Is Development Innovation a Good Investment?

Which Innovations Scale?

Evidence on social investing from

USAID's Development Innovation Ventures[1]

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December 2019

DRAFT

[1] This is a research working paper. It does not reflect the view of the United States Agency for International Development or the United States Government. Thanks to Ken Chomitz, Joaquin Carbonell, Alison Fahey, Garance Genicot, Anne Healy, Adam Jaffe, Josh Lerner, Louis Kaplow, Fanele Mashwama, Krish Ramadurai, Duc Tran, Adam Trowbridge, Kevin Xie, and Noam Yuchtman for helpful comments and the staff of Dimagi, *gui[2]de*, Evidence Action, and VisionSpring for providing information.

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Executive Summary

Over the past two decades, aid donors have established many new initiatives to invest in innovation for international development. Economic theory suggests a potential case for such innovation investments as global public goods. Yet while supporters can point to cases of successful innovations supported by such initiatives, skeptics can also point to prominent failures. There is a widespread view that few innovations scale and most innovation investments are unsuccessful (Kenny and Sandefur, 2013). To assess the case for development innovation investment, it is important to move beyond anecdotes and compare portfolio-wide social returns on investment in innovation with returns on standard development investments. Moreover, understanding which types of investment are most successful and how to effectively structure innovation funds requires quantitatively examining the characteristics of innovation investments associated with higher rates of scaling.

Unfortunately, little evidence exists on how social returns on development innovation compare with the returns on other forms of aid investment, or even on the predictors of innovations scale. Estimating innovation portfolio returns is difficult for several reasons: 1) innovations often take a decade or more to scale; 2) many innovations lack impact evaluation data on benefits per user, or even administrative data on costs and the numbers of users; and 3) it is conceptually difficult to put a monetary value on the benefits of some types of innovations.

This paper first develops an approach to assess whether the return on an innovation portfolio exceeds a benchmark even when data is limited. Because a small fraction of innovation investments accounts for the great majority of benefits, it may be possible to estimate an informative lower bound on the benefit-cost ratio for the portfolio as a whole by comparing the social benefits of just a few innovations with the cost of the entire portfolio. To avoid the implicit double counting

involved when multiple innovation funders claim credit for the same innovation, each claiming that it leveraged the others' funding, the methodology includes only the share of benefits from each innovation corresponding to the funder's share of innovation funding. While this approach still does not assess the counterfactual of what would have happened without a particular funder, if all innovation funders adopted such an approach, it would be possible to estimate the overall return to innovation investment by aggregating returns across funders.

This approach is applied to the early portfolio of the U.S. Agency for International Development (USAID) Development Innovation Ventures (DIV) program, a tiered, evidence-based, open innovation fund. The focus is on the early years of DIV because it takes time for innovations to scale. Over its first three years, from 2010 to 2012, DIV invested in 41 innovations, at a total cost of $19.2 million.

Ten out of the 41 innovations reached over one million direct beneficiaries. Those ten innovations account for over 95% of the 55 million people reached by innovations in the portfolio, and likely generated the vast majority of the portfolio's social return. For some of the innovations that reached over one million users, such as innovations to reduce electoral fraud, it is conceptually difficult to value the benefits in monetary terms. For others, important data is unavailable, for example because no impact evaluation was undertaken on the innovation. Other innovations are still in the process of scaling, were scaled in a form that substantially differed from that which was subject to impact evaluation, or did not have a rigorous impact evaluation, so estimating total benefits would require very strong assumptions. However, sufficient data are available to at least roughly estimate the net social benefits of four innovations that have reached over one million people.

By the end of 2018, after eight years, DIV's investments in just these four innovations had already generated an estimated $86 million in discounted social benefits. Dividing the $86 million in benefits of these four innovations by the $16 million discounted cost of DIV's entire early portfolio over this period implies that the innovation portfolio returned over $5 in social benefit for each dollar invested - even setting aside any future benefits of these innovations and the benefits generated by the other 37 innovations supported by DIV. This corresponds to a social rate of return of over 77%, substantially greater than standard estimates of the rate of return on foreign aid (~10%, Arndt et al. 2016), historical stock market returns (~7%, Baldwin 2017), the typical financial returns on impact investment funds (~6%, GIIN 2017), and the target set when DIV was established (15%). Because the approach used to calculate the lower bound includes the benefits of only four innovations, and excludes any future benefits, DIV's true social rate of return is likely considerably higher. Under conservative assumptions of continued operation through 2023 by three of the innovations, a benefit-cost ratio of over $9 is projected.

Many social entrepreneurs focus on sales to individual consumers as the route to scale, and many development innovation funders seem to have a similar mental model of scaling, drawn perhaps from Silicon Valley. Yet for social innovations aimed at base of the pyramid consumers, customer acquisition costs are often large relative to potential profits per customer, making this route to scale and financial sustainability difficult. Innovations that leveraged existing distribution platforms (often government, businesses, and established NGOs) were three times more likely to scale than those that attempted set up new networks. DIV's early portfolio also suggests a strong correlation between rigorous evaluation and scaling. Investments that already had evidence of impact at the time of application were seven times more likely to scale than those that did not, while those that included development economics researchers were six times more likely to scale than those that did not.

Methodologically, a key lesson of this paper is that since a small number of innovations account for the bulk of reach, and almost certainly of the benefits, a portfolio-level approach is essential to assess whether the benefits of innovation investment exceed the costs. This analysis shows that such an approach is possible even without complete data. Since scaling takes time, and is often undertaken by entities other than those funded, it is important to track results after award financing has ended. as long as estimates of the number of people reached and net benefits per person can be obtained for a subset of high-impact innovations. The methodology could also be applied to assess innovation investment in development as a whole.

Substantively, the results from DIV's early portfolio suggest that open, tiered, evidence-based innovation funds with a rules-based, peer-review driven decision process have the potential to deliver high social returns. Engagement with frontier researchers and rigorous evaluation should be seen as complementary with scaling. While high customer acquisition costs make scaling through direct sales to bottom-of-the-pyramid customers difficult, many innovators were able to scale by engaging with existing organizations with wide reach, such as developing country governments and large businesses. This creates a path through which initial innovation investments by donors, philanthropies, and governments can spur increasingly self-reliant economies and societies.

TABLE OF CONTENTS

1. INTRODUCTION

In recent decades, international donors have created a number of initiatives to invest in innovation for development. The Bill & Melinda Gates Foundation (BMGF) has invested in research on the health problems of the developing world. USAID, Grand Challenges Canada, and others have funded innovations to address specific challenges facing developing countries in areas from mental health to agricultural water needs. The World Bank and the UK's Department for International Development (DFID) have supported randomized controlled trials designed to test development innovations. Impact investors have supported social entrepreneurs seeking to innovate for development.

Economic theory suggests a potential rationale for this: innovations are global public goods, likely to be undersupplied by markets, by individual developing country governments, and even by aid programs organized to support individual countries. Moreover, from a donor standpoint, innovation investment may be preferable to forms of aid that are seen as supporting consumption in developing countries, and thus potentially spurring dependence. Whereas some types of aid ostensibly directed toward investment might displace investments that developing countries would make otherwise, aid directed toward the global public good of development innovation may increase the long-run potential for developing countries to become self-reliant.

Yet whatever the theoretical benefits of innovation investment may be, assessing the desirability of such investment requires empirically compare returns on innovation initiatives with estimates of returns on standard development assistance investments. Unfortunately, much current discussion is limited to anecdotes. Advocates can point to some successful examples, but skeptics can point to failed innovations, such as play pumps (Kenny and Sandefur, 2013). Simply examining the fraction of successful investments in an innovation portfolio (Shah et al., 2015) provides little information on the rate of return on innovation, since the distribution of returns on innovation investments is highly skewed (with many investments generating negligible returns and a small fraction of investments generating large returns), just as it is for investments in the venture capital industry and citations of patents (Silverberg and Verspagen, 2007) and research papers (Aksnes and Sivertsen, 2004). Venture capital investors know that returns will be low on the vast majority of their investments. However, if they invest in a single Google or Facebook, the rate of return on their portfolio may be very high. To assess the return on innovation investment, it is important to compare the cost of an entire innovation portfolio against its benefits.

Estimating the return on an entire innovation portfolio is challenging for three reasons. First, it typically takes more than a decade for innovations to be refined and to reach scale[6]. Second, placing a monetary value on the benefits of some innovations is conceptually difficult (innovations to reduce voter fraud, for example). Third, data on the number of innovation users and on benefits and costs per user is often unavailable or costly to collect.

To address these challenges, a procedure is developed for determining whether the return on an innovation portfolio exceeds a benchmark, such as the economy-wide return on capital or the opportunity cost of more conventional development assistance investments. It is argued that determining whether the return on an innovation portfolio exceeds such a benchmark is a much easier task than estimating the return on an innovation portfolio and may be feasible even in the absence of good data on social returns for many innovations in an innovation portfolio. Because the returns on innovation investments are highly skewed, it may be possible to determine if the return

[6] Microfinance has been present in the modern developing world since the 1970s, but it took four decades to scale-up and reach 139 million clients (Microfinance Barometer, 2018). Similarly, Oral Rehydration Therapy was developed in the 1940s, but did not become commonly used until the 1970s after it played a key role during the Bangladeshi refugee crisis (Selendy, 2011). Norman Borlaug, who developed high-yield, disease resistant wheat varieties while working in Mexico in the 1940s and 1950s, was nearly pushed out of the sector by his employer before his innovations started to show their full potential and contributed to the Green Revolution in Asia starting in the 1960s (Wright, 2012).

on the innovation portfolio exceeds a benchmark by comparing the costs of the entire portfolio to the benefits of even a few innovations that reached at least a minimum number of users and for which data on costs, impact, and the number of people reached are available.

This bounding approach builds on the social returns on innovation literature (see Stevenson et al., 2018 for a global review on agriculture research), making contributions specific to development innovation investments that is useful when there are conceptual or data difficulties in getting a complete set of benefit-cost estimates. The approach recognizes that when assessing portfolio or sector-wide returns, focusing on mean and median returns on single investments (e.g., Hurley et al., 2016) can be misleading if the returns are skewed. While much of the literature focuses either on returns to natural science research (starting with Griliches, 1958) or industrial research and development (e.g., Hall et al., 2009), this analysis also differs in examining public sector investments in innovation, and development innovations in particular. Similar methods could be applied to look at returns for other innovation portfolios, and to assess investments in development innovation as a whole.

The procedure is then applied to assess the performance of the early portfolio of Development Innovation Ventures (DIV), a tiered, evidence-based open innovation fund at USAID. For this assessment, the focus is on DIV's early portfolio – the 43 awards made to 41 innovations between September 2010 and December 2012 – to allow at least some time for innovations to scale. The distribution of the number of people reached by the 41 innovations is highly skewed, with ten innovations that have so far reached over a million users accounting for the vast majority of the total population reached.

Data are currently available on the net social benefits of four of the innovations reaching over one million users (more data may become available in the future). Data on innovation scale and impact are used to estimate the net benefits created by those four innovations through 2018. Setting aside any potential future benefits and any realized benefits of the other 37 innovations supported during the early portfolio period, and counting benefits from each innovation in proportion to DIV's share of innovation funding, those four innovation investments had generated $86 million in social benefits by 2018. The discounted cost of the entire DIV early portfolio was $16 million, so benefits of these four innovations would have paid for the cost of the entire DIV portfolio at least five times over, yielding a social rate of return of over 77%. This is far in excess of estimates of conventional estimates of the rate of return on foreign assistance investments (Arndt et al., 2016) and local cost of capital in developing countries (MCC, 2016), both of which are around 10%. It is also much greater than the 7% historical market rate of return in the U.S. (Baldwin, 2017) and the 15% social rate of return target established at DIV's inception. While data on the social rate of return to impact investing funds are not available, the social rate of return on DIV is high relative to the private return on impact investing (GIIN 2017).

Using the same million user threshold as in the benefit-cost analysis, the correlates of innovation scale are identified. Several commonly-held beliefs about innovation success factors based on anecdotal evidence and small samples are systematically investigated. That analysis suggests that innovations that scaled typically leveraged existing organizations as distribution platforms, had low cost per person reached, demonstrated evidence of impact prior to the DIV application, and had researcher involvement during the DIV performance period.

The remainder of this paper is organized as follows. Section 2 provides background on DIV, analyzes the scaling rate of DIV-supported innovations, and highlights how the skewed distribution of innovation scale motivates the approach to estimating the portfolio benefit-cost ratio. Section 3 proposes a general methodology that could be applied by many innovation funders, defining the benefit-cost ratio and social rate of return of an innovation portfolio, and the assumptions and choice of parameter values that will be used in this particular analysis. Section 4 presents data on the net benefits, number of people reached, and per person of costs of four innovations supported by DIV: a water treatment innovation, a road safety innovation, an eyesight innovation, and a health service innovation. Innovation-level benefit data and portfolio-level cost data are used to estimate a lower bound on the portfolio social rate of return, present sensitivity analysis, and interpret the results. Section 5 analyzes correlates of innovation scale in DIV's early portfolio. Section 6 concludes with broad lessons on investing in development innovation.

