The Role of Public Transit

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Why Transit? I

- Auto: Operating cost ≈ 31¢/vm
  - 1.5 peak passengers / car
  - 20.7¢ / passenger mile
- Bus Transit Operating costs ≈ $2.95 / vm
  - 50 peak passengers / bus
  - 5.9¢ / passenger mile
- Clearly, transit is a cheaper way of moving people around (at least on an operating cost basis)

Why Transit? II

- But wait: transit operates at nowhere near 50 people per vehicle
- In fact, average load factors are about 15%, so about 7.5 people per bus
- With an operating cost of $2.95/vm, this is about 40¢ / passenger mile
- Transit’s advantage has disappeared

Why Transit? III

- How many people would transit buses need to carry in order to justify transit on an operating cost basis?
- We solve
  
  \[
  \frac{\text{auto cost/passenger}}{\text{transit cost/pasenger}} = \frac{0.31/1.5}{2.95/x}
  \]
  
  for \( x \), the number of passengers to make transit cost-competitive with the auto.
- We find that if transit buses serve \( x = 15+ \) people, then transit is cost-competitive
- But this is approximately double transit’s observed demand. Is this realistic, given the way transit is operated today?
Role of Public Transit

This raises at least two questions:

- What is it worth to have (say) bus transit available? How would people be affected if some transit mode disappeared?
- What role should public transit play in the urban economy?

But before we get to this, we need some background

Preliminaries I

- Suppose we contemplate a change in COTA’s characteristics, say an improvement in its coverage of the city.
- If we implement this, it will have impacts on two different classes of people
  - Existing COTA users will find their trips made more convenient
  - Some non-COTA users will decide that COTA is now better than their current mode and will switch.

To decide whether this change is a good idea, we need to know how people value it
- And because we will eventually need to compare this value to the cost to COTA, we want the value of people’s changes to be measured in money.

Preliminaries II

Thus, in order to understand the impacts on people of any proposed change, we need to understand

- The demand for transportation modes, so we can predict how many people will switch after any change.
- The perceived benefits of any change to the people themselves.

Preliminaries III

We shall therefore study briefly:

- Modern formulations of the demand for urban transportation
  See handout: Discrete-Choice Logit in a Nutshell
- A money measure of the (individual) benefits of a change in the transportation environment
  See handout: Logit and WTP
We now return to the main thread of our analysis, where we raised two questions: the importance of transit as it is organized today, and the appropriate role of transit in the urban economy.

We shall try to answer both of these questions following the analysis of Winston and Shirley.

All the answers depend on having a model for the demand for urban transportation.

W+S estimate such a model, based on the 116 largest urban areas in the US in 1990.

### Demand for Urban Transportation

The W+S model:

- Aggregate logit model of modal shares (for each urban area the dependent variable is the share of the population using a given mode).
- Choice set is two-dimensional: modes and departure time. The modal part of the choice set contains: Auto-alone, carpool, bus transit, rail transit (where available), and taxi. The departure time dimension is categorized by half-hour or hourly increments in the morning. In effect, we are modelling work-trip decisions: W+S will later make an assumption about non-work-trips in relation to these.
- Decisions are differentiated by travel distance (distance blocks), on the plausible view that people who live a long way from their destination are likely to behave differently from people who live close.
- See separate handout for model results.

### Values of Time $1990 ($/hour) : work trips

The following table shows the values of time implied by the results of the Winston+Shirley choice model, for work trips.

<table>
<thead>
<tr>
<th>Distance Block</th>
<th>Peak</th>
<th>Non-Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 mile</td>
<td>1.24</td>
<td>0.81</td>
</tr>
<tr>
<td>1–5 miles</td>
<td>3.97</td>
<td>2.89</td>
</tr>
<tr>
<td>6 – 10 miles</td>
<td>6.80</td>
<td>4.82</td>
</tr>
<tr>
<td>11-25 miles</td>
<td>8.03</td>
<td>5.43</td>
</tr>
<tr>
<td>&gt; 25 miles</td>
<td>6.83</td>
<td>4.44</td>
</tr>
</tbody>
</table>

Peak: 7:00 – 9:00 am; Non-Peak: all other times.

W+S assume that non-work trips are valued at 50% of work trips.

### Benefits of Current Transportation Modes I

Here we ask: what is the value in having a specific mode available? We approach this by asking: how much harm would we do if a mode was eliminated? We expect two kinds of impacts:

1. People would have to switch modes, typically to a mode they regarded as worse than the mode they currently use. This is a dis-benefit.
2. But in the case of subsidized modes, they would also save (via the tax system) the subsidies they are now paying (though they might need to pay more to subsidize substitute modes).

