Bridges to Prosperity

BETTER PLANET LABORATORY

MODELING THE IMPACT OF SMALL-SCALE TRANSPORTATION INFRASTRUCTURE TO MOST EFFICIENTLY ENABLE CONNECTIVITY FOR RURAL COMMUNITIES

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Interactive impact model web application

bit.ly/fikaimpact

1 CONTEXT & METHODS

For decades, national infrastructure strategies have mainly focused on large-scale infrastructure expansion to stimulate macroeconomic growth. While this top-down approach successfully connects major trade corridors, it structurally ignores sparsely populated rural areas deemed "not cost-effective" to serve. This legacy has left millions trapped in the "first mile" gap—physically severed from the national grid by natural barriers like rivers. In this study, we develop a novel modeling framework to quantify this access gap across seven African countries and evaluate the potential of pedestrian trail bridges to efficiently connect the most isolated populations.


Photo credit: Robb Hohmann

Fig. 1: A child navigates a dangerous river crossing in Jigesa, Ethiopia.

Methodology: The Fika Impact Framework

We developed a scalable hierarchical pathfinding model designed to solve continent-scale accessibility problems.

- **Hierarchical Graph Construction:** We model the landscape as a weighted graph \$G(V, E$G(V, E)$ing OpenStreetMap pedestrian networks, Copernicus GLO-30 digital elevation models, and WorldPop demographic data.
- **Anisotropic Travel Cost:** Walking velocity is modeled as a function of terrain gradient using Campbell et al. (2019), penalizing steep ascents.
- **Hierarchical Routing:** To scale across countries, we use a two-level abstraction (Subregion vs. Region graphs) running a Multi-Source Dijkstra's algorithm to compute travel times.
- **Equity Optimization:** Sites are prioritized using a greedy algorithm that maximizes a composite equity metric:

$$M_i = \sum_{k \in \text{cells}} \mathrm{Pop}_k \times \Delta t_k \times (1 - Q(\mathrm{RWI}_k))$$

Where -$\mathrm{Pop}_k$the population in cell k, Dt_. is$k$hΔt_ke saved, and -------- is the weal$Q(\mathrm{RWI}_k)$quantile.

- **Validation**: The model was ground-truthed against household survey data from an RCT in Rwanda, achieving high accuracy (MAE=8.5min, RMSE=13.8 min).

2 THE GEOGRAPHY OF EXCLUSION

The poorest walk the furthest

Using the Fika Impact model, and sampling population across seven countries, we compared the poorest 10% of the population to the wealthiest 10%.

The disparity is stark: the poorest families travel, for example, 8x longer to reach health facilities than the wealthy. For education, the poorest 10% face average travel times of 632 minutes—over 10 hours—effectively severing them from the school system. This confirms that physical isolation is not random; it is a structural trap that systematically targets the most vulnerable.

