Yale SCHOOL OF MANAGEMENT

Kevin Donovan
Assistant Professor of Economics

PO Box 208200
New Haven CT 06520-8200
T +1 203 432-4333
kevin.donovan@yale.edu
http://som.yale.edu/donovan

courier
165 Whitney Ave.
New Haven CT 06511

Measuring Return on Investment for a Footbridge in Nicaragua and Rwanda

October 2023

Prepared by:
Wyatt Brooks (Arizona State University)
Kevin Donovan (Yale University)

1 Introduction

This document provides calculations on the return on investment for the average bridge in the B2P Nicaragua study (Brooks and Donovan, 2020). We then discuss preliminary results in Rwanda and how they relate to those Nicaraugan results.

Throughout this document our measure of return is the *internal rate of return* (IRR), sometimes also referred to as the *economic rate of return.* It calculates the discount rate at which the cost of the intervention will equal the benefits over its useful life. The specific formula is

$$\text{Cost of a Bridge} = \sum_{t=1}^{T} \frac{\text{Total Benefit of a Bridge}}{(1+r)^t} \tag{1.1}$$

where T measures the total useful life of a bridge. The goal is to find the discount rate r that equalizes the cost on the left-hand side and the present discounted value of benefits on the right-hand side. Calculating r requires three pieces of information: costs, the useful life of a bridge, and the total benefit. The first two are measured directly by B2P. We measure the direct, causal benefits of bridges using the statistical analysis discussed below.

2 Nicaragua Study

In Brooks and Donovan (2020), we report the results of a study with Bridges to Prosperity (B2P) in which we studied the construction of footbridges in rural Nicaragua. Measuring the direct, causal impact of infrastructure is difficult. It naturally tends to be placed in areas of high perceived need, and given the required costs, tends to be quite politically visible.

While the full set of results are available in Brooks and Donovan (2020), we bullet point them here to keep the document self-contained. For the average person,

- During a flooded week, a bridge causes wage earnings to rise by C$148.68 relative to the average person without a bridge, or about 19 percent over baseline weekly earnings. This occurs because it makes it easier to get to town labor markets.
- During non-flooded weeks, a bridge also causes weekly wage earnings to rise by C$159.56. This is 20 percent increase over baseline weekly earnings. This occurs because individuals take different jobs once the risk of flood-induced isolation is removed.

- Farm profit rises by 75 percent (C$6489.82) for the average household, despite those same farmers spending nearly 60 percent more on fertilizer and pesticide.

Figure 1 shows the results on wage earnings graphically for some sense of what these numbers represent.

Figure 1: Density of Income Realizations

(a) No Bridge (b) Bridge

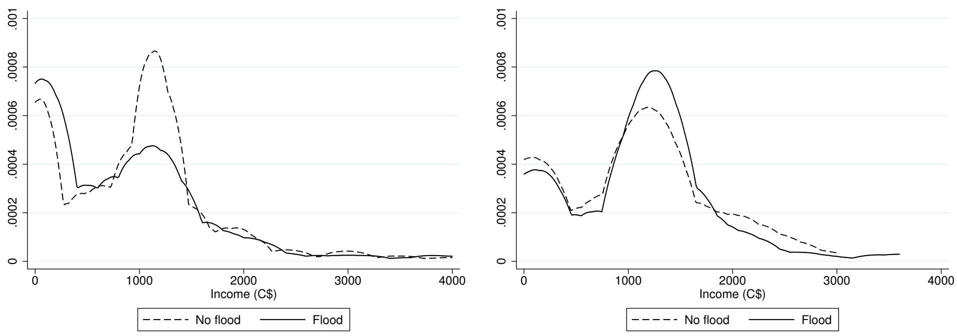

Figure notes: Figure 1a includes all village-weeks without a bridge, including those villages that eventually receive a bridge. Figure 1b includes all village-weeks post-construction.

