Evaluating Transportation Improvements Quantitatively: A Primer

Treb Allen
Dartmouth College & NBER

Simon Fuchs
FRB of Atlanta

Woan Foong Wong
University of Oregon & CEPR, NBER

UEA North America Meeting

October 2025

Motivation

- Question: What is the best way to quantitatively evaluate the welfare impacts of a transportation infrastructure investment?

Motivation

- Question: What is the best way to quantitatively evaluate the welfare impacts of a transportation infrastructure investment?
  - **Traditional approach**: Social Savings (Fogel, 1962)

> In the year 1890, a certain bundle of agricultural commodities was shipped from the primary markets to the secondary markets. The shipment occurred in a certain pattern, that is, with certain tonnages moving from each primary market city to each secondary market city. This pattern of shipments was carried out by some combination of rail, wagon, and water haulage at some definite cost. With enough data, one could determine both this cost and the alternative cost of shipping exactly the same bundle of goods from the primary to the secondary markets in exactly the same pattern without the railroad. The difference between these two amounts I call the social saving attributable to the railroad in the interregional distribution of agricultural products—or simply "the social saving." This difference is in fact larger than what the true social saving would have been.[20] Forcing the pattern of shipments in the nonrail situation to conform to the pattern that actually existed is equivalent to the imposition of a restraint on society's freedom to adjust to a new technological situation. If society

  - Social Savings: holding constant shipping patterns, what is the cost savings from an infrastructure improvement?

Motivation

- Question: What is the best way to quantitatively evaluate the welfare impacts of a transportation infrastructure investment?
  - **Modern approach**: Value of Time Savings (VTTS)

1 Introduction

VTTS is an indispensable parameter that plays a pivotal role in the development of comprehensive transport management strategies and informs evidence-based decision-making for the most effective use of resources in transportation investments. For example, the Highway Development and Management (HDM) framework[4] allows for the inclusion of time savings for both car occupants and bus passengers. Within developed countries, they can often account for up to 80 percent of the overall benefits. However, no default values are recommended and many projects in LMICs lack the resources to conduct extensive studies on VTTS, resulting in a dearth of local information. It poses a significant challenge for project evaluation by the World Bank, as there may be substantial differences in travel time values across cultures.

The World Bank convention on VTTS valuation for economic analysis references a two-decade-old-technical note and research works from Gwilliam (1997), Mackie et al. (2003), and IT Transport (2002). As VTTS plays a critical role in project evaluation, and there has been a growing body of evidence from LMICs since the last update, it is necessary to revise the technical note.

  - VTTS: holding constant traffic patterns, what is the value of time saved from an infrastructure improvement?

Motivation

- In either the social savings or value of time savings approach, the welfare impact of improving one link in the transportation network is proportional to the value of traffic on that link.

- Can express this mathematically as a social savings sufficient statistic:

$$-\frac{\partial \ln W}{\partial \ln t_{kl}} = \Xi_{kl},$$

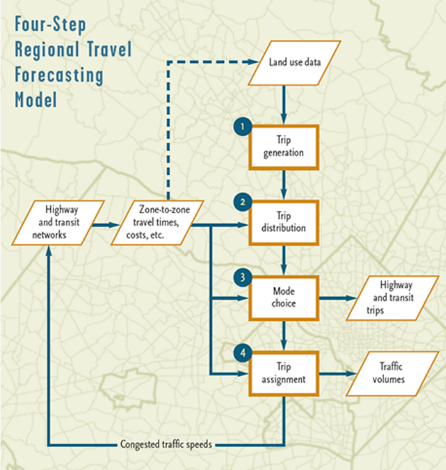
  where

  - W is the aggregate welfare
  - t_{kl} the (ad valorem) cost of transiting a link kl
  - Ξ_{kl} the value of traffic on that link

Motivation

- Limitations of the traditional approach:

- Traffic may respond: Changes in transportation infrastructure will affect trip demand.



Motivation

- Limitations of the traditional approach:
- Traffic may respond: Changes in transportation infrastructure will affect trip demand.
  - Approaches in transportation economics model this traffic response, e.g. the “user equilibrium” of Beckmann et al. ’57, the “Four step travel model” (above).

