Transportation Capital and its Effects on the U.S. Economy: A General Equilibrium Approach

Trevor Gallen\textsuperscript{1} Clifford Winston\textsuperscript{2}

NBER Summer Session
Urban Economics
July 2018

\textsuperscript{1}Purdue University
\textsuperscript{2}Brookings Institution
Motivation

Question A: Because the US has underspent on new projects, maintenance, or both, the federal government has an opportunity to increase average incomes by spending more on roads, railways, bridges and airports.

Also asked in 2013 and 2017, with similar results.
In the last recession, many macroeconomists treated transportation infrastructure spending as a “G”

Big macro literature on government spending and transfer multipliers (Leeper, Traum and Walker, 2015)

Big micro literature on effects of transportation capital (Melo, Graham, and Brage-Ardano, 2013)

**Goal**

- Build a macro model that features government investment in infrastructure, taking micro transportation estimates seriously

**Lessons:**

- Welfare and GDP are potentially significantly different in this context (compared to “T” or “G”)

- Even if long-run multipliers are above one and long-run flow utility gains, transportation infrastructure spending can reduce utility, especially with construction-related congestion

- Japan’s low government investment multiplier can be reconciled with higher US investment multiplier

- Slow infrastructure spending announced long in advance may be better than rapid spending

- Efficient transportation spending is important (not discussed here)
Literature

- Output elasticity of transportation capital: Aschauer (1989), Munnell (1990), Melo et al. (2013)


Model Overview

1. Households

2. Government

3. Firms
Model Overview

1. Households
   - Provide labor, save, consume, pay taxes

2. Government

3. Firms
Model Overview

1. Households
   - Provide labor, save, consume, pay taxes

2. Government
   - Taxes, determines government non-transportation expenditures, transfers, and transportation expenditures

3. Firms
Model Overview

1. Households
   - Provide labor, save, consume, pay taxes

2. Government
   - Taxes, determines government non-transportation expenditures, transfers, and transportation expenditures

3. Firms
   - Take in labor and capital and produce goods
**Model Overview**

1. **Households**
   - Provide labor, save, consume, pay taxes

2. **Government**
   - Taxes, determines government non-transportation expenditures, transfers, and transportation expenditures

3. **Firms**
   - Take in labor and capital and produce goods

4. **Standard competitive equilibrium**: government decisions taken as given.
Standard period utility over consumption $c$ and labor $L$ with two adjustments: commuting loss of time ($\omega_t$) and shopping loss of time ($\xi_t$):

$$U(c_t, L_t) = \frac{c_t^{1-\sigma}}{1-\sigma} - \psi \frac{\epsilon}{1+\epsilon} (L_t(1+\omega_t) + \xi_t c_t)^{\frac{1+\epsilon}{\epsilon}}$$

With period budget constraint over consumption, denoting investment $i$, various taxes $\tau^H$, $\tau^G$, and $\tau^T$, investment income $rK$, transfers $T$, and profits remitted to the household $\pi$:

$$c_t + i_t = w_t L_t (1 - \tau^H_t - \tau^G_t - \tau^T_t) + (1 - \tau^K_t) r_t K_t + T_t + \pi_t$$
Household FOC’s & Capital LOM

- Household’s intratemporal tradeoffs slightly perturbed:

\[
\frac{1}{c_t^\sigma} - \xi_t \psi(L_t(1 + \omega_t) + \xi_t c_t)^\frac{1}{\epsilon} = \lambda_t
\]

\[
(1 + \omega_t)\psi(L(1 + \omega_t) + \xi_t c_t)^\frac{1}{\epsilon} = \lambda_t w_t(1 - \tau_t^H - \tau_t^G - \tau_t^T)
\]

- Result: shopping wedge is tax on labor and capital, commuting wedge is tax on labor

- Macroeconomist’s view: wedges \( \omega \approx 0.11 \) and \( \xi c/L \approx 0.27 \) are big!

- Physical (non-transportation) capital LOM with adjustment costs:

\[
K_{t+1} = (1 - \delta)K_t + i_t - \frac{\kappa}{2} \left( \frac{i_t}{K_t} - \delta \right)^2 K_t
\]
Firms

- Perfectly competitive firm with productivity $A$, chosen inputs to production structural and equipment capital $K$, labor hours $L$, and unchosen input to production transportation capital $K^T$, with output elasticities $\alpha$, $1 - \alpha$, $\lambda_K$

$$ Y_t = A_t K_t^\alpha L_t^{1-\alpha} (K_t^T)^{\lambda_K} $$

- Note that for the firm, production is CRS (not for a social planner)