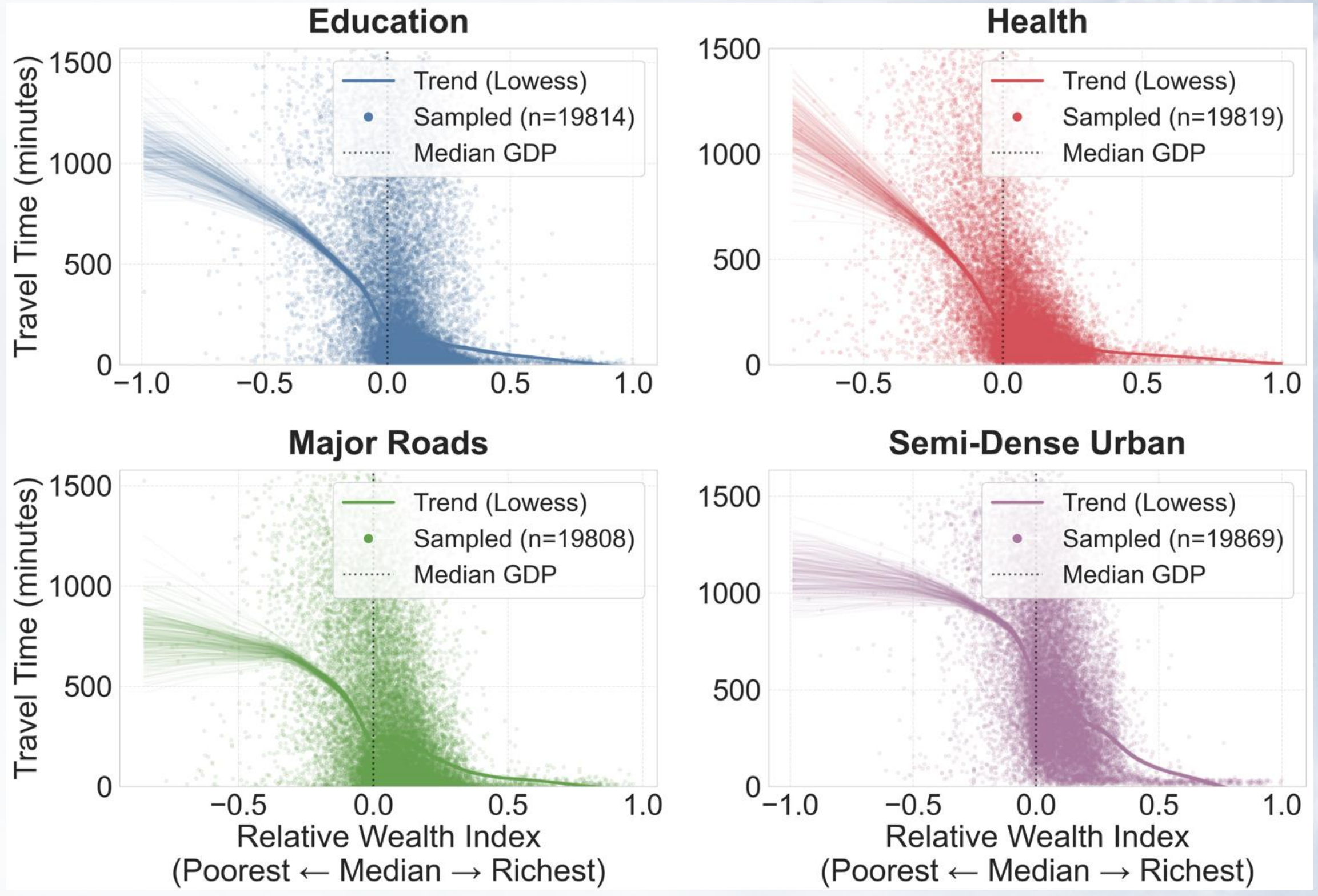

Fig. 2: Modeled walking travel time plotted against Relative Wealth Index (RWI). The steep negative curves visually confirm that access barriers are not uniform but rise exponentially for the poorest populations (left side of x-axis).

3 QUANTIFYING IMPACT

Minutes saved

We analyzed constructed trailbridges in Rwanda to measure time savings across isolation levels. The results confirm that impact is non-linear and transformative.

First, for populations previously facing regular exclusion, the bridge is not an improvement - it is a lifeline. It eliminates hours of detour, saving the 80th percentile beneficiary over 2.5 hours (148 min) per trip in some cases.

Second, scaling metric reveals an "80/30 Rule": constructing ~30% of candidate bridges is sufficient to unlock access for 80% of the total isolated population.

