i$</td>
<td>-0.74</td>
<td>-</td>
<td>-43.50***</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(0.86)</td>
<td></td>
<td>(0.18)</td>
<td></td>
</tr>
<tr>
<td>$D_{ikt}^0 T_i$</td>
<td>-</td>
<td>0.45</td>
<td>-</td>
<td>-0.09***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.05)</td>
<td></td>
<td>(0.02)</td>
</tr>
<tr>
<td>$F_{ikt} / K_k$</td>
<td>-</td>
<td>1758.23***</td>
<td>-</td>
<td>0.22***</td>
</tr>
<tr>
<td>$T_i$</td>
<td></td>
<td>(351.97)</td>
<td></td>
<td>(0.03)</td>
</tr>
<tr>
<td>$F_{ikt} / F_{kt}$</td>
<td>-</td>
<td>-2.20***</td>
<td>-</td>
<td>-63.54***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.72)</td>
<td></td>
<td>(0.58)</td>
</tr>
<tr>
<td>$Goods_i$</td>
<td>-12.96***</td>
<td>-12.94***</td>
<td>-0.38***</td>
<td>-0.38***</td>
</tr>
<tr>
<td></td>
<td>(0.53)</td>
<td>(0.53)</td>
<td>(0.18)</td>
<td>(0.18)</td>
</tr>
<tr>
<td>$Area_k$</td>
<td>0.45***</td>
<td>0.46***</td>
<td>-0.38***</td>
<td>-0.38***</td>
</tr>
<tr>
<td></td>
<td>(0.22)</td>
<td>(0.22)</td>
<td>(0.18)</td>
<td>(0.18)</td>
</tr>
<tr>
<td>$Paris_k$</td>
<td>14.08***</td>
<td>14.13***</td>
<td>0.34***</td>
<td>0.34***</td>
</tr>
<tr>
<td></td>
<td>(0.21)</td>
<td>(0.022)</td>
<td>(0.01)</td>
<td>(0.01)</td>
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<tr>
<td>Observations</td>
<td>49,822</td>
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<td>49,822</td>
<td>49,822</td>
</tr>
<tr>
<td>$R^2$</td>
<td>84.9</td>
<td>84.9</td>
<td>96.2</td>
<td>96.2</td>
</tr>
</tbody>
</table>
**ECONOMETRIC ANALYSIS**

**Discussion of results**

- The longer the distance and/or the lower the authorized maximal speed, the longer the travel time, whatever the model considered.

- The time spent by class \( i \) vehicles is positively correlated with the flow to capacity ratio of similar vehicles, and the influence of dissimilar vehicle flows is even more important.

- If we look at the model with interaction terms: the trucks are more sensitive than small vehicles to the minimal travel time, and to the similar and dissimilar vehicle flows.

- The control variables are all statistically significant:
  - Trips linked to goods movements are shorter than passenger trips.
  - The bigger the OD area, the shorter the travel time (in the preferred log-log model).
  - Trips having Paris as origin or destination are longer than other trips.
ECONOMETRIC ANALYSIS
Using the estimation results

- The log-log model was favored (because of the higher $R^2$). This allows us to calibrate travel time-flows relationships

\[
\log D^S_{kt} = 1.07 + 0.63\log D^S_{k0} + 0.21\log \frac{F^S_{kt}}{K_k} + 70.08\log(1 + \frac{F^L_{kt}}{F_{tk}}) \quad (5)
\]

\[
\log D^L_{kt} = 0.56 + 0.54\log D^L_{k0} + 0.43\log \frac{F^L_{kt}}{K_k} + 6.54\log(1 + \frac{F^S_{kt}}{F_{kt}}) \quad (6)
\]

- Using the estimation results, equation (5) and (6) can be re-written as:

\[
D^S_{kt} = e^{1.07} (D^S_{k0})^{0.63} \left( \frac{F^S_{kt}}{K_k} \right)^{0.21} \left( 1 + \frac{F^L_{kt}}{F_{kt}} \right)^{70.08} \quad (7)
\]

\[
D^L_{kt} = e^{0.56} (D^L_{k0})^{0.54} \left( \frac{F^L_{kt}}{K_k} \right)^{0.43} \left( 1 + \frac{F^S_{kt}}{F_{kt}} \right)^{6.54} \quad (8)
\]
ECONOMETRIC ANALYSIS

Travel times of vehicles as a function of the share of different traffic classes

- Average duration of small vehicles
- Average travel time of large vehicles
CONCLUSION

- We suggest a theoretical framework in order to differentiate the impacts of small and big vehicles on the total traffic.

- The impact of large vehicles on the travel time is more important than the impact of small vehicles.

- We can use these results to calculate marginal congestion costs for passenger vehicles and for freight vehicles (trucks AND vans), a work in progress.
Thank you for your attention

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