**Title:** Do public transit investments reduce vehicle use across the income spectrum?

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**Abstract**
We study which types of public investments are the most effective at reducing vehicle use and for whom these investments are the most impactful. We use subway and bus rapid transit network expansions to estimate the causal effects of access rapid transit on transit and vehicle use. We complement this analysis with a quantitative spatial model that admits rich non-homotheticity in preferences over transit modes, travel times, destinations, and vehicle ownership, to study who is most impacted by transit and provide insight into mechanisms.

**Statement of Merit and Value to DOT**

- We pay "particular attention to the distribution of costs and benefits and the impact of transportation policies on disadvantaged communities" by examining heterogeneity of effects by income and incorporating rich non-homotheticity into our model.
- We provide a new way to quantify the value of private automobiles, thus making a contribution to the "economics of light-duty vehicle demand" and the "effects of the long-term trends … on the demand for transportation services."
- We link "differences in access to transportation services" to "disparities in economic outcomes…across income."

**Motivation**

Increased prosperity leads to higher demand for mobility, and this demand is often met by private automobiles (Glaeser et al. 2008, Millard-Ball & Shipper 2011). However, automobiles impose substantial public costs such as congestion, pollution, greenhouse gas (GHG) emissions, and land use pressure (see, e..g., Bryan et al. 2020; Gendron-Carrier et al. 2022). Investments in public transit infrastructure offer one option to reduce the externalities that private vehicles generate. Indeed, public transit investments are key components of the Bipartisan Infrastructure Law of 2023. But to successfully mitigate negative externalities, providing transit is insufficient if it does not lead to substitution away from private vehicles.

We explore what features of large-scale investments in public transportation decrease demand for private vehicles, and for whom the effects are most consequential. To do this, we estimate the causal effects of different types of transit investments on travel behavior and vehicle ownership in the medium run using newly harmonized travel survey data from Mexico City spanning 1994 to 2017. Mexico City has both expanded the service area and increased the network density of its rapid transit systems in the last three decades, building both subway and bus rapid transit lines. As such, it provides an ideal setting to determine whether expanding

[1] The authors declare **no conflict of interest**. *The views expressed in this proposal are solely those of the authors and do not necessarily reflect those of the Federal Reserve Bank of Philadelphia or the Federal Reserve System. All errors or omissions are the responsibility of the authors.*

transit or increasing transit density has a greater impact, whether the type of rapid mode matters to potential riders, and whether the transfer penalty for multimodal travel is substantial. To do so, we build upon the literature that explores the impacts of transit infrastructure (Baum-Snow et al. 2005; Tsivanidis, 2023; Zarate, 2023). Exploring the role of economies of scale in transit networks impact demand is especially important: access to a single rapid line has muted effects on behavior relative to access to denser portions of the network. This may explain the sometimes underwhelming estimates of the benefits of transit (as in, e.g., Severen 2023).

It is also vital to understand who benefits from transportation investments (Barwick et al, 2021; Akbar 2024). Several studies have found that low-income and minority communities face disproportionate environmental impacts from transport infrastructure (Kerr et al, 2021) while also experiencing limited benefits from these investments (bunten et al, 2023). We study the heterogeneous impacts of transit infrastructure across the income distribution, and allow rich non-homothetic heterogeneity in preferences for transit modes, travel time, destinations, and vehicle ownership. To do this, we develop a latent-class representation of a quantitative spatial model that admits continuous heterogeneity in income. Not only does this expand the utility of these models beyond discrete heterogeneity (e.g., Tsivanidis 2023), we can simulate outcomes under counterfactual distributions of income, increasing external validity.