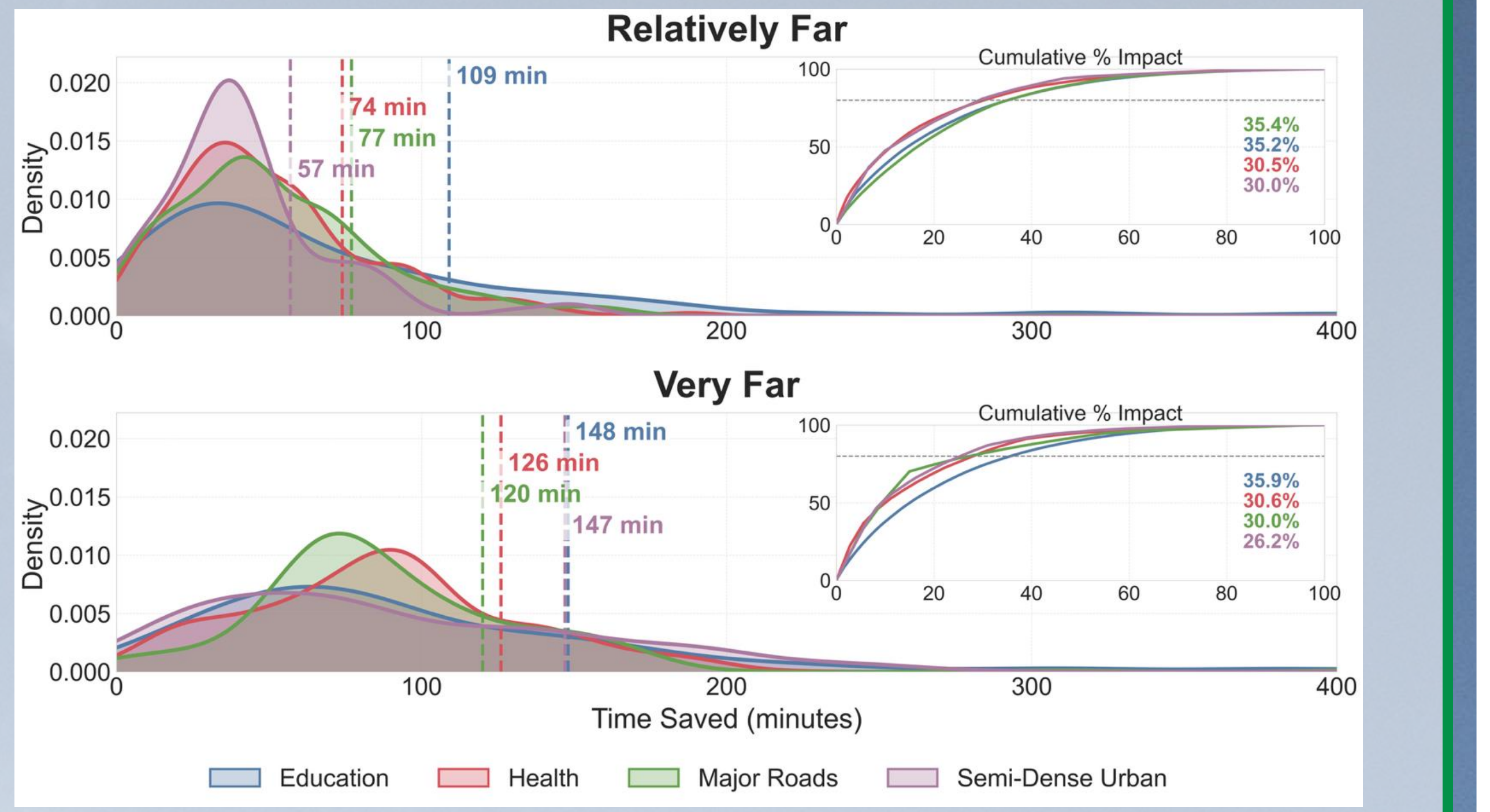

Fig. 3: Population-weighted Kernel Density Estimates (KDE) of travel time reductions in Rwanda. The heavy tail to the right illustrates the non-linear impact of bridges. The vertical dashed lines mark the 80th percentile of beneficiaries.


Photo credit: Bridges to Prosperity

4 SCALING UP

The Pareto Trap

We scaled our optimization algorithm across seven countries and multiple destinations (Health, Education, Markets). Remarkably, the "80/30 Rule" replicates in every context. This confirms that inequality is a structural feature of the network. While strategic targeting allows us to solve the bulk of the problem efficiently, the curve creates a "Pareto Trap." The final 20% of the population requires exponentially higher investment per capita, ensuring they will always be excluded by standard cost-benefit models.