2. BACKGROUND

This section provides background on DIV (Subsection 2.1) and outlines the early portfolio. Subsections 2.2 and 2.3 show that a minority of innovations accounted for the vast majority of people reached by the portfolio, setting up the benefit-cost (Section 4) and correlates of innovation scale (Section 5) analyses.

2.1: Development Innovation Ventures

DIV differs from many other innovation funders in several ways. First, it is *open.* It defines innovation broadly to include new applications of technology as well as novel business models, delivery models, production processes, products, or services that are expected to improve development outcomes[7]. Instead of the funder setting specific challenges to be addressed (as in the X-Prize), DIV takes a bottom-up approach that is open across sectors, geographies, organization types (for-profit firms, NGOs, governments, researchers, start-ups, faith-based entities, or established firms), and scaling strategies (delivering the innovation through private or public sector channels or through a hybrid approach).

[7] DIV's open approach can thus be seen as complementary to targeted programs that seek to spur innovation in particular areas that are judged to be priorities for USAID.

Second, DIV is tiered. The grant competition funds three stages of innovation: piloting (Stage 1, up to $100,000 in 2010-2012), testing for impact and cost effectiveness (Stage 2, up to $1 million), and transitioning innovations with rigorous evidence of impact and cost effectiveness to scale (Stage 3, up to $15 million). Innovators can apply at any stage (rather than needing to have been funded by DIV from the beginning), and since modifications and refinements are typically needed for innovations to scale, applicants can apply more than once for the same innovation.

Third, DIV is *evidence-based*. While DIV makes small Stage 1 grants to pilot a variety of promising ideas, it also provides larger-scale funding (Stage 2 and 3) only to innovations designed to improve social outcomes that either a) demonstrated rigorous evidence of impact and cost effectiveness based on an impact evaluation that could distinguish causal impact from potential confounding factors, or b) could pass a market test. To pass the market test, it is insufficient to demonstrate that someone would buy the product; instead, the applicant must demonstrate that revenues would be sufficient to fully cover costs in existing markets or that others were willing to invest on a commercial basis. DIV's evidence-based approach included peer review of proposals, by experts both internal and external to USAID, and deep engagement with the development economics research community and individuals with successful track records in the private sector as proposal reviewers and members of decision panels.

During the 2010-12 period covered in this analysis, DIV had a very small staff. Decision Panels included internal and external experts, and proposals were judged based on materials submitted by the applicant, feedback solicited from additional external reviewers, and feedback provided by USAID missions and bureaus.

2.2: DIV Awards, 2010-2012

DIV made 43 awards totaling $19.2 million to support 41 innovations[8]. The range of awards made during this period is shown in Table 1. Classifications are based on the characteristics of the award at the time of application to DIV.

[8] To date DIV has supported over 209 innovations in 46 countries.

Table 1: DIV Awards, 2010-12

Award title (abridged)	**Sector**	**Organization Type**[A]	**Countries**	**Stage**[B]	**Low cost**[C]	**Researcher involvement**[D]
Affordable Glasses for Presbyopia	Econ. Growth	For-Profit	India	2	No	No
Developing a Supply Chain for Hermetic Storage of Grain	Agriculture	Academic	Afghanistan	1	Yes	No
Developing an Affordable Balloon Tamponade for Postpartum Hemorrhage	Health	Non-profit	Ghana	1	No	No
Developing a Sustainable Distribution Model for Improved Cook Stoves	Energy	Non-profit	Ethiopia, Sudan	2	No	Yes
Developing Sustainable Sanitation in Urban Slums	WASH	For-Profit	Kenya	1	Yes	No
Digital Attendance Monitoring	Health	Non-profit	India	2	No	Yes
Election Monitoring Technology	Democracy	Academic	Afghanistan	1	No	Yes
Evaluating the Impact of Mobile Banking and Business Skills	Econ. Growth	Academic	Mozambique	2	No	Yes
Examining Barriers to Fertilizer Use	Agriculture	Non-profit	Kenya	1	No	Yes
Experimental Evidence of the Components of Entrepreneurship	Econ. Growth	Non-profit	Uganda	1	No	Yes
Fighting Tuberculosis through Community Based Counselors	Health	Non-profit	India	1	No	Yes
Ghana National Apprenticeship Program Impact Evaluation	Econ. Growth	Non-profit	Ghana	2	Yes	Yes
Home Solar Systems	Energy	For-Profit	Uganda	2	Yes	Yes
Household Hand-Washing Device-Commercial Development	WASH	Non-profit	Vietnam	1	No	No
Improving Health Service Delivery Through Community Monitoring	Health	Non-profit	Sierra Leone	2	No	Yes

Table 1 (continued)						
Award title (abridged)	**Sector**	**Organization Type**	**Countries**	**Stage**	**Low cost**	**Researcher involvement**
Improving patient safety in Pakistan's hospitals	Education	Non-profit	Pakistan	1	No	No
Increased Uptake and the Use of Safe Water Filters at Scale	WASH	Non-profit	Kenya	1	No	Yes
InSight: Mobile Accounting and Financial Inclusion in Emerging Markets	Econ. Growth	For-Profit	India	1	No	No
Inventory Credit: Combining Storage and Savings To Increase Income	Agriculture	Non-profit	Sierra Leone	2	Yes	Yes
Leveraging Public-Private Partnerships for the Environment	Environment	Non-profit	India	2	No	Yes
Life-changing and Revenue-generating Electricity	Energy	For-Profit	Tanzania	1	Yes	No
Milele Tube Final Testing and Marketing Introduction	Econ. Growth	Non-profit	Kenya	1	No	No
Mobile Agriculture Extension	Agriculture	Non-profit	Kenya	1	No	Yes
Proteinuria Self-Test For Early Detection of Pre-Eclampsia	Health	For-Profit	Nepal	1	No	No
Psychometric Credit Assessment	Econ. Growth	Academic	Egypt	2	No	Yes
Recruiting and Compensating Community Health Workers	Health	Non-profit	Zambia	1	Yes	Yes
Remittances for Educational Finance	Education	Academic	Philippines	1	Yes	Yes
Renewable Powered Micro Grids for Rural Lighting	Energy	For-Profit	India	2	Yes	No
Road safety stickers	Health	Academic	Kenya	2	Yes	Yes
Rural Solar Accessibility via Consumer Cooperative Enhanced Society Retails	Energy	Non-profit	Uganda	1	No	No

Table 1 (continued)						
Award title (abridged)	**Sector**	**Organization Type**	**Countries**	**Stage**	**Low cost**	**Researcher involvement**
Scaling Biochar: Improving livelihoods and sequestering carbon	Econ. Growth	Non-profit	Kenya	1	No	Yes
SiGNa Chemistry, Inc.	Energy	For-Profit	U.S.	1	No	No
Smoothing the Costs of Education: Microsavings in Primary Schools	Education	Non-profit	Uganda	2	Yes	Yes
Software for Community Health Workers	Health	For-Profit	India	1	Yes	Yes
Software for Community Health Workers	Health	For-Profit	India	2	Yes	Yes
Testing a Digital Platform's Ability to Recreate Rural CLTS	WASH	Non-profit	Ghana	1	Yes	No
The Role of Mobile Banking in Business Development	Econ. Growth	Non-profit	Kenya	2	Yes	Yes
Turning the Tap Off on Drug Resistant TB	Health	Non-profit	India, Cambodia	2	No	Yes
Viability of Cyanobacterial Bio-fertilizer to Improve and Crop Yields	Agriculture	For-Profit	Ethiopia	1	Yes	No
Voter Report Cards	Democracy	Non-profit	India	1	Yes	Yes
Voter Report Cards	Democracy	Non-profit	India	2	Yes	Yes
Water Treatment Dispensers	WASH	Non-profit	East Africa	3	Yes	Yes
Women's Network to Improve Clean Energy	Energy	Non-profit	East Africa	2	Yes	No

A: "Academic" organizations include university-based organizations and independent research organizations (notably Innovations for Poverty Action).
B: Stage 1 are pilot awards. Stage 2 are testing awards, and Stage 3 are scaling-up awards.
C: "Low cost" awards are those whose estimate unit cost per person served was less than $3.
D: "Researcher involvement" means that an academic researcher was on the applying team.

Awards were made in eight sectors (agriculture, governance, health, education, economic growth, energy, environment, and water/sanitation/hygiene) and 23 countries. 24 Stage 1 awards, 16 Stage 2 awards, and one Stage 3 award were made. Although DIV made awards to for-profit firms, DIV was limited to grants and could not make equity or loan investments, distinguishing it from some impact investors.

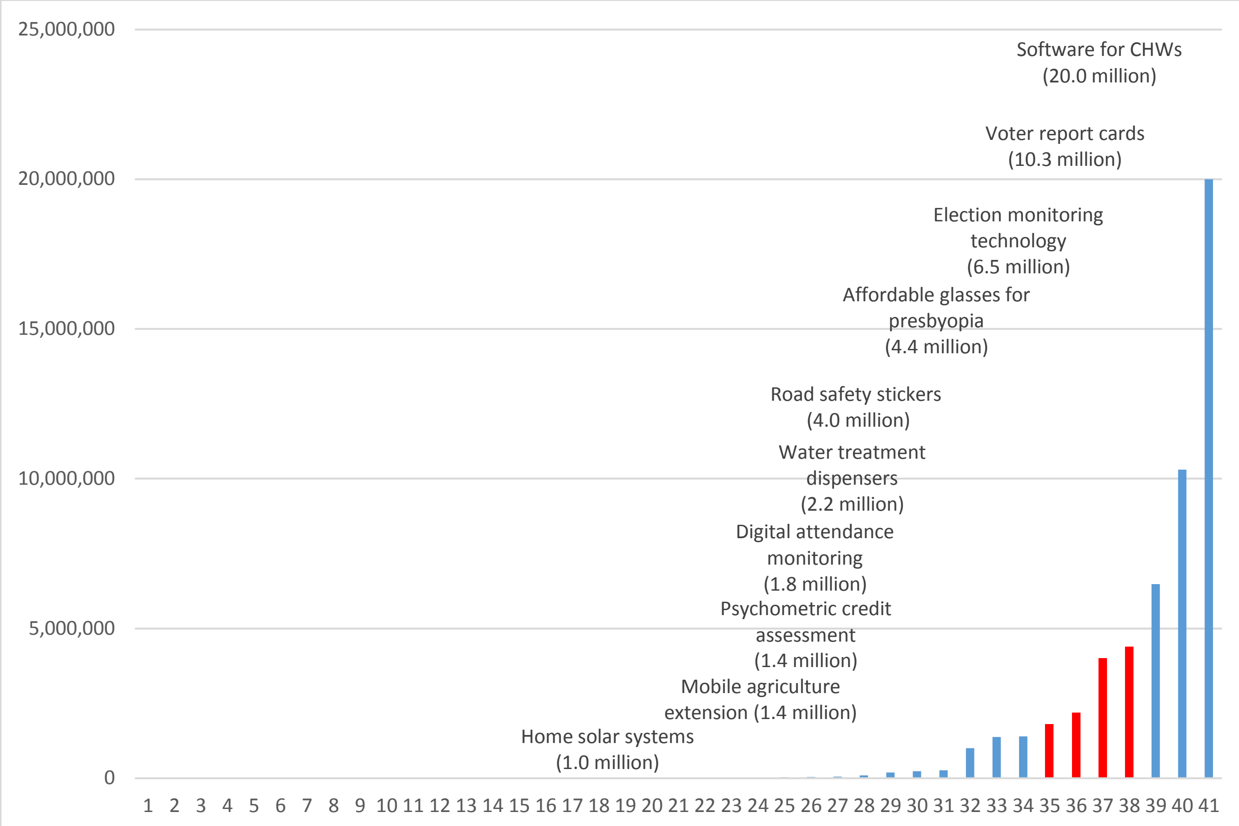
2.3: Innovations reaching more than one million users

For both of the analytical exercises in this paper (bounding the social return on the portfolio, and analyzing the correlates of innovation scale), it is useful to provide background on which innovations have reached more than one million users. As is discussed in more detail in Section 3, the gross social benefit of an innovation is the number of people reached by the innovation times the average net benefit per person. This makes it clear that one key driver of the total benefits of an innovation will be the number of people reached[9].

Figure 1 shows the number of people reached by each innovation in the early portfolio. It updates an analysis by Duflo and Kremer (2015), using the most recent publicly available (or third-party verified) data for each innovation, and defines reach as the number of direct users of the innovation. Figure 1 suggests that the distribution of the number of people reached by DIV investments is highly skewed, such that just a few innovations accounted for the vast majority of those reached by DIV-supported innovations.

[9] Theoretically, innovation return could be large even with low number of people reached. But given the range of benefits per person that is reasonable for the types of innovations supported by DIV, innovations that didn't reach at least 100,000 people are unlikely to contribute a large share of the portfolio benefit.

