GHG Emissions, Urban Mobility and Efficiency of Urban Morphology: A Hypothesis

“Carbon based energy pricing could trigger demand shift toward transit in dominantly monocentric cities providing adequate zoning changes were made. Is the zoning approach currently used in Singapore and New York applicable to other cities?”

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The questions we are trying to answer

- We focus on GHG emissions produced by commuting trips
- Mobility is indispensable for a city economy, reduction of GHG therefore has to come from a shift toward better technology and a mode shift from cars to transit
- Carbon pricing through a carbon tax or carbon cap and trade is the only way to accomplish this change
- Transit however operates efficiently only for trips from the urban periphery toward a dense center with a concentration of jobs and amenities
- Can land markets and urban planning reinforce dense and active city cores in the future?
- Two cities, New York and Singapore, have deliberately and successfully increased the job density in their central business district while investing in transit and new amenities
- Can their experience be replicated in other cities? Under which conditions?
1. The link between GHG emissions, transport cost, transport speed and city shape

2. Energy pricing, GHG emissions and market based incentives

3. Linkages between urban spatial structures and transport mode: monocentric vs. polycentric structure

4. The experience and performance of Singapore and New York and the counter experience of Mumbai

5. Which type of city should try to retain a dominantly monocentric structure? How to do it?

6. Conclusions
The link between GHG emissions, transport cost, transport speed and city shape

**Urban transport represents about 30% of CO2 urban emissions**

**CO2 emissions per capita in large cities are only a fraction of countries CO2 emissions.**

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**Mobility is the lifeblood of cities’ economy**

“[...] mobility, which I would argue is the centerpiece of our national productivity, is neither highly valued nor understood among public officials.” (Pizarski, 2006)

- Poor migrants moving to large cities have usually difficulties in participating in the urban economy either because their housing is located too far from the urban transport networks or because they cannot afford the cost of transit or motorized transport.
Mobility is the lifeblood of cities' economies

• Because mobility is a necessity for economic survival in large cities, a reduction of GHG should not be made by reducing mobility and certainly not by preventing an increase in mobility for the poor.

• The reduction of the number of Passengers Kilometer Traveled (PKmT) should not be targeted for reduction in order to reduce GHG emissions.

• Because of the lack of mobility of a large number of poor people living in large cities, PKmT should increase in the future.

How to identify the key parameters in urban transport GHG Emission sources?

GHG emissions from transport are produced by trips that can be divided into 3 broad categories:

1. commuting trips
2. non-commuting trips, and
3. Freight.
How to identify the key parameters in urban transport GHG Emission sources?

Commuting trips could be disaggregated into three broad modes:

1. Non motorized mode (walking and cycling, and increasingly included in this category, people working at home and telecommuting)
3. Transit mode (minibuses, buses, bus rapid transit (BRT), light rail, subways and suburban rail).

- The GHG emission performance of vehicles (private or transit) varies enormously
- In addition, within each mode – Self Operated Vehicles (SOV) and transit – each city has a fleet of vehicles, which GHG emissions performance differs often by orders of magnitude depending on:
  1) the technology used,
  2) the maintenance,
  3) the age of the vehicle,
  4) the energy source, and
  5) the load (the average number of passengers per vehicle)
The emission performance of the various types of vehicles used in motorized mode vary enormously.

### GHG emissions for various vehicles with various passengers load assumptions

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Gr Co2 e.per passkm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLUV</td>
<td>258</td>
</tr>
<tr>
<td>Average US car</td>
<td>227</td>
</tr>
<tr>
<td>Motor buses</td>
<td>137</td>
</tr>
<tr>
<td>Light rail</td>
<td>111</td>
</tr>
<tr>
<td>Commuter rail</td>
<td>93</td>
</tr>
<tr>
<td>Hybrid gas</td>
<td>91</td>
</tr>
<tr>
<td>Toyota Prius</td>
<td>73</td>
</tr>
<tr>
<td>Hybrid Diesel</td>
<td>63</td>
</tr>
<tr>
<td>Metro</td>
<td>56</td>
</tr>
<tr>
<td>New York MTA</td>
<td>45</td>
</tr>
<tr>
<td>New York subway</td>
<td>36</td>
</tr>
</tbody>
</table>


A simple model could show the differences in carbon emission equivalent when there is mode shift (car to transit for ex), when the population increases, or when the performance of the fleet of vehicle changes.

\[
Q = T \sum_{i=1}^{N} \frac{2 \cdot D_i \cdot P_i \cdot E_i}{L_i \cdot 10^6}
\]