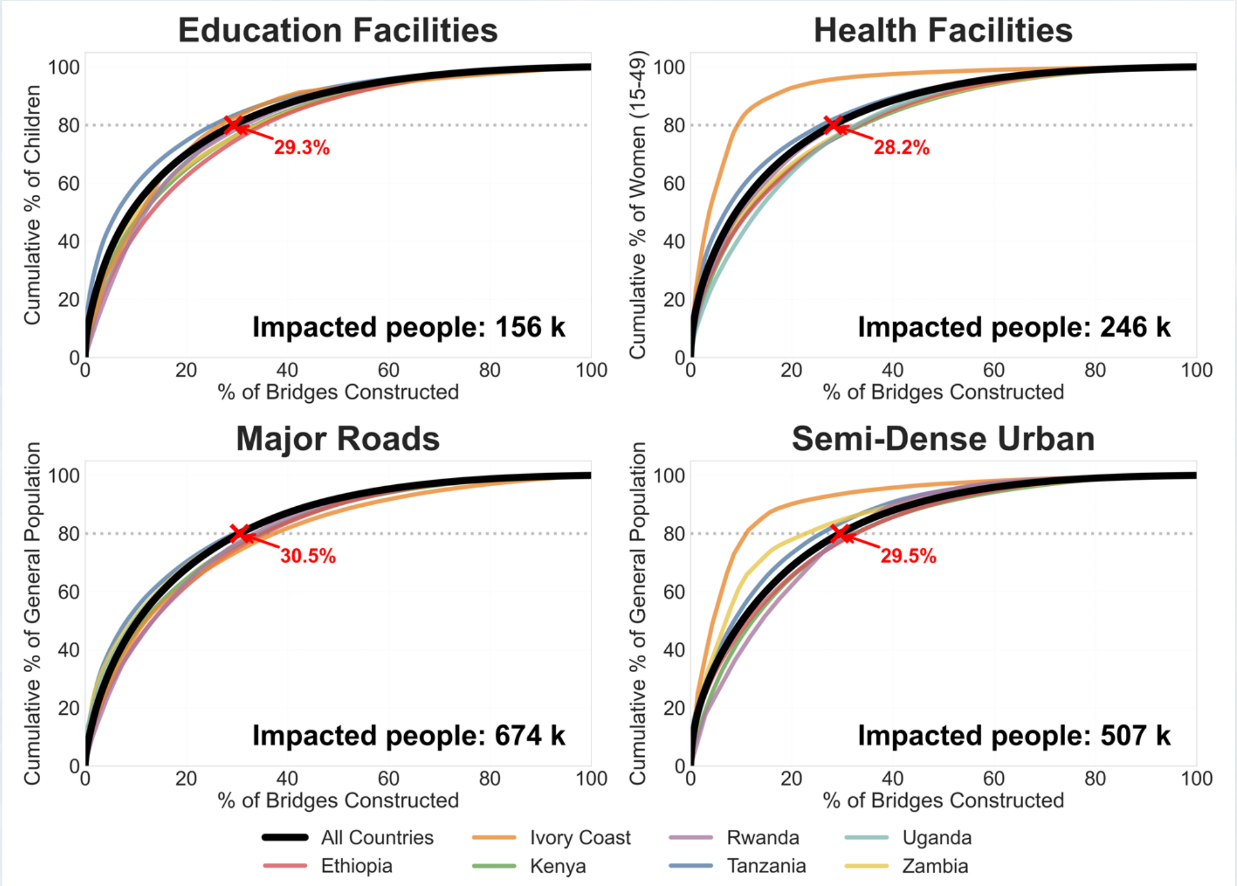

Fig. 4: The 'Red Cross' marks the point of diminishing returns. While the first ~30% of bridges deliver massive returns, the curve flattens rapidly.