Motivation

- Limitations of the traditional approach:

- Traffic may respond: Changes in transportation infrastructure will affect trip demand.

- The economy may respond

Railroads in American Economic Growth 171

had had to ship interregionally by water and wagon without the railroad, it could have shifted agricultural production from the Midwest to the East and South, and shifted some productive factors out of agriculture altogether. Further, the cities entering our set of secondary markets and the tonnages handled by each were surely influenced by conditions peculiar to rail transportation; in the absence of the railroad some different cities would have entered this set, and the relative importance of those remaining would have changed. Adjustments of this sort would have reduced the loss in national income occasioned by the absence of the railroad, but estimates of their effects lie beyond the limits of tools and data. I propose, therefore, to use the social saving, as defined, as the objective standard for testing the hypothesis stated above.

Motivation

- Limitations of the traditional approach:
- Traffic may respond: Changes in transportation infrastructure will affect trip demand.
- The economy may respond
- Recent advances in quantitative spatial economics have modeled this economic response.

Goal of this primer

1. Present recent advances that **combine** the modeling of the traffic and economic responses in a single framework.
2. **Compare** these recent advances to the traditional gains from the social savings sufficient statistic.
3. **Apply** the new framework to calculate the welfare gains from improving each segment of the Interstate Highway System.

Outline of Talk

1. **Model**

2. Traditional & Extended Approaches

3. Data & Results

4. Discussion & Conclusion

Model & equilibrium (eigen view)

- **Geography**: N nodes; iceberg $\tau_{ij} \geq 1$ from network.
- **Technology**: one variety; labor only; perfect competition.
- **Preferences**: CES, elasticity $\sigma > 1$.
- **Mobility**: $U_i = w_i P_i^{-1} \bar{u}_i$ equalized.
- **Second-nature**: $A_i = \bar{A}_i L_i^{\alpha}$, $u_i = \bar{u}_i L_i^{\beta}$.

- **Eigen equilibrium** (Allen & Arkolakis, 2014):

$$\lambda \mathbf{x} = \mathbf{K}\mathbf{x}, \quad \lambda \mathbf{y} = \mathbf{K}^{\top}\mathbf{y},$$

- where $x_i = w_i^{\sigma} L_i$, $\quad y_i = w_i^{1-\sigma}$, and $K_{ij} = \left(\frac{A_i u_j}{\tau_{ij}}\right)^{\sigma-1}$, $\quad \lambda = W^{\sigma-1}$
- Matrix Perturbation + envelope:

$$-\frac{\partial \ln W}{\partial \ln \tau_{ij}} = X_{ij}.$$

Network, routing & recursive equilibrium

- **Links**: directed $(k \to l)$, ad valorem cost $t_{kl} \geq 1$.
  - **Multimodal**: $t_{kl} = (\sum_m t_{kl,m}^{\eta})^{1/\eta}$ (cross-mode elasticity $\eta > 0$).
- **Congestion (optional)**: $t_{kl} = \bar{t}_{kl}\, \Xi_{kl}^{\lambda}$ (or by mode λ_m).
- **Routing (soft-min)**:

$$\tau_{ij}^{1-\sigma} = \mathbf{1}\{i = j\} + \sum_{k \in \mathcal{N}(i)} t_{ik}^{1-\sigma}\, \tau_{kj}^{1-\sigma}.$$

- **Recursive equilibrium (local)**:

$$A_i^{1-\sigma} w_i^{\sigma} L_i = W^{1-\sigma} u_i^{\sigma-1} w_i^{\sigma} L_i + \sum_{k \in \mathcal{N}(i)} \kappa_{ik}^{1-\sigma}\, A_k^{1-\sigma} w_k^{\sigma} L_k,$$

$$w_i^{1-\sigma} u_i^{1-\sigma} = W^{1-\sigma} A_i^{\sigma-1} w_i^{1-\sigma} + \sum_{k \in \mathcal{N}(i)} \kappa_{ki}^{1-\sigma}\, w_k^{1-\sigma} u_k^{1-\sigma}.$$