Figure 1: Number of people reached by early DIV innovations, rank ascending[10]



Bars in red represent the four DIV-supported innovations discussed in depth in this paper.

[10] The full distribution is approximated well by a lognormal distribution (with μ=10.56 and σ=3.23), while the top quartile of the distribution is approximated well by a power law distribution (with α=0.83). Gabaix (2009) provides a review of the many empirical power laws observed in economics and finance.

3. BENEFIT-COST RATIO METHODOLOGY

Subsection 3.1 defines the benefit-cost ratio and social rate of return for innovations and portfolios. Subsection 3.2 discusses the assumptions under which portfolio-level lower bounds on the benefit-cost ratio and the social rate of return can be established. Subsection 3.3 discusses the decisions on key parameters in the analysis. Subsection 3.4 identifies the subset of innovations for which the net social benefits generated by DIV's investment can be estimated.

3.1: Benefit-cost ratio definition

Benefit-cost ratio (BCR) is used as the main measure of innovation portfolio performance. In the formulas below, the number of people reached by innovation i in time period t is denoted as $N_{i,t}$, the estimated benefits per person reached (net of operating costs) of innovation i in time period t as $B_{i,t}$, and the innovation costs as $C_{i,t}$. Innovation costs refers to any investment that contributes to the formative development of an innovation (piloting, testing, experimenting with ways to scale-up). This is distinct from operating costs, which includes both recurrent and capital investment that did not contribute to the development of the innovation. r is the discount rate used to make monetary values from different time periods comparable.[11]

Definitions and examples of BCR and SROR are below, first in the simplest case for a single innovation with a single innovation funder before moving to the more complex case of an innovation portfolio with each constituent innovation supported by multiple innovation investors.

[11] Due to the opportunity cost of capital, benefits and costs that are incurred earlier should be valued more highly than benefits and costs that are incurred later. Refer to Subsection 2.3 for more information on discounting.

Benefit-cost ratio

The benefit-cost ratio (BCR) is the ratio of discounted value of net benefits generated by the innovation investment to the discounted value of the innovation cost. If the innovation operates from time t=0 to t=T, ratio of benefits to innovation costs for innovation i is[12]:

$$BCR_i = \frac{\sum_{t=0}^{T} \frac{N_{i,t}B_{i,t}}{(1+r)^t}}{\sum_{t=0}^{T} \frac{C_{i,t}}{(1+r)^t}}. \qquad (1)$$

For a simple example, suppose that in Year 0, $1,000,000 is invested in innovation i. Suppose also that the innovation generates no net benefits in Year 0. In the following year, there is no additional investment, but the innovation delivers $2,000,000 of net total benefits to innovation users before shutting down. With a 10% discount rate, the BCR is

$\frac{\sum_{t=0}^{1} \frac{N_{i,t}B_{i,t}}{(1+r)^t}}{\sum_{t=0}^{1} \frac{C_{i,t}}{(1+r)^t}} = \frac{\frac{N_{i,0}B_{i,0}}{(1+r)^0} + \frac{N_{i,1}B_{i,1}}{(1+r)^1}}{\frac{C_{i,0}}{(1+r)^0} + \frac{C_{i,1}}{(1+r)^1}} = \frac{\frac{0}{(1+0.1)^0} + \frac{\$2{,}000{,}000}{(1+0.1)^1}}{\frac{\$1{,}000{,}000}{(1+0.1)^0} + \frac{0}{(1+0.1)^1}} = 1.81.$ This indicates that each dollar from the investor returned $1.81 in social value. Assuming that the alternative use of funds would have generated a 10% return, investment in an innovation is socially beneficial if it has a benefit-cost ratio greater than 1.

Social rate of return

A closely-related measure of social impact is the social rate of return (SROR)[13]. The SROR of an investment in an innovation is the discount rate below which the innovation investment is socially

[12] Throughout this section, summation notation is used to write long sums of numbers in a condensed way. The number at the bottom of the summation sign tells us the index of summation and the starting point (lower limit of summation). The top of the summation operator tells us the stopping point of the summation. The number to the right of the summation sign tells us the elements being summed. For example, given a list of numbers $x_1, x_2, x_3, \ldots x_n$, the sum of all n numbers can be conveniently written as $\sum_{i=1}^{n} x_i$.

beneficial, i.e. the rate that equalizes the discounted value of the benefits generated by innovation investment and the discounted value of investment in the innovation[14]:

$$\sum_{t=0}^{T} \frac{N_{i,t} B_{i,t}}{(1 + SROR_i)^t} = \sum_{t=0}^{T} \frac{C_{i,t}}{(1 + SROR_i)^t}. \qquad (2)$$

Following the same example used for the benefit-cost ratio, the social rate of return is 100%. This is because using a 100% discount rate (instead of 10% as in the example above), the discounted value of benefits and costs balance out: $\left(\frac{\$2{,}000{,}000}{(1+1)^1} = \frac{\$1{,}000{,}000}{(1+1)^0}\right)$.

Extension to investor-specific, portfolio-level definitions

In the examples above, the innovation being assessed was supported by a single investor. In many portfolios, innovations receive innovation funding from multiple sources. With this in mind, let $S_{i,t}^{INV}$ denote the share of innovation i's cumulative innovation costs from innovation inception up to period t that were covered by the investor, and let I denote the total number of innovations in the investor's portfolio. The source of innovation spending is indicated using superscripts (e.g., $C_{i,t} = C_{i,t}^{INV} + C_{i,t}^{OTHER}$). Moving from innovation-level to portfolio-level returns, it must also be recognized that some innovation costs (e.g. portfolio administration) are not innovation-specific. The investor's administrative costs in time period t that are not specific to a single innovation (portfolio administrative costs) are denoted by $C_t^{INV,,admin}$.

[13] Calculating the SROR and BCR of an investment uses all of the same information, but those calculations differ in their assumptions. While the BCR assumes a discount rate (chosen by the analyst) and then calculates the ratio of discounted benefits to costs, the SROR solves for the discount rate assuming that the ratio of discounted benefits to costs equals 1. This is analogous to solving the algebraic equation y=5x for y, given that x=3, versus solving for x, given that y=15. They rely on the same underlying mathematical relationship, but they vary in what the free variable is.

[14] A unique SROR solves Equation 2 if the annual net cash flow of the innovation (or portfolio) being evaluated does not change sign more than once. While that may fail to hold for some innovation investments, it holds for the portfolio being evaluated in this paper, and possibly most others.

If one is interested in the social return on each dollar from a particular investor, the benefit-cost ratio for the portfolio can be defined as the ratio of the sum of the discounted benefits generated by innovation investments to the discounted portfolio cost (investments and administration)[15]:

$$BCR_{portfolio} = \frac{\sum_{t=0}^{T}\sum_{i=1}^{I}\frac{S_{i,t}^{INV}N_{i,t}B_{i,t}}{(1+r)^t}}{\sum_{t=0}^{T}\sum_{i=1}^{I}\frac{C_{i,t}^{INV}}{(1+r)^t}+\sum_{t=0}^{T}\frac{C_{t}^{INV,admin}}{(1+r)^t}}. \tag{3}$$

That is, the portfolio-level benefit-cost ratio of the investor's portfolio is the sum of net benefits of each innovation (scaled by the investor's share of cumulative innovation costs) in the portfolio divided by the total cost of the portfolio.

While it does not involve any counterfactual estimation and therefore does not yield a causal estimate of a funder's impact, scaling each innovation's net benefits by $S_{i,t}^{INV}$ in Equation 3 at least ensures that net social benefits are additive across investors, so no social benefits are double-counted from a societal perspective when multiple innovation investors assess their overlapping portfolios[16]. This approach is an improvement over the flawed common practice of the sector, wherein many donors report success of supported projects without addressing attribution in any way.

Note that funding from other sources can enter Equation 3 in one of two ways. If it covers operating costs, it is netted from the innovation's social benefits $B_{i,t}$. If the funding covers innovation costs, it enters the calculation by lowering $S_{i,t}^{INV}$. The application in Section 4 demonstrates that distinguishing an operating cost from an innovation cost is often a judgmental

[15] When there are two summation operators in a row, one first sums over the index of the inside operator, and then over the index of the outside operator.

[16] Note that this approach weighs earlier investments more heavily due to discounting, but that it does not adjust for the greater risk associated with earlier investments. Dollars from different funders are thus treated equally, avoiding judgmental calls on which funders' support was more important or which investments came at critical stages.

call, and categorization can be made defensibly through investigation of financial records and discussions with funders on the original intent of the funding.

The portfolio pays for itself if the portfolio benefit-cost ratio is greater than 1, and the portfolio-level SROR equalizes the discounted benefits and costs of the entire portfolio:

$$\sum_{t=0}^{T}\sum_{i=1}^{I}\frac{S_{i,t}^{INV}N_{i,t}B_{i,t}}{(1+SROR_{portfolio})^{t}} = \tag{4}$$

$$\sum_{t=0}^{T}\sum_{i=1}^{I}\frac{C_{i,t}^{INV}}{(1+SROR_{portfolio})^{t}} + \sum_{t=0}^{T}\frac{C_{t}^{INV,admin}}{(1+SROR_{portfolio})^{t}}.$$

The SROR can then be compared with a benchmark (e.g., an alternative investment or the market rate of return) to assess a portfolio's relative performance.

3.2: Bounding the portfolio benefit-cost ratio

Fully estimating the measures described in Subsection 3.1 is a labor-intensive procedure (especially for large portfolios) and it may not even be possible for portfolios that supported innovations with benefits that are difficult to quantify (e.g., governance innovations). However, analysis based on a subset of innovations can potentially be informative in determining whether the return on the portfolio exceeds that of a benchmark alternative investment if a large fraction of a portfolio's benefits is concentrated in a few innovations.

This subsection discusses how it is possible to establish lower bounds on the social return on investment using data on the realized returns to a subset of the investment portfolio up to any given date, based on two assumptions. Those two assumptions will not necessarily be reasonable for all innovation portfolios, but they are highly conservative for DIV and may be for many other funders as well.

Assumption 1: On average, innovations outside the subset examined did not lead to net social costs beyond the funder's investment

> Under this assumption, on average, the innovations not included in the subset examined did not result in net social costs beyond the value of the funder's innovation investment. This allows for the possibility that investments created no net benefits, but assumes that they did not lead other investors to make negative-valued investments on average (as would be implied under rational expectations). It is also assumed that innovation investments did not create negative net externalities that exceeded their value to beneficiaries on average. For DIV, this seems reasonable given USAID's environmental and other safeguards. This assumption is also conservative for DIV because innovations outside of the evaluated subset likely generated substantial benefits.

Assumption 2: Net future benefits of portfolio innovations are non-negative

> Since the future benefits of innovations are unknown, it is assumed that the innovations generate either zero or positive net benefits beyond the last period for which data are available. This is a conservative assumption for DIV because multiple DIV-supported innovations may continue to generate benefits, and in some cases, these benefits seem likely to grow over time.

Assumptions 1 and 2 underpin the proposition behind the lower bound approach: the social rate of return calculated based on net benefits from a subset of innovations and investment cost of all innovations up to the present must be less than or equal than the social rate of return for the portfolio over a longer (projected) horizon. Algebraically, $SROR_{J,T} \leq SROR_{I,T'}$ where:

1) $SROR_{portfolio}$ is such that

$$\sum_{t=0}^{T'}\sum_{i=1}^{I}\frac{S_{i,t}N_{i,t}B_{i,t}}{(1+SROR_{portfolio})^t}=\sum_{t=0}^{T}\sum_{i=1}^{I}\frac{C_{i,t}^{INVESTOR}}{(1+SROR_{portfolio})^t}+\sum_{t=0}^{T}\frac{C_t^{INVESTOR,admin}}{(1+SROR_{portfolio})^t}.$$

2) $SROR_{subset}$ is such that

$$\sum_{t=0}^{T}\sum_{i=1}^{J}\frac{S_{i,t}N_{i,t}B_{i,t}}{(1+SROR_{subset})^t}=\sum_{t=0}^{T}\sum_{i=1}^{I}\frac{C_{i,t}^{INVESTOR}}{(1+SROR_{subset})^t}+\sum_{t=0}^{T}\frac{C_t^{INVESTOR,admin}}{(1+SROR_{subset})^t}.$$

3) $T \leq T'$

4) $J \subseteq I$

For a proof of this result, see Appendix 1.

3.3: Parameters

This subsection discusses two key parameters that will be central in the innovation portfolio analyses.

Parameter 1: Value of a DALY

Many development innovations yield health benefits. To express the value of health innovations in financial terms requires making assumptions on the value of health improvements or of a statistical life. One common approach in health economics is to assign a value to a disability-adjusted life years (DALYs) saved, while another is to assign a value to a statistical life. The DALYs saved for a population benefitting from an innovation includes years of life lost (YLL) averted (by preventing fatalities) and the years of life lost to disability (YLD) averted (by preventing morbidity). YLL is estimated by multiplying the number of fatalities averted by the discounted average number of remaining years of life. YLD is estimated by multiplying the number of instances by the average duration of the condition and including a disability weight between 0 and 1 that represents the severity of the disability.

