Twenty Year Economic Impacts of Deworming

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Abstract

This study exploits a randomized school health intervention that provided deworming treatment to Kenyan children and utilizes longitudinal data to estimate impacts on economic outcomes up to 20 years later. The effective respondent tracking rate was 84%. Individuals who received 2 to 3 additional years of childhood deworming experience an increase of 14% in consumption expenditure, 13% in hourly earnings, 9% in non-agricultural work hours, and are 9% more likely to live in urban areas. Most effects are concentrated among males and older individuals. Given deworming's low cost, a conservative annualized social internal rate of return estimate is 37%.

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The belief that investing in child health and nutrition can generate improvements in individuals' future quality of life is the rationale for many policy initiatives around the world. Yet there remains limited evidence on the causal impacts of child health gains on adult living standards, especially in low- and middle-income countries (LMICs). While there has been some recent progress in wealthy countries (Almond, Currie, and Duque 2018, Hendren and Sprung-Keyser 2020), few studies in LMICs are able to exploit credibly exogenous variation in child health status, combined with long-term participant tracking and detailed adult outcome measures. This is in part due to the lack of high-quality administrative data on workers, as well as widespread participation in the informal sector and subsistence agriculture.[1]

This study contributes new evidence that addresses leading methodological concerns. First, we exploit exogenous variation in child health via a randomized health intervention (the Primary School Deworming Project, PSDP) that provided deworming treatment to Kenyan children. Starting in 1998, 50 schools that we term the treatment group received 2 to 3 years of additional deworming relative to the 25 control group schools. Second, we estimate impacts on individual living standards up to 20 years later, using data from the Kenya Life Panel Survey (KLPS), which we designed to follow a representative sample of PSDP participants. Specifically, we utilize a detailed consumption questionnaire, considered the gold-standard of living standards measurement in LMICs, and gather rich information on adult labor and earnings, including in the informal sector and subsistence agriculture. Third, we successfully survey respondents over time: at the 20 year follow-up (round 4, 2017-19), the effective respondent survey rate was 84% among those still alive, with rates balanced across treatment arms; rates were similarly high in the 10-year (round 2, 2007-09) and 15-year (round 3, 2011-14) rounds. This is in part due to the decision to track migrants beyond the original study region, to other parts of Kenya, East Africa, and beyond.

In our main analysis, we find those in the deworming treatment group experience a 14% gain in consumption expenditures (p-value < 0.10), 7% increase in total earnings, and an 13% gain in hourly earnings (p-value < 0.10) during the period 10 to 20 years after the start of treatment. There are also shifts in sectors of residence and employment: treatment group individuals are 9% more likely to live in urban areas (p-value < 0.05), and experience an 9% increase in non-agricultural work hours (p-value < 0.05). Effects are concentrated among males (though we typically cannot reject equal effects across genders), and impacts are also typically larger for individuals who are older (those above age 12 at baseline); below we return to interpretation of these patterns. The observed consumption and earnings benefits,

1. A notable exception is the 35-year follow-up (Martorell et al. 2010) of the four villages in the Guatemala INCAP nutritional intervention for pregnant women and young children (63% respondent tracking rate). Bouguen et al. (2019) finds few studies of development interventions with more than a 7 year follow-up.

together with deworming's low cost when distributed at scale, imply that a conservative estimate of its annualized social internal rate of return is 37%, a high return by any standard.

As background, intestinal helminth infections are widespread, infecting one in five people worldwide (Pullan et al. 2014), and have adverse health and nutritional consequences for children, including stunted growth, weakness, and anemia (Stephenson et al. 1993; Stoltzfus et al. 1997; Guyatt et al. 2001; Silva et al. 2004; Disease Control Priorities Project 2008). The infections also may have broader immunological effects, for instance, by making individuals more prone to other infections such as malaria (Kirwan et al. 2010; Wammes et al. 2016) and altering the gut microbiome (Guernier et al. 2017; Zaiss and Harris 2016); worm infections in pregnant mothers may also reduce child birthweight (Larocque et al. 2006). These adverse health effects form the basis for the World Health Organization's (WHO) long-standing recommendation to provide mass school-based treatment in regions with infection prevalence above 20% (WHO 1992; 2017). Mass treatment is attractive because common deworming drugs are safe and cost less than US$1 per year per child, while diagnosing infections (through stool sample analysis) is imprecise and far more expensive (Ahuja et al. 2015). The appropriateness of this recommendation has been actively debated following a survey article that claimed few population-wide child gains from mass treatment (Taylor-Robinson et al. 2012). However, a recent meta-analysis incorporating more studies finds larger positive and significant impacts on child weight, height and mid-upper arm circumference (Croke et al. 2016). There is little evidence regarding long-run economic impacts, with the exception of Bleakley (2007), which finds that deworming in the U.S. South in the early 20th century led to higher adult educational attainment and income.

Several studies analyze the PSDP experiment. Miguel and Kremer (2004) find improvements in child school participation in treatment schools over the first two years of the program, with absenteeism falling by one quarter. They also estimate sizeable treatment externalities, presumably as treatment kills off worms already in the body, reducing transmission to others in the community; in particular, they document reductions in worm infection rates among both untreated children attending treatment schools, and children attending other schools located within 4 km of the treatment schools.[2] Ozier (2018) provides further evidence on externalities, showing that young children living in the treatment communities – who were not yet school aged and thus did not themselves receive deworming – experienced gains in learning outcomes up to ten years later, equivalent to 0.5 years of schooling on average. The current study most directly builds on Baird et al. (2016), which documented deworming

2. For discussions of the original school participation cross-school externalities estimates, see Aiken et al. (2015), Davey et al. (2015), Miguel and Kremer (2014), Clemens and Sandefur (2015), and Miguel, Kremer, and Hicks (2015); the current analysis employs a new dataset.

impacts 10 years later, including improved self-reported health, educational attainment (by 0.3 years on average), test scores and secondary schooling attainment (concentrated among females), as well as higher incomes among wage earners (20% gains), more meals eaten, hours worked and manufacturing employment (concentrated among males).