Outline of Talk

1. Model

2. Traditional & Extended Approaches

3. Data & Results

4. Discussion & Conclusion

Traditional result (efficient benchmark)

Traditional Social Savings

Efficient benchmark: CES ($\sigma > 1$), perfect competition; no externalities ($\alpha = \beta = 0$), no congestion ($\lambda_m = 0$); routing/multimodal arbitrary. Define

$$\Xi_{kl,m} = t_{kl,m}^{1-\sigma} P_k^{1-\sigma} \Pi_l^{1-\sigma}, \qquad \Xi_{kl} = \sum_m \Xi_{kl,m}.$$

Then welfare elasticities equal link-value shares:

$$-\frac{\partial \ln W}{\partial \ln t_{kl,m}} = \Xi_{kl,m}.$$

- *Reading.* In the efficient benchmark, the first-order welfare loss from a 1% increase in the cost on a link equals the link's value share. This holds *even with* endogenous re-routing, multimodal substitution, and GE price/population responses (envelope logic).

Extended result (congestion & externalities)

Extended (Congestion & Externalities)

Assume soft–min routing ($\theta = \sigma - 1$); congestion $t_{kl,m} = \bar{t}_{kl,m}\,\Xi_{kl,m}^{\lambda_m}$; second nature $A_i = \bar{A}_i L_i^{\alpha},\ u_i = \bar{u}_i L_i^{\beta}$. Then

$$\frac{d \ln W}{d \ln t_{kl,m}} = \rho\,\Xi_{kl,m}\Big(M_k^{\mathrm{in}} + M_l^{\mathrm{out}}\Big), \qquad \rho = \frac{1+\alpha+\beta}{1+\beta(\sigma-1)+\alpha\sigma},$$

where $M^{\mathrm{in}}, M^{\mathrm{out}}$ are local multipliers from the market-access recursion. Special case $\alpha = \beta = 0,\ \lambda_m = 0 \Rightarrow$ Traditional.

- *Reading.* Start from the traditional value-of-traffic term $\Xi_{kl,m}$, scale it by ρ (capturing agglomeration/dispersion) and by *local propagation* at the tail/head (capturing re-routing and congestion feedback through the access recursions).

- **Multipliers** $M^{\mathrm{in}}, M^{\mathrm{out}}$: local propagation via market-access recursions. Details

- **Special case**: $\alpha = \beta = 0,\ \lambda_m = 0 \Rightarrow$ Traditional result.