The cost-effectiveness of DALY loss aversion is frequently assessed using thresholds based on per capita GDP (Marseille et al. 2014). The World Health Organization's *Choosing*

Interventions that are Cost-Effective (WHO-CHOICE), stipulates that an intervention is considered "cost-effective" if it costs less than three times the national annual GDP per capita per DALY saved, and "highly cost-effective" if it costs less than the national annual GDP per capita per DALY saved. To be conservative, each DALY averted is treated as delivering a benefit equivalent to per capita GDP in this paper.

Parameter 2: Discount Rate

In the following analysis, the opportunity cost of the capital used to fund an investment is assumed to be 10%. A standard threshold rate of return for foreign aid is 10% (MCC 2016). Ten percent is also in line with rates typically used for benefit-cost analysis by development banks and developing country governments (Zhuang et al. 2007).

This methodology is applied to the early DIV portfolio in Section 4, using the subset of innovations identified in Subsection 3.4.

3.4: Innovation selection

Table 2 provides details on the ten early DIV innovations in Figure 1 that have so far reached over 1 million people (see Appendix 2 for further details), and are therefore likely to have significantly contributed to portfolio social return.

Table 2: Innovations supported by DIV in 2010-2012 that reached over one million users in original or adapted form

Innovation	Purpose	Reach[A]	Source	Countries	Scaling Organizations
Software for CHWs	Provides data to help CHWs improve their performance via smartphone	20.0 million people	Dimagi (2019)	105 countries	Dimagi, Government of India, Gates Foundation
Voter report cards[B]	Improve governance by providing information on politicians	10.3 million people	Duflo and Kremer (2015)	India	NGOs, newspapers
Election monitoring technology[B]	Facilitate election observation at polling stations	6.5 million people	Duflo and Kremer (2015)	Afghanistan, Kenya, Uganda, South Africa	Political party
Affordable glasses for presbyopia	Distribute inexpensive glasses to consumers	4.4 million people	VisionSpring (2019)	Various	NGOs, businesses
Road safety stickers	Encourage minibus passengers to speak up against unsafe driving	4.0 million people	gui2de (2018)	Kenya, Uganda, Tanzania	Insurance company, government
Water treatment dispensers	Facilitate water purification at point of collection	2.2 million people	Dispensers for Safe Water (2018)	Kenya, Uganda, Malawi	NGO
Digital attendance monitoring	Biometric monitoring of staff attendance at health centers	1.8 million people	Duflo and Kremer (2015)	India	Government
Psychometric credit assessment	Increase lending to SMEs using tool that applies psychometrics to credit scoring.	1.4 million people	EFL Global (2018)	15 countries in Latin America, Africa, and Middle East	Banks

Table 2 (continued)

Innovation	Purpose	Reach	Source	Countries	Scaling Organizations
Mobile agriculture extension	Provide agriculture extension services via mobile phone	1.4 million people	Precision Agriculture for Development (2019)	7 countries	NGOs, universities, governments
Home solar systems	Provide reliable and affordable solar lighting to households	1.0 million people	d.light (2016, assumes that each system serves a household of four)	Global	NGOs, businesses

A: *"Reach" refers to the best estimate of number of people directly impacted through use of the innovation, according to "Source." In many cases, these estimates were not reported directly to DIV, as they scaled-up after the DIV award performance period. Furthermore, the reach numbers were at least partially verified by a third-party auditor for the innovations assessed in this paper. For further details on these innovations, see Appendix 2.*

B: *These two innovations were scaled up in a form that differed and was less intensive than the form tested in the randomized controlled trial used to test the innovations impact. Therefore, it is difficult to assess the impact of the scaled up version.*

The first innovation in Table 2, software for community health workers (CHWs), has users in 105 countries. In India alone (where the innovation applied for DIV support), it has reached over 20 million people, and the Indian government plans to scale it up to reach 1.4 million civil service CHWs by 2020, which may increase the number of people reached to 200 million. In a cluster randomized controlled trial, Hackett et al. (2018) show that a smartphone-based intervention using this software increased the facility-based delivery rate by 17% among mothers in rural Tanzania. This innovation is not incorporated in the lower bound estimation because of challenges in valuing benefits and costs across the 105 countries in which the innovation is used, but it may be included in a future update. The annual cost of equipping a CHW is estimated at around $300 per year. That cost includes training and hardware (some of which serves as compensation for the CHW), and is therefore difficult to break down with respect to the distinctions made in Subsection 3.1. While this is not an inexpensive innovation, a mobile-based health technology using this platform was found to be highly cost-effective in reducing maternal and newborn mortality (Prinja et al. 2018). That is among the principal applications of this innovation, and thus its operating costs are unlikely to pose a threat to Assumption 1.

The second and third innovations, voter report cards and rapid transfer of polling station-level vote counts, likely generated very large social benefits, but they are not included in the calculations of a lower bound on the social rate of return, as it is difficult to know how to value them. This is for two reasons. First, they were both governance innovations, designed to improve democratic institutions. One was designed to improve voter information, while the other was designed to reduce a particular type of election fraud. It is difficult to know how to place a monetary value on these outcomes. Second, while RCTs found positive results in each case (voter report cards increased voter turnout by 2 percentage points and reduced vote-buying by 19 percentage points (Banerjee, Pande, Kumar, and Su 2011), while transmission of polling station-level vote counts reduced theft of election materials by 60% and reduced votes for politically powerful candidates by 25% (Callen and Long 2015)), the scaled-up form of the innovations were adapted, lower-cost versions, and may not have had the same impact.[17]

The fourth, fifth, sixth, and seventh innovations in Table 2 are discussed and analyzed in Section 4, so they are not detailed here. Those four are the focus not because they were the most important innovations supported by DIV during the period, but because these are innovations for which benefits can be expressed in dollar terms, and because high-quality data on impact (reduced diarrhea through improved water, reduced traffic mortality through safer driving and reach, increased productivity for agricultural workers through better eyesight, reduced infant mortality through improved antenatal care) and financial history are currently available.

Psychometric credit scoring, the eighth largest-reach innovation, has been used to facilitate over $1.5 billion in lending. In a non-experimental study of a participating bank in Peru, Arraiz et al. (2015) show that the eighth innovation increased access to credit for unbanked entrepreneurs relative to traditional credit-scoring methods (without increasing the lender's portfolio risk). But since there is no experimental evidence on the innovation's impact and in 2018 the organization that was awarded the grant to scale the innovation merged with Lenddo (a Singapore-based consumer finance software company), it is difficult to measure the social benefits generated by DIV's investment in it.

Some high-touch variants of the ninth innovation[18], mobile phone-based agriculture extension, have been shown via RCT to improve yield of staple crops by 12% in Kenya (Casaburi et al. 2014) and 9% in India (Cole and Fernando 2016). However, lower-touch variants account for the majority of

[17] The necessary exclusion of the second and third innovations from this (and any future) social return estimates may raise concerns about biasing innovation selection against this type of governance innovation, which can create large social value. For this reason, one estimate in Subsection 4.5 only includes the cost of awards to innovations which generate benefits that could potentially be expressed in monetary terms. That estimate is presented only after the primary calculations for expositional purposes, but it could be argued that the alternative measure is of greater interest.
[18] The non-profit organization that emerged from this innovation was co-founded by Michael Kremer.

people reached by this innovation, and the evidence on their impact on yields is inconclusive. The tenth innovation has provided solar power to over one million people while offering pay-as-you-go financing, but no impact evaluation of its economic impact has been conducted.

The list of analyzed innovations could expand in future iterations of this paper as more innovations achieve scale and better evidence on their impact becomes available. Even some innovations that did not reach one million people (which is an arbitrary cut-off motivated by the costliness of detailed data collection) may have generated substantial benefits. For example, in a complementary paper, Martinez, Oliver and Trowbridge (2017) conduct a benefit-cost analysis of four off-grid solar energy investments in the DIV portfolio on the impact of DIV's investment in solar energy programs, finding that $17 million in economic gains were generated in East Africa (albeit using a different methodology).

While they are not necessarily the innovations that created the greatest net benefit, the data suggest that the top ten innovations account for over 95% of the 55 million total beneficiaries of innovations in DIV's early portfolio. It therefore seems likely that a subset of these innovations also account for a large share of the social benefits that have been generated by the DIV portfolio so far.

4. BENEFIT-COST RATIO CALCULATIONS

This section details each input and calculation that goes into estimating a lower bound on the portfolio social return. Subsections 4.1-4.4 present brief descriptions of the innovations, explain the calculation of the benefits generated by the innovations, and then estimate the innovation costs, distinguishing between recurring operating costs (which are subtracted from benefits to estimate net benefits) and innovation costs. For the four innovations, only the innovations' direct health impacts on immediate beneficiaries (people who avoided accidents involving minibuses, water treatment dispenser users) are valued. The indirect benefits of the innovations (e.g., reduced traffic congestion, emissions, and vehicle damage from safer driving; epidemiological externalities from reduced transmission of diarrheal disease to others[19]) are not accounted for.

Subsection 4.5 compares the estimated benefits with the costs of the full 2010-2012 portfolio to establish a lower bound on the portfolio social return and compares this social return to that from standard development investments. Subsection 4.6 shows how the portfolio social return varies when the conservative assumptions are modified. Subsection 4.7 discusses the generalizability of the results to innovation investment more broadly.

4.1: Road safety stickers

This product innovation places stickers in public minibuses to encourage passengers to speak up against reckless driving. It was piloted in Kenya with support from the Center for Global Development and Safaricom (Habyarimana and Jack 2011). DIV later supported testing in Kenya (a Stage 2 investment that was in the early portfolio). DIV also later made a follow up grant after the 2010-12 period (which therefore is not included in the early portfolio calculations) that supported scaling in Kenya, and testing of impact and exploration of potential opportunities for scale-up in Uganda, Rwanda, and Tanzania. In Kenya, the innovation was scaled-up by an insurance company (which requires stickers as a condition for coverage and incentivizes sticker use through a lottery for drivers, owners, and conductors), and the government, in particular the National Transportation and Safety Authority of Kenya (which facilitates checks for stickers compliance during the annual routine inspections of the minibuses).

[19] When one individual adopts water treatment, even non-adopters in the community could benefit because their risk of exposure to disease falls.

Subsection 4.1.1 explains the data on the benefits and Subsection 4.1.2 explains the costs of this innovation, and how those estimates are used to measure innovation-level performance (Subsection 4.1.3).

4.1.1: Road safety sticker benefits

It will be useful to switch from accounting for benefits and costs of the innovation in per capita terms to per unit of innovation terms, where a unit constitutes a minibus with a sticker, one installed dispenser, one pair of glasses provided, or one pregnant woman served with antenatal care. When an innovation is health-related, the benefit of the innovation in a given time period t can be expressed as[20]:

$$Social\ benefit\ of\ a\ health\ innovation\ in\ USD_t = DALYs\ saved\ per\ unit\ _t \times$$
$$Units\ of\ innovation_t \times Value\ of\ a\ DALY\ in\ USD_t \qquad (5)$$

DALYs saved per stickered vehicle: The innovation averts DALYs loss through the prevention of traffic accidents. Table 3, Panel A summarizes the inputs that go into calculating the expected Disability Adjusted Life Years (DALYs) saved per stickered minibus. A 2015 randomized controlled trial study by Habyarimana and Jack published in the *Proceedings of the National Academy of Science* finds that stickers reduced the proportion of vehicles involved in an accident by 0.017 per year. It also estimates of the number of deaths per accident (0.105) along with the number of injuries per accident (1.05). 24 years (which is the gender-weighted, discounted life expectancy at the age of an average minibus rider - see Online Supplement A2) of life are lost per accident death. Seven DALYs are assumed to be lost per injury, which is at the conservative end of the range provided by Habyarimana and Jack (2015). Multiplying the number of accidents averted by the average number

[20] Note that Equations (1)-(4) were based on people reached by an innovation, while Equation (5) is based on the active units of each innovation. This change makes the innovation-specific data on dispensers and stickers easier to work with.

of deaths and injuries per accident, as well as the associated number of DALYs lost due to death and injury respectively, produces the DALYs loss averted per stickered minibus. The DALY calculations in Table 3, Panel A do not account for benefits such as reductions in congestion, energy savings, or improved passenger experience due to safer driving. They also exclude direct non-health benefits (see Habyarimana and Jack 2015 for an estimate of the large financial returns on the innovation through averted vehicle damage).

Road safety sticker reach: Georgetown University Initiative on Innovation, Development and Evaluation (gui2de) provided the data on number of stickered minibuses in each month from March 2011 to March 2018 (Online Supplement A2). The latest number is in Table 3, Panel B. For social return calculations, the average number of stickered vehicles is adjusted downward in each year to account for non-compliance (including sticker depreciation and vehicle turnover).