Baird et al. (2016) was subject to several limitations that the current study was designed to address. First, because many respondents were still in school at the 10 year follow-up, estimation of some labor market effects was necessarily conducted on selected samples. Second, only partial information was collected on subsistence agricultural production. Third, consumption data was not available for that round, leading to a reliance on a proxy (meals eaten). The current paper makes several novel contributions. The analysis utilizes two additional survey rounds to estimate impacts at 15 and 20 years after deworming treatment – an unusually long timeframe for experimental studies (Bouguen et al. 2019) – when most respondents were between 29 to 35 years old, allowing us to estimate impacts during individuals' prime working years. The measurement of economic outcomes was also improved: KLPS round 4 incorporates a detailed consumption expenditure questionnaire (modeled on the World Bank Living Standards Measurement Survey, LSMS, see Grosh and Glewwe 2000) for all respondents, and round 3 collected this for a representative subsample. Both KLPS rounds 3 and 4 also contain improved measures of agricultural productivity, including in subsistence agriculture, which, combined with other measures, provides a measure of total household earnings. Finally, while earlier PSDP deworming cost-benefit analyses were necessarily speculative, our use of long-run follow-up data means the calculations here are based almost entirely on observed outcomes.

1 Data and Estimation Strategy

1.1 Program Background and Data Collection

The PSDP study area is Busia District (since renamed Busia County), a largely agrarian region in western Kenya that is fairly representative of rural Kenya in terms of living standards. At the start of the program in 1998, the vast majority of children attended primary school, but dropout rates were high in grades 6, 7 and 8 (the final three years) and fewer than half went on to secondary school. Secondary schooling rates increased dramatically in the region over the next decade. Among adults, occupational and family roles continue to differ markedly by gender. This segmentation makes it plausible that the impacts of a health intervention could differ by gender, for instance, as hypothesized in Pitt, Rosenzweig, and Hassan (2012), who argue that child health gains in low-income, "brawn-based" economies may translate into greater labor market gains for males.

In 1998 a non-governmental organization (NGO) launched the PSDP in two geographic divisions of Busia, in 75 schools enrolling over 32,000 pupils. Baseline parasitological surveys indicated that helminth infection rates were over 90%, and over a third had a moderate-heavy infection according to a modified WHO infection criteria (Miguel and Kremer 2004).[3] The 75 schools were experimentally divided into three groups (Groups 1, 2, and 3) of 25 schools each: the schools were first stratified by administrative sub-unit (zone), zones were listed alphabetically within each geographic division, and schools were then listed in order of pupil enrollment within each zone, with every third school assigned to a given program group. The three treatment groups were well-balanced along baseline characteristics (see Miguel and Kremer 2004, Baird et al. 2016 and Appendix Figure A.1 for project details).

Due to the NGO's administrative and financial constraints, the schools were phased into deworming treatment during 1998-2001: Group 1 schools began receiving free deworming and health education in 1998, Group 2 schools in 1999, and Group 3 in 2001. Children in Group 1 and 2 schools were thus on average assigned 2.41 more years of deworming than Group 3 children; these two early beneficiary groups are denoted the treatment group here, following Baird et al. (2016). Drug take-up rates were high, at approximately 75% in the treatment group, and under 5% in the control group (Miguel and Kremer 2004).

The Kenya Life Panel Survey was launched in 2003 to track a representative sample of approximately 7,500 respondents enrolled in grades 2-7 in the PSDP schools at baseline. During round 1 (2003-2005), sample respondents were still mainly teenagers and few were active in the labor market; the subsequent survey rounds collected between 2007 and 2019 are the focus of this study. From the start, KLPS enumerators have traveled throughout Kenya and beyond to interview respondents (Appendix Figure A.2). The spread of mobile phones in Kenya during the study period has greatly facilitated tracking, and as a result, the effective tracking rate has remained high across KLPS rounds (Appendix Table A.1).[4] In KLPS-4, 87% were found and 83.9% surveyed among those still alive (Panel A, column 1). Rates are similar and not statistically significantly different across the treatment and control groups, and the same holds by gender (columns 4-6) and among those above and below median age (specifically, baseline age 12, Table A.2). Notably, rates are similarly high and balanced in earlier rounds.[5] In all, 86% of the KLPS sample was surveyed at least once

3. Rates this high are also found in some other African settings (Pullan et al. 2014).

4. The effective tracking rate is calculated as a fraction of those found, or not found but searched for during intensive tracking, with weights adjusted appropriately, in a manner analogous to the approach in the U.S. Moving To Opportunity study (Orr et al. 2003; Kling, Liebman, and Katz 2007), and Baird et al. (2016).

5. A representative subsample of respondents were visited again in KLPS-3 for the consumption expenditures module; the effective tracking rate is lower in this subsample (74.7%, Panel C), though rates are balanced across treatment arms. The survey rate among those still alive in KLPS-2 is 83.9% (Panel D).

during the 10, 15 or 20 year rounds.

