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Engineering environmental resilience: A matched cohort study of the community benefits of trailbridges in rural Rwanda

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HIGHLIGHTS

- Rainfall induced flooding in Rwanda can cause increased rural isolation.
- Bridges to Prosperity is constructing hundreds of trailbridges in Rwanda.
- A cohort study evaluated the community benefits of trailbridges.
- Labor market income increased by 25%.
- Anticipate additional outcomes with 200 site, 4 year trial.

GRAPHICAL ABSTRACT

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ABSTRACT

Rural isolation can limit access to basic services and income-generating opportunities. Among some communities, rainfall induced flooding can cause increased uncertainty where first-mile transportation infrastructure is limited. In Rwanda, this challenge is apparent, where 90% of the population below the poverty line live in rural areas that are typically mountainous with frequent flooding - events that may be increasing in frequency and severity as the climate changes. To reduce these transportation barriers, the non-profit organization Bridges to Prosperity (B2P) plans to construct hundreds of trailbridges in Rwanda between 2018 and 2023. This scale of rural infrastructure services presents an opportunity for experimental investigation of the effects of these new trailbridges on economic, health, agricultural and education outcomes in rural communities. In this paper, we present a cohort study evaluating the potential community benefits of rural trailbridges - including economic, health and social outcomes for Rwandan communities experiencing environmental change. We examined households living near 12 trailbridge sites and 12 comparison sites over February 2019–March 2020. We found that labor market income increased by 25% attributable to the trailbridges. We did not observe any significant effects on agricultural income, education or health outcomes, however given the small sample and short duration of this study we anticipate observing additional outcomes within the recently started 200 site, 4 year trial.
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1. Introduction

Bridges to Prosperity (B2P, www.bridgestoprosperity.org) is a US-based non-profit organization that builds trailbridges to connect isolated rural communities to national road networks and critical destinations and services including markets, hospitals and schools. Fig. 1 illustrates an example bridge in Rwanda. To date, B2P has constructed more than 340 trailbridges in 21 countries. B2P's program in Rwanda started in 2012 and includes 75 trailbridges offering safer transportation for an estimated 385,000 people. Over the next five years, B2P plans to construct 200 trailbridges in Rwanda, which will serve more than a million people. These trailbridges serve pedestrians, livestock as well as bicycles and motorcycles. This rapid program growth presents an opportunity for rigorous investigation of the effects of new trailbridges on a number of key economic, health, agricultural and education outcomes in rural communities.

Recent research by co-authors Brooks and Donovan in collaboration with B2P investigated economic outcomes associated with B2P bridges among rural villages in Nicaragua (Brooks and Donovan, 2020). This three-year study examined rural villages' increased access to larger, higher-paying labor markets in nearby towns and the spillover effects of this access back in the village, including changes in commodity and product prices and agricultural choices and practices. Brooks and Donovan found that seasonal flash floods in Nicaragua result in uncertain access to labor markets and reduced agricultural productivity. When a village does not have a trailbridge, floods can prevent reliable access to higher-pay day-labor jobs in nearby communities and in this context induced 18% lower wage earnings compared to communities with a trailbridge. Spillover effects of the trailbridges included reduction of the average wage gap between intervention villages and nearby towns, an increase in women from intervention villages entering the labor market and increased farm profit in the intervention villages. The results of this Nicaragua study contributed to the understanding of the economic impact of trailbridges and informed the study presented in this paper.

In this paper, we present the results of a cohort study evaluating the potential community benefits of rural trailbridges - including economic, health and social outcomes for Rwandan communities experiencing environmental change. This evaluation included 12 trailbridge sites and 12 comparison sites over the course of one year (March 2019–February 2020) and was designed in part to inform a large scale trailbridge construction effort, and an associated 200-site, 4-year study which started in August 2020. The objectives of the study presented here are to investigate the economic, health, agricultural and educational impacts of the B2P trailbridges among nearby households.

Fig. 1. An example Bridges to Prosperity trailbridge in Rwanda (Credit: Envision Photography/Bridges to Prosperity).

2. Background

2.1. Environmental variability

Rainfall variability in east Africa, attributable in part to climate change, has caused both floods and drought, as well as increased variability in agricultural yields - conditions expected to increase in severity and frequency in the coming decades (Ongoma et al., 2018). Community resilience to environmental change in East Africa is increasingly imperative and priorities include increasing agricultural intensification (Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa, 2015; Ministry of Agriculture and Animal Resourcese, 2018), strengthening electrical and water services (Enhancing the Climate Resilience of Africa's Infrastructure, 2015), and mitigating the impact of floods and droughts on communities (Kalantari et al., 2018; Thomas et al., 2020a).

