Is Public Transit's 'Green' Reputation Deserved?

Justin Beaudoin  
*University of Washington Tacoma*

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Is Public Transit’s “Green” Reputation Deserved?

Evaluating the Effects of Transit Supply on Air Quality

Justin Beaudoin
(with Cynthia Lin Lawell)

University of Washington Tacoma

Portland State University: Friday Transportation Seminar
Motivation

- Transit advocated as a “sustainable” alternative to the car
  - Reducing congestion
  - Improving air quality

Is there evidence to support these claims?
Improving Air Quality

Ambient Pollution (Mean Daily Maximum, 1991 = 1.00)

- $O_3$
- PM10
- $NO_2$
- $SO_2$
- CO

Beaudoin (UWT)
Transit and Air Quality
November 2, 2018
Recent Transit Trends: *Prima Facie* Evidence?

Beaudoin (UWT)

Transit and Air Quality

November 2, 2018 3/51
Motivation

Sound Transit (ST3) in WA: initiative passed in Nov 2016

- $54 billion in capital expenditures
- Plus additional operating subsidies
- $170 per capita increase in annual taxes

Claim: ST3 will...

- ↓ auto VMT by 200-300m
- Help mitigate climate change
They also recognized the important role public transportation plays in addressing population growth, economic development, increased traffic congestion, and reducing pollution.
Research Questions

- Should public transit investment be increased as a means to address traffic congestion and air pollution?

- How effective have past public transit investments been in reducing congestion and improving air quality?

Implications

How we evaluate future transit investments

($\approx$ $18$ billion per year in U.S.)
Recent Transit Trends: *Prima Facie* Evidence?

![Graph showing correlation between % change pollution (1991-2011) and % change transit supply (1991-2011).]
Recent Transit Trends: *Prima Facie* Evidence?

![Graph showing the relationship between % change in pollution and % change in transit supply from 1991 to 2011.](image)

- **NO2**
- **% change pollution (1991-2011)**
- **% change transit supply (1991-2011)**
Recent Transit Trends: *Prima Facie* Evidence?

![Scatter plot showing the relationship between % change pollution and % change transit supply (1991-2011).](scatter_plot.png)
Recent Transit Trends: *Prima Facie* Evidence?

![Scatter plot showing the relationship between % change in pollution (1991-2011) and % change in transit supply (1991-2011) for PM10.](image)

- The scatter plot illustrates the correlation between changes in pollution and changes in transit supply over the period from 1991 to 2011 for PM10.

- The data points are distributed across the graph, indicating a visual trend but not necessarily a strong statistical correlation.

- Beaudoin (UWT) Transit and Air Quality November 2, 2018
Recent Transit Trends: *Prima Facie* Evidence?

Beaudoin (UWT)
Recent Transit Trends: Prima Facie Evidence?

![SO2 pollution vs transit supply graph](image-url)
Many studies linking auto travel and pollution

- Interest in adverse health effects

Uptick of recent studies linking public transit and pollution

- Chen and Whalley (2012)
- Bauernschuster, Hener and Rainer (2017)
- Rivers, Saberian, Schaufele (2017)

No clear empirical consensus
Link between transit supply and air quality depends on:

1. Modal distribution of vehicle-miles traveled (VMT)
   - Cross-elasticity of auto and transit demand wrt transit supply
   \[ \Rightarrow \approx 4x \text{ greater than fare elasticity} \]

2. Emission rates per VMT by mode

3. Spatial and temporal distribution of trips by mode
Auto Externalities: Our Second-Best World

The diagram illustrates the relationship between prices ($\$\$\$)$ and congestion externality ($\tau^*_c$, $\tau^*_{c+e}$) as well as the impact of emissions on the market. The curves represent different scenarios:

- $MSC^*_A$: Congestion + emissions
- $MPC^*_A$: Congestion
- $D_A$: Demand curve

Notations:
- $\widehat{V}_A$: Initial value
- $V^*_A$: Value with congestion
- $V'^*_A$: Value with congestion + emissions
- $\bar{K}_A$: Upper limit

The diagram shows how changes in emissions affect the equilibrium levels of congestion and the associated external costs.
Empirical Model Setup