Value of a DALY in USD: As discussed in Subsection 3.3, a DALY is valued at the GDP per capita of the country in which the innovation operates. Kenya's GDP per capita at purchasing power parity (PPP) was $3,156 in 2016 according to the World Bank.

4.1.2: Road safety sticker costs

Innovation costs: Table 3, Panel B lists the DIV investment cost for the road safety innovation. DIV initially made a Stage 2 testing award for $290,000, and subsequently awarded a $2.96 million Stage 3 scale-up award in 2014 after the innovation demonstrated evidence of impact and cost-effectiveness. The Stage 3 award is treated as though it was made by another investor, since it was made outside of the early portfolio period, so the discounted value of DIV's investment was $207,000 (Table 3, Panel C). During its piloting phase (which started with an RCT before the DIV award period), the organization received $155,000 in support from Safaricom, Center for Global Development, and the Government of Kenya.

DIV share of innovation costs: Discounting the innovation costs described above, the DIV early portfolio's share of cumulative discounted innovation costs is estimated at 49% in 2013, falling to 14% by 2018.

Operating costs: The operating costs of this innovation include program administration, monitoring, purchasing, sorting, and packing stickers, staff training, compliance incentives, and tracking software. The organization received a $900,000 award from GiveWell that was used in parallel with DIV funding to cover those operating costs between March 2017 and May 2018. 43% of that award was expected to be spent in Kenya. The GiveWell award counts as covering operating costs rather than as innovation costs, because GiveWell made the award on the basis of demonstrated cost-effectiveness at scale following the DIV award. gui2de estimates that moving forward, the operating cost in Kenya is $177,000 per year. These operating costs are subtracted from benefits to calculate the innovation's net benefits in each month.

Table 3: Road safety stickers

Panel A: DALYs saved per stickered vehicle	**Value**	**Source**
1. Reduction in annualized rate of accidents	0.017	Habyarimana & Jack (2015), Table 5
2. Death per accident	0.105	Habyarimana & Jack (2015), Table 3
3. Injuries per death	4	Habyarimana & Jack (2015) page E4668.
4. Injuries per accident	1.05	Calculated as (2) x (3)
5. Discounted DALYs lost due to death	23.8	Online Supplement A2.
6. DALYs lost per minibus injury	7	Habyarimana & Jack (2015) page E4668.
7. Annual DALYs saved per stickered vehicle	0.09	Calculated as [(1)*(2)*(5) + (1)*(4)*(6)]
Panel B: Calculation inputs	**Value**	**Source**
<u>Benefits</u>		
1. Annual DALYs saved per minibus	0.09	Table 4, Row 8
2. Number of stickered minibuses, 2018	41,000	Online Supplement A1
3. Vehicle compliance rate	0.76	Online Supplement A7
<u>Costs (undiscounted)</u>		
4. DIV Award (2011)	$290,000	DIV Portfolio
5. Annual operating cost in Kenya at 2018 scale	$177,000	Online Supplement A8
Panel C: Social BCR	**Value**	**Source**
1. Discounted value of DIV Award	($207,000)	Model, Sheet 2, Column F
2. DIV's average share of cumulative innovation investment through 2018	30%	Model, Sheet 2, Column S
3. Discounted social benefits generated by innovation	$81,963,000	Model, Sheet 2, Column R
4. Discounted social benefits generated by DIV investment	$5,100,000	Model, Sheet 2, Column U
5. Benefit-cost ratio	24.65	Calculated as (3)/(1)

Costs are rounded to nearest thousand for presentation only.

4.1.3: Innovation-level social return

Next, the net benefits per period are estimated using Equation (5). The social benefit-cost ratio for the innovation is presented in Table 3, Panel C. The benefit-cost ratio is calculated by dividing the discounted net benefits by the discounted DIV investment using the formula described in Subsection 3.1. Based on these data, the innovation returned over $24 per dollar invested by DIV.

4.2: Water treatment dispensers

This delivery model innovation is installing point-of-collection water treatment dispensers to promote water treatment and increase access to safe drinking water. Dispensers of diluted chlorine solution are placed at wells and springs in rural communities in Kenya, Malawi, and Uganda. Treatment of water reduces the likelihood of early childhood diarrhea, which is a major cause of child mortality in these countries.[21] Dispensers provide free treatment to users and serve as a visual reminder to treat water.

The calculation of the benefits (Subsection 4.2.1), costs (Subsection 4.2.2), and social return of this innovation (Subsection 4.2.3) follows the same procedure and layout as for the road safety innovation in Subsections 4.1.1-4.1.3.

4.2.1: Water treatment dispenser benefits

DALYs saved per dispenser: Table 4, Panel A summarizes the inputs for calculating the expected number of DALYs saved per dispenser in each of the three countries where dispensers have been installed at scale: Kenya, Uganda, and Malawi. First, the reduction in diarrhea cases per dispenser is calculated using the baseline rate of diarrhea per child (Demographic and Health Surveys for each country), the number of children with access to a dispenser (Online Supplement B1), the rate of

[21] For a review of the impact of chlorination on diarrhea, see Clasen et al. (2015)

reduction in diarrhea from water treatment (based on meta-analyses by Arnold and Colford 2007 and Clasen et al. 2015), and dispenser adoption given access to a dispenser (available at *Dispensers for Safe Water).* The averted cases of diarrhea per dispenser is then multiplied by the number of child deaths per incident of diarrhea[22] (from Walker et. Al 2013) and standard life expectancy at age of child death (Online Supplement B2) to estimate years of life saved per dispenser (YLL). DALYs saved from disability per dispenser (YLD) are estimated based on Lamberti et al. (2012) and Pruss-Ustan et al. (2003). Years of life lost due to death and DALYs lost due to disability are summed to estimate DALYs saved per dispenser.

Table 4: Water treatment dispensers

Panel A: DALYs saved per dispenser	**Kenya**	**Uganda**	**Malawi**	**Source**
1. Rate of diarrhea per child	5.07	7.35	5.30	Demographic and Health Surveys, 2011-2015
2. Children per dispenser	16.86	45.47	28.49	Average for 2013-2018, Online Supplement B1.
3. Increase in treatment from dispenser access	0.40	0.44	0.78	Dispensers for Safe Water (Average adoption rate)
4. Reduction in diarrhea from treatment	0.40	0.40	0.40	Ahuja (2017) based on Arnold and Colford (2007), Clasen et al. (2015)
5. Reduction in diarrhea from dispenser access	0.16	0.18	0.32	Calculated as (3)x(4)
6. Deaths per 100 diarrhea cases	0.08	0.08	0.08	Walker et al. (2013) p. 1407
7. Life years lost to diarrheal death	31.1	30.99	31.22	Online Supplement B2.
8. YLL saved per dispenser	0.35	1.49	1.18	(1)x(2)x(5)x(6)x(7)
9. YLD saved per dispenser	0.02	0.09	0.07	Online Supplement B7
10. Annual DALYs saved per dispenser	0.37	1.58	1.26	Calculated as (8)+(9)

[22] This assumes that the reduction in diarrhea deaths due to chlorination is proportional to the reduction in diarrhea cases.

Panel B: Calculation inputs	Value	Source
Benefits		
Annual DALYs loss averted/dispenser, Kenya	0.37	Table 7, Row 10
Number of active dispensers, 2018, Kenya	18,000	Dispensers for Safe Water
Annual DALYs loss averted/dispenser, Uganda	1.58	Table 7, Row 11
Number of active dispensers, 2018, Uganda	5,700	Dispensers for Safe Water
Annual DALYs loss averted/dispenser, Malawi	1.26	Table 7, Row 11
Number of active dispensers, 2018, Malawi	3,700	Dispensers for Safe Water
Costs (undiscounted)		
DIV Award (2012)	$7,416,000	DIV Portfolio
Non-DIV Operating Cost, Jan. 2018-Dec. 2018	$5,110,000	Online Supplement B6
Panel C: Social BCR	**Value**	**Source**
1. Discounted value of DIV award	($5,199,000)	Model, Sheet 3, Column F
2. DIV's average share of cumulative innovation investment through 2018	70%	Model, Sheet 3, Column AF
3. Discounted social benefits generated by innovation	$246,215,000	Model, Sheet 3, Column AE
4. Discounted social benefits generated by DIV investment	$62,380,000	Model, Sheet 3, Column AH
5. Benefit-cost ratio	12.00	Calculated as (3)/(1).

Costs are rounded to nearest thousand for presentation only.

Water treatment dispenser reach: The number of dispensers active in each country over time are available at *Dispensers for Safe Water.* Table 4, Panel B presents data from 2018.

Value of a DALY in USD: As discussed in Subsection 3.3, DALYs are valued at the GDP per capita of the country in which the innovation operates. The GDP per capita at purchasing power parity of Kenya, Uganda and Malawi were $3,156, $1,849, and $1,169 respectively according to the World Bank (2016).

4.2.2: Water treatment dispenser costs

Innovation costs: Table 4, Panel B shows DIV's investment cost for the water treatment dispenser innovation. DIV's award of $7.4 million was disbursed in 14 payments in from 2012 to 2015, and the discounted value of the award was $5.2 million (Table 4, Panel C). The innovation website lists its institutional investors since 2013. Although precisely what each funder supported is unknown, it is assumed that the funding from donors similar to DIV (i.e. those whose missions include supporting innovation) were used to cover innovation costs. Those include Skoll Foundation and the Stone Family Foundation. In addition, because financial records from the organization's early stages were not available, it is conservatively assumed that $500,000 had been invested in testing the innovation prior to 2010 (the early development of the innovation predates Evidence Action, the organization that was awarded the DIV grant).

DIV share of innovation costs: Based on the interpretation of the innovation's history above, DIV's share of cumulative discounted innovation costs is estimated at 53% in 2012, rising to 71% by 2018.

Operating costs: Program cost estimates can be found in Online Appendix B3-B6. The costs include installation, repair, refilling, chlorine supply and transport, community engagement, field and program offices, U.S. and in-country overhead. Some of these operating costs were covered by revenue from carbon credits[23]. Carbon emissions reductions are not included as part of the dispensers' benefits.

[23] The innovation has been awarded $2 million in carbon credits under Clean Development Mechanism of the Kyoto Protocol.

4.2.3: Innovation-level social return

The social return for the dispenser innovation is presented in Table 4, Panel C. The innovation returned $12 per dollar invested by DIV.

4.3: Affordable glasses for presbyopia (near-sightedness)

This product and business model innovation leverages the distribution networks of local partners (governments, NGOs, businesses) to sell inexpensive glasses for near-sightedness. In an RCT, Reddy et al. (2018) found that receiving the eyeglasses led to a 22% increase in yield for rural Indian tea pickers. The calculation of the benefits (Subsection 4.3.1), costs (Subsection 4.3.2), and social return of this innovation (Subsection 4.3.3) follows the same procedure and layout as for the road safety innovation in Subsections 4.1.1-4.1.3.

4.3.1: Glasses benefits

Economic productivity increase per pair of glasses: The vast majority of glasses distributed by this innovation to date were to working age adults, but a sectoral breakdown of their occupations is not available. To be conservative, the average productivity increase for users is assumed to be half of that estimated by Reddy et al. (2018), and that glasses last two years per user (the typical minimum lifespan of the glasses). Furthermore, the productivity increase is valued against the agriculture, forestry and fishing value added per worker in low-income countries ($641 per year according to World Bank data after adjusting for inflation), which is conservative since nearly half of glasses distributed to date went to India, which is lower-middle income.

Affordable glasses reach: The number of glasses distributed in every year between 2012 and 2018 is provided by VisionSpring. Table 5, Panel A shows the glasses distributed in the most recent year.

4.3.2: Affordable glasses costs

Innovation costs: DIV's award of $585,000 million was disbursed between 2012 and 2015, and the discounted value of the award was $430,000 (Table 5, Panel B). Innovation costs that were not covered by DIV are estimated using records of the organization's top donors. As for the dispensers innovation, it is assumed that the funding from donors similar to DIV were used to cover innovation costs. Those funders were Skoll Foundation, Mulago Foundation, Grand Challenges Canada, and Peery Foundation. Since information is unavailable pre-2012, and the innovation began operating in 2001, it is conservatively assumed that the innovation funding in year with missing data matched the 2012 level.

Table 5: Affordable glasses for presbyopia

Panel A: Calculation Inputs	**Value**	**Source**
Benefits		
Economic gain per pair of glasses	11%	Half of Reddy et al. estimate
Number of glasses distributed in 2018	1,180,000	VisionSpring (2019)
Costs (undiscounted)		
DIV Award (2012)	$585,350	DIV Portfolio
Operating Cost	$6 per pair	VisionSpring (2019)
Panel B: Social BCR	**Value**	**Source**
1. Discounted value of DIV award	($430,000)	Model, Sheet 4, Column G
2. DIV's average share of cumulative innovation investment through 2018	5%	Model, Sheet 4, Column T
3. Discounted social benefits generated by innovation	$1,087,660,000	Model, Sheet 4, Column S
4. Discounted social benefits generated by DIV investment	$17,623,000	Model, Sheet 4, Column V
5. Benefit-cost ratio	$41.02	Calculated as (3)/(1).