Two other cross-cutting experiments are relevant for the analysis. First, in 2001 the NGO required cost-sharing contributions from parents in a randomly selected half of the Group 1 and Group 2 schools, reducing deworming drug take-up from 75% to 18% (Appendix Figure A.1); Group 3 schools received free deworming treatment in 2001. In 2002-2003, the NGO again provided free deworming in all 75 schools (Kremer and Miguel 2007). We estimate the effect of this temporary reduction in deworming on later outcomes. Second, in early 2009, approximately 1,500 individuals in the KLPS sample additionally took part in a vocational training voucher RCT prior to the start of the KLPS-3, and a subset of these also took part in a randomized cash grant program prior to KLPS-4; 1,070 of these individuals were randomly selected to receive a training voucher and/or cash grant. To focus the present analysis on deworming impacts, and avoid possible interactions with other programs, these individuals are dropped from the analysis for survey rounds after their assignment to the other treatments.[6] The randomly assigned voucher and cash control group (non-recipient) individuals are retained throughout, and given greater weight in the econometric analysis to maintain the representativeness of the original PSDP sample.

1.2 Estimation strategy

The analytical approach builds on Baird et al. (2016) and follows our pre-analysis plan (PAP) (Baird et al. 2017). We exploit the PSDP's experimental research design, namely, that the program exogenously provided individuals in treatment schools (Groups 1 and 2) two to three additional years of deworming. We focus on intention-to-treat (ITT) estimates for two main reasons: first, since treatment compliance was relatively high, and second, because previous research shows that untreated individuals within treatment communities experienced gains (Miguel and Kremer 2004), complicating estimation of treatment effects on the treated (TOT) within schools.

The analysis focuses on two main approaches, namely: i) pooled regressions that use data from KLPS rounds 2, 3 and 4 to estimate the overall long-run deworming effects 10 to 20 years after treatment, and ii) regressions using only KLPS-4, the longest-term follow-up. These two approaches, as well as the main outcome measures, were pre-specified in Baird et al. (2017) prior to conducting any analyses on the KLPS-4 data. The first approach has the advantage of utilizing all possible data, including information on the vocational training and cash grant recipients (who are dropped from the later rounds, as noted above), and is

6. Specifically, vocational training voucher winners are dropped from both the KLPS rounds 3 and 4 analysis, and cash grant winners dropped from round 4; those interventions are studied in separate work. The results below are robust to including these voucher and grant winners in the analysis, see Appendix A.

our focus here, with the KLPS-4 only results presented in the Appendix.

The dependent variable Y_{ijt} is an outcome for individual i in original PSDP school j as measured in survey round t:

$$Y_{ijt} = \alpha + \lambda_1 T_j + \lambda_2 C_j + \lambda_3 P_j + X'_{ij,0}\beta + \varepsilon_{ijt}. \quad (1)$$

The outcome is a function of $T_j \in \{0, 1\}$, the assigned deworming program treatment status of the individual's school. The pre-specified main coefficient of interest is λ_1, which captures gains accruing to individuals in the 50 treatment schools relative to the 25 control schools. Since deworming was assigned by school rather than at the individual level, some of the gains in treatment schools are likely due to within-school externalities. This is an attractive coefficient to focus on since it is a lower bound on the overall effect of deworming in the presence of cross-school treatment externalities, as shown in Baird et al. (2016).[7]

The vector $X_{ij,0}$ of individual and school covariates includes baseline school characteristics (average test score, population, number of students within 6 km, and administrative zone indicators), baseline individual characteristics (gender and grade), indicators for the KLPS survey calendar month, wave and round, and an indicator for the vocational training and cash grant control group. Estimates are weighted to maintain representativeness with the baseline PSDP population, taking into account the sampling for KLPS, the two-stage tracking methodology, and inclusion in the vocational training and cash grant program. Finally, ε_{ijt} is the error term clustered at the school level, allowing for correlation in outcomes both across individuals in those schools and across survey rounds.

We consider two secondary sources of exogenous variation in exposure to deworming, namely, the 2001 cost-sharing school indicator, $C_j \in \{0, 1\}$, and the proportion of students in neighboring schools within 6 km that received deworming, $P_j \in [0, 1]$, which we call local deworming saturation. While not the main focus, Appendix B presents evidence on their effects on outcomes. Conceptually, we expect (and find) λ_2 to generally have a sign opposite to that estimated for λ_1 (since cost-sharing reduced treatment). While we expect λ_3 to have the same sign as λ_1, in practice few estimates are significant, and we cannot reject that there is no relationship between the sign of the local saturation effect and the direct deworming effect. Baird et al. (2016) analyzed interactions between treatment and local saturation, and non-linearities in saturation, but cannot reject that T_j and P_j are additively separable and enter linearly; we thus use a similarly parsimonious specification here.[8]

7. In the presence of within-school epidemiological externalities, we cannot separately identify the effects of individual treatment versus schoolmates' deworming status. We can, however, identify the aggregate school-level effect, and thus classify all individuals in treatment schools as "treated" in the analysis.

8. Note that the bound proven in Baird et al. (2016) is still valid, albeit looser, if the geographic spread

We present results for the entire sample and broken out by gender and respondent age (namely, baseline age greater than 12), as mentioned in the pre-analysis plan.[9] We interact an indicator for females (baseline age > 12) with the main explanatory variables in equation 1, and use the resulting estimates to construct gender-specific (cohort-specific) effects.

2 Main Results

Here we present treatment effect estimates on adult living standards, earnings, labor market outcomes, and residential choice.[10]

2.1 Impacts on living standards

All KLPS round 4 (20 year follow-up) respondents and a representative subset of one sixth of round 3 (15 year) respondents were administered a detailed consumption expenditure module featuring questions on over 150 distinct items. It is often argued that the resulting measure of consumption may more accurately capture total household income (and living standards) than direct income measures in settings like rural Kenya. In the PAP, we specified that per capita household consumption expenditures would be one of two main outcomes; the other is total respondent earnings (presented in the next subsection). We present results for both in constant 2017 USD PPP, and trim the top 1% of observations (as pre-specified) to reduce the influence of outliers. We present real values below that account for urban-rural price differences, based on regular price surveys we collected in multiple Kenyan regions and cities (including Nairobi and Mombasa).