For pollutant \( p \in \{\text{CO, NO}_2, \text{O}_3, \text{PM}_{10}, \text{PM}_{2.5}, \text{SO}_2\} \) in region \( r \) and year \( t \):

\[
\text{Air quality}_{prt} = \beta_1 \cdot \text{Transit Capacity}_{rt} + \beta_2 \cdot \text{Freeway Capacity}_{rt} \\
+ \beta_3 \cdot \text{Arterial Road Capacity}_{rt} + \beta_4 \cdot \text{Fuel Cost}_{rt} \\
+ \beta_5 \cdot \text{Transit Fare}_{rt} + \beta_6 \cdot \text{Trucking activity}_{rt} \\
+ \beta_7 \cdot \text{Employment}_{rt} + \beta_8 \cdot \text{Income}_{rt} \\
+ \beta_9 \cdot \text{Population}_{rt} + \beta_{10-11} \cdot \text{Pollution Point Sources}_{rt} \\
+ \beta_{12-15} \cdot \text{Weather Controls}_{rt} \\
+ \beta_{16-17} \cdot \text{NAAQS Standard Dummies} \\
+ \text{UZA and Census-Division Fixed Effects} + \varepsilon_{prt}
\]

- Travel volumes not included on RHS to allow for induced demand effect
### Pairwise correlation between pollutant concentrations, 1991-2011

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>NO₂</th>
<th>O₃</th>
<th>PM₂.₅</th>
<th>PM₁₀</th>
<th>SO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>1.000</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NO₂</td>
<td>0.553</td>
<td>1.000</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>O₃</td>
<td>0.009</td>
<td>0.253</td>
<td>1.000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>0.049</td>
<td>0.446</td>
<td>0.502</td>
<td>1.000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>0.341</td>
<td>0.498</td>
<td>0.268</td>
<td>0.379</td>
<td>1.000</td>
<td>-</td>
</tr>
<tr>
<td>SO₂</td>
<td>0.318</td>
<td>0.334</td>
<td>0.128</td>
<td>0.538</td>
<td>0.174</td>
<td>1.000</td>
</tr>
</tbody>
</table>

**Notes:**
- CO and O₃ are in units of parts per million (ppm).
- NO₂ and SO₂ are in units of parts per billion (ppb).
- PM₂.₅ and PM₁₀ are in units of micrograms per cubic meter (µg/m³).
Focus is on variation in air quality & transit supply *within* urban areas

Using urban area fixed effects to control for time-invariant regional heterogeneity

Potential endogeneity of transit investment

1. As policy measure to address existing congestion or environmental concerns

2. Component of growth/development strategy
Instrument for Transit Investment

- **Require:** variable(s) correlated with transit capacity but uncorrelated with unobserved factors affecting congestion & air quality

- **Instrument:** *Federal transit funding for capital expenses*
  - Excludes State and Local funds (≈ 67% of capital funding)
  - Supported by 2009 GAO report
Data Overview

- 96 ‘Urban Areas’ (UZAs) across the U.S.
  - 44 states; 351 counties
  - More of a *regional* focus than existing studies
    - Considering intensive margin (more policy-relevant)
<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>NO₂</th>
<th>O₃</th>
<th>PM₂.₅</th>
<th>PM₁₀</th>
<th>SO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.76</td>
<td>3.29</td>
<td>6.97</td>
<td>5.99</td>
<td>4.10</td>
<td>2.83</td>
</tr>
<tr>
<td>Median</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Minimum</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Maximum</td>
<td>19</td>
<td>18</td>
<td>30</td>
<td>35</td>
<td>32</td>
<td>12</td>
</tr>
<tr>
<td># of UZAs with ≥ 1 monitor for ≥ 2 years</td>
<td>91</td>
<td>82</td>
<td>96</td>
<td>96</td>
<td>94</td>
<td>88</td>
</tr>
<tr>
<td>Units of Measurement</td>
<td>ppm</td>
<td>ppb</td>
<td>ppm</td>
<td>µg/m³</td>
<td>µg/m³</td>
<td>ppb</td>
</tr>
</tbody>
</table>

Notes: Each monitor also records the AQI for each pollutant.