So the question is about the net effect of both of these.
Benefits of Current Transportation Modes II

- To estimate the harm done by the elimination of a mode we compute a compensating variation, comparing the current world with a world in which a specific mode was no longer available. To do this, we set its cost (fare) sufficiently high, and its positive modal characteristics sufficiently low, to result in zero probability of that mode being chosen.
- Typically, if we eliminate a mode people will be willing to pay a positive quantity to avoid this. So the consumer impact is the negative of this willingness-to-pay.
- Finally, if a mode is eliminated, we will need to accommodate the former users on other modes. This may require additional subsidies to these modes, which will change tax bills. This is the impact on government balances.

Results: Value of Current Transportation Modes I

Values are in billions of 1990 dollars relative to current situation

<table>
<thead>
<tr>
<th>Mode</th>
<th>Consumer Impact</th>
<th>Government Balance</th>
<th>Total Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto</td>
<td>-161.9</td>
<td>-21.7</td>
<td>-183.6</td>
</tr>
<tr>
<td>Carpool</td>
<td>-20.8</td>
<td>9.9</td>
<td>-22.1</td>
</tr>
<tr>
<td>Bus</td>
<td>-4.1</td>
<td>9.9</td>
<td>5.8</td>
</tr>
<tr>
<td>Rail</td>
<td>-3.0</td>
<td>3.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Taxi</td>
<td>-0.8</td>
<td>0.0</td>
<td>-0.8</td>
</tr>
</tbody>
</table>

Note: this is W+S Table 3–4 with the signs reversed

Consumer impact: negative numbers indicate that consumers see the elimination of the mode in question as dis-benefit.
Government balances: negative numbers indicate that public-sector expenditures (on other modes) after elimination of the mode in question increase, resulting in a higher tax bills for individuals. Positive numbers mean that tax bills decrease.

Results: Value of Current Transportation Modes II

We see:

- Eliminating bus transit (in its current form) would result in a net benefit of $5.8b per year
- Rail transit is a wash
- For the auto-based modes, eliminating any of them is a net loss to the urban economy, with (as expected) the option of eliminating auto transport resulting in a huge loss.

Optimal Transit Provision

We have seen that eliminating bus transit — the major current mode — would be a net benefit to the community
But could this be because bus transit is operated badly?
We therefore turn to our second question: how should urban transportation be provided?

- We formulate this as an optimization question: what modes should people use and how should they be configured in order to maximize net social welfare (NSW)?
- NSW Components:
  - Net User Benefits
  - Revenues from auto congestion tolls
  - Net revenues from bus transit
  - Net revenues from rail transit
Problem Setting

We follow Winston + Shirley:

- Work with the existing road network: no optimization of capacity or durability (after all, it’s what we have).
- Rail transit: no right-of-way construction (for the same reason).
- All transit: we optimize transit’s frequency (number of times a route-mile is covered in an hour).

Net User Benefits

- We measure this by the Compensating Variation, the money (income) equivalent of a change in the transportation environment relative to current conditions. (This means that current conditions are effectively irrelevant, since they are a constant)
- If prices are a part of the transportation environment, the CV will capture the impact of price changes, so we do not need to subtract prices explicitly when computing Net User Benefits.
- For W+S, the transportation environment is prices (fares), plus travel times for the auto based modes, and the level of frequency for the transit modes. It is important to note that (although they tried) they were unable to optimize transit route coverage.

Transit Net Revenues

For transit mode $j$:

\[
\text{Net Revenues}_j = \text{Revenues}_j - \text{Costs}_j \\
\text{Revenues}_j = \text{Commuters} \times \text{Fare}_j \times P_j
\]

where $P_j$ is the probability of using mode $j$ (possibly disaggregated over distance blocks and summed)

Costs of Bus Transit

- Simple linear model
- Total cost $= \beta_0 + 0.27 \text{[passenger miles]} + 0.05 \text{[seat miles]}
  \[ R^2 = 0.98 \]
- Seat miles $= \text{Frequency} \times \text{Average Vehicle Size} \times \text{Route Miles}$
- We take vehicle size and route miles as exogenous
- So we can express bus transit costs in terms of passenger miles and frequency
- Passenger miles depend on distance travelled (a function of the distance block) and the number of passengers, which depends on the demand (logit) model.
Costs of Rail Transit

- Also a simple linear model
- Total Cost = γ₀ + 0.17 [passenger miles] + 0.03 [seat miles]
- \( R^2 = 0.98 \)
- We can also express rail costs as a function of passenger miles and frequency

\[
\text{Total Cost} = \gamma_0 + 0.17 \text{ [passenger miles]} + 0.03 \text{ [seat miles]}
\]

Road Networks

- Expressways:
  - Speed-flow curve taken from Keeler+Small, Eastshore Freeway
  - \( u_\ell = 46 + \sqrt{471 - 0.26 (Q_\ell / c)} \)
- Other roads:
  - \( u_\ell = 18.38 \left( 1 - 0.01 \left( \frac{D}{w} \right)^{1.239} \right)^{2.58} \)
    