Deworming treatment has a positive impact on total household per capita consumption expenditures between 15 to 20 years after treatment: pooling KLPS rounds 3 and 4, the estimated effect is USD PPP 305 (s.e. 159, p-value < 0.10), a 14% increase relative to

of epidemiological externalities over time means that even "pure control" (i.e., $T_j = 0$, $P_j = 0$) schools are subject to some spillovers. In particular, those whose infection intensity falls due to cross-school externalities could themselves generate positive spillovers for other nearby schools, and so on. While such effects may fade over time, no school in the study area of roughly 15 by 40 km can definitively be considered a "pure control", making meaningful long-run cross-school spillover effects less likely.

9. Baird et al. (2016) show that those older than 12 at baseline experienced larger gains in terms of hours worked, meals eaten, and non-agricultural earnings, a finding they attribute to the fact that these individuals – who were at least 22 by KLPS-2 – had largely completed their schooling while younger individuals had not. The hypothesis that differential age effects were driven by school enrollment patterns led us to postulate in the PAP that there would be only minimal age differences in impacts by KLPS-4, as only 3% of the sample was still enrolled in school then. We show that there remain meaningful cohort differences in treatment effects in rounds 3 and 4, and discuss explanations below.

10. Baird et al. (2019) pre-specifies other outcome domains that are the subject of ongoing data collection, e.g., health, marriage, fertility, etc., and will be the focus of future research.

the control mean of USD PPP 2156 (Table 1, Panel A, column 1). A shift to the right in the distribution of consumption is visually apparent (Appendix Figure A.3, Panel A). Estimated effects by round are presented in Appendix Figure A.4 (Panel A). In the 20 year data, treatment group individuals report a 10% increase in consumption (USD PPP 199, s.e. 130, Table A.3, column 1). We find positive point estimates on sub-categories, including both food and non-food consumption (see Layvant, Miguel, and Walker (2020)).

Effects on consumption are larger in magnitude for male (USD PPP 513, p-value < 0.10) than female respondents (USD PPP 89) in both absolute and percentage terms (Panel A, cols. 2 and 3), although the gender difference is not significant at traditional levels. Women also have far lower average consumption, a pattern mirrored for all living standards and labor market measures, and likely indicative of the limited economic opportunities open to many women in Kenya.[11] Consumption effects are also far larger for older individuals (those older than 12 at baseline, who were typically 32 to 36 years old by KLPS-4), at USD PPP 886 (col. 4, p-value< 0.01), an effect that remains significant at traditional levels accounting for the false discovery rate (FDR) adjustment (Anderson 2008). Note that average living standards (in the control group) are considerably higher for younger than older individuals (col. 5), which likely at least partially reflects rapidly rising schooling levels in western Kenya in the years following the launch of the PSDP (Appendix Table A.10, Panel C).

2.2 Impacts on earnings and other labor outcomes

The second pre-specified main outcome measure, total individual earnings, includes the sum of earnings in the past year in wage employment (across all jobs), non-agricultural self-employment profits (for all businesses), and farming profits, including in subsistence agriculture. Note that those without any reported earnings in the last year are included in the analysis as zeros. To be sure we are focusing on *individual* labor productivity, we first only include farming profits in activities (e.g., growing a particular crop) for which the respondent reported providing all household labor hours. This measure thus misses agricultural profits derived from activities to which the respondent contributed jointly with other household members. The data indicate that 70% of agricultural activities are in fact conducted jointly with others, making it challenging to confidently assess individual agricultural productivity; this is a well-known concern in development economics. We later present a measure of total household income per capita that includes all household agricultural profits as well as earnings generated by the respondent and other adult household members.

Across the 10 to 20 year follow-up rounds, individual earnings are USD PPP 80 (s.e.

11. Gender differences in reporting or household structure could also potentially contribute to these gaps.

76) higher in the deworming treatment group (Table 1, Panel B, column 1). This estimate corresponds to a 6.5% increase in earnings. The estimated treatment effect is quite stable across across survey round 2 (USD PPP 87), round 3 (USD PPP 83) and round 4 (USD PPP 85, see Appendix Figure A.4), although none are statistically significant. The effect falls as a percentage of the control mean across rounds, as average earnings rise over time. The increase in the confidence interval surrounding estimates from rounds 2 through 4 also appear likely to be driven by the growth in both the mean and variability of earnings as individuals move into their prime working years.

As with consumption, estimated effects are larger for males (USD PPP 118) than females (USD PPP 41, cols. 2 and 3), though this difference is also not significant. Average individual earnings are nearly three times larger for males than females, again highlighting women's labor market disadvantages. Earnings gains are far larger for older (USD PPP 258, p-value$<$ 0.05) than younger (USD PPP -75) individuals, and once again the effect for the older group remains significant when the FDR multiple testing adjustment is applied.

Effects on the narrow measure of individual reported farming profits are close to zero, but as noted above, these exclude most household agricultural activity. In contrast, there is a sizeable deworming effect on total household earnings per capita (only collected in KLPS-4), at USD PPP 239 (p-value $<$ 0.10, Panel C, col. 1), and this effect is reassuringly similar in magnitude to the estimated impact on total household consumption per capita in round 4 (USD PPP 199, Appendix Table A.3). Total household earnings gains are again concentrated among males (USD PPP 439, p-value $<$ 0.10, col. 3) and older individuals (USD PPP 565, p-value $<$ 0.05, col. 4).[12]

There are meaningful changes in other labor market outcomes. Log annual earnings increase by 9 log points among those with non-zero earnings, and the likelihood that individuals have non-zero earnings rises by 2 percentage points (p-value $<$ 0.10, Table 2, Panel A, col. 1). Gains in both wage earnings and self-employed profits appear to be contributing to the overall effect, and individual earnings per hour also increases, by USD PPP 0.14 (p-value $<$ 0.10), or 13%. Patterns are similar in the KLPS round 4 data (Appendix Table A.4). Treatment individuals live in households with roughly 13% greater wealth per capita (collected in KLPS-4), although this effect is not significant at traditional levels. For most measures, gains are meaningfully larger among males and older individuals (cols. 2-3).