**Data**

We combine data from many sources, including:

- *Travel surveys:* We harmonize three waves of confidential microdata that include spatially explicit travel diaries and measures of income from 1994, 2007, and 2017 to study how behavior changes in response to expansions in rapid transit service. These data are from travel surveys conducted in the Mexico City metropolitan area. The repeated cross-sections link residential locations and trip origins and destinations.
- *Census data:* We couple the travel surveys with neighborhood-level socioeconomic data covering 1990–2020 from the Mexican National Institute of Statistics and Geography.
- *Transit infrastructure:* We obtain geographic data on existing metro and bus rapid transit lines in Mexico City, and planned lines from Mexico City's *Plan Maestro* 1985, which details expansion plans for public transit in Mexico City from 1985. We use planned lines as counterfactuals for built lines to overcome endogeneity in transit placement.
- *Historical travel time simulation:* We backcast modern transit infrastructure and service (GTFS) data to prior years. We then simulate travel times between all origins and destinations on all mode combinations using the R5 algorithm (Conway, Byrd, and Van Eggermond 2018). We plan to supplement these with historical automobile travel times estimated using convolutional neural networks.

**Methods**

We study the impacts of transit expansions on transit and vehicle use by exploring how changing proximity to transit infrastructure shifts transit's modal split across time. We first estimate the following staggered difference-in-differences specification:

$$Y_{it} = \beta D_{ct} + X'_{it}\gamma + \delta_c + \varsigma_t + e_{ict}, \quad (1)$$

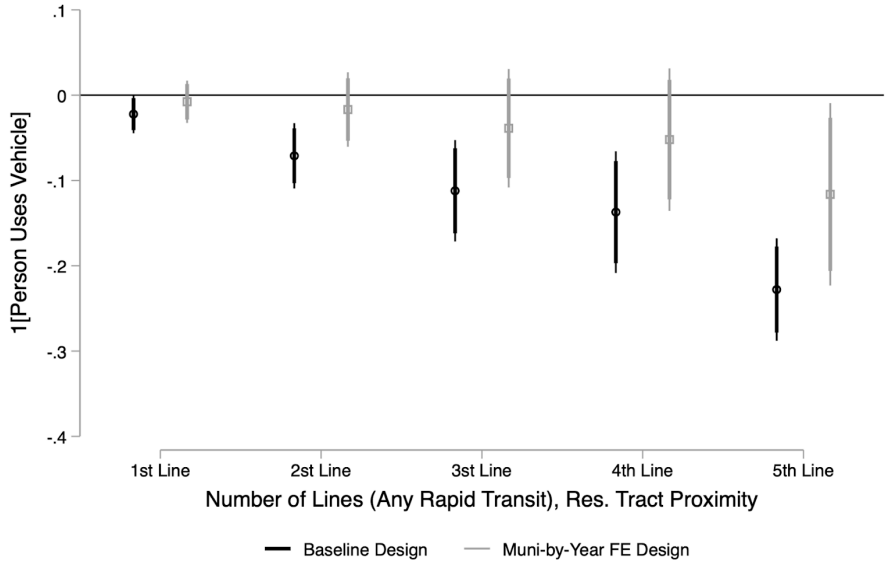
where $Y_{it}$ is an outcome of interest for individual $i$, $D_{ct}$ measures the transit proximity of census tract $c$ in year $t$. Crucially, $\delta_c$ are residential fixed effects that control for time-invariant confounders of $D_{ct}$, and $\varsigma_t$ are year fixed effects. We define proximity by using a piecewise functional form that is linear in negative normalized distance up to a maximum level, at which proximity becomes zero. We then explore economies of transit density by extending Equation (1) with reversed order statistics of line proximity and heterogeneity in effects by income via extending Equation (1) with interacted bins of predicted wages.

**Preliminary findings**

Preliminary estimates indicate that residential access to a single transit line increases rapid transit use by 15pp-19pp, but does little to change private vehicle use or induce new transit usage overall. Estimated effects are consistent across several designs, including those using unbuilt *Plan Maestro 1985* lines and stations as counterfactuals, and are similar for both subway and bus rapid transit. These results suggest at most small substitution effects away from vehicles in response to *any* residential rapid transit access.

However, there are substantial effects of being near *more than one* rapid transit line. Figure 1 shows that increasing the density of transit provision can induce substantial substitution away from private vehicle use. While access to one line has a marginally significant effect of -2pp, access to two lines shifts vehicle use by -7pp. This effect grows linearly as the number of lines are added. Alternative models that very flexibly allow for heterogeneous regional trends support increasing returns to transit density, as does an alternative "scaffolded" design that only compares marginal changes in access (a la Callaway et al. 2021).

