Evaluating Transportation Improvements Quantitatively: A Primer

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Outline of Talk

1. Introduction
2. A Simple Quantitative Spatial Model
3. Evaluating Transportation Infrastructure Improvements
4. Conclusion

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?

The modern version of social savings: 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?

The social savings sufficient statistic

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The social savings sufficient statistic

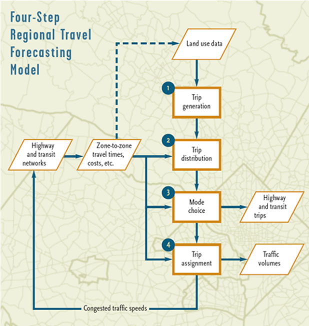
- In either the social savings or value of time savings approach, the welfare impact of improving one link in the transportation network is proportional to the value of traffic on that link.
- Can express this mathematically as a **social savings sufficient statistic**:

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

  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.

Limitation #1 of the traditional approach: Traffic may respond

- Changes in transportation infrastructure will affect trip demand.



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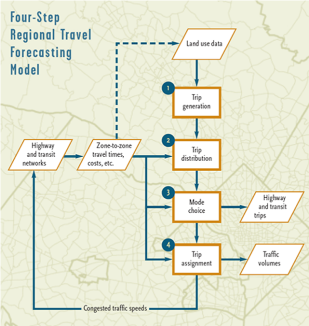

- Approaches in transportation economics model this *traffic* response, e.g. the "user equilibrium" of Beckmann et al. '57, the "Four step travel model" (above).

Limitation #2 of the traditional approach: The economy may respond

- Changes in transportation infrastructure may result in shifting of economic activity toward new locations (as Fogel noted):

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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.

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- Recent advances in quantitative spatial economics have modeled this *economic* response.

Goals of this primer

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2. **Compare** these recent advances compare 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.

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   3.1 A first pass (efficient equilibrium, fixed routes)
   3.2 A second pass (efficient equilibrium, endogenous route choice)
   3.3 A third pass (efficient equilibrium, endogenous route & mode choice)
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Model Setup: Geography and Production

- Geography
  - N locations.
  - Each location differs in its productivity ($\bar{A}_i$) and amenity ($\bar{u}_i$) and the good it produces.
  - Pairs of locations are separated by (ad valorem) *trade cost* $\tau_{ij} \geq 1$.

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- Consumption
  - Measure $\bar{L}$ of perfectly mobile agents choose where to live/consume.
  - Agents have CES preferences over varieties (with EoS σ).

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  - The expenditure of a location is equal to its total purchases and is equal to its income.
  - Welfare is equalized across all locations.

Equilibrium (ctd.)

- In equilibrium, the distribution of economic activity is determined by the following eigen-equation (see Allen and Arkolakis (2014)):

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

  where:

  - $x_i \equiv w_i^\sigma L_i$ and $y_i \equiv w_i^{1-\sigma}$ are the equilibrium distribution of economic activity.
  - $K_{ij} \equiv (A_i u_j / \tau_{ij})^{\sigma-1}$ is the geography.
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- Can use matrix perturbation methods to show that elasticity of welfare to change in bilateral trade costs is proportional to trade flows, i.e.:

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

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- Can then calculate the trade cost as the product of link costs along the route:

$$\tau_{ij} = \prod_{k,l} t_{kl}^{\mathbf{1}_{kl}^{ij}},$$

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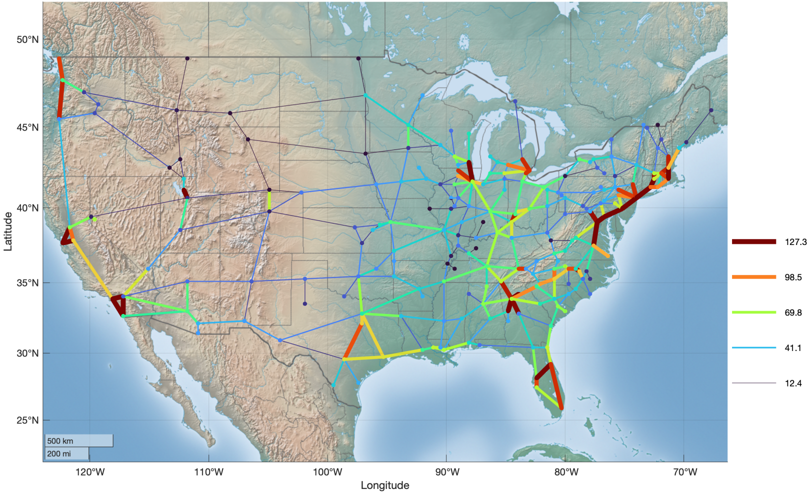
- Note: Common assumption, see e.g. Ahlfeldt, Redding, Sturm, and Wolf (2015), Donaldson and Hornbeck (2016), Donaldson (2018)

Illustration: The U.S. interstate highway system



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- Applying the chain rule:

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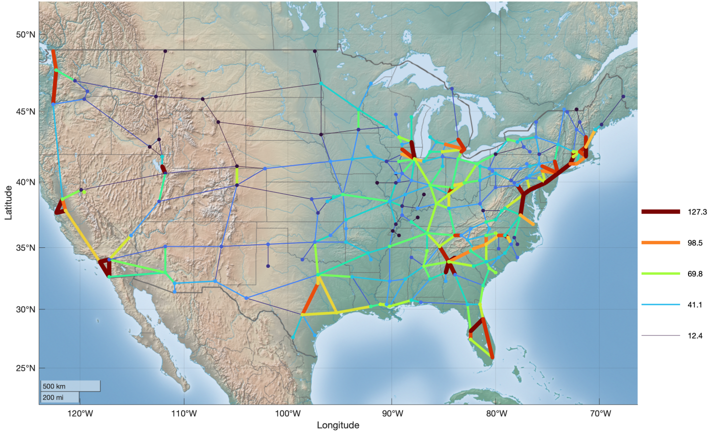
- Or, more simply:

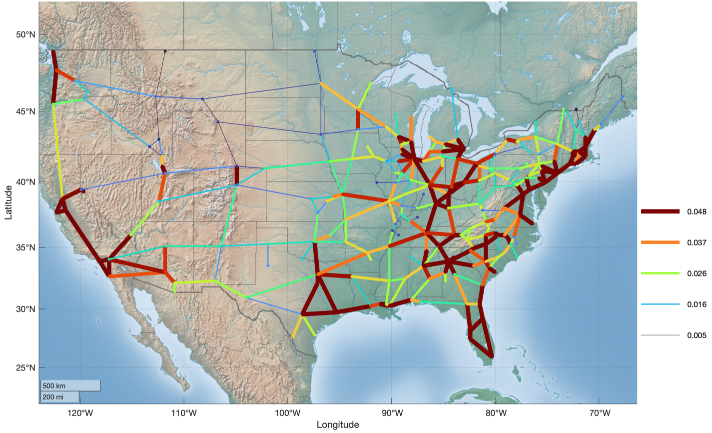
$$-\frac{\partial \ln W}{\partial \ln t_{kl}} = \Xi_{kl}.$$

- **Implication**: The social savings sufficient statistic holds after incorporating the **GE economic response**!