Costs are rounded to nearest thousand for presentation only.

DIV share of innovation costs: Based on the interpretation of the innovation's history above, it is estimated that DIV's share of cumulative discounted innovation costs started at 3% in 2012 and had risen to 5% by 2018.

Operating costs: The organization estimates the production and distribution cost of the glasses is $6 per pair. This is multiplied by glasses distributed to estimate operating costs. Alternatively, financial statements of operating costs from the organization could be used. The former approach yields higher operating cost estimates, and is therefore preferred for the sake of conservativeness.

4.3.3: Innovation-level social return

As is shown in Table 5, Panel B, the innovation returned over $41 per dollar invested by DIV.

4.4: Digital attendance monitoring

This technology innovation is designed to reduce absenteeism of workers at primary health care centers in India using a biometric attendance device. Although this innovation was not scaled beyond the initial RCT, it had substantial reach, simply because the RCT was itself conducted at scale.

As with the previous innovation, the focus on antenatal care underestimates benefits, since many other types of services are provided at primary health care centers. The calculation of the benefits (Subsection 4.4.1), costs (Subsection 4.4.2), and social return of this innovation (Subsection 4.4.3) follows the same procedure and layout as for the road safety innovation in Subsections 4.1.1-4.1.3.

4.4.1: Attendance monitoring benefits

DALYs saved per patient served: Table 6, Panel A summarizes the inputs for calculating the expected number of DALYs saved per patient served at the primary healthcare centers. Dhaliwal and Hanna (2017) found that this innovation increased the proportion of doctor-delivered births in the catchment area by 8 percentage points. However, doctor attendance at PHCs did not increase overall, and the intervention was discontinued. Tura et al. (2013) find that attended births reduce infant mortality by 29%. This estimate is used to calculate the social benefit of the monitoring system in the one year that the innovation operated before the study ended.

Attendance monitoring reach: The catchment area served by primary healthcare centers in the treatment area of the RCT was 2.5 million people (Dhaliwal and Hanna 2017).

Value of a DALY in USD: As Subsection 3.3 discussed, a DALY is valued at the GDP per capita of the country in which the innovation operates. The GDP per capita at purchasing power parity of India was $1,717 in 2016.

4.4.2: Attendance monitoring costs

Innovation costs: DIV's award of $173,000 was disbursed from 2011 to 2013 (Table 5, Panel B), and the discounted value of the award was $148,000 (Table 6, Panel C). The other major funders that supported this RCT were J-PAL and Harvard University.

DIV share of innovation costs: According to the researchers in charge of the RCT, DIV covered about 80% of the cost of the experiment.

Operating costs: Since the innovation was piloted at scale, all costs were covered by the grants that supported the RCT (i.e., all costs count as innovation costs).

4.4.3: Innovation-level social return

The social return for the attendance monitoring innovation is presented in Table 6, Panel C. The innovation returned over $4 per dollar invested by DIV.

Table 6: Digital attendance monitoring

Panel A: DALYs saved per patient	**Value**	**Source**
1. Pregnancy rate	1%	Calculation based on Dhaliwal and Hanna (2017)
2. Increase in proportion of doctor attended births	0.08	Dhaliwal and Hanna (2017)
3. % reduction in infant mortality due to attended birth	29%	Tura et al. (2013)
4. Infant mortality rate, 2017	32/1000	World Bank (2018)
5. DALY gain per infant death averted	30.4	Mathers et al. (2006)
Panel B: Calculation inputs	**Value**	**Source**
Benefits		
Benefit per patient served in USD	$0.39	Product of all entries in Panel A and GDP per capita
Number of people in catchment area	2,500,000	Dhaliwal and Hanna (2017)
Costs (all nominal)		
DIV Award (2011)	$173,000	DIV Portfolio
Other grants	$43,000	Dhaliwal and Hanna
Panel C: Social BCR	**Value**	**Source**
1. Discounted value of DIV award	($148,000)	Model, Sheet 5, Column C
2. DIV's average share of cumulative innovation investment through 2018	80%	Model, Sheet 5, Column K
3. Discounted social benefits generated by innovation	$969,000	Model, Sheet 5, Column J
4. Discounted social benefits generated by DIV investment	$641,000	Model, Sheet 5, Column L
5. Benefit-cost ratio	4.32	Calculated as (3)/(1).

Costs are rounded to nearest thousand for presentation only.

4.5: Lower bounds on portfolio social return

The ratio of net benefits from the four innovations to investment spending for the whole portfolio yields a lower bound on the portfolio-level social return, as shown in Equations (2) and (4). DIV's 2010-2012 portfolio included of 43 awards to 41 innovations, totaling $19.2 million. $7.5 million went to the four analyzed innovations, and $11.7 million went to the other 37 innovations[24]. These awards were obligated in USAID's fiscal years 2010, 2011 or 2012, and funding was then disbursed according to milestone-based contracts over three to four years.

The entirety of every award is counted in the portfolio cost, and the stream of DIV disbursements is modeled at annual frequency. DIV made a follow-on award to further test and scale the road safety innovation in 2014, but to be conservative, the follow-on award was treated as though it was made by a separate funder, so it does not contribute to the early portfolio cost and also does not increase the DIV's share of innovation costs. Subsection 4.6 shows the higher estimate benefit-cost ratio if this is included.

In addition to award spending, the portfolio cost includes administrative costs such as salaries and rent. It is difficult to estimate those costs with precision, since on the one hand, DIV staff undertook non-DIV work for the Agency, but on the other hand, USAID staff who are not part of DIV provide a variety of services for DIV (e.g. legal, HR, and procurement.) It is assumed that $2.25 million (corresponding to 12% overhead) was spent on administrative costs between 2010 and 2012[25]. The discounted value of estimated award spending and administrative costs is thus $16.0 million.

[24] $0.6 million was awarded to innovations in governance and environment. Since it is not possible to put a dollar value on the contributions of those innovations to global democracy and security, an alternate estimate that excludes the cost of those awards is presented. This is discussed further in the following sections.

[25] The estimated benefit-cost ratio is not sensitive to reasonable changes in the administrative costs for 2010 to 2012.

The summary of results is presented in Table 7. Table 7's "Discounted value of DIV spending" includes all discounted 2010-2012 portfolio investment costs and DIV administration costs. DIV's early portfolio returned over $5 per dollar invested by DIV, delivering a social rate of return of over 77%. These are valid lower bound estimates under the conservative assumptions, which are relaxed in the following section.

Table 7: Lower bounds on portfolio social return

	Value	Source
1. Discounted value of DIV spending	($15,974,000)	Model, Sheet 1, Cell B8
2. Discounted net social benefits generated by four DIV investments	$85,744,000	Model, Sheet 1, Cell B7
3. Benefit-cost ratio	5.37	Calculated as (2)/(1)
4. Social rate of return	77%	Discount rate that sets BCR=1

Dollar figures are rounded to nearest thousand for presentation only. These figures are calculated under the highly conservative assumptions that benefits ceased in December 2018 and other 37 innovations generated zero net benefits.

4.6: Sensitivity analysis

The results of relaxing various assumptions are shown in Table 8.

1) If the four innovations continue to operate through 2023 at their 2018 levels of operating costs and benefits, operating costs continue unchanged, and no further innovation funding is received, the benefit-cost ratio will increase to $9.39. This scenario is likely still conservative. While there is always a risk of innovation shutdown, there is also the possibility of continued expansion.
2) This paper calculates the social benefit-cost ratio for analytic purposes, and hence focus on a conservative calculation that includes the costs of all innovation investments. If this approach were used as a management tool, then to avoid biasing project selection to sectors

for which it is feasible to measure social benefits, this type of analysis should only be applied ex-post to the subset of projects with benefits that can be expressed in monetary terms. Excluding costs of innovations in sectors where that is not possible (notably governance and certain environment innovations), the benefit-cost ratio increases to $5.54.

3) Modifying the treatment of DIV's portfolio cost so that any follow-on funding from DIV that was awarded outside of the early portfolio years as well as associated benefits are included would yield a benefit-cost ratio of $5.68.
4) Using a 5% discount rate instead of 10%, the benefit-cost ratio increases to $6.26.

Table 8: Sensitivity Analysis

Scenario	Benefit-cost ratio
0. Conservative base case	5.37
1. Operations continue through 2023	9.39
2. Only include cost of innovations that can be valued in DALY terms*	5.54
3. Include costs and benefits of follow-on funding (post-2012)	5.68
4. 5% Discount Rate	6.26

**Health, for-profit, and other innovations with economic productivity impact.*

While Table 8 confirms that DIV delivered a high return, the largest limitation to the analysis cannot be meaningful addressed with sensitivity analysis. The estimated lower bounds may be far below the true social returns on the portfolio, due to the inability to account for several high-reach innovations.

4.7: Discussion of lower bound results

While one of the purposes of this paper is to investigate whether development innovation is a good investment, there are reasonable concerns with drawing broad conclusions from the DIV's portfolio. DIV was not randomly selected from the set of organizations investing in development, so this analysis of its portfolio returns is arguably not a good guide to returns in the sector as a whole. It is possible is that DIV's unique structure drove its returns, rather than the availability of good deals in the sector. In addition, it is possible that DIV's returns may have been driven by luck. A third issue is that what would have happened to the 41 innovations in the absence of DIV support is unknown. The histories of the stickers and dispensers innovations and their ongoing efforts to secure funding both strongly suggest that DIV's support was pivotal to their development and scale-up. A strong case for additionality can be made for those two innovations, but other innovations in Table 2 (such as the software for CHWs and glasses for presbyopia) may have achieved large social impact even without DIV's support (DIV's innovation cost share was relatively low for both).

The first concern may be addressed by recalling the details on DIV's investment approach (Subsection 2.1). DIV's openness and flexibility make it a highly replicable model. DIV was not able to co-create proposals. It had procurement rules and extremely limited staff during its early portfolio that prevented it from doing so. While the returns estimated in this paper may not be representative of innovation returns achieved thus far, they could be representative of what is generally achievable when following DIV's replicable strategy, in which peer review, market tests, cost-effectiveness, and impact evidence are central criteria for investment. The finance literature suggests that attempting to pick winners is futile when it comes to financial portfolios (Jenkinson et al. 2016), but that does not necessarily hold for development innovation portfolios. The goal of maximizing social rate of return is very different from financial investing, in that the goal of a development innovation funder is to identify innovations likely to eventually scale (whether by the grant awardee itself, an adopting government, or a private organization iterating on the original innovation), without concern about appropriating returns.

The second concern can be addressed by applying different forms of the lower bound approach to DIV and other innovation portfolios. Variations of the lower bound approach developed in this paper can be applied for a number of evaluation purposes. If one were simply trying to figure out whether the return on an innovation portfolio exceeded a benchmark, then one could choose innovations to examine partly on the basis of data availability and partly on the basis of some indicator like scale, and then iteratively add innovations to the analysis until the threshold is reached. As in this paper, it might quickly become clear that the threshold was exceeded after considering a small number of high-reach innovation investments. Instead of using that approach to analyze DIV's early portfolio, the exercise would have assessed the social benefits of just the water treatment innovation and stopped, because the lower bound based on its social benefits and the cost of the entire portfolio (63%) already surpasses the social rate of return target, with the portfolio delivering $3.91 per DIV dollar invested, and indicating that the water treatment innovation alone covers the cost of the entire DIV portfolio. If a sufficient number of innovation funders (and not just the self-selected top-performing investors) applied this approach to check whether they were clearing their portfolio benchmarks and made these results public, it would contribute to knowledge about the returns on development innovation investment more broadly. Even in the absence of impact data, the approach could be turned on its head and used to estimate an upper bound: given knowledge that only a handful of innovations scaled and optimistic assumptions on benefit per person, one could assess whether it is even plausible that a portfolio is reaching its social return target.

At the other end of the spectrum, a more intensive approach can be taken if the purpose of portfolio assessment is to infer something about the investor's underlying approach. If one found that the portfolio return was positive due to a single innovation, the evaluator could be concerned that the portfolio's success was due to a luck, rather than its investment strategy[26]. In such a case, one natural step would be to continue the analysis even after the estimated lower bound has surpassed the predetermined threshold. One would look for multiple hits to assess whether the portfolio would have yielded returns above the benchmark even without the investments that counted for the bulk of the returns. The investment in affordable glasses also generated sufficient returns up to 2018 ($18 million) to carry the portfolio. Thus two out of 41 innovations have already generated at least $16 million (the discounted cost of the portfolio) in discounted benefits independently, implying that the 90% confidence interval for the unconditional probability of a single innovation generating sufficient returns to cover the entire portfolio within eight years is (0.01, 0.15). That is likely an understatement, since other innovations in agriculture extension and solar energy are expected to surpass one million users soon, and are likely already generating large social benefits. Even the lowest-reach innovation in Table 2 (which has lent over $1.5 billion to date) may have been sufficient to cover the cost of the early portfolio. Clearly, the portfolio's achievement of its social rate of return goal does not rely on any one innovation. The existence of multiple innovations that could single-handedly cover the cost of the entire portfolio suggests that DIV's strong returns were not a fluke.

