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Is Public Transit's 'Green' Reputation Deserved?

Justin Beaudoin

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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?
Recent Transit Trends: *Prima Facie* Evidence?

![Graph showing trends in different transit metrics over time.](image-url)
Sound Transit (ST3) in WA: initiative passed in Nov 2016

- $54 billion in capital expenditures
- Plus additional operating subsidies
- \( \approx \$170 \) 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
(≈ $18 billion per year in U.S.)
Recent Transit Trends: *Prima Facie* Evidence?

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

![Graph showing the relationship between % change in pollution (1991-2011) and % change in transit supply (1991-2011) for NO2.](image)
Recent Transit Trends: *Prima Facie* Evidence?

![Graph](image-url)
Recent Transit Trends: *Prima Facie* Evidence?

![PM10 Scatter Plot](image)

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

![Graph showing PM2.5 pollution and transit supply trends](image)
Recent Transit Trends: *Prima Facie* Evidence?

The graph shows the correlation between the percentage change in pollution (1991-2011) and the percentage change in transit supply (1991-2011) for SO2 emissions. The scatter plot includes data points that suggest a weak relationship between the two variables.
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

\[ \tau_{c+e}^* \leq \tau_c^* \]

\[ D_A \]

\[ V_A^{*, \text{congestion} + \text{emissions}} \]

\[ V_A^{*, \text{congestion}} \]

\[ V_A^u \]

\[ \widetilde{V}_A \]

\[ \bar{K}_A \]

\[ M_{SC_A} \text{ congestion + emissions} \]

\[ M_{SC_A} \text{ congestion} \]

\[ M_{PC_A} \]

\[ D_A \]

Beaudoin (UWT)  Transit and Air Quality  November 2, 2018 15/51
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 $t$:

$$\text{Air quality}_{prt} = \beta_1 \cdot \text{Transit Capacity}_{rt} + \beta_2 \cdot \text{Freeway Capacity}_{rt}$$

$$+ \beta_3 \cdot \text{Arterial Road Capacity}_{rt} + \beta_4 \cdot \text{Fuel Cost}_{rt}$$

$$+ \beta_5 \cdot \text{Transit Fare}_{rt} + \beta_6 \cdot \text{Trucking activity}_{rt}$$

$$+ \beta_7 \cdot \text{Employment}_{rt} + \beta_8 \cdot \text{Income}_{rt}$$

$$+ \beta_9 \cdot \text{Population}_{rt} + \beta_{10-11} \cdot \text{Pollution Point Sources}_{rt}$$

$$+ \beta_{12-15} \cdot \text{Weather Controls}_{rt}$$

$$+ \beta_{16-17} \cdot \text{NAAQS Standard Dummies}$$

$$+ \text{UZA and Census-Division Fixed Effects} + \epsilon_{prt}$$

- 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>NO$_2$</th>
<th>O$_3$</th>
<th>PM$_{2.5}$</th>
<th>PM$_{10}$</th>
<th>SO$_2$</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>NO$_2$</td>
<td>0.553</td>
<td>1.000</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>O$_3$</td>
<td>0.009</td>
<td>0.253</td>
<td>1.000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>0.049</td>
<td>0.446</td>
<td>0.502</td>
<td>1.000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PM$_{10}$</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>SO$_2$</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 O$_3$ are in units of parts per million (ppm).

NO$_2$ and SO$_2$ are in units of parts per billion (ppb).

PM$_{2.5}$ and PM$_{10}$ are in units of micrograms per cubic meter ($\mu g/m^3$).
Identification and Potential Endogeneity

- 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)
UZAs Included
### EPA Air Quality Monitors

<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><strong>Mean</strong></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><strong>Median</strong></td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td><strong>Minimum</strong></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Maximum</strong></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><strong>Units of Measurement</strong></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

Population (millions)

Population (000s) per sq. mile

% of transit VRM by FG modes

Transit DRM per sq. mile

Transit VRM per capita

Transit PMT per auto VMT
Spatial Heterogeneity: Population Density

![Graph showing the relationship between population density and elasticity with 95% confidence interval. The graph plots population density (thousands per square mile) on the x-axis and elasticity on the y-axis. The data points are shown as black squares, and the 95% confidence interval is represented by a dashed line. The graph illustrates a downward trend as population density increases.](image-url)
Cross-Elasticity: Induced Demand

Elasticity of auto travel with respect to transit capacity

Population, Income & Employment: Lagged 0 to 10 years

Beaudoin (UWT)
Transit and Air Quality
November 2, 2018 28/51
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$, O$_3$, PM$_{10}$, PM$_{2.5}$, SO$_2$}\}$ in region $r$ and year $t$:

$$\text{Air quality}_{prt} = \beta_1 \cdot \text{Transit Capacity}_{rt} + \beta_2 \cdot \text{Freeway Capacity}_{rt} + \beta_3 \cdot \text{Arterial Road Capacity}_{rt} + \beta_4 \cdot \text{Fuel Cost}_{rt} + \beta_5 \cdot \text{Transit Fare}_{rt} + \beta_6 \cdot \text{Trucking activity}_{rt} + \beta_7 \cdot \text{Employment}_{rt} + \beta_8 \cdot \text{Income}_{rt} + \beta_9 \cdot \text{Population}_{rt} + \beta_{10-11} \cdot \text{Pollution Point Sources}_{rt} + \beta_{12-15} \cdot \text{Weather Controls}_{rt} + \beta_{16-17} \cdot \text{NAAQS Standard Dummies} + \text{UZA and Census-Division Fixed Effects} + \epsilon_{prt}$$
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Emission Share, On-Road Sources (2011)</strong></td>
<td>33.9%</td>
</tr>
<tr>
<td><strong>Emissions, Million Tons (2011)</strong></td>
<td>27.4</td>
</tr>
<tr>
<td><strong>Short-run elasticity</strong></td>
<td>- (slightly insig.)</td>
</tr>
<tr>
<td><strong>Medium-run elasticity</strong></td>
<td>- (slightly insig.)</td>
</tr>
<tr>
<td><strong>Long-run elasticity</strong></td>
<td>- (slightly insig.)</td>
</tr>
</tbody>
</table>

*Some evidence that transit may modestly reduce CO*
Emission Share, On-Road Sources (2011) 38.0%

Emissions, Million Tons (2011) 5.9

Short-run elasticity + (slightly insig.)

Medium-run elasticity + (slightly insig.)

Long-run elasticity +

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 $O_3$
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></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>+</td>
</tr>
<tr>
<td>(slightly insig.)</td>
<td></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>Description</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>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission Share, On-Road Sources (2011)</td>
<td>0.5%</td>
</tr>
<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 SO$_2$
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
Accessibility = Mobility x Proximity

Transportation (congested travel)

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

Location Choices  
Amenities  
Infrastructure  
Congestion  
Urban Form  
Proximity  
Uncongested Mobility  
Accessibility  
Travel Choices

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

Annual % Change in Real Prices

VMTC Construction Begins
VMTC Opens

2013 2014 2015 2016 2017 2018

Vancouver Census Tracts near VMTC
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

Map showing accessibility zones around Vancouver Mall with a marker indicating Walnut Grove.
Transit’s Effect on Accessibility

Vancouver Mall: Walking Accessibility (minutes)

10
15
20
25
30
% 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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