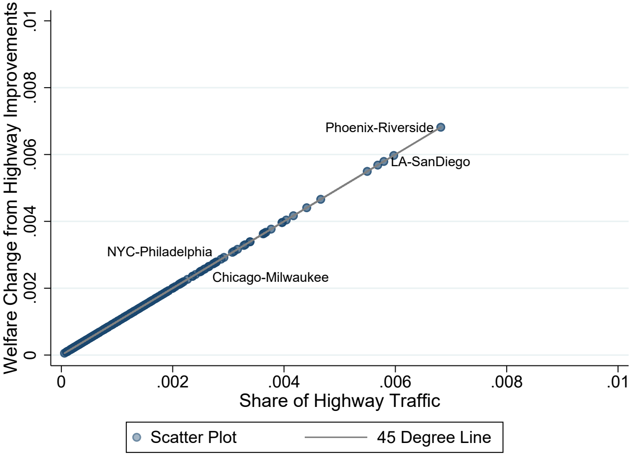
The interstate highway system: Traffic



The interstate highway system: Welfare



The interstate highway system: Welfare impacts and traffic flows



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Incorporating route choice

- Suppose there are agents $\nu \in [0,1]$ who choose their route r from i to j to minimize total trade costs:

$$\tau_{ij}(\nu) = \min_{r \in \mathcal{R}_{ij}} \tau_{ij}(r)\, \varepsilon(\nu, r),$$

  where:

  - $\mathcal{R}_{ij}$ is the set of possible routes from i to j
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- See Allen and Arkolakis (2022) for details.

What is the welfare impact of improving a link? A second pass (with route choice).

- Applying the envelope theorem to the route choice problem, we have:

$$\frac{\partial \ln \tau_{ij}}{\partial \ln t_{kl}} = \pi_{kl}^{ij},$$

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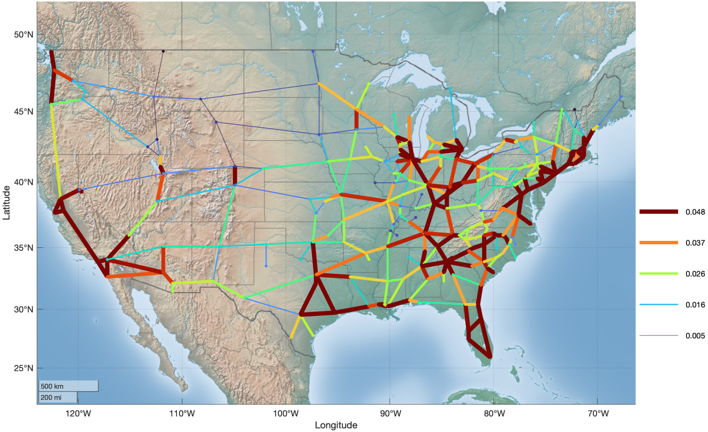
The interstate highway system: Welfare impacts of link improvements (without route choice).



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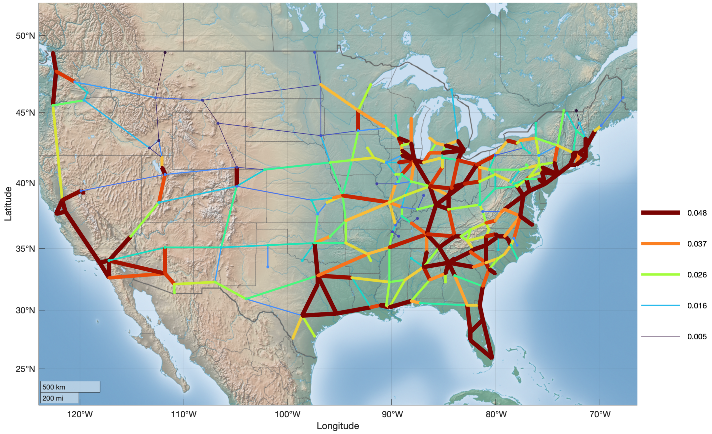
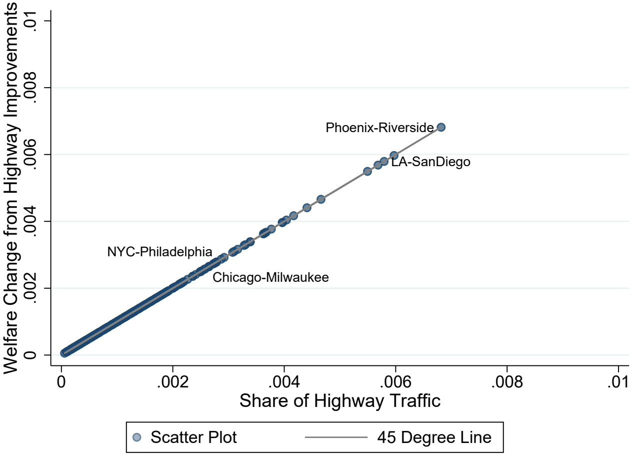