- We can absorb the unchosen input into the TFP term:

$$ A_t^* = A_t (K_t^T)^{\lambda_K} $$

- After that, firms are standard: capital affects productivity

$$ Y_t = A_t^* K_t^\alpha L_t^{1-\alpha} $$
Government

- Government spends money on one of three things, financing each with a labor income tax:
  - Non-transportation government expenditures $G (\tau^G)$
  - Lump-sum transfers to households $T (\tau)$
  - Transportation capital $K^T (\tau^T)$

- $G$ and $T$ are standard:

$$G_t + T_t = \tau^G_t w_t L_t + \tau^H_t w_t L_t + \tau^K_t r_t K_t$$
TRANSPORTATION CAPITAL

- Transportation capital is raised from labor income tax
  \[ i_t^T = \tau_t^T w_t L_t \]

- Transportation capital is nonstandard: average depreciation rate \( \delta_{1,K^T} \) and marginal depreciation rate \( \delta_{2,K^T} \):
  \[
  K_{t+1}^T = (1 - \delta_{1,K^T}) K_t^T - \delta_{2,K^T} (K_t^T - K^T) + \sum_{j=0}^{T} \phi_j i_{t-j}
  \]

- Gets at increasing costs of infrastructure or decreasing efficiency & potential congestion, time-to-build

- Other than taxes, transportation infrastructure has three important elasticities that impact the real economy:
  \[
  \Delta \log A_t^* = \lambda_K \tilde{K}^T \\
  \Delta \log \xi_t = \gamma_{\xi} \tilde{K}^T \\
  \Delta \log \omega_t = \gamma_{\omega} \tilde{K}^T
  \]
Model Summary

- Basic NCG model adjusted to have transportation capital

- Increased transportation capital:
  - Increases labor income tax rates
  - Increases firm productivity (constant returns)
  - Decreases labor wedge (commuting)
  - Decreases consumption wedge (shopping)

- Transportation capital dynamics may display congestion, time-to-build

- Transportation capital has flexible cost function, absorbs any decreasing returns
Calibration

- Calibrate to the U.S. economy in 2016: some direct, some jointly.

- Omit most calibration discussion for time

  - Joint calibration moments
  - Joint calibration parameters
  - Directly-calibrated parameters

- Seven important parameters & moments (prime denotes a 5% increase in infrastructure)

  - $\lambda^K$: 0.038, Melo et al. (2013), U.S. Median
  - $\{\phi_0, \phi_1, \phi_2\}$: $\{-0.5, 0.5, 1\}$, Al-Kaisy & Hall (2003)
  - $\gamma_\xi$: $(\xi' - \xi)c = -4$, close to Duranton & Turner (2009)
  - $\gamma_\omega$: $(\omega' - \omega)L = -0.5$, close to Duranton & Turner (2009)
  - $\delta_{2,KT}$: $\frac{Y' - Y}{w'L'(\tau^1)' - wL(\tau^1)} = 1.5$, CEA (2015)
Calibration-II

- $\delta_{2,K^T} = 0.114$ in calibration
- Seems high!
- Functional forms load diminishing returns on increasing costs
- Ratio of physical elasticity to monetary elasticity informative
  - 2.17 in our model
  - 2.34 taking average ratio in Melo et al.
  - 3.8 taking median ratio in Melo et al.
Robustness: Marginal depreciation rate

GDP Multiplier as a Function of Marginal Cost Increase

Range of CEA (2014) multipliers
Baseline Calibration
Ratio of Average of Marginal Products (Melo et al.)
Ratio of Median of Marginal Products (Melo et al.)
# Long-Run Results

Baseline & Counterfactual Static Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline</th>
<th>$K^T \uparrow 5%$</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor hours</td>
<td>1,510</td>
<td>1,512</td>
<td>2</td>
</tr>
<tr>
<td>Investment</td>
<td>9,499</td>
<td>9,537</td>
<td>38</td>
</tr>
<tr>
<td>Gov. transportation spending</td>
<td>2,259</td>
<td>2,504</td>
<td>245</td>
</tr>
<tr>
<td>Consumption</td>
<td>63,227</td>
<td>63,311</td>
<td>84</td>
</tr>
<tr>
<td>Gov. non-transportation spending</td>
<td>15,358</td>
<td>15,358</td>
<td>0</td>
</tr>
<tr>
<td>GDP</td>
<td>90,342</td>
<td>90,710</td>
<td>368</td>
</tr>
<tr>
<td>Equivalent variation</td>
<td></td>
<td>.</td>
<td>139</td>
</tr>
</tbody>
</table>

Numbers annually, in dollars per working age capita and hours per working age capita.