**Figure 1:** Returns to scale in rapid transit access on private vehicle use

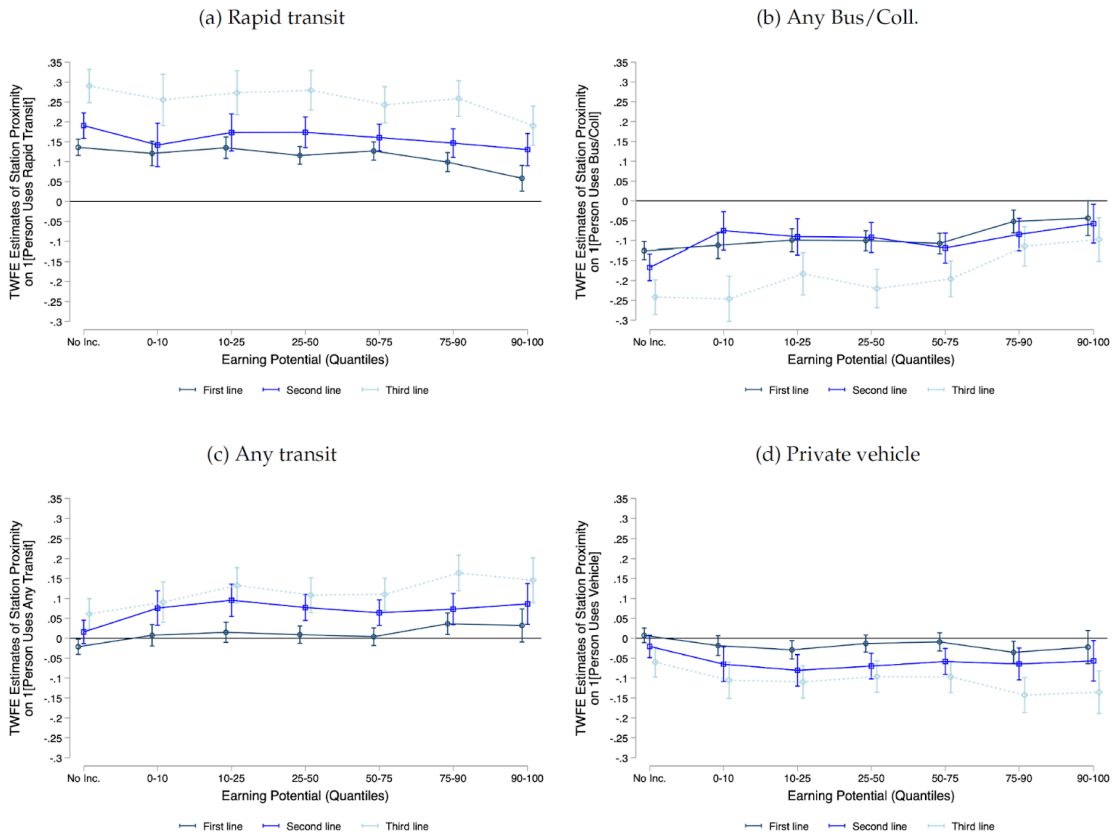



We have also estimated heterogeneous transit responses by income levels. Figure 2 shows the impacts of transit access on mode choice across the income distribution. We find that

individuals increase transit use at a similar rate as access increases regardless of income, however, low-income travelers reduce informal transit use as rapid transit density increases and higher income individuals shift more from private vehicle use.

These preliminary results suggest that rapid transit expansions can induce substitution away from vehicles and towards transit. This substitution occurs across the income spectrum but is more pronounced in the highest income quartile. These heterogeneous responses suggest that some transit expansions might not induce much change in travel behavior. Funding from the NBER will allow us to support PI research time to use our model (below) to assess which expansions might be more effective inducing substitution towards transit and to quantify how much change in behavior can be achievable through transit expansions.