In Rwanda there are four climatic seasons: a long rainy season (March–April-May), a long dry season (June–July-August), a short rainy season (September–October-November), and a short dry season (December–January-February) (Muhire et al., 2015). Meteorological data has shown that the two rainy seasons are potentially becoming shorter and more intense (Rwanda State of Environment and Outlook, 2009). Rainfall variability in Rwanda leads to increased drought in eastern Rwanda and reduced crop yields (Nahayo et al., 2018), and flooding and landslides in the mountainous west (Mind'je et al., 2019). Deaths, displacement and destruction attributable to flooding in some areas of Rwanda have increased significantly between 2013 and 2020 (Rutagengwa et al., 2020). Additionally, temperatures in Rwanda are expected to increase up to 2 degrees Celsius by mid-century (Rwanda Climate Data Projections, 2020) which, past a certain threshold, will lead to decreased crop yields (Austin et al., 2020). These conditions will increasingly and disproportionately affect small-scale farmers with low adaptation capacity (Müller et al., 2011).

2.2. Rural transportation infrastructure

Rural isolation can limit access to basic services and income-generating opportunities within low- and middle-income countries (LMIC) (Gollin et al., 2014). The World Bank estimates that one billion people worldwide lack access to an all-weather road, illustrating the scope of the problem and the challenge of addressing it at scale (The World Bank, n.d.). Uncertain access to markets, income-generating opportunities, and health and education facilities contributes to persistent rural poverty (Hasan Khan, 2000). Among some communities, rainfall induced flooding can cause increased uncertainty where first-mile transportation infrastructure is limited. In Rwanda, this challenge is apparent, where 90% of the population below the poverty line live in rural areas that are typically mountainous with frequent flooding - events that may be increasing in frequency and severity as the climate changes (Pachauri and Reisinger, 2007; Pachauri et al., 2014).

In response to these first-mile transportation challenges, governments and international organizations have spent billions on infrastructure improvements (Hine and Starkey, 2014). Studying the impact of such spending as a pro-poor policy can be difficult, as the high profile and cost of such projects tend to incentivize placement in areas where economic growth would be maximized. Although infrastructure investments can make travel safer and faster, they often disproportionately benefit non-poor people who have existing resources and capital (Hine and Starkey, 2014; Ansoms, 2008).

Transportation infrastructure has been found to have a positive impact on economic, education and health outcomes. In India, after construction of new village access roads, a positive impact on school attendance was found, independent of socioeconomic status (Mukherjee, 2013). Transportation infrastructure has also generally been found to improve access to healthcare for poor households by reducing time taken to reach care (Brenneman and Adam, n.d.).

Economically, we have shown a significant improvement in household earnings associated with trailbridges in Nicaragua (Brooks and Donovan, 2020).

2.3. Labor market

Our study was informed in part by the earlier Nicaragua trailbridge study with updates for context. In Nicaragua, over 80% of the rural population relies on agriculture work for their main income (The World Bank, 2015). In Rwanda, the 2016/2017 National Poverty Profile found that for over 80% of poor households, the main source of income was independent farming (National Institute of Statistics of Rwanda (NISR), 2018). In this study, 94% of the baseline sample respondents report harvesting crops either for their own consumption or for sale. The agriculture sector in Rwanda is mainly composed of of small-scale farmers with over 85% of households cultivating less than 1 hectare (Ministry of Agriculture and Animal Resourcese, 2018). Small-scale farmers, who mainly produce staple crops for household consumption, often cannot produce at a level required to exit poverty (Ministry of Agriculture and Animal Resourcese, 2018; The World Bank, 2015). Rwanda's poverty reduction plan for the agriculture sector of the labor market includes the Strategic Plan for Agricultural Transformation (SPAT) (Ministry of Agriculture and Animal Resources, 2009). One goal of SPAT is reducing the percentage of the population who depend on agricultural wages. Because of the transition away from subsistence farming, many of the agricultural growth strategies are more practical for cash crop or commercial farmers who have existing financial resources and ability to cope with risk (Ansoms, 2008).

2.4. Agriculture

For several decades, agricultural intensification has been practised in Rwanda. The Crop Intensification Program (CIP) is the latest government-led program which was designed to increase productivity of priority crops selected for mainly their economic value, including beans, cassava, maize and rice (Clay, 2018). Launched in 2007, the goal of CIP is to increase the productivity of selected crops in order to achieve food sufficiency for the farmers and obtain the surplus that is taken to the market. CIP encompasses different activities to achieve this objective including among others, adoption of improved seeds, increased use of fertilizers, and post-harvest storage mechanisms (Kathiresan, 2011; Daniel, 2012; Nahayo et al., 2017). Land consolidation is the practice of 20–25 farmers at the Umudugudu (village) level who plant the same crops, coordinate the timing of their cropping, and collectively sell the crops at market. Joining the program is optional, but participating farmers may receive benefits like subsidized inputs and intermediates and agricultural extension services like trainings (Kathiresan, 2011).

The two primary growing seasons in Rwanda correspond to the short and long rainy seasons. A third growing season happens between the short and long rainy seasons. Maize is the primary crop in the first two growing seasons while the third growing season is used to supplement household diets (Austin et al., 2020). Through different government-led programs including CIP and Rural Sector Support Program (RSSP), particular crops have been given priority due to their economic value. These eight priority staple crops (maize, wheat, rice, Irish potato, beans, cassava, banana, and soybeans) (Nahayo et al., 2017).