Measure equivalent variation using baseline BC multiplier $\lambda$:

$$EV = \frac{U' - U}{\lambda}$$  \hspace{1cm} (1)
**Static Results**

- Why is general equilibrium so important?
- We can break down GDP changes into direct changes due to productivity and endogenous responses:

\[
\frac{dY}{Y} = \frac{dA}{A} + \alpha \frac{dK}{K} + (1 - \alpha) \frac{dL}{L}
\]

- Decomposing,
  - A: 25%
  - K: 47%
  - L: 28%

- Result: output multiplier determines \( \frac{dY}{Y} \) and output elasticity determines \( \frac{dA}{A} \), so endogenous responses must make up 75% of GDP increase!
Static Results

Totally differentiate the utility function, to get five sources of utility gains

\[
du = \frac{dc}{c} - \psi \left( L(1 + \tau^W) + \xi_{sc}c \right)^{\frac{1}{\epsilon}}
\]

\[
\cdot((1 + \tau^W)dL + Ld\tau^W + \xi_{sc}dc + cd\xi_{sc})
\]

1. Change in consumption: +$98
2. Change in labor: -$62
3. Change in commuting wedge: +$13
4. Change in consumption travel time: -$14
5. Change in consumption travel wedge: +$104
6. Total: +$139
Japan has displayed much lower infrastructure GDP multipliers (Doi and Ihori, 2009)

\[ \lambda_K = 0.038 \] says strongly diminishing returns! Lower \( L \) and lower \( TFP \), combined with higher \( K^T \) gives low marginal productivity.

Re-calibrate parts of our model to Japan: \( \left( \frac{i^T}{Y} = 0.07, \tau^k = 0.55 \right) \)

Spending dramatically higher, per-capita capital stock 44% higher

Long-run GDP Multiplier of 0.96, or 0.41 if \( \delta \) fit to \( \delta = \delta_0 e^{\rho K^T} \)

Welfare losses of $0.09 per dollar spent, or $0.64 per dollar spent
SUMMARY OF LONG-RUN RESULTS

1. Long-run flow welfare gains fairly robust to changes in wedges, productivity, or costs (not shown)

2. Much of increase in GDP comes from GE modeling: partial equilibrium would miss.

3. Because labor and investment increase, welfare and GDP split (more than G or T).

4. Diminishing returns (increasing cost per effective unit) appear present in estimates, can explain Japan’s low multiplier

▶ Move to dynamic results...
Dynamic Results

Graphs showing dynamic results for variables Y, K^T, τ^G + τ^H, U (in dollars), C, and L over time from 5 to 25.
Dynamic Results

- Welfare gains move from $139 yearly gain ($2,388 NPV) to a $\sim 1$ average yearly loss (-$16$ NPV)

- Significant portion due to costly-time-to-build: $19$ gain ($369$ NPV) without costly aspect

- Bigger losses due to transition path itself

- Tax smoothing relatively unimportant (but could be with low interest rates)

- Smaller loss when transportation infrastructure building is delayed
CONCLUSION

- Transportation is important for macro (large wedges)
- Macro is important for transportation (necessarily large GE effects)
- Utility and GDP gains can (more) easily diverge with transportation infrastructure
- Positive long-run impact on flow utility not a guarantee of positive NPV EV
- Slow infrastructure spending announced long in advance may be better than rapid spending
### Joint Calibration

#### Calibrating Moments

<table>
<thead>
<tr>
<th>Description</th>
<th>Equation</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor hours</td>
<td>$L=1510$</td>
<td>ATUS</td>
</tr>
<tr>
<td>GDP</td>
<td>$Y=90342$</td>
<td>NIPA</td>
</tr>
<tr>
<td>Transfers as frac. of GDP</td>
<td>$\frac{wLT^H}{Y} = 0.12$</td>
<td>NIPA</td>
</tr>
<tr>
<td>Wasted time shopping</td>
<td>$\xi c = 402$</td>
<td>ATUS</td>
</tr>
<tr>
<td>Change in times wasted</td>
<td>$(\xi' - \xi)c = -4$</td>
<td>See text</td>
</tr>
<tr>
<td>shopping and commuting</td>
<td>$(\omega' - \omega)L = -0.5$</td>
<td>text</td>
</tr>
<tr>
<td>Gov. exp. as a frac. of GDP</td>
<td>$\frac{wLT^G}{Y} = 0.17$</td>
<td>NIPA</td>
</tr>
<tr>
<td>Trans. as a frac. of GDP</td>
<td>$\frac{i_T}{Y} = 0.025$</td>
<td>CBO (2015)</td>
</tr>
<tr>
<td>Transportation multiplier</td>
<td>$\frac{Y' - Y}{(wLT^T)' - wL(\tau^T)} = 1.5$</td>
<td>CEA (2014)</td>
</tr>
</tbody>
</table>