Outline of Talk

1. Model

2. Traditional & Extended Approaches

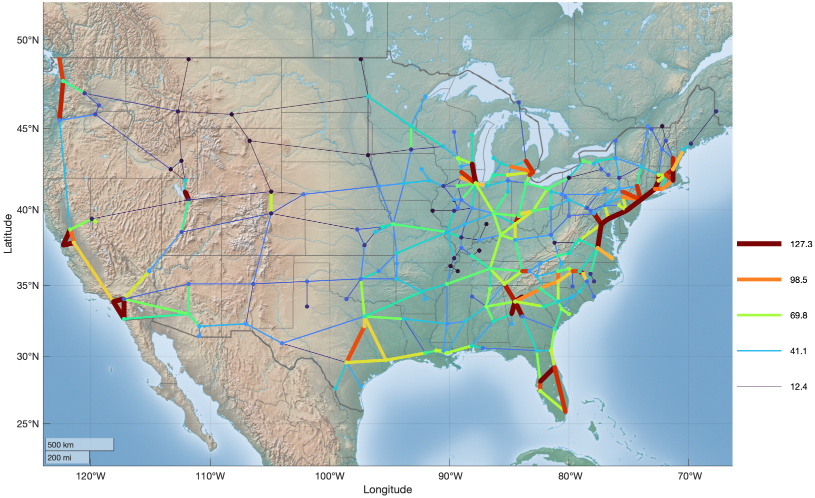
3. **Data & Results**

4. Discussion & Conclusion

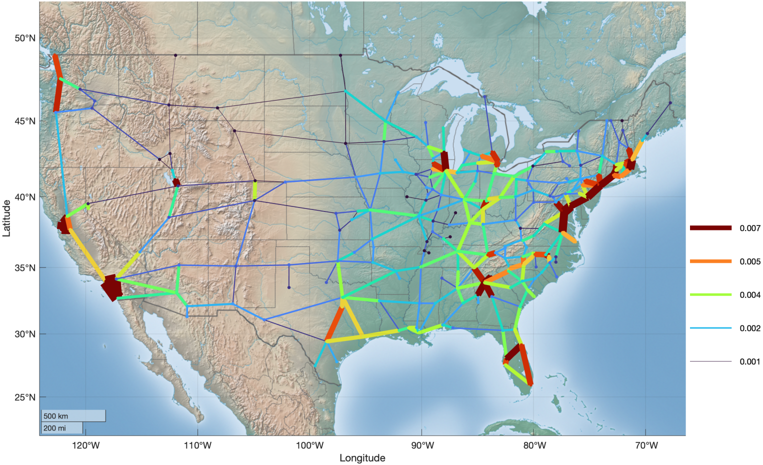
Data & calibration

- **Network**: rail/road/waterways + ports/terminals $\rightarrow$ sparse graph (nodes: CBSAs/ports/ramps; links by mode).
- **Traffic**: STB Waybill (rail), HPMS AADT (road), USACE (waterways).
- **Targets**: 2018 GDP & population; 2012 CFS flows by mode.
- **Parameters**: $\sigma = 9$; $\alpha = 0.10$, $\beta = -0.30$; $\lambda_{\text{road}} = 0.092$, $\lambda_{\text{port}} = 0.096$.

Interstate traffic (baseline)

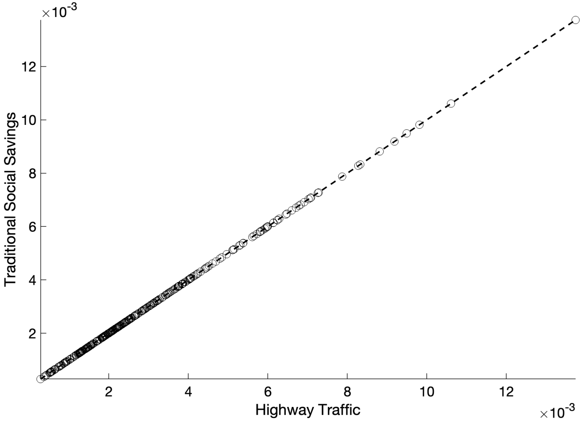


Traditional: welfare gains from 1% link improvement



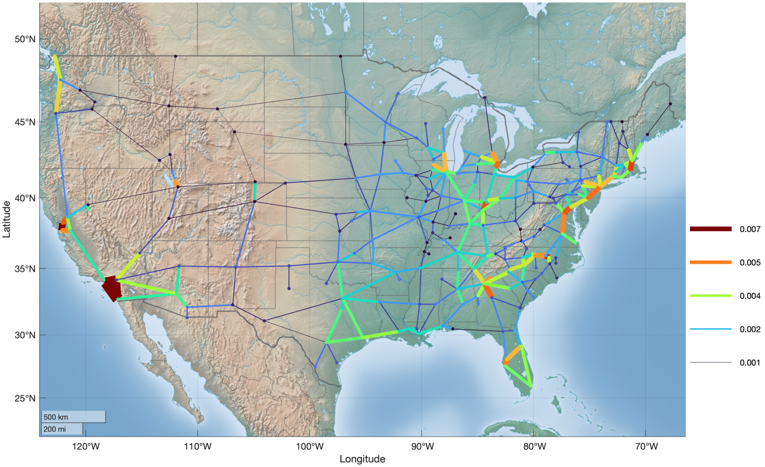
- Median +0.023 p.p.; mean +0.028 p.p.; largest along Eastern Seaboard and hub junctions (Chicago/Memphis/Dallas).