There are also shifts in the nature and sector of employment. While total labor supply (hours worked) increases only slightly, if at all, in the treatment group (1.04 hours, s.e. 0.66,

12. The FDR adjustment is not presented in Panel C since the total household earnings measure was not one of the two pre-specified primary outcomes. If the FDR adjustment is carried out across the six λ_1 coefficient estimates in columns 4-5 across the three panels, all three estimates for the older subgroup are significant with q-value $<$ 0.05.

Table 2, Panel B, col. 1), there is a significant increase in hours worked in non-agricultural employment (1.99 hours, p-value < 0.01), concentrated among males (2.77 hours, p-value < 0.01, col. 2) and older individuals (2.24 hours, p-value < 0.05, col. 3). Some of this shift is likely related to the substantial increase in urban residence, which rises by 4 percentage points on a base of 45 percent (p-value < 0.05), or 9%; note that roughly one third of urban migrants live in Nairobi, and many others live in Mombasa or other large cities.[13] In contrast to Baird et al. (2016), there is no significant change in employment in manufacturing or other broad job categories (among wage workers) overall or for males or older individuals when pooling rounds 2, 3 and 4 (Panel B) or round 4 alone (Appendix Table A.4).

2.3 Heterogeneous effects and mechanisms

The concentration of deworming effects among males and those older than 12 at baseline is notable. Here we briefly discuss potential explanations for this heterogeneity, and what it suggests about the mechanisms underlying long-run impacts.

It is puzzling that females show fewer economic benefits than males since they experience larger gains in schooling attainment, test scores, and self-reported health than males (Baird et al. 2016 and Appendix Table A.11, Panel B). A possible explanation is that these human capital gains alone may be insufficient in a context where many women face important constraints and fewer economic opportunities than men (USAID 2020). For instance, KLPS sample women spend roughly three times more hours than men doing household chores and more than twice as much time providing childcare, and their participation in the non-agricultural labor force is far lower (Appendix Table A.10, Panel C).

The larger estimated gains among older participants may also be surprising at first given an intuitive sense that younger children might gain more from human capital investments, but note that all sample individuals are already outside of hypothesized "critical" windows of early childhood development (Appendix Table A.10, Panel A). One piece of evidence that could help explain the age pattern is the finding that deworming led to larger human capital gains among older individuals. Older individuals in the control group have lower levels of schooling than younger individuals (Appendix Table A.10, Panel C),[14] but the deworming effect for the older group is +0.45 years of schooling (s.e. 0.18, p-value < 0.05, Appendix Table A.11, Panel B), while for younger individuals it is closer to zero (+0.04 years). While schooling gains alone are not sufficient to guarantee later labor market benefits – as demonstrated by the experience of females – they are plausibly driving some of the long-

13. Urban residence was included as an outcome in the later Baird et al. (2019) PAP, as we collect more a more detailed migration history as part of ongoing survey modules relative to the data utilized in this paper.

14. This reflects the rapid increase in schooling over the decade following the start of PSDP.

run gains in the older group.

Since deworming was assigned at the school level, changes in social networks could also be a channel. We find that older individuals in the treatment group are indeed more likely to learn of a job through a primary school classmate (+6 percentage points on a base of 13%, p-value < 0.05, Appendix Table A.11), suggesting this could also be a partial explanation.

A more speculative explanation is that the *level* of deworming treatment is playing a role. While the average *difference* in assigned years of deworming between treatment and control schools is the same for younger and older cohorts (Appendix Table A.10), the distributions are different, and in particular the average years of assigned treatment in the control group is far higher among younger individuals (Appendix Table A.11), as many older control group students graduate from (or leave) primary school before receiving any deworming (Appendix Figure A.5, Panels B and C). If the marginal benefit of deworming is declining with each additional year of treatment (leading to a concave functional form), this could lead treatment effects to be larger among the older subgroup. For the primary consumption per-capita outcome, treatment effects are (reassuringly) monotonically increasing with additional years of deworming treatment assignment, and there is some evidence of concavity, especially at greater than 4 years (Panel A). While promising, this explanation remains tentative given limited epidemiological evidence on the deworming dose response function.

We are also able to rule out several alternative explanations for differential treatment effects, see Appendix C. The most obvious explanation for heterogeneous effects would be differential baseline worm infection levels across subgroups, or varying degrees of infection reduction, but we do not find meaningful differences along these lines by gender or age (Appendix Tables A.10, A.11). Nor did Baird et al. (2016) estimate significant differences in impacts as a function of baseline local area infection levels, although this latter analysis is somewhat statistically under-powered. The differential gains by age do not appear to be due to life cycle or age-at-survey explanations, but instead are driven by cohort effects (Appendix Table A.9). There are differences in average levels of parental education across older and younger cohorts, but little evidence of heterogeneous treatment effects by level of parental education (Appendix Table A.8).

3 Rate of return and fiscal impacts of deworming

Here we present deworming cost-effectiveness estimates (see Appendix D for details).

The social net present value (NPV) of providing free deworming treatment takes into account the cost of deworming medication, the cost of additional schooling resulting from deworming (Baird et al. 2016), and economic gains measured via consumption or earnings.