    \( D = \text{density} \quad w = \text{number of lanes} \)

Equilibration Procedure

Results I

<table>
<thead>
<tr>
<th>Item</th>
<th>Initial value</th>
<th>Optimal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Auto Tolls ($/mi)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6:30–7:00 am</td>
<td>0</td>
<td>1.9</td>
</tr>
<tr>
<td>7:00–7:30 am</td>
<td>0</td>
<td>4.8</td>
</tr>
<tr>
<td>7:30–8:00 am</td>
<td>0</td>
<td>6.4</td>
</tr>
<tr>
<td>8:00–8:30 am</td>
<td>0</td>
<td>2.6</td>
</tr>
<tr>
<td>8:30–9:00 am</td>
<td>0</td>
<td>2.6</td>
</tr>
<tr>
<td>9:00–10:00 am</td>
<td>0</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Transit Fares ($/mi)</strong></td>
<td>13.2</td>
<td>55.2</td>
</tr>
<tr>
<td>Bus</td>
<td>17.4</td>
<td>34.8</td>
</tr>
<tr>
<td><strong>Transit Frequency</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bus</td>
<td>0.95</td>
<td>0.26</td>
</tr>
<tr>
<td>Rail</td>
<td>20.80</td>
<td>12.40</td>
</tr>
</tbody>
</table>
Results II

<table>
<thead>
<tr>
<th>Mode</th>
<th>Initial value</th>
<th>Optimal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto</td>
<td>79.1</td>
<td>82.0</td>
</tr>
<tr>
<td>Carpool</td>
<td>14.3</td>
<td>15.6</td>
</tr>
<tr>
<td>Bus</td>
<td>4.7</td>
<td>0.9</td>
</tr>
<tr>
<td>Rail</td>
<td>1.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Taxi</td>
<td>0.8</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Results III

<table>
<thead>
<tr>
<th>Source</th>
<th>Consumer Benefits</th>
<th>Govt Balances</th>
<th>Net Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total: auto, bus, rail</td>
<td>−13.5</td>
<td>24.4</td>
<td>10.8</td>
</tr>
<tr>
<td>Bus component</td>
<td>−3.6</td>
<td>9.7</td>
<td>6.1</td>
</tr>
<tr>
<td>Rail component</td>
<td>−2.3</td>
<td>3.6</td>
<td>1.3</td>
</tr>
</tbody>
</table>

$$b, 1990$$

Non-linearities mean that totals do not add up exactly

Results under Alternative Assumptions

<table>
<thead>
<tr>
<th>Source</th>
<th>Consumer Benefits</th>
<th>Govt Balances</th>
<th>Net Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>−13.5</td>
<td>24.4</td>
<td>10.8</td>
</tr>
<tr>
<td>Transit MC reduced 15%</td>
<td>−13.3</td>
<td>24.8</td>
<td>11.5</td>
</tr>
<tr>
<td>Nonwork trips valued 30% of work trips</td>
<td>−9.8</td>
<td>24.7</td>
<td>14.9</td>
</tr>
<tr>
<td>Nonwork trips valued 70% of work trips</td>
<td>−16.5</td>
<td>24.6</td>
<td>8.1</td>
</tr>
<tr>
<td>Include accident costs</td>
<td>−13.2</td>
<td>24.6</td>
<td>12.2</td>
</tr>
<tr>
<td>Pollution costs incl but not charged</td>
<td>−13.2</td>
<td>24.7</td>
<td>11.1</td>
</tr>
<tr>
<td>Pollution costs incl + charged</td>
<td>−28.0</td>
<td>25.0</td>
<td>11.6</td>
</tr>
<tr>
<td>MC pricing only</td>
<td>−13.3</td>
<td>19.9</td>
<td>6.6</td>
</tr>
<tr>
<td>Total: auto, bus, rail</td>
<td>−6.8</td>
<td>10.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Auto tolls component</td>
<td>−3.6</td>
<td>5.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Bus component</td>
<td>−2.0</td>
<td>2.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Rail component</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Do We Believe It?

Some questions:

- Is transit’s LOS described by more than frequency (e.g., route coverage)?
- Is it reasonable to force transit to offer just one fare and one level of service at all times of day, and in all corridors, no matter how densely populated?
- What about load factors for transit? Is it reasonable to assume that they are fixed at observed levels?
- Is anything lost by not modelling trip-making explicitly?
- Is the nationwide (aggregate) demand model appropriate? We’ve seen that W+S’s results vary by city. If preferences do too, then, given that the travel demand literature concludes that choice models are not transferable, this may be a problem.
References

Clifford M. Winston and Chad Shirley. 
*Alternate Route: Toward Efficient Urban Transportation.*