Traditional: elasticities vs traffic share



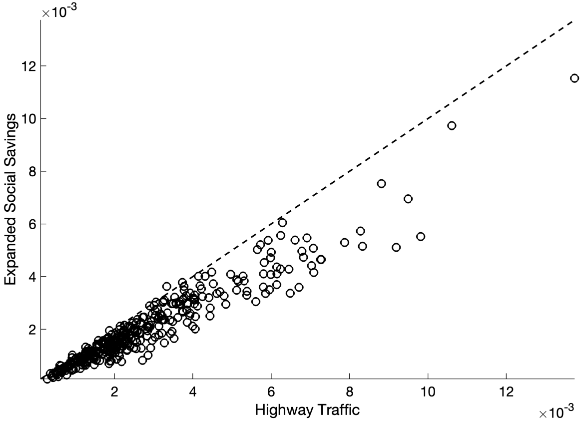
- Near one-for-one by construction in the efficient benchmark.

Extended: welfare gains from 1% link improvement



- Congestion feedbacks attenuate crowded corridors; dispersion can elevate connectors; multimodal unlocks shift values.

Extended: elasticities vs traffic share



- High correlation but < 1; re-ranking reflects ρ and local multipliers $M^{\text{in}}, M^{\text{out}}$.

Mechanisms & investment re-ranking

- **Congestion feedback**: added traffic raises generalized costs on spokes; reduces marginal gains on saturated links.
- **Externalities**: with net dispersion ($\alpha + \beta < 0$), dense hubs lose relative weight; some periphery connectors rise.
- **Multimodal spillovers**: road upgrades that unlock rail/barge itineraries can dominate road-only rankings.

Outline of Talk

1. Model
2. Traditional & Extended Approaches
3. Data & Results
4. **Discussion & Conclusion**

What is the traditional approach missing?

- **Route choice**: Agents may change their routes in response to infrastructure improvements. $\leftarrow$ **Same sufficient statistic.**
- **Mode choice**: Agents may change their transport modes in response to infrastructure improvements. $\leftarrow$ **Same sufficient statistic (measurement matters).**
- **Congestion**: Changes to route/mode choices may affect congestion on different segments of the infrastructure network. $\leftarrow$ **Modified sufficient statistic!**
- **Spillovers**: Economic responses to infrastructure improvements may affect productivities/amenities across locations.

What is the traditional approach missing?

- **Route choice**: Agents may change their routes in response to infrastructure improvements. $\leftarrow$ **Same sufficient statistic.**

- **Mode choice**: Agents may change their transport modes in response to infrastructure improvements. $\leftarrow$ **Same sufficient statistic (measurement matters).**

- **Congestion**: Changes to route/mode choices may affect congestion on different segments of the infrastructure network. $\leftarrow$ **Modified sufficient statistic!**

- **Spillovers**: Economic responses to infrastructure improvements may affect productivities/amenities across locations. $\leftarrow$ **Modified sufficient statistic!**

Fogel foresaw this in 1962!

In treating the differential in transportation costs as a differential in levels of national income, I am assuming that there would have been no obstacles to an adjustment to a nonrail situation. In other words, I am abstracting from market problems by assuming that national income would have dropped only because it took more productive resources to provide a given amount of transportation, and that all other productive resources would have remained fully employed. The relationship between the railroad and the demand for output is the subject of one of the other essays in my study (cf. note 10).

Future directions

- **Costs**: engineering + project accounting to pair with benefits.
- **Policy design**: GE-aware prioritization (Fajgelbaum and Schaal, 2020; Bordeu, 2024; Hierons, 2025).
- **Dynamics**: adjustment paths & timing (Balboni, 2025).

Extended approach & local multipliers (formal)

Environment.