**Figure 2:** The effects of transit proximity across income percentiles




## Model

While the reduced-form analysis studies whether transit expansions induce substitution away from vehicles, it is important to understand the mechanisms behind these effects. To do so, we develop a model of vehicle ownership that allows us to assess which transit expansions have a high potential of increasing transit use and quantify just how much change in behavior is achievable by expanding transit. The model features rich heterogeneity in preferences over mode choice, travel time, place of work, and car ownership that varies by income. The model embeds a latent class representation of heterogeneity in workplace and transit mode, enabling the use of quantitative spatial modeling (e.g., Ahlfeldt et al., 2015) with continuous

heterogeneity. The model provides a generalizable framework to quantify the relative market access of car ownership and of transit, measure how agents differ in their valuation of relative market access, and how network expansions impact relative market access.

**Funding Results and Deliverables**

This proposal describes research in progress. Funding this research at this point will enable us to provide the following deliverables:

1. Estimate a model of mode choice, workplace travel, and car ownership with preferences for transit attributes and locations that vary by income.
2. Add an explicit model of retail/consumption market access to the utility framework (i.e., in addition to labor market access) (e.g., Miyauchi et al. 2021).
3. Use convolutional neural networks to simulate historical travel times.
4. Characterize the most valuable transit interventions.

**References**


Ahlfeldt, Gabriel M, Stephen J Redding, Daniel M Sturm, & Nikolaus Wolf. (2015). "The economics of density: Evidence from the Berlin Wall." *Econometrica* 83 (6): 2127–2189.

Baum-Snow, Nathaniel, Matthew Kahn, & Richard Voith. (2005). "Effects of urban rail transit expansions: Evidence from sixteen cities, 1970-2000." *Brookings-Wharton Papers on Urban Affairs*, 147–206.

Barwick, P. J., Li, S., Waxman, A. R., Wu, J., & Xia, T. (2021). "Efficiency and equity impacts of urban transportation policies with equilibrium sorting." NBER WP 29012.

Bryan, Gharad, Edward Glaeser, & Nick Tsivanidis. (2020). "Cities in the developing world." *Annual Review of Economic*s 12:273–297.

bunten, D., Fu, E., Rolheiser, L., & Severen, C. (2023). The problem has existed over endless years: Racialized difference in commuting, 1980–2019. *Journal of Urban Economics*, 103542.

Callaway, Brantly, Andrew Goodman-Bacon, & Pedro HC Sant'Anna. (2021). "Difference-in-differences with a continuous treatment."

Conway, M. W., Byrd, A., & Van Eggermond, M. (2018). Accounting for uncertainty and variation in accessibility metrics for public transport… *Journal of Transport and Land Use*, 11(1), 541-558.

Gendron-Carrier, Nicolas, Marco Gonzalez-Navarro, Stefano Polloni, & Matthew A Turner. (2022). "Subways and urban air pollution." *American Economic Journal: Applied Economics* 14 (1): 164–196.

Glaeser, E. L., Kahn, M. E., & Rappaport, J. (2008). Why do the poor live in cities? The role of public transportation. *Journal of Urban Economics*, 63(1), 1-24.

Kerr, G. H., Goldberg, D. L., & Anenberg, S. C. (2021). COVID-19 pandemic reveals persistent disparities in nitrogen dioxide pollution. *Proceedings of the National Academy of Sciences*, 118(30).

Millard-Ball, A., & Schipper, L. (2011). Are we reaching peak travel? Trends in passenger transport in eight industrialized countries. *Transport Reviews*, 31(3), 357-378.

Miyauchi, Y., Nakajima, K., & Redding, S. J. (2021). "The economics of spatial mobility: Theory and evidence using smartphone data." NBER WP 28497.

Severen, Christopher. (2023). "Commuting, Labor, and Housing Market Effects of Mass Transportation: Welfare and Identification." *Review of Economics and Statistics* 105 (5): 1073–1091.

Tsivanidis, Nick. (2023). "Evaluating the Impact of Urban Transit Infrastructure: Evidence from Bogotá's TransMilenio."

Zárate, David R. (2023). "Spatial Misallocation, Informality and Transit Improvements: Evidence from Mexico City."