Since 2008, importation of agricultural inputs has substantially increased by the government of Rwanda under CIP (Kathiresan, 2011; Rutikanga, 2016). Both improved seeds and fertilizers are imported from neighboring countries and distributed to farmers at subsidized prices through private distributors and dealers.

3. Methods

The study employed a matched-cohort design, in which 12 bridge sites were matched to 12 comparison sites. Fig. 2 shows these locations. Data collection was primarily conducted with household survey instruments.

3.1. Site selection and study design

The bridge sites were identified by B2P staff in cooperation with government officials through a systematic needs assessment conducted in 2013. B2P's method for assessing a need for a trailbridge considers administrative and governance structures, telecommunications infrastructure, ease of mobility, and social and cultural norms (Shirley et al., 2020). In Rwanda, an official letter was submitted to each district to introduce the needs assessment and document the support from the national government. Using contact information provided by the district, B2P worked with leaders at multiple administrative levels of local government to collect information about potential bridge sites. Screening was conducted to first establish if a serviceable all-season crossing was within 300 m. B2P then conducted site assessments to verify both apparent need and technical feasibility for bridge installations.

B2P subsequently developed a memorandum of understanding between national and local government entities in Rwanda that reflected funding, construction and inspection and repair responsibilities. B2P's construction and repair standards were implemented throughout the site assessment, construction and operating phases. Subsequent to bridge construction, regular inspection of the bridge decking and foundation ensures safe and reliable bridge use (Bridges to Prosperity, 2016).

In this study we compare the sites that were chosen to have bridges constructed in 2019 to sites that were not yet known at the time when the 2019 build schedule was completed, but were later determined to be viable build sites. Specifically, for each build site in 2019 we selected the nearest site that was later approved, but had not yet been identified and selected when the 2019 build list was created. Therefore identification in the study relied on an absence of correlation between characteristics of villages and the timing of when B2P conducted their assessment in the local district. Of the 12 bridge sites that were selected for the study, seven were located in the Southern Province, and five were located in the Western Province. Comparison sites were identified from a 2018 needs assessment carried out by B2P. As with the bridge sites, seven of the comparison sites are in the Southern Province and five are in the Western Province.

Our sampling frame was designed for minimum detectable effects (MDE) of 4% change in food expenditure, a 13% change in household income, a 6% change in fertilizer use, a 5% change in clinic visits, and at least a 1% change in mid-upper arm circumference. Using these target outcome MDE, we selected a sample of 100 households per site as the detectable effect size flattens after this point.

With these 24 sites, we surveyed representatives from 100 households at each of the intervention and comparison sites. For both intervention sites and comparison sites, B2P identified the "more impacted" side of the potential bridge crossing – the side of the crossing with communities that would benefit most significantly from a new bridge, based on proximity to essential services. Our research team then obtained the administrative list of households from the Umudugudu chief (village leader) or cell secretary for the village that is closest to the bridge on the impacted side. If the village closest to the bridge had fewer than 100 households, all households would be surveyed. To reach 100 total households, the household list from the next closest village then randomized and the remainder of households were selected from this list.

To motivate this study, during our baseline survey we asked respondents to estimate walking time to various economically significant locations. Those results are in Fig. 3. Nearly 70% of households live at least a 50 min walk from the nearest market (Fig. 3b), health clinic (Fig. 3c), or bank (Fig. 3d). Wage jobs (Fig. 3a) are more uniformly distributed across space. This is because unlike health clinics and banks, jobs exist inside the village. One can see the bi-modal distribution here, with