In addition to varying the depth of lower bound estimation for different purposes, valuable lessons could be drawn from varying the scope of assessment. Assessing sub-portfolio returns could give an indication of what types of innovation investments yield the highest returns. It is worth examining, for example, whether investments are particularly likely to be successful in certain sectors, or whether investments in early stage ideas or more mature innovations have higher returns. Applied to sub-portfolios separated by time period instead of innovation type, the approach could also be used

[26] The investment portfolios of Eduardo Saverin and Peter Theil presumably both show good returns on the basis of their Facebook investments alone. But the odds that this was luck rather than alpha are greater for Saverin, given Peter Thiel's role in PayPal and Palentir.

to test whether the returns on innovation are declining over time (Bloom et al. 2018), as low-hanging fruit gets picked.

5. CORRELATES OF INNOVATION SCALE

As was discussed in Section 2, ten out of 41 innovations (24%) in the early portfolio have scaled to over one million users in original or adapted form[27]. It is likely that the conditional probability for different types of innovation investments varies substantially with innovation characteristics. Which innovations scale is a question closely linked to the question of whether or not development innovation is a good investment. There is a lack of evidence of this question, with most analyses relying on ex-post, subjective judgements. Seemingly based on small samples and anecdotes, there are entrenched beliefs that pilots never scale, RCTs and research interfere with scaling, funders must play a non-financial supportive role in the growth of innovations, and government financial participation is critical for the scaling of innovations by the public sector. Although DIV's awards are not necessarily representative of their respective investment categories, experience from the early portfolio enables more systematic investigation of the correlates of scale

Duflo and Kremer (2015) analyze DIV's early portfolio and identify several correlates of innovation scale. Their findings are extended in this paper based on an update of innovation scale. Throughout this subsection, follow-on awards are treated as though they were part of the initial grant, to avoid double-counting DIV innovations that scaled. Therefore, there are 41 awards instead of 43.

Table 9 shows that Stage 1 awards had a lower scaling rate than Stage 2 awards, but the difference is not statistically significant. This contradicts the widely-held view pilots never scale, which may have emerged based on the law of small numbers fallacy. Overgeneralizing from other small samples is

[27] Treating innovation scale as a binomial outcome, this implies that the 90% confidence interval of the probability of an innovation reaching over one million users is (0.13, 0.36).

particularly problematic for pilot investments (which have small costs but a low absolute probability of success), because with a small sample it is easy to too quickly learn the lesson that pilots do not scale and give up. Table 9 also shows that early stage awards delivered more reach per dollar spent.

Table 9: Breakdown of DIV awards by stage

Award Stage	Number of Awards	Number Reaching >1 million	Scaling rate	Award Value	People Reached	Expenditure per Person
Stage 1 (<$100K)	24	4	17%	$2,353,000	11,452,000	$0.21
Stage 2 (<$1M)	16	5	32%	$9,558,000	41,284,000	$0.23
Stage 3 (<$15M)	1	1	100%	$7,417,000	2,200,000	$3.37
ALL	41	10	24%	$19,328,000	54,936,000	$0.35

Values are rounded to nearest thousand for presentation only.

Table 20: Scaling rates by characteristics at time of DIV application

	Yes			No		
	Awards	Awards that scaled	Scaling rate	Awards	Awards that scaled	Scaling rate
For-profit	9	2	22%	32	8	25%
Local partner	10	2	20%	31	8	26%
High population country	11	4	36%	30	6	20%
Researcher involvement**	25	9	36%	16	1	6%
Previous RCT***	10	7	70%	31	3	10%
Pre-existing distribution*	23	8	35%	18	2	11%
Low unit cost***	18	8	44%	23	2	9%

*Stars signify a statistically significant difference between "Yes" and "No." ***: p<.01; **: p<.05; *: p<0.1.*

In Table 20, awards are further categorized based on: 1) whether the innovation was run by a for-profit organization or an academic/non-profit organization, 2) whether the organization had a local partner, 3) whether the innovation primarily operated in a country with population greater than 100 million, 4) whether a researcher was involved with the innovation, 5) whether the innovation had experimental impact evidence supporting it prior to DIV application; 6) whether innovation used a pre-existing distribution platform (typically a government organization, large business, or established NGO) as opposed to a newly created network (typically a direct-to-consumer sales by a social enterprise) and 7) whether the estimated unit cost of the innovation was less than $3 per person reached. All of these distinctions are based on information from the time of DIV application.

Although firm conclusions cannot be drawn on every dimension due to the relatively small sample, several differences in scaling rates are statistically significant.

Innovations with low unit costs were four times more likely to scale than those that were more expensive[28]. Awards that leveraged the distribution network of an existing organization (often a government, but also large businesses) were three times more likely to scale than those that set up new distribution networks (e.g., social enterprises that sold directly to consumers). These last two points are interrelated, since avoiding the cost of setting up new distribution networks would help to keep costs low. On this front, VisionSpring was an illustrative case study (see Appendix 2). It employed two distribution models. One partnered with existing channels, while the other trained entrepreneurs to distribute the product directly to consumers. The organization has since decided to focus on the former, finding it to be less capital-intensive and more cost-effective. Furthermore, close working arrangements with entrenched institutions (which have yielded commitments from the Government of Kenya and India to transform two of the innovations into policy) signal that most of the high-reach innovations supported by DIV are building local capacity, contributing to the host country's journey to self-reliance.

[28] Applying the least absolute shrinkage and selection operator (LASSO) method with scaling to one million users as the dependent variable, previous evidence of impact and low unit cost are the only significant explanatory variables among the eight variables discussed. This is likely because of collinearity among explanatory variables (e.g. awards with high unit costs were likely to have set up a new distribution platform; awards with previous evidence were likely to have a researcher involved).

Unsurprisingly, innovations that had previous empirical evidence in support of it (through a randomized controlled trial) prior to the DIV performance period were significantly more likely to scale than those that had no previous RCT supporting them. Awards with researcher involvement (often coupled with an RCT) were also significantly more likely to scale. Most researchers were U.S. based, but innovations with researchers were especially likely to scale if the researcher had ties to the region (four out of seven of such innovations scaled, versus five out of 18 that had a researcher who was not from the region). These statistically significant correlations could be due to a number of causal mechanisms. For instance, impact evaluation and researcher involvement could have played a formative role in innovation development, or researchers may have chosen which innovations to be involved with based in part on pre-existing likelihood of success. Either way, these findings call into question conventional wisdom on a tradeoff between rigorous evaluation and scaling-up.

6. CONCLUSION

Economic theory suggests a potential case for innovation investment initiatives since many types of innovations are global public goods. The social benefits of successful innovations such as oral rehydration therapy and conditional cash transfers are not fully captured by the innovator, so weak incentives for private firms would result in suboptimal investment in innovations from a societal perspective. Successful innovations typically generate substantial consumer surplus and even producer surplus is typically only partially protected by patents, intellectual property rights, trade secrets or first-mover advantage. To the extent that aid donors are organized with separate offices focused on single countries, country-based teams may not have strong incentives to invest in developing and testing innovations that could benefit other countries. This provides a rationale for aid donors to invest in innovations that could potentially be applied in multiple countries. Similarly, many funders silo their operations by sectors, making it difficult to identify and support interventions that work in multiple sectors without open innovation funds. Investments in development innovations are also less likely to crowd out government spending (e.g., on consumption, infrastructure) than other forms of aid, and thus may be valued by donors that seek to limit future reliance on aid.

While there is a clear theoretical case for investing in innovation, little work has been done to assess the returns on innovation portfolios. A bounding method is developed for measuring portfolio return that is consistent with the skewness observed in venture-type portfolios. Other development funders could adapt the approach for their own portfolios and contribute more needed evidence on investing in innovation. Applying the approach to DIV, the net social benefits of four of the 41 innovations in DIV's early portfolio (normalized by DIV's share of the innovation costs of each innovation) are weighed against all investment costs incurred during the period and conclude that DIV's overall portfolio of investments returned over $5 for every dollar spent, and delivered a social rate of return of over 77%. Even conservatively assuming that there were no benefits of any of the other 37 innovations funded during this period and that all innovations ceased to operate after 2018, the return from the portfolio far exceeds DIV's initial ambitious target of 15% social return. The portfolio's returns are strong compared with its social return target, the economic returns to development projects (Ospina and Block 2016, IEG 2010), and the financial returns typically observed for impact investing portfolios (GIIN 2017).

This high rate of return suggests the presence of market distortions in innovation investing that result in opportunities being left on the table. It may be that risk-averse donors and philanthropists (or the staff who manage the funds) are reluctant to invest in early-stage innovations with a high probability of failure, despite their high reach per dollar spent. This reluctance could be particularly pronounced in the public sector, where risk-taking may be more difficult than in the private sector for institutional reasons. The high rate of failure associated with individual development innovations could be politically unacceptable. Maintaining an open approach and large portfolios could attenuate this distortion, by helping funders to diversify across sectors and approaches, while taking a portfolio-level view of returns could help frame innovation investing in a more politically acceptable way.

None of this is to say that investing in innovation is a superior mode of supporting development, or that it should be the vehicle for a larger share of development aid. Comparisons of different forms of aid do not follow from the analysis, and it is unknown if the high returns observed from DIV's early investments would have increased proportionally if more funding had been awarded in 2010-2012. Rather, the experience from DIV's early portfolio suggests several lessons for social impact funders.

First, open innovation funds can deliver large and measurable results. DIV's early portfolio was constructed by taking many smart, relatively small bets, being open to ideas from researchers, testing rigorously, and investing larger amounts to scale cost-effective innovations. Innovations that did not fit in to preconceived strategies were given an opportunity to build on or establish evidence of their impact, demonstrating how DIV's openness and evidence focus are complementary. The water treatment innovation was supported through a partnership with BMGF, which was kept open across sectors to pick up low hanging fruit. While road safety was not a priority of USAID or the Kenyan government, DIV's open approach enabled it to foster the highly cost-effective sticker innovation, which works in the transportation sector to address a major public health problem in developing countries. Being open to evidence-based funding regardless of sector yielded high returns, and DIV's openness continued to be central after awards had been made. Its outcomes-focused milestones and flexible grants management enabled grantees to adjust their approach when a scaling strategy failed.

Second, DIV's early portfolio highlights the need to take an expanded view of routes to scaling, and complement direct sales to customers with scaling routes other than the social enterprise model that is emphasized by many innovation funders. Nearly all of the innovations that reached one million users in DIV's portfolio leveraged the distribution networks of governments and large businesses, which helped to keep customer acquisition costs low. Organizational tactics changed over time for several of the most successful innovations. Initial funding for the concept often led to an evolution of strategy and management that opened up new distribution channels and funding sources for low-cost innovations that proved highly cost effective. The road safety innovation was intended to scale through the private sector (insurance companies), but the Kenyan government also decided to require installation of stickers during vehicle safety inspections. The glasses for presbyopia has shifted from a social entrepreneurship model in its early years to a model that leverages the distribution channels of other NGOs, businesses, and governments. The water treatment innovation was initially intended to scale with government funding, but a key source of funding has been revenue from carbon credits. The software for CHWs innovation received funding from BMGF and is being scaled-up nation-wide in India with government support. All of these innovations attracted financial support from other sources after the conclusion of DIV support.

Third, much of the social return on innovations may be accrued outside the initial country of development. This relates to the previous point that the team that develops an innovation need not be the one that scales it. DIV's openness to countries and sectors meant that applicants could propose ideas that work in one country and adapt it to others. While the dispenser innovation was developed in Kenya, it has been adopted in Malawi and Uganda, and a substantial share of its social benefits are generated there. Similarly, while the returns on the road safety innovation were measured in Kenya, the program is being tested in other countries. The election monitoring innovation was initially supported in Afghanistan, before being adapted in Kenya, Uganda, and South Africa. These innovation investments are global public goods. They might not have been high domestic priorities initially and it might not have been clear ex-ante that they were good investments, but it was worth making these risky investments because of the potential benefits to developing countries more broadly.

Finally, not every innovation should be expected to achieve impact at scale, much like in the venture fund model, in which fewer than 10% of investments yield substantial returns (Ghosh 2012). A few highly successful innovations can cover the cost of large portfolios, so focus must be maintained on portfolio return. The lower bound exercise shows the importance of collecting high-quality data on social impact and reach of investments. Although some fraction of innovations will yield benefits that cannot be valued in monetary terms, an innovation funder can learn much about the performance of a portfolio from a subset of investments. Since most innovations that scaled did not require additional DIV support and governments, firms, and NGOs leverage innovation funding, it is critical to collect data on scaling and applications in new settings after the end of grants. Social innovation funders should go beyond looking at scaling during the duration of the grant and by the funded organization, or risk systematically underestimating the return on supported innovations. It will especially understate returns to innovations designed to be adopted by others (early-stage innovation and innovations by researchers). A widespread effort to collect data over the full developmental cycle of innovations would enable extension of the findings on social return and correlates of scale beyond DIV's experience, completing the record of investing in development innovation to date and influencing how innovation investment is conducted going forward.