Figure 1 displays these components graphically, where the direct costs are illustrated in the darkest gray in the first years. We use 2018 deworming drug costs, while schooling costs come from multiplying secondary schooling rate increases (Baird et al. 2016) by recent Kenyan teacher salary figures (Nyanchama 2018; Oduor 2017). On the benefit side, we use λ_{1t} estimates for consumption and earnings generated from our pooled specification across KLPS rounds 2, 3, and 4. For earnings, we assume these gains start 10 years after deworming treatment, roughly coinciding with entry into adulthood and KLPS round 2. Since we do not have consumption data until KLPS-3, we conservatively assume that the average estimated effect from KLPS 3 and 4 only pertains during the period from 15 to 25 years after treatment. We also make the conservative assumption, presented graphically in Figure 1, that effects last for five years, roughly the time between survey rounds, and fall to zero five years after round 4 (at $t = 25$).[15] The main estimates use an annual discount rate of 10%, the median real interest rate in Kenya during 1998-2018, which is conservative if other potential funders (e.g., international donors) face lower rates. We also compute the internal rate of return (IRR). The dotted horizontal line in Figure 1 shows the magnitude of average annual treatment effects needed to attain an annualized IRR of 10% is USD PPP 7.99. We also calculate the NPV and IRR of additional government tax revenue generated by deworming by multiplying earnings or consumption gains by the average Kenyan tax rate.

The estimated deworming consumption and earnings gains are both an order of magnitude larger than the USD PPP 7.99 needed to attain the social IRR of 10% noted above (Figure 1, Appendix Table A.12), and are also far larger than the gains needed to attain a fiscal IRR of 10% (USD PPP 29.12 and 48.21, respectively, Appendix Table A.12). The social and fiscal NPV estimates are positive for both the consumption and earnings effects, and for annual discount rates of 10%. In the most conservative scenario, focusing on earnings gains and the 10% discount over 25 years, the social NPV is USD PPP 230.71 and the fiscal NPV is USD PPP 16.74 (Panel B). The implied social and fiscal IRR estimates in this case are 40.7% and 15.5%, with values higher if we allow gains to persist beyond year 25 (Panel C). If we focus on consumption and consider gains out to 25 years, the social and fiscal IRR estimates are 36.7% and 19.6%, respectively.

15. This calculation is also conservative by not including direct child health benefits or any persistent health gains, and ignoring cross-school externalities among sample individuals and other community members (Ozier 2018).

4 Discussion

This study provides novel causal evidence on the long-run effects of child health investments on adult living standards and labor market outcomes. Individuals who received deworming as children experience substantial increases in adult consumption, hourly earnings, non-agricultural employment, and urban residence. These findings add to growing evidence that the Primary School Deworming Project had meaningful positive effects on recipients (Miguel and Kremer 2004; Baird et al. 2016). Even ignoring spillovers and making other conservative assumptions, the social rate of return appears to be very high.

From a policy perspective, it is important to consider external validity. Intestinal worm infections are widespread globally, with high infection rates in many parts of Africa, South Asia, and Latin America, and even a possible (and unfortunate) resurgence in the rural U.S. South (McKenna et al. 2017). The ubiquity of the infections suggests that this study's findings have relevance for many other settings. At the same time, the degree to which school-based mass deworming generates positive long-run benefits is plausibly linked to the extent of infection. The study setting featured high baseline infection prevalence, at over 90%, and a large share of children with intense infections. The PSDP intervention also began during the strong 1997-1998 El Niño–Southern Oscillation event, which brought torrential rains to the region, and the related deterioration in hygiene and sanitation likely contributed to elevated worm infection levels. Deworming treatment impacts would presumably have been smaller had worm infection levels been lower.

The analysis does not resolve the issue of exactly why and through what channels deworming affected adult outcomes. Since changes to health, education, social activity among schoolmates, marital choices, and income levels may all affect each other in various directions, the impacts should not be interpreted strictly as all reflecting deworming's direct health effects, but rather are likely to be the result of a cumulative process of interaction among these factors.[16] Our examination of heterogeneous treatment effects by gender and age sheds some light on the importance of certain factors, but cannot definitively adjudicate between channels. Further research is needed to understand how institutional and contextual factors interact with child health investments, to better understand mechanisms (Almond, Currie, and Duque 2018). Another area of ongoing debate is whether child health and nutrition investments must fall within a "critical" early period of development for long-term gains to accrue (Bundy et al. 2018). Our findings indicate that even health programs focused on school-age children can yield substantial benefits, consistent with recent US findings

16. To be clear, we do not expect that child deworming treatment would have a direct impact on respondents' adult worm loads decades later, given worms' relatively short average lifespan in the human body.

(Hendren and Sprung-Keyser 2020).

As most study participants have already also become parents themselves, another interesting future direction will be to investigate possible deworming effects on the next generation. The economic impacts we document suggest that such effects are plausible; it is also possible that the education gains experienced by women could improve life outcomes for their children. The existence of any inter-generational benefits would further bolster deworming's cost-effectiveness.

References

Ahuja, Amrita, Sarah Baird, Joan Hamory Hicks, Michael Kremer, Edward Miguel, and Shawn Powers. 2015. "When should governments subsidize health? The case of mass deworming." *World Bank Economic Review* 29 (supplement) (June): S9–S24.

Aiken, Alexander M., Davey Calum, James R. Hargreaves, and Richard J. Hayes. 2015. "Re-analysis of health and educational impacts of a school-based deworming programme in western Kenya: a pure replication." *International Journal of Epidemilogy* 44 (5): 1572–1580.