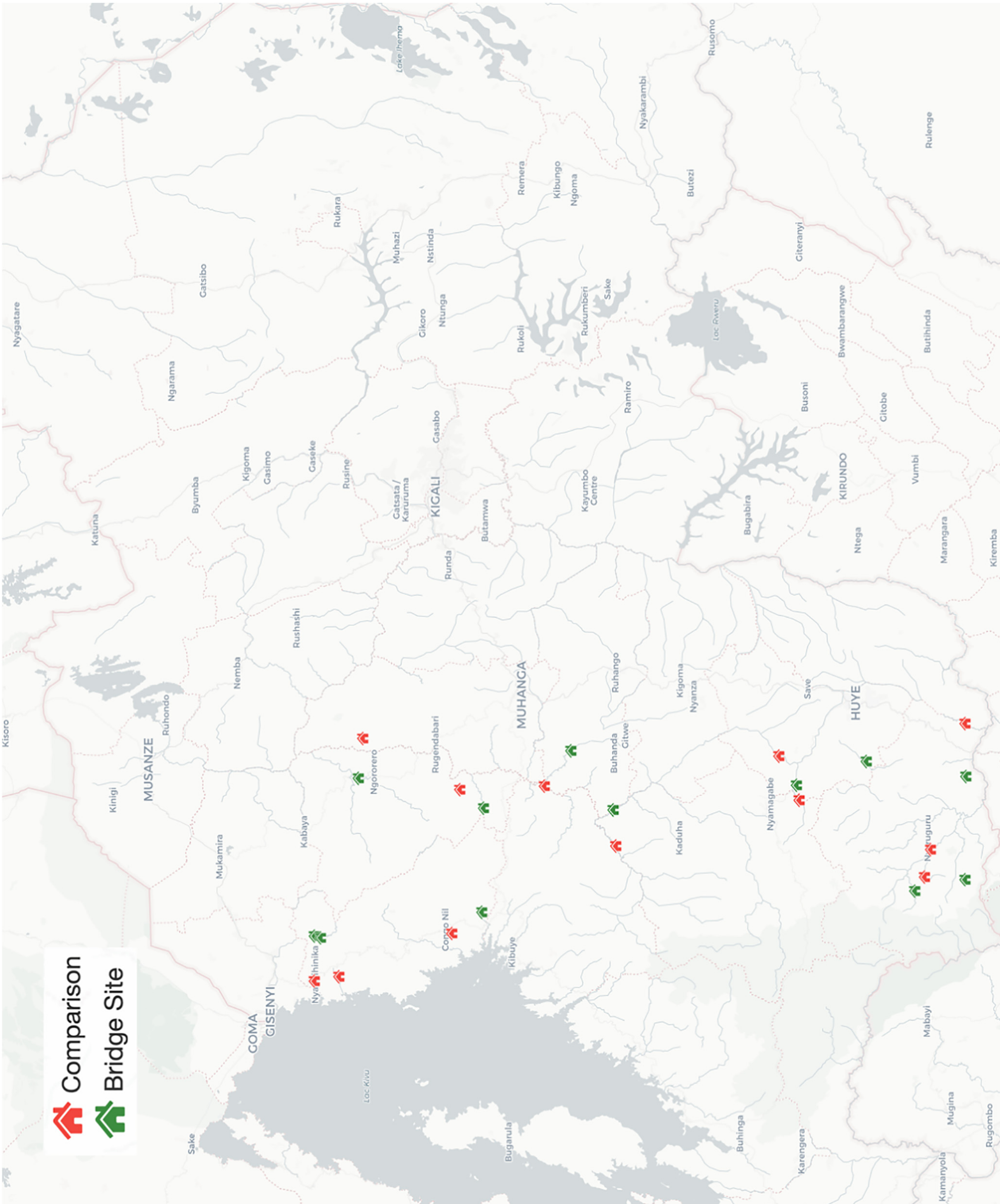

Fig. 2. Bridge and comparison study locations.

Fig. 3. Walking time (minutes) to various destinations.

34% of jobs less than 20 min away, and 31% of jobs more than 50 min away.

3.2. Household surveys

Household survey questions in this study covered household composition, educational attainment, health status, sources of income, farming operations, consumption, debt, and resilience. The baseline data was collected March–May 2019. Bridges were constructed in June–July 2019. The first follow-up was collected in August–October 2019. The first follow-up was not designed to study agricultural outcomes such as harvest or yield, since the main harvest occurs in January and February. A second follow-up in February–March 2020 studied such outcomes. We refer to these three waves as $t = 0,1,2$ throughout. Surveys were conducted in Kinyarwanda by a team of trained enumerators.

Enumerators were instructed to survey the head of household or another adult member of the household. The respondent answers questions for all members of the household. Respondents were told that the purpose of the study was evaluating the effect of new trailbridges on economic, health, and educational outcomes. To meet requirements of the Institutional Review Board (IRB), B2P was listed as a sponsor on the household consent form but enumerators were instructed to clarify that participation in the study would not effect whether or not the village would receive a trailbridge. The same households were visited in each subsequent survey round; if the household was not available in a follow-up round, they were considered as lost to follow-up. In baseline data collection, the average size of households surveyed was 4.7 people.

A major complication during $t = 2$ data collection was the COVID-19 crisis. This stopped data collection after only some data was collected, and generates an unbalanced panel of households, which will be important for interpreting data from the $t = 2$. Throughout this paper, we will highlight where this plays a role.

3.3. Household wage earnings and consumption

Our survey included collecting household income reported by the respondent on behalf of each person in their household. This included labor market earnings both within and outside the community, and agricultural earnings. We further explored household consumption for potential application across varying types and locations of interventions in an outcomes-based funding model. Household consumption, which is most often measured through surveys, is frequently relied upon by investigators when trying to measure living standards and poverty in low- and middle-income countries (Smith et al., 2014).

Consumption questions include both consumption of goods purchased at a market and consumption of goods produced in the household. Households may have also received food or other products as gifts (in-kind donations) but these were not included in this study. For produce, flours, and meats, respondents were asked to classify the quantities consumed from household production, quantities purchased in market, and price paid at market. Creating clear categories separating acquisition and consumption between home production and markets ensures individual identification of sources (Smith et al., 2014). Respondents were also asked about totals spent on products like fuel, toiletries, and airtime. The recall period for these purchases is one week.

3.4. Education

Educational attainment questions were informed by the International Household Survey Network (Policy and Center, 2009) report. Household members who previously attended school and household members who currently attend school were asked different sets of questions about their educational attainment and access to school facilities. Measures of literacy were not included in the current study but is being considered for the scale-up study.