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Appendix 1: Proof for the lower bound result

Assumption 1: $B_{i,t} > 0 \; for \; all \; i.$

Innovations did not lead to net social costs beyond DIV's investment.

Assumption 2: $B_{i,T'} \geq 0 \; for \; all \; T' > T.$

Net future benefits of portfolio innovations are either positive or zero, but not negative.

Proposition: $\mathrm{SROR}_{\mathrm{T}',\mathrm{I}} \geq \mathrm{SROR}_{\mathrm{T},\mathrm{J}}$ for all $\mathrm{T}' \geq \mathrm{T}$ and all J⊆I.

Calculating the SROR up to the present year T accounting for the benefits of a subset of innovations gives a lower bound on the social rate of return up to a future (projected) year T' accounting for the benefits of the full portfolio of innovations.

Proof:

Part 1: Recall that the social rate of return (SROR) is the discount rate that equalizes discounted benefits with discounted costs. The true SROR for the innovation investment is measured over a longer time range, $t = 0$ to $t = \mathrm{T}'$:

$$\sum_{t=0}^{T'} \frac{N_t B_t}{(1 + SROR_{\mathrm{T}'})^t} = \sum_{t=0}^{T'} \frac{C_t}{(1 + SROR_{\mathrm{T}'})^t}. \tag{6}$$

We cannot estimate $\mathrm{SROR}_{\mathrm{T}'}$ since the benefits and costs in the future are unknown. But consider a shorter time horizon from $t = 0$ to $t = T$, with $T < \mathrm{T}'$ and over which the net benefits are known or estimable. $\mathrm{SROR}_{\mathrm{T}}$ is the rate which satisfies:

$$\sum_{t=0}^{T} \frac{N_t B_t}{(1+SROR_T)^t} = \sum_{t=0}^{T} \frac{C_t}{(1+SROR_T)^t}.$$

(7)

We can show that $SROR_{\mathrm{T}\prime} \geq SROR_T$ must hold (i.e. $\mathrm{SROR_T}$ is a lower bound for $\mathrm{SROR_{T'}}$) if net future benefits are always non-negative (Assumption 2). Decompose Equation (6) as follows:

$$\sum_{t=0}^{T\prime} \frac{N_t B_t}{(1+SROR_{T\prime})^t} - \sum_{t=0}^{T\prime} \frac{C_t}{(1+SROR_{T\prime})^t}$$

$$= \sum_{t=0}^{T} \frac{N_t B_t}{(1+SROR_{T\prime})^t} - \sum_{t=0}^{T} \frac{C_t}{(1+SROR_{T\prime})^t} + \sum_{T}^{T\prime} \frac{N_t B_t}{(1+SROR_{T\prime})^t}$$

$$- \sum_{T}^{T\prime} \frac{C_t}{(1+SROR_{T\prime})^t}.$$

(8)

Note by the definition of SROR, the difference between the two left-hand side terms of Equation (8) is 0. Also, note that by the non-negative net expected future benefits assumption, the difference between last two terms on the right-hand side is weakly positive (i.e., the Net Present Value of the innovation after period T is greater than or equal to zero).

Moving terms around leaves Equation (9):

$$\sum_{t=0}^{T} \frac{N_t B_t}{(1+SROR_{T\prime})^t} - \sum_{t=0}^{T} \frac{C_t}{(1+SROR_{T'})^t} \leq 0.$$

(9)

Plugging Equation (7) in for the right-hand side yields:

$$\sum_{t=0}^{T}\frac{N_t B_t}{(1+SROR_{T'})^t}-\sum_{t=0}^{T}\frac{C_t}{(1+SROR_{T'})^t}\leq\sum_{t=0}^{T}\frac{N_t B_t}{(1+SROR_T)^t}-\sum_{t=0}^{T}\frac{C_t}{(1+SROR_T)^t}.$$

(10)

Equation (10) implies that $SROR_{T'} \geq SROR_T$ for a single innovation investment.

Part 2: Assumption 1 brings us to the portfolio-level Proposition. Recall that the portfolio SROR is such that:

$$\sum_{t=0}^{T}\sum_{i=1}^{I}\frac{N_{i,t}B_{i,t}}{(1+SROR_I)^t}=\sum_{t=0}^{T}\sum_{i=1}^{I}\frac{C_{i,t}}{(1+SROR_I)^t}.$$

(11)

Consider any subset of innovations $J \subseteq I$, and define $SROR_J$ such that:

$$\sum_{t=0}^{T}\sum_{i=1}^{J}\frac{N_{i,t}B_{i,t}}{(1+SROR_J)^t}=\sum_{t=0}^{T}\sum_{i=1}^{I}\frac{C_{i,t}}{(1+SROR_J)^t}.$$

(12)

Since $B_{i,t} > 0$ for all i by Assumption 1, it must be the case that $SROR_J \leq SROR_I$. This can be proved by way of contradiction. Suppose by way of contradiction that $SROR_J > SROR_I$. Then (11) and (12) together yield:

$$\sum_{t=0}^{T}\sum_{i=1}^{J}\frac{N_{i,t}B_{i,t}}{\left(1+SROR_J\right)^t}$$
$$= \sum_{t=0}^{T}\sum_{i=1}^{I}\frac{C_{i,t}}{\left(1+SROR_J\right)^t} < \sum_{t=0}^{T}\sum_{i=1}^{I}\frac{C_{i,t}}{(1+SROR_I)^t} = \sum_{t=0}^{T}\sum_{i=1}^{I}\frac{N_{i,t}B_{i,t}}{(1+SROR_I)^t}$$

which simplifies to:

$$\sum_{t=0}^{T}\sum_{i=1}^{J}\frac{N_{i,t}B_{i,t}}{(1+SROR_J)^t} < \sum_{t=0}^{T}\sum_{i=1}^{I}\frac{N_{i,t}B_{i,t}}{(1+SROR_I)^t}.$$

But $SROR_I > SROR_J$ if $B_{i,t} > 0$ for all i not in J (which follows from Assumption 1). This is a contradiction of the initial premise that $SROR_J > SROR_I$, so the conclusion is that $SROR_J \leq SROR_I$.

Combining results from Part 1 and Part 2, $SROR_{T',I} \geq SROR_{T,J}$. The practical implication of this is that under Assumptions 1 and 2, the rate of return estimated through year t for a subset of the portfolio is a lower bound for the rate of return estimated through a projected year for the full portfolio.

Appendix 2: Details on innovations reaching over 1 million beneficiaries

These details on the top ten high-reach innovations are drawn from the Appendix of Duflo and Kremer (2015).

1. Smartphone software for Community Health Workers (CHWs)

CommCare is a mobile platform that enables CHWs to enroll and manage clients, to create patient intake forms, to conduct more timely visits, and to access learning resources with information about healthy behavior. Developed by Dimagi, a social enterprise that makes open source software to improve healthcare in developing countries and for the underserved, CommCare provides actionable data to help CHWs improve their performance. CHWs can submit patient data in real-time to a central cloud server, where it is privacy-protected and backed up. Supervisors can view each CHW's performance indicators, including daily activity, number of clients, length of visits, and follow-up rates.

2. Voter report cards

Researchers conducted a multi-year project in India to test 1) whether better electoral outcomes can be achieved by directly providing voters with information, either on politician responsibilities or on actual politician performance and qualifications, 2) whether anticipation of and actual public disclosures on responsibilities and/or performance can cause incumbents to improve their service delivery and performance and change decisions on whether to stand for re-election, and 3) whether governance can be strengthened by directly providing elected officials with information about the quality of service and if this, in turn, affects usage of these amenities.

3. Election monitoring technology

One low-cost alternative to having international election observers is to use mobile technology to record and transmit information about votes cast at specific polling stations. Researchers designed an anti-fraud technology called “photo quick count,” which allows local election monitors to photograph provisional vote tally sheets at individual polling centers and compare them to the official vote count after aggregation. (In a clean election, the before and after tallies should be identical.) Letters announcing the photographic vote count verification were sent to a random sample of polling stations during the 2010 parliamentary elections in Afghanistan. This study covered 471 polling stations, about 5% of the national sample.

4. Affordable glasses for presbyopia

VisionSpring reaches base of the income pyramid (BoP) customers in rural and peri-urban areas through outreach efforts that provide vision screenings and access to affordable glasses. Its business model supports the sale of glasses to the poorest customers (targeting 70 percent of all customers) with revenue from higher-priced products sold to wealthier customers. VisionSpring has ten years of experience serving the global BoP optical market including successful implementation of the BoPtical Care Model in El Salvador. DIV supported this program in India, which was designed to reach 1.2 million people in six years. Each of VisionSpring's 10 “BoPtical Care” Hubs established under this award aimed to reach 12,000 individuals annually with high-quality affordable eye care. With this last-mile distribution system, VisionSpring drove down total costs from $18 to approximately $6 for each pair of glasses, increasing their affordability for BoP customers.

5. Road safety stickers

Researchers partnered with a local NGO and Safaricom, a major telecom company, to design and implement a road safety messaging campaign in Kenya. "Speak Up!" stickers encouraging passengers to speak up against bad driving were placed in a random sample of minibuses, and drivers were rewarded through a lottery for keeping the stickers in place. These rewards ranged from US $25 to $60. The stickers, about 11 by 3 inches, were placed on the metal panel between a passenger window and the ceiling of the vehicle, ensuring that at least one sticker was within eyesight of each passenger sitting in the main cabin. The first study (prior to DIV funding) covered 2,400 matatus operating along a set of long-distance routes.

6. Water treatment dispensers

A free, point-of-collection water chlorination system was designed to address the issue of recontamination and low usage rates of dilute chlorine available for purchase. Chlorine dispensers are placed at water sources, which serve as a visual reminder to treat water when it is most salient at the time of collection. The source-based approach makes drinking water treatment convenient because the dispenser valve delivers an accurate dose of chlorine to treat the most commonly used water collection containers, while the public nature of the dispenser also contributes to learning and habit formation. In addition, local promoters provide frequent reminders and encouragement to other community members to use the product. At scale, chlorine dispensers could cost less than $0.50 per person annually, making them one of the most cost effective ways to reduce diarrheal disease and save lives.

7. Digital attendance monitoring

The government of Karnataka state in India partnered with researchers to implement and evaluate a biometric monitoring system that objectively records attendance and reports it to supervisors in real time, combined with a robust system of incentives and penalties for unauthorized absences to improve staff attendance and patient health. From a sample of 322 primary healthcare centers across five socio economically diverse districts, 140 were randomly selected to receive the biometric devices consisting of a fingerprint reader and a mobile phone, while the remaining 182 continued with the status quo paper system of marking attendance. The device was used to record staff attendance via thumb impression at the beginning and end of each day. It was also capable of recording details about cash benefits paid to patients along with photographs and signatures and thumb impressions of beneficiaries taken at the clinic, and statistics regarding number of patients seen and the diseases treated. In practice it was primarily used for attendance monitoring. Attendance data could be transferred wirelessly using the existing cellular network to the state health headquarters in Bangalore so supervisors could track staff attendance in near real time. These data were analyzed and processed and then communicated back to the districts. This attendance information was coupled with an extensive system of incentives and penalties to encourage better attendance. Based on the attendance data, the government planned to issue both positive incentives, such as awards for staff members with good attendance records, as well as negative incentives, such as reprimand letters, disciplinary action, suspension from service, docking of pay, and deduction of earned leave for employees with unauthorized absences.

8. Psychometric credit assessment

The Entrepreneurial Finance Lab (EFL) applies psychometrics and behavioral science to loan repayment. Their credit-scoring technology enables better lending decisions for banks in emerging markets by revealing new dimensions of information about potential borrowers, whether or not they have credit history and collateral. Banks administer the EFL application on a computer or mobile device. The app uses psychometric methods to assess default risk, focusing on the applicant's intellect, business acumen, ethics, and attitude and beliefs, and other qualities. EFL creates a robust credit risk evaluation that is more powerful than traditional credit screening methods.

9. Mobile agriculture extension

Precision Agriculture for Development (an organization that emerged from the DIV grant to Innovations for Poverty Action's mobile agriculture extension innovation in Kenya) reaches farmers with personalized agricultural advice through their mobile phones. They implement this model in collaboration with partner organizations and governments and gather evidence on its impact.

10. Home solar systems

d.light provides a solar power alternative to households. Its home solar system includes a solar panel, two fixed LED lights, a portable LED lantern and a mobile phone charger. Via pay-as-you-go financing, d.light helps consumers avoid heavy up-front cost. d.light's financing mechanism is similar to a layaway model, and consumers are able to use the product while paying it off.