**Table:** This table depicts our 9 equations for 9 parameters: $\psi$, $\tilde{A}$, $\tau^H$, $\delta_1, K_T$, $\delta_2, K_T$, $\bar{\xi}$, $\gamma \xi$, $\gamma \omega$, $\tau^G$. 
# Direct Calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>IES</td>
<td>$\sigma$</td>
<td>1.38</td>
<td>SW 2007</td>
</tr>
<tr>
<td>Labor supply elasticity</td>
<td>$\epsilon$</td>
<td>0.75</td>
<td>C 2011</td>
</tr>
<tr>
<td>Capital’s output share</td>
<td>$\alpha$</td>
<td>0.283</td>
<td>GR 2007</td>
</tr>
<tr>
<td>$K$ depreciation</td>
<td>$\delta$</td>
<td>0.064</td>
<td>GR 2007</td>
</tr>
<tr>
<td>Commuting wedge</td>
<td>$\overline{\omega}$</td>
<td>0.11</td>
<td>ATUS</td>
</tr>
<tr>
<td>Capital tax rate</td>
<td>$\tau^K$</td>
<td>0.29</td>
<td>GR 2007</td>
</tr>
<tr>
<td>Cap. adjustment costs</td>
<td>$\kappa$</td>
<td>8</td>
<td>CCD 2005</td>
</tr>
<tr>
<td>Trans. Elas. of $A$</td>
<td>$\lambda_K$</td>
<td>0.038</td>
<td>MGR 2013</td>
</tr>
<tr>
<td>Discount rate</td>
<td>$\beta$</td>
<td>0.95</td>
<td>GR 2007</td>
</tr>
<tr>
<td>Time-to-build</td>
<td>${\phi_0, \phi_1, \phi_2}$</td>
<td>${-0.5, 0.5, 1}$</td>
<td>AK 2003</td>
</tr>
</tbody>
</table>
## Joint Calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expenditure tax</td>
<td>$\tau^G$</td>
<td>0.237</td>
<td>$G(X, \Theta)$</td>
</tr>
<tr>
<td>Shopping wedge</td>
<td>$\bar{\xi}$</td>
<td>0.006</td>
<td>$G(X, \Theta)$</td>
</tr>
<tr>
<td>Baseline $K^T$ depreciation</td>
<td>$\delta_{1,K^T}$</td>
<td>0.097</td>
<td>$G(X, \Theta)$</td>
</tr>
<tr>
<td>Marginal $K^T$ depreciation</td>
<td>$\delta_{2,K^T}$</td>
<td>0.114</td>
<td>$G(X, \Theta)$</td>
</tr>
<tr>
<td>Baseline TFP</td>
<td>$\bar{A}$</td>
<td>16.35</td>
<td>$G(X, \Theta)$</td>
</tr>
<tr>
<td>Disutility of labor</td>
<td>$\psi$</td>
<td>1.98$ \cdot 10^{-10}$</td>
<td>$G(X, \Theta)$</td>
</tr>
<tr>
<td>Transfer tax rate</td>
<td>$\tau^H$</td>
<td>0.05</td>
<td>$G(X, \Theta)$</td>
</tr>
<tr>
<td>Trans. Elas. of $\xi$</td>
<td>$\gamma_{\xi}$</td>
<td>-0.24</td>
<td>$G(X, \Theta)$</td>
</tr>
<tr>
<td>Trans. Elas. of $\omega$</td>
<td>$\gamma_{\omega}$</td>
<td>-0.08</td>
<td>$G(X, \Theta)$</td>
</tr>
</tbody>
</table>
Robustness: $\Omega$ and $\lambda_K$

Welfare gains as a function of GDP multiplier and output elasticity

- $\Omega = 0.9$
- $\Omega = 1$
- $\Omega = 1.5$
- $\Omega = 2.5$

Output Elasticity

Welfare Gain

Graph showing welfare gains for different values of $\Omega$. The graph displays lines for $\Omega = 0.9$, $\Omega = 1$, $\Omega = 1.5$, and $\Omega = 2.5$. The x-axis represents output elasticity, ranging from 0.02 to 0.10.
Welfare gain as a function of commuting and shopping wedge reductions

- 6 hour reduction in shopping travel time
- 4 hour reduction in shopping travel time
- 2 hour reduction in shopping travel time
- No reduction in shopping travel time

Reduction in commuting travel time (hours/year) from a 5% change in $K^T$