- ppm: parts per million, daily maximum.
- ppb: parts per billion, daily maximum.
- µg/m³: micrograms per cubic meter, daily maximum.
Data Sources

- **Auto**: congestion, capacity, travel, fuel
  - Texas Transportation Institute Urban Mobility Report
  - Federal Highway Administration (FHWA): Highway Statistics

- **Transit**: investment, ridership, fares/funding
  - Federal Transit Administration: National Transit Database (NTD)

- **Air Quality**: ambient pollution levels
  - Environmental Protection Agency (EPA)

- **Weather**: precipitation, temperature
  - National Oceanic and Atmospheric Administration (NOAA)

- **Socioeconomic**: population, employment, income
  - Bureau of Economic Analysis (BEA)
Spatial Heterogeneity: UZA Characteristics

Population

Population Density

% of FG Transit

Transit Accessibility

Transit Capacity

Transit Use

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Cross-Elasticity: Induced Demand

Elasticity of auto travel with respect to transit capacity

Population, Income & Employment: Lagged 0 to 10 years
Empirically, transit investment **does** help alleviate congestion

- On average, 10% ↑ transit capacity ⇒ 0.8% ↓ congestion

However, congestion-reduction effect dependent upon:

- Population size and density of region
- Characteristics and technology of public transit network
- The timing of the change and role of induced/latent demand

**Elasticity range: -0.02 to -0.3**
Empirical Model Setup

For pollutant $p \in \{\text{CO, NO}_2, \text{O}_3, \text{PM}_{10}, \text{PM}_{2.5}, \text{SO}_2\}$ in region $r$ and year $t$:

$$\text{Air quality}_{prt} = \beta_1 \cdot \text{Transit Capacity}_{rt} + \beta_2 \cdot \text{Freeway Capacity}_{rt}$$
$$+ \beta_3 \cdot \text{Arterial Road Capacity}_{rt} + \beta_4 \cdot \text{Fuel Cost}_{rt}$$
$$+ \beta_5 \cdot \text{Transit Fare}_{rt} + \beta_6 \cdot \text{Trucking activity}_{rt}$$
$$+ \beta_7 \cdot \text{Employment}_{rt} + \beta_8 \cdot \text{Income}_{rt}$$
$$+ \beta_9 \cdot \text{Population}_{rt} + \beta_{10-11} \cdot \text{Pollution Point Sources}_{rt}$$
$$+ \beta_{12-15} \cdot \text{Weather Controls}_{rt}$$
$$+ \beta_{16-17} \cdot \text{NAAQS Standard Dummies}$$
$$+ \text{UZA and Census-Division Fixed Effects} + \epsilon_{prt}$$
Some evidence that transit may modestly reduce CO
<table>
<thead>
<tr>
<th>Emission Share, On-Road Sources (2011)</th>
<th>38.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions, Million Tons (2011)</td>
<td>5.9</td>
</tr>
<tr>
<td>Short-run elasticity</td>
<td>+ (slightly insig.)</td>
</tr>
<tr>
<td>Medium-run elasticity</td>
<td>+ (slightly insig.)</td>
</tr>
<tr>
<td>Long-run elasticity</td>
<td>+</td>
</tr>
</tbody>
</table>

Some evidence that transit may modestly increase NO\textsubscript{x}; with CO result, consistent with some cross-modal substitution
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Emission Share, On-Road Sources (2011)</strong></td>
<td>4.5%</td>
</tr>
<tr>
<td><strong>Emissions, Million Tons (2011)</strong></td>
<td>2.6</td>
</tr>
<tr>
<td><strong>Short-run elasticity</strong></td>
<td>- (quite insig.)</td>
</tr>
<tr>
<td><strong>Medium-run elasticity</strong></td>
<td>+ (quite insig.)</td>
</tr>
<tr>
<td><strong>Long-run elasticity</strong></td>
<td>+ (quite insig.)</td>
</tr>
</tbody>
</table>

*Transit has no effect on $O_3$*
<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission Share, On-Road Sources (2011)</td>
<td>3.2%</td>
</tr>
<tr>
<td>Emissions, Million Tons (2011)</td>
<td>0.2</td>
</tr>
<tr>
<td>Short-run elasticity</td>
<td>+  (slightly insig.)</td>
</tr>
<tr>
<td>Medium-run elasticity</td>
<td>+</td>
</tr>
<tr>
<td>Long-run elasticity</td>
<td>+</td>
</tr>
</tbody>
</table>