The interstate highway system: Welfare impacts and traffic flows (with route choice).



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- **Mode choice**: Agents may change their modes in response to infrastructure improvements.
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- **Spillovers**: Economic responses to infrastructure improvements may affect productivities/amenities of different locations.

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- **Route choice**: Agents may change their routes in response to infrastructure improvements. $\leftarrow$ **Same sufficient statistic**.
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- See Fuchs and Wong (2025) for details.

What is the welfare impact of improving a link? A third pass (with route + mode choice).

- Applying the envelope theorem to the route choice problem with multimodal transportation networks, we have:

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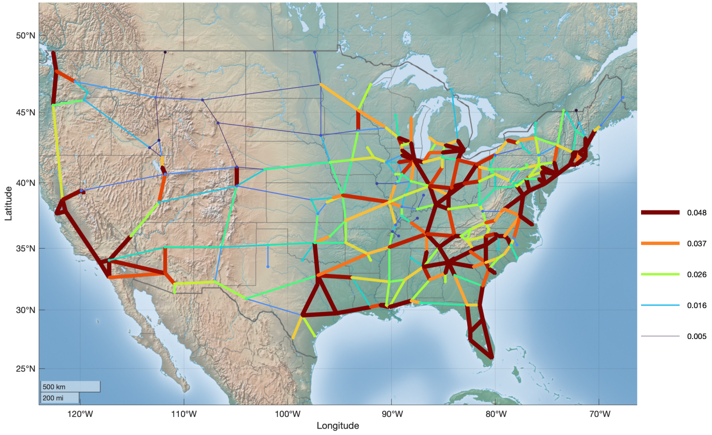
- **Implication**: The social savings sufficient statistic holds after incorporating the **GE economic response, route choice, & mode choice**!
  - But how you measure the value of traffic matters.

What is the welfare impact of improving a link? (Without mode choice).



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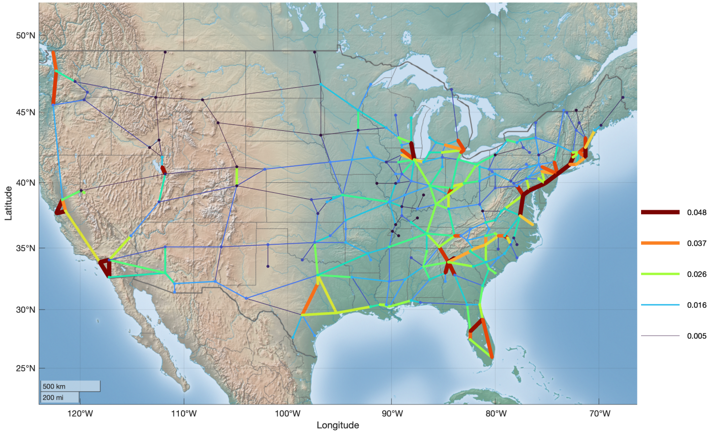