We refer interested readers to Brooks and Donovan (2020) for the underlying economic mechanisms that tie these results together. Here, we focus specifically on measuring the return on investment (ROI). Doing so relies on three key features of the world: (i) the causal impact of a bridge on economic outcomes, (ii) the useful lifespan of a bridge, and (iii) the cost of bridge construction. We measure (i) in our results. We assume the useful lifespan of a bridge is 40 years and that construction costs 40,000 USD. At the time of construction, this bridge cost was C$ 1,100,000 (the currency used is the Nicaragua córdoba, and the exchange rate was approximately $C\$29 = 1\text{USD}$). We are explicit about how we use these numbers below, so they can be easily adjusted as necessary.

Measuring the Change in Total Village Income from a Bridge To measure the ROI, we need to compute an annualized change in total income. This depends on (i) wage earnings in the households and (ii) farm income. We discuss these in turn. We compute the annual effect on wage earnings as

$$\begin{aligned}\text{Annual Effect on Wage Earnings} &= 26 \times (\%\text{ of weeks flooded} \times \text{Earnings impact in flood weeks} \\ &\quad +\%\text{ weeks not flooded} \times \text{Earnings impact in non-flooded weeks}) \\ &= 26 \times (0.095 \times 148.68 + 0.905 \times 159.55) \\ &= C\$4106.83\end{aligned}$$

This equation says the following. First, we make the conservative assumption that the bridge is only valuable in the rainy season. We emphasize that this is a conservation assumption because we observe changes in job choice that extent beyond the rainy season. Within the 26-week rainy season, floods occurred in 9.5% of weeks. During those flooded weeks, a bridge caused earnings to rise by C$148.68. The remaining 90.5% of weeks there was no flood. Here, a bridge caused earnings to rise by C$159.42. Over the course of a full year, the average household sees their wage earnings rise by C$4106.83 due to the construction of a bridge.

The second piece is farm profit. Farm profit rises by C$1975.61. Combining the two, total income for the average household rises by C$4106.83 + C$1975.61 = C$6082.44. Since there are on average 33.5 households per village, this implies a total village benefit of C$203,761.70.

Measuring the Return of a Bridge Putting these pieces together, we can compute the internal rate of return as

$$\begin{aligned}
\text{Bridge Cost} &= \sum_{t=1}^{T} \frac{\text{Total Increase in Income}}{(1+r)^t} \\
C\$1,100,000 &= \sum_{t=1}^{40} \frac{C\$216,739}{(1+r)^t} \\
\Rightarrow & \quad \mathbf{r = 18.5\%}
\end{aligned}$$

A key component of this high IRR is the fact that spillovers are measured properly. If we simply measured the wage earnings without taking into account the fact that farm profits rose, the IRR would be r = 12.4%. This would underestimate the annual return of market access for rural communities by 33 percent. Our headline IRR of 18.5% compares extremely favorably to almost all development interventions, despite the cost.

Note also that this IRR assumes that the benefit of a bridge is exclusively *income*. This is likely an understatement of the IRR in terms of *welfare*. To the extent that households are more easily able to access health clinics or education, these features would be important to capture in a broader return on a bridge but are not included here. Even more, households likely value directly the reduction in uncertainty of market access; it allows for better planning of household spending, fewer unexpected adjustments to household budgets, etc.. In Brooks and Donovan (2020) we estimate an economic model to measure the increase in welfare that includes this risk-reduction benefit. The total welfare gains are approximately double the consumption gains (see Brooks and Donovan, 2020, for the econometric details).

3 Preliminary Results from Rwanda

In part due to the high IRR reported uncovered from our study in Nicaragua, we are now in the process of conducting a large-scale follow-up study in Rwanda. This study will involve 147 bridges across 23 Rwandan districts, with the construction timing randomized to facilitate causal measurement. As of this writing, we are in year 4 of a 5-year study.

While these results are still incomplete and therefore preliminary, we report them here to help facilitate comparison to the Nicaragua results and highlight some similar changes observed. Again, we provide brief bullet points to keep the document as self-contained as possible. All reported results are statistically significant using conventional cut-offs.

- Ninety percent of households engage in farming. A bridge causes the value of total harvest to increase by 10 percent of its average baseline value, or 10,517 RWF.
- The value of cash crop harvest specifically has increased by 18 percent of its average baseline value. The number of different cash crops grown, and the likelihood of growing coffee, by households also increases.