Almond, Douglas, Janet Currie, and Valentina Duque. 2018. "Child Circumstances and Adult Outcomes: Act II." *Journal of Economic Literature* 56, no. 4 (December): 1360–1446.

Anderson, Michael L. 2008. "Multiple Inference and Gender Differences in the Effects of Early Intervention: A Reevaluation of the Abecedarian, Perry Preschool, and Early Training Projects." *Journal of the American Statistical Association* 103 (484): 1481–1495.

Baird, Sarah, Joan Hamory Hicks, Michael Kremer, and Edward Miguel. 2016. "Worms at Work: Long-run Impacts of a Child Health Investment." *The Quarterly Journal of Economics* 131, no. 4 (July): 1637–1680.

———. 2017. "Pre-Analysis Plan for "The 20-year Impacts of Child Deworming in Kenya"." RCT ID: AEARCTR-0001191.

Baird, Sarah, Joan Hamory Hicks, Michael Kremer, Edward Miguel, and Michael Walker. 2019. "Pre-Analysis Plan for "The 20-year Impacts of Child Deworming in Kenya: Additional Domains"." RCT ID: AEARCTR-0001191.

Bleakley, Hoyt. 2007. "Disease and Development: Evidence from Hookworm Eradication in the American South." *Quarterly Journal of Economics* 122 (1): 73–117.

Bouguen, Adrien, Yue Huang, Michael Kremer, and Edward Miguel. 2019. "Using Randomized Controlled Trials to Estimate Long-Run Impacts in Development Economics." *Annual Review of Economics* 11 (1): 523–561.

Bundy, Donald A.P., Nilanthi de Silva, Susan Horton, George C. Patton, Linda Schultz, Dean T. Jamison, the Disease Control Priorities-3 Child, Adolescent Health, and Development Authors Group. 2018. "Investment in child and adolescent health and development: key messages from Disease Control Priorities, 3rd Edition." *The Lancet* 391 (10121): 687–699.

Clemens, Michael, and Justin Sandefur. 2015. "Mapping the Worm Wars: What the Public Should Take Away from the Scientific Debate about Mass Deworming." Center for Global Development Blog.

Croke, Kevin, Joan Hamory Hicks, Eric Hsu, Michael Kremer, and Edward Miguel. 2016. "Does mass deworming affect child nutrition? Meta-analysis, cost-effectiveness, and statistical power." NBER Working Paper No. 22382.

Davey, Calum, Alexander M. Aiken, Richard J. Hayes, and James R. Hargreaves. 2015. "Re-analysis of health and educational impacts of a school-based deworming programme in western Kenya: a statistical replication of a cluster quasi-randomized stepped-wedge trial." *International Journal of Epidemiology* 44:1581–1592.

Disease Control Priorities Project. 2008. *Deworming Children Brings Huge Health and Development Gains in Low-Income Countries.* Technical report.

Grosh, Margaret, and Paul Glewwe, eds. 2000. *Designing Households Survey Questionnaires for Developing Countries: Lessons from 15 Years of the Living Standards Measurement Study.* Vol. 3. Washington, DC: World Bank.

Guernier, Vanina, Bradley Brennan, Laith Yakob, Gabriel J. Milinovich, Archie C. A. Clements, and Ricardo J. Soares Magalhaes. 2017. "Gut microbiota disturbance during helminth infection: can it affect cognition and behaviour of children?" *BMC Infectious Diseases* 17 (58): 58.

Guyatt, Helen L., Simon Brooker, Charles M. Kihamia, Andrew Hall, and Donald A.P. Bundy. 2001. "Evaluation of efficacy of school-based anthelmintic treatments against anaemia in children in the United Republic of Tanzania." *Bulletin of the World Health Organization* 79 (8): 695–703.

Hendren, Nathaniel, and Ben Sprung-Keyser. 2020. "A Unified Welfare Analysis of Government Policies." *The Quarterly Journal of Economics* 135, no. 3 (March): 1209–1318.

Kirwan, Patrick, Andrew Jackson, Samuel Asaolu, Síle Molloy, Titilayo Abiona, Marian Bruce, Lisa Ranford-Cartwright, Sandra O'Neill, and Celia Holland. 2010. "Impact of repeated four-monthly anthelmintic treatment on Plasmodium infection in preschool children: A double-blind placebo-controlled randomized trial." *BMC Infectious Diseases* 10 (September): 277.

Kling, Jeffrey R., Jeffrey B. Liebman, and Lawrence F. Katz. 2007. "Experimental Analysis of Neighborhood Effects." *Econometrica* 75 (1): 83–119.

Kremer, Michael, and Edward Miguel. 2007. "The Illusion of Sustainability." *The Quarterly Journal of Economics* 122, no. 3 (August): 1007–1065.

Larocque, R., M. Casapia, E. Gotuzzo, J.D. MacLean, J.C. Soto, Rahme E., and T.W. Gyorkos. 2006. "A double-blind randomized controlled trial of antenatal mebendazole to reduce low birthweight in a hookworm-endemic area of Peru." *Tropical Medicine & International Health* 11 (10): 1485–1495.

Layvant, Michelle, Edward Miguel, and Michael Walker. 2020. "Pre-Analysis Plan Report for Twenty Year Economic Impacts of Deworming." Available at `https://osf.io/gx96j`.

Martorell, Reynaldo, Paul Melgar, John Maluccio, Aryeh Stein, and Juan Rivera. 2010. "The Nutrition Intervention Improved Adult Human Capital and Economic Productivity." *The Journal of Nutrition* 140 (February): 411–4.

McKenna, Megan, Shannon McAtee, Peter Hotez, Patricia Bryan, Rebecca Jeun, Maria Bottazzi, Catherine Flowers, Tabitha Ward, Jacob Kraus, and Rojelio Mejia. 2017. "Human Intestinal Parasite Burden and Poor Sanitation in Rural Alabama." *The American Journal of Tropical Medicine and Hygiene* 97 (5).