3.5. Health

Reliable transportation infrastructure is a key component of both regular and emergency healthcare. Infrastructure can influence a household's decision to visit a clinic or hospital as well as the travel time and opportunity cost of the visit. This type of access also supports preventative and developmental care for newborns and children (Babinard and Roberts, 2006).

The study investigated health status of household members, with primary focus on the respondent and children. The respondent was allowed to consent to health questions for children but were only asked non-identifying health questions about other adult household members. The respondent was also asked about their personal health status and access to healthcare.

For children between six months and five years old, mid-upper arm circumference (MUAC) was measured as an indicator of severe acute malnutrition. The measurements were taken at the mid-upper arm point on the child's left arm, using the specialized MUAC tape. The MUAC tape has three color-coded zones indicating a healthy child, moderate malnutrition, or severe malnutrition. Children in this age range who have a MUAC less than 11.5 cm are considered severely malnourished (World Health Organization and United Nations, 2009). MUAC measurements are taken following standard UNICEF practices (UNICEF, 1986). If a child was not present or nearby during the survey, they were not measured for MUAC. In other words, not all eligible members of the sample were contacted. (See Fig. 4.)

For children under five years old, caregivers were asked to present the child's vaccination card. If the caregiver did not have the vaccination card, they were asked to recall which vaccines the child had received. Otherwise, the card was used to record the child's vaccination history. A photo of the vaccination card was taken, with consent, as relying on caregiver recall can introduce error (Danovaro-Holliday et al., 2018). Vaccination data is collected to confirm and supplement administrative data like reported national vaccination rates. The photographed vaccination cards were transcribed during data cleaning by recording vaccination dates and checking that they aligned with the recommended vaccination schedule. Incomplete or illegible cards were marked accordingly.

Pregnant women were asked a different subset of questions about their health. This includes attainment of prenatal care and services including vaccines, anti-malarials, and bednets. Pregnant women are also asked to confirm receipt of the tetanus vaccine.

3.6. Agriculture

Only one full year of crop growth and harvest data was captured in the pilot study because of the limited timeline. Due to COVID-19 restrictions during end-line data collection, less than a full year of crop growth and harvest data was captured at some households. In the scale-up study, crop growth and harvest seasons will be captured more than once, over at least four surveys per site, over four years.

Households were asked whether they farm and about their participation in agricultural co-ops. Each co-op is listed along with the services it provides and the location. For each crop grown, the respondent listed most recent harvest quantities, amounts stored, and amounts sold or gifted. They are also asked about farmland that they own or rent, amount spent on inputs like fertilizer or seed, and market locations where the crops are sold.

3.7. Household assets

Enumerators were asked to observe different qualities of the respondents house such as the roof materials, floor material, and wall material. If respondents own farm animals, they list quantities of each animal along with information about butcher, sale, and purchases.

Fig. 4. Data collection methods including household surveys, mid-upper-arm-circumference measures, and digital cameras installed at bridge crossings.

3.8. Bridge use

As part of this study, we deployed motion-activated digital cameras at the bridge crossings. Adapting an open source computer vision algorithm to identify and count bridge use, we found a reliable correlation with less than 3% mean error of bridge crossings per hour between manual counting and those sites at which the cameras logged short video clips. This method and results are presented in another paper (Thomas et al., 2020b).

4. Results

In this section we present the results of selected outcomes. Table 1 presents the outcomes analyzed. Our analysis takes the broad form of a difference-in-difference regression. Throughout, we cluster standard errors at the village level and trim all outcomes at 1% to eliminate any severe mis-reporting or outliers.

We examined various specifications designed to deal with the potential bias introduced by COVID-19. Our preferred specification is to include household-level fixed effects to control for any time invariant differences across households. We prefer this methodology because it allows us to control for both observable and unobservable characteristics. This regression takes the form,

$$y_{ivm} = \alpha + \beta Bridge_{vm} + \gamma_m + \theta_i + \varepsilon_{ivm}. \tag{1}$$

for individual i in village v surveyed in month m. We include survey-month fixed effects because the surveys span multiple months and we wish to remove seasonality that could potentially bias the results (e.g. Bryan et al., 1671–1748; Rosenzweig and Udry, 2020).

Of the outcomes examined, we saw no effect on education or health outcomes and do not report them here as the sample sizes were small and unbalanced. However, these outcomes will be collected during the on-going larger and longer study. With respect to economic and agricultural outcomes, we report wage earnings, agricultural income, harvest practices, and consumption and debt.

Table 1
Selected outcomes examined. Survey questions are abbreviated. Indented questions were asked when appropriate based on previous responses. Monetary units are Rwandan Francs (RWF).