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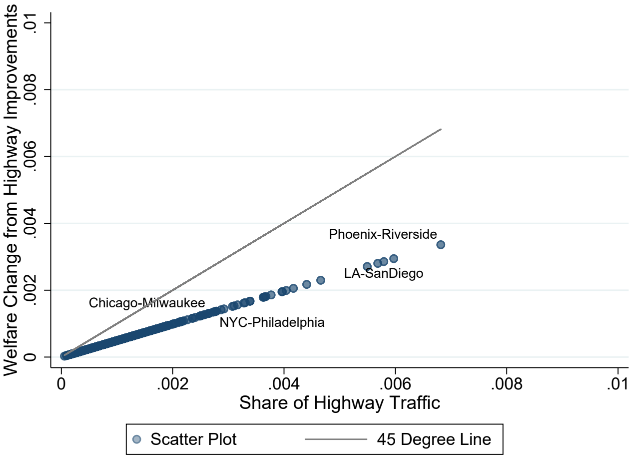

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Incorporating congestion

- Suppose that the cost of traversing a link depends in part on the traffic on the link, e.g.:

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- Note: **Feedback loop** from economic changes to the cost of traversing the infrastructure network.

What is the welfare impact of improving a link? A fourth pass (with route/mode & congestion)

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- **Implication**: The social savings sufficient statistic must be modified to account for traffic congestion feedback.

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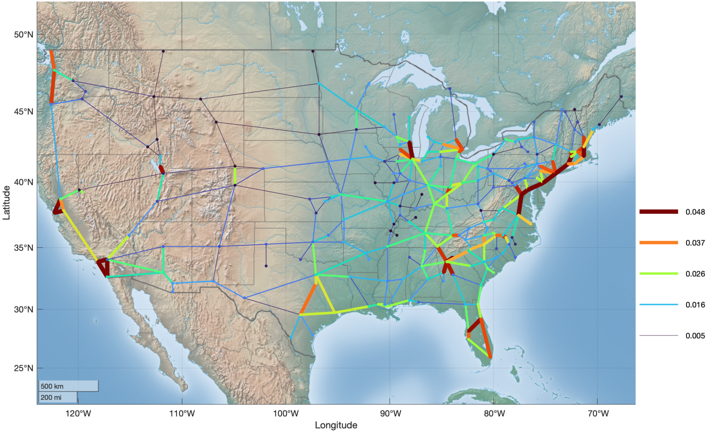

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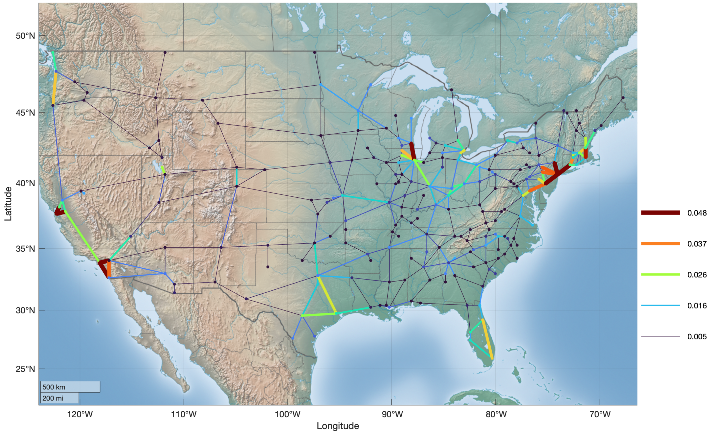

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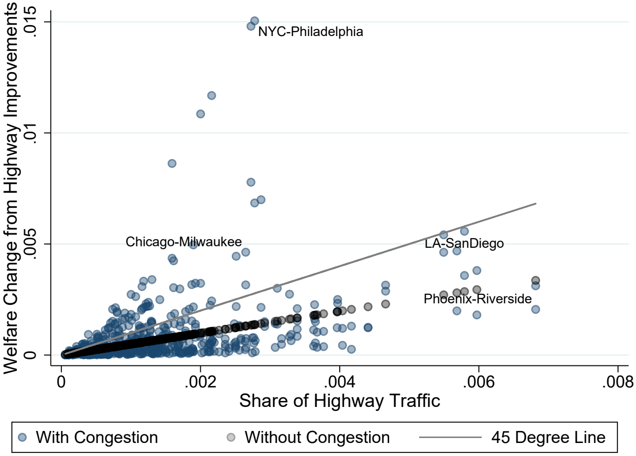

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- Examples:
  - Marshallian externalities ($\alpha > 0$), fixed factors of production ($\alpha < 0$)
  - Public goods ($\beta > 0$), land/housing ($\beta < 0$).