5 OUTLOOK

High impact, low cost

Finally, our analysis confirms that rural infrastructure is a financially viable intervention. Annualized costs of $1.05–$22.32 per person are competitive with recurrent programs like deworming (~$0.65) or malaria prevention and provide durable access for decades. **Conclusion**: Efficiency has a limit. The most isolated 20% remain expensive to connect and will be excluded by standard cost-benefit models. To ensure no one is left behind, we must adopt a Universal Access Mandate, prioritizing rural connectivity as a fundamental human right.

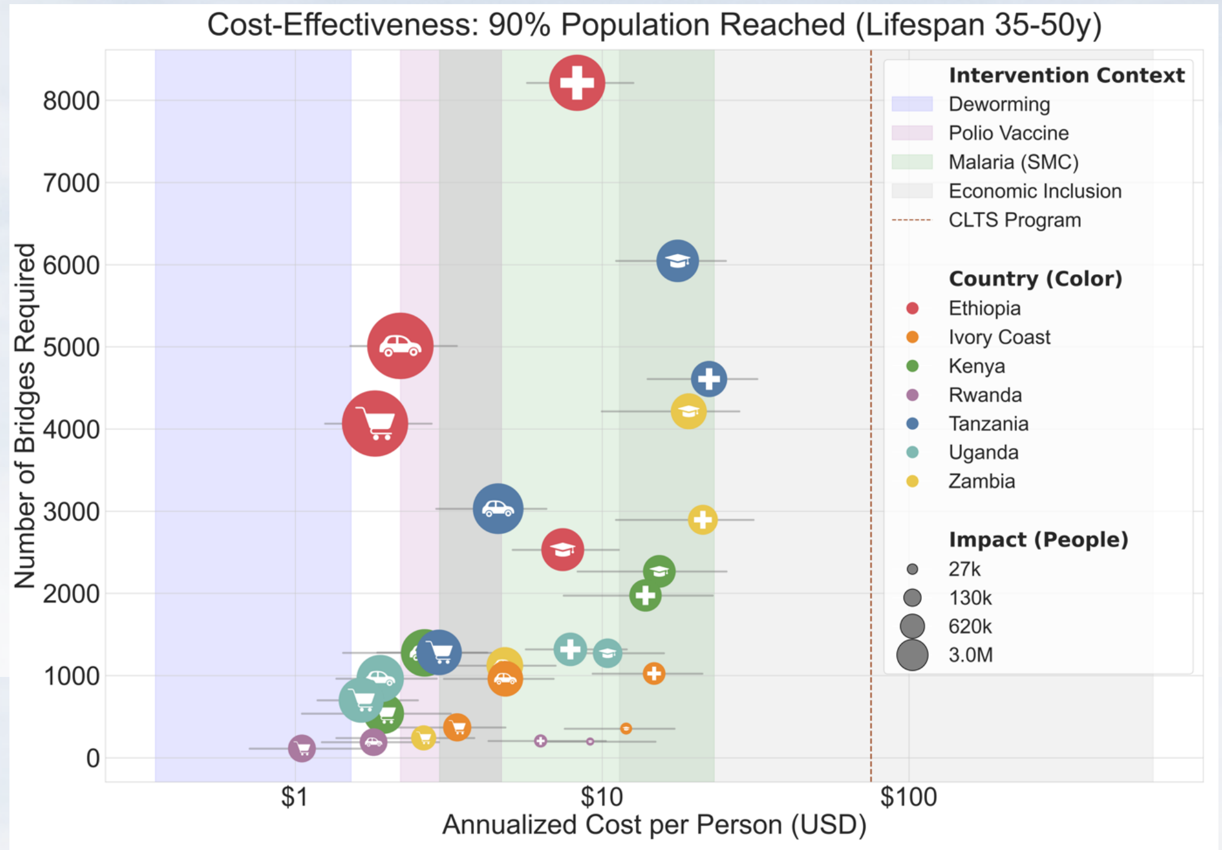

Fig. 5: Annualized cost per person impacted vs. total bridges required to reach 90% coverage. Icons indicate destination type: Education (cap), Health (cross), Roads (car), and Urban/Markets (cart).