Outcome	Level	Data type
Walking times		
To wage job	Each member	Range minutes
Market	Household	Range minutes
Health clinic/hospital	Household	Range minutes
Bank	Household	Range minutes
School	Household	Range minutes
Economic		
Debt	Household	RWF
Non-farm income		
Labor market in village	Economic	RWF
Labor market outside village	Economic	RWF
Family, friends, gifts, government	Economic	RWF
Consumption		
Food purchased	Household	RWF
Fuel purchased	Household	RWF
Household items purchased	Household	Select list
Agriculture		
Crop earnings	Household	RWF
Fertilizer, seed, pesticide spending	Household	RWF
Crops harvested	Household	Kilos
Crops stored	Household	Kilos
Crops gifted	Household	Kilos
Land use for crops	Household	Acres
Education		
Years of school completed	Each Member	Number
Days of school missed in past month	Each Child	Select range
Health		
Vaccinations	Children	Records
Mid Upper Arm Circumference (MUAC)	Child under 5	mm
Medical care in the past month	Each member	Yes/no
Unable to visit clinic/hospital	Each member	Yes/no
Any members of family pregnant	All members	Yes/no
Visited a clinic for prenatal care	Any pregnancy	Yes/no
Given birth in the past month	All members	Yes/no
Birth attended	Any birth	Yes/no

4.1. Wage earnings

We begin by considering household earnings. Table 2 reports the results. A brief explanation of the table format is in order. Each row is a separate regression. The first uses household fixed effects on all data collected. The remaining three rows change only the data including in the regression. The second row ("controls") uses all data, while three and four sequentially drop the final follow-up ("controls, drops $t = 2$") and the first follow-up ("controls, drop $t = 1$"). The goal with these various specifications is to show that the results seem to hold regardless of the specification, suggesting some confidence that we are not picking up spurious results from the COVID-19 induced constraints.

Overall, earnings rise. We observe a 25% increase in labor market earnings. This comes from changes both inside and outside the village, where household earnings increase by 48 and 21% respectively. These results are consistent with the bridge linking households to labor markets, a key finding in our previous Nicaragua work as well.

The remaining columns provide some rationale via daily wages. First, note that outside labor markets offer an 11% higher daily wage at baseline (763 RWF compared to 690 RWF within the village). Thus, simply allowing households to more easily access higher paying jobs will increase earnings. Note the outside wages do not change in response to a bridge, as the villages are small relative to the size of the labor market. However, column (6) shows that village daily wages increase substantially and contribute to the increased earnings within the village. One simple rationale for this is that access to higher paying jobs puts upward pressure on the village wage. Thus, even those who do not start working in the market are likely to benefit from connection.

Overall, these results are consistent with our previous results in Nicaragua and are robust to specification, though the inside wage varies somewhat depending on the specification.

Table 2
Effects on market earnings.

	Earnings			Avg HH daily wage		
	Total	Inside	Outside	Total	Inside	Outside
	(1)	(2)	(3)	(4)	(5)	(6)
Bridge (household FE)	337.59***	193.45**	173.53*	72.71**	166.52***	4.29
	(99.06)	(73.17)	(93.14)	(34.63)	(57.36)	(27.73)
Bridge (controls)	332.43***	191.53**	151.91	53.23	48.00	19.81
	(98.70)	(72.52)	(93.11)	(34.23)	(51.67Li)	(32.99)
Bridge (controls, drop t=2)	277.06*	90.62	230.95*	45.50	29.14	17.48
	(147.45)	(74.15)	(122.48)	(47.02)	(81.24)	(45.47)
Bridge (controls, drop t=1)	373.93**	202.87	91.02	57.84	87.75*	−27.20
	(141.68)	(126.02)	(106.68)	(47.46)	(48.84)	(47.96)
Obs.	5796	5793	5787	2369	1219	1416
R-squared	0.30	0.10	0.24	0.18	0.21	0.32
Baseline Mean	1353.81	400.89	813.92	732.31	690.06	763.35

Standard errors in parenthesis are clustered at the village level. $^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$. Each row is a separate coefficient on the bridge indicator, with specification differences as defined in the text. Baseline mean is reported over the whole sample (that is, everyone for whom baseline data is collected). Similarly, number of observations and R^2 are recorded from the first regression using the controls. Outcomes trimmed at 1%. Daily wages are run only on those with reported earnings.

Table 3
Agricultural inputs and outputs.

	Inputs			Harvests	
	Fertilizer	All intermediates	Land	Maize	Beans
	(1)	(2)	(3)	(4)	(5)
Bridge (household FE)	31.17	−36.30	−15.80	−1.02	1.63
	(457.11)	(706.28)	(30.45)	(2.04)	(2.47)
Bridge (controls)	−114.10	−172.61	−10.49	−1.35	1.67
	(496.18)	(714.29)	(32.02)	(2.31)	(2.47)
Bridge (controls, drop t=2)	−21.43	−378.11	−18.17	−1.71	2.51
	(333.07)	(465.39)	(49.77)	(2.04)	(3.44)
Bridge (controls, drop t=1)	−391.72	−650.88	21.17	0.42	−0.66
	(971.88)	(1254.62)	(17.09)	(3.85)	(2.77)
Obs.	5799	5793	5562	5794	5816
R-squared	0.41	0.38	0.03	0.31	0.29
Baseline Mean	3976.29	6727.35	135.16	17.23	21.01

Standard errors in parenthesis are clustered at the village level. *$p<0.1$, **$p<0.05$, ***$p<0.01$. Each row is a separate coefficient on the bridge indicator, with specification differences as defined in the text. Baseline mean is reported over the whole sample (that is, everyone for whom baseline data is collected). Similarly, number of observations and R^2 are recorded from the first regression using the controls. Outcomes trimmed at 1%.