What is the welfare impact of improving a link? A final pass

- With externalities, the competitive equilibrium is no longer efficient:

$$-\frac{\partial \ln W}{\partial \ln \tau_{ij}} = X_{ij} \left(1 + \kappa_i + \nu_j\right),$$

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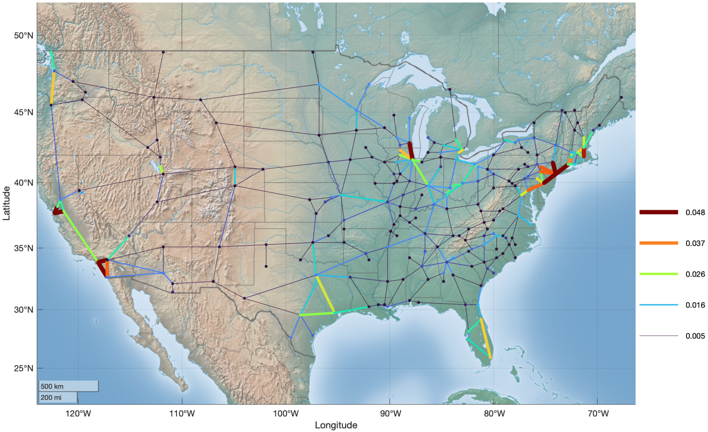

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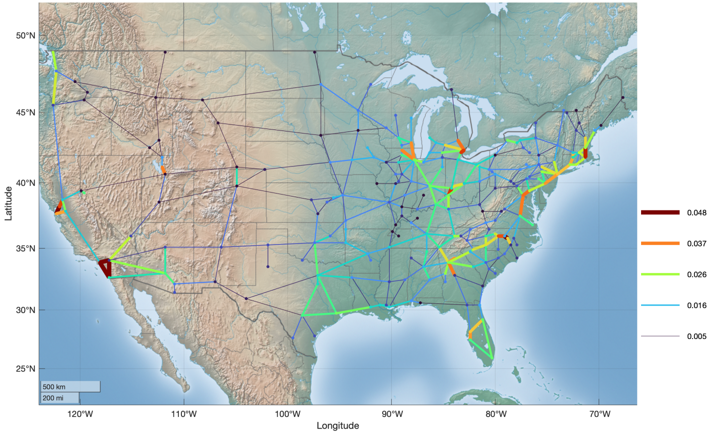

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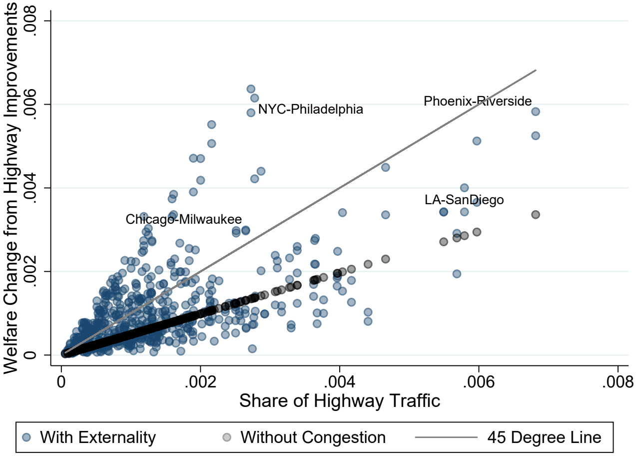

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Fogel foresaw this in 1962!

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).

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    - Recent advances in modeling make it feasible to calculate the welfare impacts of infrastructure improvements with both traffic congestion feedback and market failures.

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Thank you!