Transit appears to increase PM$_{2.5}$
<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission Share, On-Road Sources (2011)</td>
<td>1.8%</td>
</tr>
<tr>
<td>Emissions, Million Tons (2011)</td>
<td>0.4</td>
</tr>
<tr>
<td>Short-run elasticity</td>
<td>+ (slightly insig.)</td>
</tr>
<tr>
<td>Medium-run elasticity</td>
<td>+</td>
</tr>
<tr>
<td>Long-run elasticity</td>
<td>+</td>
</tr>
</tbody>
</table>

Transit appears to increase PM$_{10}$
<table>
<thead>
<tr>
<th>Emission Share, On-Road Sources (2011)</th>
<th>0.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions, Million Tons (2011)</td>
<td>0.03</td>
</tr>
<tr>
<td>Social cost per ton</td>
<td>?</td>
</tr>
<tr>
<td>Short-run elasticity</td>
<td>+ (very insig.)</td>
</tr>
<tr>
<td>Medium-run elasticity</td>
<td>+ (very insig.)</td>
</tr>
<tr>
<td>Long-run elasticity</td>
<td>+ (very insig.)</td>
</tr>
</tbody>
</table>

Transit has no effect on SO₂
Interpreting Results

- Are the effects (statistically) zero? What is the economic significance?
- Appears to be masking **heterogeneity**:

In areas with:
- More FG transit (particularly *long-established* rail networks),
- High existing transit accessibility, and
- High existing transit ridership,

Additional transit supply:
- Decreases CO, and
- Lessens the increase in NO$_X$ and PM, relative to other regions.
Bus

Very low cross-elasticity & higher marginal pollution per rider (?)
Transit Technology: Fixed Guideway

- Commuter rail
- Light rail
- Heavy rail

Higher cross-elasticity & lower marginal pollution per rider (?)
From 1991-2011, % of VRM by FG increased from 34.5% to 39.2%:
From 1991-2011, % of PMT on FG increased from 52.1% to 61.8%:
No direct effect found by:

1. Treating FG and MT transit capacity separately

Future/Ongoing Work

- Extend dataset from 2011 to 2014
- Analyze the data at the monitor level
- Explore spatial heterogeneity in more detail
Transit’s Effect on Accessibility

Accessibility = Mobility x Proximity

Transportation (congested travel)

Location & land use (uncongested travel)
Transit’s Effect on Accessibility

Source: adapted from lecture by Gilles Duranton at the 2018 Canadian Economics Association annual meeting (6/2/2018, McGill University)
$53 million BRT line ("The Vine")
44,787 transactions in Clark County from 2012-2018
Transit’s Effect on Accessibility

![Graph showing Annual % Change in Real Prices](image)

- VMTC Construction Begins
- VMTC Opens

Legend:
- Solid line: Vancouver Census Tracts near VMTC
- Dashed line: Vancouver Census Tracts away from VMTC
Transit’s Effect on Accessibility

Vancouver Mall: Driving Accessibility (miles)

- 0.4
- 0.6
- 0.8
- 1
- 1.2
Transit’s Effect on Accessibility

Vancouver Mall: Walking Accessibility (minutes)

- 10
- 15
- 20
- 25
- 30

[Map of Vancouver Mall showing walking accessibility zones]
% change in property values due to Vine opening in Jan 2017

<table>
<thead>
<tr>
<th>Walk Time</th>
<th>Lower Bound</th>
<th>Mean</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 10 minutes</td>
<td>8.5%</td>
<td>10.7%</td>
<td>12.9%</td>
</tr>
<tr>
<td>10 - 15 minutes</td>
<td>5.2%</td>
<td>7.1%</td>
<td>9.0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Driving Distance</th>
<th>Lower Bound</th>
<th>Mean</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.4 miles</td>
<td>3.0%</td>
<td>5.0%</td>
<td>7.1%</td>
</tr>
<tr>
<td>0.4 - 0.6 miles</td>
<td>8.7%</td>
<td>11.5%</td>
<td>14.4%</td>
</tr>
<tr>
<td>0.6 - 0.8 miles</td>
<td>7.0%</td>
<td>9.1%</td>
<td>11.2%</td>
</tr>
</tbody>
</table>
Preliminary Conclusions

- Public transit has the potential to reduce *congestion* in some regions

- Less likely that public transit improves *air quality* (and may make it worse!), but there may be exceptions

  How does the story change if proper regulations are in place?

- Transit does lead to localized *accessibility/livability* benefits

  Adjust CBA and political debate accordingly
Thank You

Justin Beaudoin

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