4.2. Agricultural outcomes and harvest uses

We next turn to studying agricultural outcomes. We begin with inputs and outputs on the farm. Table 3 shows the results under all specification. Overall, we observe no changes in agricultural inputs or outputs. An important caveat to these results is that $t = 2$ was the first harvest available and was impacted by COVID-19 (the $t = 1$ followup was post-bridge, but before harvest). With that in mind, we find that households do not seem to spend more fertilizer or intermediates (the sum of the fertilizer, pesticide, and seed). They do not bring more land into production. Perhaps as expected, we see no changes in harvest quantities. Thus, overall, the bridges do not seem to change agricultural outcomes, at least at this relatively short time horizon.

While agricultural production does not change, a separate question is what households do harvest after collection. We measure the share of harvest stored for home consumption, sold in market, or given to others. The remainder is already-consumed food in the household, and thus our results below need not sum to one. Table 4 shows the results.

Table 4
Harvest uses.

	Maize			Beans		
	Stored	Sold	Given	Stored	Sold	Given
	(1)	(2)	(3)	(4)	(5)	(6)
Bridge (household FE)	−0.07 *	0.00	−0.01 **	−0.01	−0.00	−0.00
	(0.04)	(0.01)	(0.01)	(0.03)	(0.00)	(0.01)
Bridge (controls)	−0.07 *	0.00	−0.01 **	−0.01	−0.00	−0.00
	(0.04)	(0.01)	(0.01)	(0.03)	(0.00)	(0.01)
Bridge (controls, drop t=2)	−0.14 **	0.01 **	−0.00	0.03	0.00	0.01
	(0.05)	(0.01)	(0.01)	(0.04)	(0.01)	(0.01)
Bridge (controls, drop t=1)	0.04	−0.01	−0.02 *	−0.05 **	−0.00	−0.01 **
	(0.03)	(0.01)	(0.01)	(0.02)	(0.00)	(0.01)
Obs.	5851	5851	5851	5851	5851	5851
R-squared	0.25	0.10	0.12	0.24	0.03	0.05
Baseline mean	0.10	0.03	0.03	0.11	0.01	0.03

Standard errors in parenthesis are clustered at the village level. *$p<0.1$, **$p<0.05$, ***$p<0.01$. Each row is a separate coefficient on the bridge indicator, with specification differences as defined in the text. Baseline mean is reported over the whole sample (that is, everyone for whom baseline data is collected). Similarly, number of observations and R^2 are recorded from the first regression using the controls. Outcomes not trimmed, since outcomes are constrained between zero and one.

Again, similar to our results in Nicaragua, we do not see stored food going down, at least for maize. Moreover, we also see an increase in the share of harvest being taken to market for sales. This increases by 55%, though off an extremely low baseline of 3%. Note, however, that those numbers suggest that a large portion of the change is being generated by the fact that households were consuming more quickly out of harvest. Given high storage costs, this likely lowers waste, which we will look into further in the full study.

4.3. Consumption and debt

We then consider whether or not the observed increase in wage earnings translates into changes in consumption or debt in Table 5. Here, we see some changes, though they are difficult to interpret. If one interprets the point estimates only, consumption seems to be declining along with debt. Thus, one interpretation would be that households were forgoing consumption to pay down debt. Of course, the p-values suggest substantially more caution in this interpretation. The coefficient on debt, RWF -2058, has a p-value of p=0.371. However, if one trims the values at 5% instead of 1%, the debt amount falls to RWF -1968 with a p-value of p=0.039.

Another potential interpretation of the point estimates is that households were replacing market-purchased food with their own consumption (recall, consumption out of their own storage is higher in treatment villages). This type of substitution is likely beneficial for households, as it frees resources to be used on other purchases.

5. Discussion

The main results are as follows. We find:

1. Labor market income increases by 25% over baseline mean.
2. No changes in market consumption expenditures or outstanding debt.
3. No change in the primary educational or health related outcomes, over the year-long observation period.
4. No changes in agricultural inputs (fertilizer, pesticide, land use) or harvest quantities. We do find that households shift their uses of harvest, storing less maize harvest and selling more (55% increase, though off a low base of 3%) in the immediate aftermath of construction. However, the COVID-19 crisis stopped data collection after only some data was collected in our final wave. This generates an unbalanced panel of households, and importantly less than a full year of crop growth and harvest data was captured at some households.

Table 5
Effects on consumption and debt.