Externalities: $A_i = \bar{A}_i L_i^{\alpha}, \quad u_i = \bar{u}_i L_i^{\beta}.$

Congestion by mode m : $\kappa_{kl,m} = \bar{\kappa}_{kl,m}\, \Xi_{kl,m}^{\lambda_m}, \qquad \lambda_m \geq 0.$

Cross–mode CES on link $(k \to l)$: $\kappa_{kl} = \Big(\sum_m \kappa_{kl,m}^{\eta}\Big)^{1/\eta}, \quad s_{kl,m} = \frac{\kappa_{kl,m}^{\eta}}{\sum_n \kappa_{kl,n}^{\eta}}.$

Soft–min routing (set $\theta = \sigma - 1$) : $\tau_{ij}^{1-\sigma} = \mathbf{1}\{i = j\} + \sum_{r \in \mathcal{N}(i)} \kappa_{ir}^{1-\sigma}\, \tau_{rj}^{1-\sigma}.$

Market access recursion: $\Pi_i^{1-\sigma} = W^{1-\sigma} u_i^{\sigma-1} w_i^{\sigma} L_i + \sum_{r \in \mathcal{N}(i)} \kappa_{ir}^{1-\sigma} \Pi_r^{1-\sigma},$

$$P_i^{1-\sigma} = A_i^{\sigma-1} w_i^{1-\sigma} + \sum_{r \in \mathcal{N}(i)} \kappa_{ri}^{1-\sigma} P_r^{1-\sigma}.$$

Link value (all modes): $\Xi_{kl} = \kappa_{kl}^{1-\sigma}\, P_k^{1-\sigma}\, \Pi_l^{1-\sigma}, \qquad \Xi_{kl,m} = s_{kl,m}\, \Xi_{kl}.$

Extended approach & local multipliers (formal) back

Extended social-savings (welfare elasticity). For any edge–mode (k, l, m),

$$\frac{d \ln W}{d \ln \kappa_{kl,m}} = \rho \, \Xi_{kl,m} \left(M_k^{\mathrm{in}} + M_l^{\mathrm{out}} \right), \qquad \rho = \frac{1 + \alpha + \beta}{1 + \beta(\sigma - 1) + \alpha\sigma}.$$

Local multipliers (definition). Let $G(\ln x, \ln y) = 0$ be the $2N$-eq. log-recursive system obtained from the two market-access balance conditions, with Jacobian DG (see Appendix). Then, writing population weights $L_i/\bar{L}$,

$$M_k^{\mathrm{in}} = \frac{1}{\Xi_k} \sum_i \frac{L_i}{\bar{L}} \left[(1-\sigma) \, (DG)^{-1}_{x,ik,1} + \sigma \, (DG)^{-1}_{y,ik,1} \right],$$

$$M_l^{\mathrm{out}} = \frac{1}{\Xi_l} \sum_i \frac{L_i}{\bar{L}} \left[(1-\sigma) \, (DG)^{-1}_{x,il,2} + \sigma \, (DG)^{-1}_{y,il,2} \right],$$

where the columns indexed "$k, 1$" and "$l, 2$" correspond to unit perturbations in the $(k \to \cdot)$ and $(\cdot \to l)$ balance equations, respectively. Intuition: M_k^{in} and M_l^{out} capture *local propagation* of a link shock through the recursive market-access system at the tail/head of the link, including congestion and externality feedback.

Special case. If $\alpha = \beta = 0$ and all $\lambda_m = 0$, then $\rho = 1$ and $M_k^{\mathrm{in}} = M_l^{\mathrm{out}} = 1$, recovering the traditional result $-\frac{\partial \ln W}{\partial \ln \kappa_{kl,m}} = \Xi_{kl,m}$.

Bibliography

Balboni, Clare. 2025. “In harm’s way? infrastructure investments and the persistence of coastal cities.” *American Economic Review*, 115(1): 77–116.

Bordeu, Olivia. 2024. “Commuting infrastructure in fragmented cities.” *Job Market Paper, University of Chicago Booth School of Business*.

Fajgelbaum, Pablo D., and Edouard Schaal. 2020. “Optimal Transport Networks in Spatial Equilibrium.” *Econometrica*, 88(4): 1411–1452.

Hierons, Thomas. 2025. “Spreading the jam: Optimal congestion pricing in general equilibrium.” *Job Market Paper, University of Chicago*.