Where:
- \( Q \) is the total carbon equivalent emitted per day by passengers while commuting to work (does not include non commuting trips) in metric tons per day.
- \( T \) is the total Number of commuters per day.
- \( N \) is the number of commuting transport modes types numbered from 1 to \( N \).
- \( D_i \) is the Average commuting distance one way per passenger in km per type \( i \) of commuting mode.
- \( P_i \) is the percentage of commuters using transport mode type \( i \).
- \( E_i \) is the carbon emissions of vehicle used for mode \( i \) in gram carbon equivalent (full life cycle) per vehicle kilometer traveled.
- \( L_i \) is the load factor expressed in average number of passengers per vehicle of type \( i \).
In New York Metropolitan area if 1/3 of current car using commuters shifted to hybrid cars it would decrease commuting GHG emissions by 28%.

A shift from car to transit by 10% of the total number of commuters would decrease GHG emissions by 13%.

### New York Metropolitan Area: Impact of vehicle shift and mode shift on CO2 e emissions

<table>
<thead>
<tr>
<th>Units</th>
<th>(A)</th>
<th>(B)</th>
<th>(C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>1. Walk</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>2. Cycle</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>3. Car (Gasoline)</td>
<td>37.5%</td>
<td>5.5%</td>
<td>5%</td>
</tr>
<tr>
<td>4. Car (Diesel)</td>
<td>5%</td>
<td>5.5%</td>
<td>0.5%</td>
</tr>
<tr>
<td>5. Car (Hybrid)</td>
<td>0.5%</td>
<td>19%</td>
<td>na</td>
</tr>
<tr>
<td>6. Car (electric)</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>7. Motorcycle 2 stroke</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>8. Minibus gasoline</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>9. Minibus Diesel</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>10. Bus Diesel</td>
<td>5%</td>
<td>5%</td>
<td>6%</td>
</tr>
<tr>
<td>11. Bus Natural gas</td>
<td>10%</td>
<td>10%</td>
<td>12%</td>
</tr>
<tr>
<td>12. Rail transit</td>
<td>21%</td>
<td>21%</td>
<td>28%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tons per day</th>
<th>51,545</th>
<th>36,918</th>
<th>44,698</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg per year per commuter</td>
<td>1,418</td>
<td>1,024</td>
<td>1,240</td>
</tr>
</tbody>
</table>

Travel time by different mode is one of the major issue affecting mode preferences.

In Singapore, with one of the most well designed transit system in the world, transit travel time is from 40 to 90% longer than by individual car.

### Average Travel Time by Mode in US Urban areas in 2000 (minutes)

### Singapore - Travel time, distance per travel mode

<table>
<thead>
<tr>
<th>Mode</th>
<th>Median Travel Time (minutes)</th>
<th>Distance (km)</th>
<th>Speed (Km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>29</td>
<td>29.2</td>
<td>65</td>
</tr>
<tr>
<td>Metro</td>
<td>41</td>
<td>11.5</td>
<td>17</td>
</tr>
<tr>
<td>Metro + Bus</td>
<td>51</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Bus alone</td>
<td>38</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Two hypothesis are tested in this paper:

**Hypothesis 1**: Price signals, including energy prices and carbon-market based incentives, road tolls, and transit fares, are the main drivers of technological change, transport modal shift and land use regulatory changes.

**Hypothesis 2**: Price signals could shift transport mode from individual cars to transit only for trips from the periphery to the CBD in cities that are dense (more than 50p/ha in built-up areas) and already dominantly monocentric.

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2. Energy pricing, GHG emissions and market based incentives
Policy instruments

1. **Regulatory instruments**, such as:
   - limitations on the number of vehicles on the road a given day (e.g. Beijing, Bogota and Mexico City “pico y placa”),
   - limitation on the number of cars registered in the city (e.g. Singapore car quota system)

2. **Pricing instruments** modifying relative prices between private car and transit modes, such as:
   - road pricing: fixed tolls and congestion pricing (e.g. Singapore, London, Stockholm)
   - fuel tax which need to be compared with an increase in the price of a barrel of oil due to oil market evolution (e.g. Bogota, Singapore, Chicago, most US cities)
   - transit fares subsidies (e.g. Los Angeles, San Francisco)
   - pricing and taxing of parking (e.g. New York, Sheffield, Peterborough, Edinburgh)

3. **Investment in transport infrastructure** in order to increase and improve supply of transit modes (e.g. Singapore, Bogota, Jakarta)