	Total expenditures	Food expenditures	Outstanding debt
	(1)	(2)	(3)
Bridge (household FE)	−137.82	−49.34	353.99
	(264.03)	(257.32)	(1314.56)
Bridge (controls)	−195.40	−104.24	−155.82
	(260.32)	(266.26)	(1373.03)
Bridge (controls, drop t=2)	−592.97 *	−494.78	−1217.53
(332.33)	(324.72)	(1944.74)	
Bridge (controls, drop t=1)	38.00	81.13	−187.88
(244.00)	(258.15)	(2200.76)	
4 Obs.	5759	5793	5799
R-squared	0.37	0.34	0.22
Baseline Mean	4105.97	3473.83	17,142.48

Standard errors in parenthesis are clustered at the village level. *$p<0.1$, **$p<0.05$, ***$p<0.01$. Each row is a separate coefficient on the bridge indicator, with specification differences as defined in the text. Baseline mean is reported over the whole sample (that is, everyone for whom baseline data is collected). Similarly, number of observations and R^2 are recorded from the first regression using the controls. Outcomes trimmed at 1%.

5.1. Household income

Labor market outcomes are made up of an increase in earnings both inside and outside the community. The reasons, however, differ. First, better connection allows households to shift labor to the higher-paying peri-urban markets. Instead of being "trapped" in only low-paying jobs within the village, some community members are able to seek work outside. This induces an increase in the wage inside the village. Thus, those who continue working in the village see their earnings increase as well.

Rwanda has recently worked to incentivize village development through their *imidugudu* program, designed to more efficiently provide and utilize community-level services and natural resources. This could be one rationale for the relatively more concentrated rural communities in this context. We also note that these results are only informative about relative distance within a village. Our study design does not allow for the possibility of inter-village spillovers, though we will study this in the scaled project.

5.2. Agricultural practices

In this study, we find that households shift their uses of harvest, storing less maize harvest and selling more (55% increase, though off a low base of 3%) in the immediate aftermath of bridge construction. The results suggest that this change may be a result of households consuming harvest more quickly. Based on 2014–2017 data, maize was one of the best performing crops in terms of kilocalories per hectare (Ministry of Agriculture and Animal Resourcese, 2018). To further investigate this finding, in the scale-up study, a larger sample will provide a broader and more representative cross-section of rural households in Rwanda. Specifically, in the scale-up study, there are more sites represented in the southwestern region and the northwestern region of the country. As in the Nicaragua study, we will examine if there are increased expenditures on intermediates as well as increased farm profit as a result of the bridge intervention. National strategies discussed above emphasize increased investment in subsidized fertilizer imports as well as increases in production of the eight priority staple crops (Nahayo et al., 2017). If participation in CIP increases, we may see subsistence farmers shift towards non-farm labor and increased outputs and sales of cash crops.

5.3. Interaction with distance

An additional result in the Nicaragua trailbridge study (Brooks and Donovan, 2020) was that the impact of the bridge faded the further the household was from the bridge site. We note that distance is not a perfect measure of access difficulty. Households can be physically close to bridge sites, but access may still require crossing difficult terrain. Alternatively, households physically far away from a site may have access to roads that facilitate bridge access.

An interesting feature of Rwanda relative to Nicaragua is that households are more geographically compressed. In the average Nicaraguan village studied by co-authors Brooks and Donovan, the average household was 1.64 km from the bridge site, compared to 1.08 km in Rwanda. More importantly, the standard deviation of household distance in Nicaragua was 0.76, compared to 0.43 in Rwanda. That is, Rwandan households are both closer and less disperse. Thus, the scope for distance to play an important role may be limited within the village.

We did not find statistically significant heterogeneity by distance to bridge site. We emphasize that this is likely a positive sign for the potential of the larger study. In our Nicaragua work, we observe large average effects *despite* some households gaining little from the new bridge. One takeaway from those results is that the gains are likely to be larger in more geographically compressed villages, where more households can gain from the bridge. These results suggest this possibility in Rwanda.

The implementer, B2P, has collected some indicators that the benefits of these bridges may extend beyond the communities immediately adjacent to the bridge crossing. These have included bridge use surveys, in which users are asked where they live, and for what purpose they are using the bridges. These limited indicators motivate future work to establish the spatial extent of bridge use and model potential benefits at a distance.

5.4. Further work

While we did not observe any significant effects on agricultural income, education or health outcomes, given the small sample, short duration and limitations imposed by the COVID-19 pandemic, we anticipate observing additional outcomes within the recently started 200 site, 4 year trial.

Furthermore, this study did not measure any impacts, positive or otherwise, outside of either the intervention or comparison communities. While neither the evaluators nor the implementers were able to recall any anecdotal concerns regarding negative impacts of these bridge installations, we are concerned with measuring the broader impact of the bridges away from the directly adjacent communities. In the scale-up study, we are presently collecting data among households within communities that are further away from the bridges to establish if there are any measurable impacts among communities at a further distance. Additionally, we are conducting regular market surveys for both consumer and agricultural products at markets across the region (and not only those in proximity to the bridges) to establish any regional-scale impact attributable to the bridges.

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CRediT authorship contribution statement

Evan Thomas: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Abigail Bradshaw:** Data curation, Investigation, Project administration, Resources, Visualization, Writing – original draft, Writing – review & editing. **Lambert Mugabo:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. **Laura MacDonald:** Conceptualization, Funding acquisition, Investigation, Methodology, Data curation, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. **Wyatt Brooks:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. Katherine Dickinson: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Kevin Donovan:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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