Return on Investment We measure the return on investment specifically on the value of harvests here. Other outcomes are still in process. We again use the internal rate of return as our preferred metric and note again that this is just a sub-sample of potential benefits and thus is likely conservative.

Key to this measure is the possibility that the treatment effect fades over space. We measure the dilution of the treatment effect on harvest value using regression analysis (see the technical details in the Appendix) to define the proper catchment area for a bridge. We use the term *catchment area* as a statistical term here: it is defined as the distance from the bridge site at which the bridge no longer generates a positive treatment effect in harvest value. We do so to make sure that we are not assuming benefits to places not implied by the statistical analysis.

When we do so, we find that the treatment effect converges to zero at 2.35 kilometers from the bridge site. We estimate that the average bridge site has 13,314 people within 2.35 kilometers. These estimates are derived from B2P using WorldPop estimates and their own needs assessment data. With an average household size of 4.6 people, this implies an average of 2,888 households within the catchment area (again, using our definition) of each bridge.

We assume the effect on agricultural output is constant over the life of the bridge. In many ways this is conservative because valuable activities make take time to generate returns. Coffee trees, for example, take 5 years to bear fruit when planted. This implies a total benefit of 10,517 RWF $\times$ 2,888 households = 30.37 million RWF.

The cost of a new bridge is 1000,000 USD or 92 million RWF at the 2021 exchange rate of 920 RWF = 1 USD. Taken together, the internal rate of return (IRR) therefore solves

$$\begin{aligned} \text{Cost} &= \sum_{t=1}^{\text{Effective Life}} \frac{\text{Benefit}}{(1+r)^t} \\ 92 &= \sum_{t=1}^{40} \frac{30.37}{(1+r)^t} \\ \Rightarrow \mathbf{r} &= \mathbf{0.493} \text{ or } \mathbf{49.3\%} \end{aligned}$$

One key difference between Rwanda and Nicaragua is household density. The sparsity of Nicaragua implied relatively few households within the bridge's catchment area. Those were made up for by the large effect of a bridge to get us IRR = 19.7%. Rwanda is one-fifth the size of Nicaragua in terms of land area and correspondingly more densely populated. This density is important to the high IRR observed here.

The Aggregate State of the Rwandan Economy Another feature of these results is that harvest values have risen substantially despite external forces disrupting Rwandan agriculture. Rwanda imports a majority of fertilizer and the Russia/Ukraine conflict has caused the price of fertilizer to rise. Figure 2 plots the change in DAP (the most commonly used fertilizer) in the months before and after Russian's invasion of Ukraine. The log price is normalized to zero in the January 2022, the month before the conflict began. The price of fertilizer has risen nearly 40 percent since the start of 2022. We expect these prices to decline as supply chain routes are adjusted and are likely to cause the impact of this infrastructure to rise.

Figure 2: Log Price of DAP

Figure notes: Event study of market vendor prices of DAP. Regression controls for baseline variation in price across markets and clusters standard errors at the vendor level. The dashed line represents the 95 percent confidence interval.

References

Brooks, Wyatt and Kevin Donovan, "Eliminating Uncertainty in Market Access: The Impact of New Bridges in Rural Nicaragua," *Econometrica*, 2020, *88* (5), 1965–1997.

Technical Appendix

Here we discuss details of how we compute spatial fade-out of harvest value. We run the regression

$$y_{ijkt} = \alpha_{kt} + \gamma_j + \beta_1 Bridge_{jkt} + \beta_2 Distance_{ijkt} \times Bridge_{jkt} + \Gamma Controls_{ijkt} + \varepsilon_{ijkt}$$

where y_{ijkt} is the outcome (harvest value) for household i in village j and district k in survey wave t. *Bridge* is an indicator function for whether or not a bridge is constructed (the village is "treated") and *Distance* is the physical straight-line distance between the bridge location (or future bridge location) and the household.

We find $\hat{\beta}_1 = 17,081$ ($p = 0.003$) and $\hat{\beta}_2 = -7,553$ ($p = 0.053$). This means that at 2.35 kilometers the bridge effect is equal to zero. Thus, we take 2.35 kilometers as our statistical catchment area. Using the population estimates discussed in the main text and the average benefit of 10,517 RWF, we arrive at the total benefit of 30.37 million RWF.