Efficiency of various policy instruments

1. **Regulatory instruments**: Not very efficient when used alone
2. **Pricing instruments**: indispensable to trigger change rapidly in vehicle technology, energy sources and shift to transit
3. **Investments in transit and infrastructure**: efficient only when combined with pricing instruments, including congestion pricing
3. Linkages between urban spatial structures and transport mode: monocentric vs. polycentric structures

Atlanta and Barcelona have about the same population; it is not difficult to know in which city transit is unlikely to become a dominant mode of transport.
Spatial structure matters for transit operation

**THE MOST COMMON URBAN SPATIAL STRUCTURES**

- **A. The Classical Monocentric Model**
  - Strong high density center with high concentration of jobs and amenities
  - Radial movements of people from periphery toward center

- **B. The "Urban Village" Model**
  - People live next to their place of employment
  - People can walk or bicycle to work
  - This model exists only in the mind of planners, it is never encountered in real life

- **C. The Polycentric Model**
  - No dominant center, some subcenters
  - Jobs and amenities distributed in a near uniform manner across the built-up area
  - Random movement of people across the urban area

- **D. The Composite Model**
  - A dominant center, some subcenters
  - Simultaneous radial and random movement of people across the urban area

*Order Without Design* Behrens 2008 (unpublished)
Transport strategies need to be consistent with cities’ spatial structures

the relationship between urban spatial structures and transit:

1. transit is efficient when trips’ origins are dispersed but destinations are concentrated
2. individual transport and microbuses are more efficient when origin and destinations of trips are both dispersed,
3. Mode shift toward transit will happen only if price and speed is competitive with other modes, therefore for trips from suburbs to concentrated areas of jobs and amenities
4. Trips toward dense downtown areas (above 150 people/ha) should be prevalently done by transit.
5. Failure to provide efficient transit service to the CBD and to regulate traffic and parking would result in a dispersion of jobs in suburban areas, making transit inefficient as a main mean of transport in the long term.

4. The experience and performance of Singapore and New York and the counter experience of Mumbai
Manhattan high job density (2160 job/ha in Mid Town) and high transit accessibility has been allowed by constant upward adjustment in floor area ratio (FAR) in the areas with the most demand.

Singapore system of radial rapid transit and feeder bus network is one of the most efficient in the world. Land use regulations have been consistent over a period of more than 20 years with infrastructure investments in roads and transit. Singapore has been the first city to apply systematically congestion pricing to the road network.
Singapore is currently more than doubling the area of its central business district with FAR values reaching 2.5 in some blocks. The creation of new amenities along the waterfront and the rehabilitation and conservation of the historical district reinforce the attraction of the CBD, which is also the area the easiest to access by transit from anywhere in the city.

In spite of the impressive governance record of Singapore (road pricing, transit investment and land use regulations) transit accounted for only 52% of all commuting trips to work!
Mumbai counter-example: inconsistency between transit accessibility and land use regulations

Mumbai suburban railway bring several 100,000 people each day to the CBD

The zoning regulations allow only an FAR of 1.33 in the CBD (compared to 25 in Singapore and 15 in Manhattan). The new CBD of Bandra Kurla has only and FAR of 4 and is not directly accessible by rapid transit.

5. Which type of city should try to retain a dominantly monocentric structure?

How to do it?
The possibility of shift toward transit mode depends on retaining a high degree of monocentricity.

Increasing the share of transit requires the following:
1. A radial transit network giving high accessibility to the CBD
2. Congestion pricing of roads and parking pricing at market value in CBD
3. Land use regulations, in particular FAR, consistent with high density
The share of transit in Mexico city has decreased from 64% to 24% in 14 years. In spite of the very extensive modern and well designed metro system. What happened?

A change of spatial structure: congested and underdeveloped traditional CBD contributed to a dispersion of jobs that are more easily reached by minibuses.

**Share of daily trips by mode for the Mexico City Metropolitan Area**

![Graph showing the share of daily trips by mode from 1986 to 2000, with a gradual take-over of public mass transit by collectivos from 1986 to 2000. Source: Secretaria de Transito y Viabilidad (SETRAVis) Embarg - World Resources Institute.]

6. Conclusions:

- GHG emissions due to urban transport can be reduced significantly by modernizing vehicle fleet, and shifting more commuting trips toward transit
- Carbon based energy pricing and congestion road pricing could trigger demand shift toward transit in dominantly monocentric cities providing adequate zoning changes were made.
- The zoning and pricing approach currently used in Singapore and New York is applicable to dense cities with a radial transit network.