Miguel, Edward, and Michael Kremer. 2004. "Worms: identifying impacts on education and health in the presence of treatment externalities." *Econometrica* 72 (1): 159–217.

———. 2014. "Worms: Identifying Impacts on Education and Health in the Presence of Treatment Externalities, Guide to Replication of Miguel and Kremer (2004)." Center for Effective Global Action Working Paper Series #39.

Miguel, Edward, Michael Kremer, and Joan Hamory Hicks. 2015. "Comment on Macartan Humphreys' and Other Recent Discussions of the Miguel and Kremer (2004) Study." CEGA Working Paper #54.

Nyanchama, Venic. 2018. "New TSC salaries and grading system for teachers 2020." https://www.tuko.co.ke/281149-new-tsc-salaries-grading-system-teachers-2020.html.

Oduor, Augustine. 2017. "Windfall for teachers as TSC releseases new salaries." https://standardmedia.co.ke/article/2001249581/windfall-for-teachers-as-tsc-releases-new-salaries.

Orr, Larry, Judith Feins, Robin Jacob, Eric Beecroft, Lisa Sanbonmatsu, Lawrence F. Katz, Jeffrey B. Liebman, and Jeffrey R. Kling. 2003. *Moving to Opportunity: Interim Impacts Evaluation.* Technical report. Washington, D.C.

Ozier, Owen. 2018. "Exploiting Externalities to Estimate the Long-term Effects of Early Childhood Deworming." *American Economic Journal: Applied Economics* 10, no. 3 (July): 235–62.

Pitt, Mark M., Mark R. Rosenzweig, and Mohammed Nazmul Hassan. 2012. "Human Capital Investment and the Gender Division of Labor in a Brawn-Based Economy." *American Economic Review* 102, no. 7 (December): 3531–60.

Pullan, Rachel, Jennifer Smith, Rashmi Jasrasaria, and Simon Brooker. 2014. "Global numbers of infection and disease burden of soil transmitted helminth infections in 2010." *Parasites & Vectors* 7 (January): 37.

Silva, Nilanthi, Simon Brooker, Peter Hotez, Antonio Montresor, Dirk Engels, and Lorenzo Savioli. 2004. "Soil-Transmitted Helminth Infections: Updating the Global Picture." *Trends in parasitology* 19 (January): 547–51.

Stephenson, Lani S., Michael C. Latham, Erin J. Adams, Stephen N. Kinoti, and Anne Pertet. 1993. "Physical fitness, growth and appetite of Kenyan school boys with hookworm, Trichuris trichiura and Ascaris lumbricoides infections are improved four months after a single dose of albendazole." *The Journal of Nutrition* 123 (June): 1036–46.

Stoltzfus, R.J., H.M. Chwaya, Tielsch J.M., Schulze K.J., Albonico M., and Savioli L. 1997. "Epidemiology of iron deficiency anemia in Zanzibari schoolchildren: the importance of hookworms" [in English (US)]. *American Journal of Clinical Nutrition* 65, no. 1 (January): 153–159.

Taylor-Robinson, David, Nicola Maayan, Karla Soares-Weiser, Sarah Donegan, and Paul Garner. 2012. "Deworming drugs for soil-transmitted intestinal worms in children: Effects on nutritional indicators, haemoglobin, and school performance." *Cochrane Database of Systematic Reviews (Online)* 7 (November): CD000371.

Udry, Christopher. 1996. "Gender, agricultural production, and the theory of the household." *Journal of Political Economy* 104 (5): 1010–1046.

USAID. 2020. "USAID 2020 Kenya Gender Fact Sheet." USAID 2020 Kenya Gender Fact Sheet.

Wammes, Linda J., Firdaus Hamid, Aprilianto Eddy Wiria, Linda May, Maria M. M. Kaisar, Margaretta A. Prasetyani-Gieseler, Yenny Djuardi, et al. 2016. "Deworming improves immune responsiveness." *Proceedings of the National Academy of Sciences* 113 (44): 12526–12531.

World Health Organization. 1992. *Model Describing Information. Drugs used in Parasitic Diseases.* Geneva.

———. 2017. *Guideline: Preventive Chemotherapy to Control Soil-Transmitted Helminth Infections in At-Risk Population Groups.* Geneva.

Zaiss, Mario M., and Nicola L. Harris. 2016. "Interactions between the intestinal microbiome and helminth parasites." *Parasite Immunology* 38 (1): 5–11.

Table 1: 10 to 20 Year Deworming Treatment Effects on Consumption and Earnings, KLPS Rounds 2, 3 and 4

	(1) Full Sample	(2) Female	(3) Male	(4) Older	(5) Younger
Panel A: Annual Per-Capita Consumption (KLPS-3 and 4)					
Treatment (λ_1)	305	89	513	886	-179
	(159)	(134)	(304)	(223)	(185)
Control Mean	2156	1715	2594	1908	2381
Treatment Effect (%)	14.15	5.21	19.76	46.44	-7.52
Treatment p-value	.058	.505	.096	.000	.337
FDR q-value	.132	.630	.623	.001	.290
Number Observations	4794	2473	2321	2402	2341
Panel B: Annual Individual Earnings (KLPS-2, 3, and 4)					
Treatment (λ_1)	80	41	118	258	-75
	(76)	(62)	(133)	(108)	(100)
Control Mean	1218	674	1728	1177	1242
Treatment Effect (%)	6.53	6.02	6.84	21.93	-6.07
Treatment p-value	.297	.515	.376	.019	.451
FDR q-value	.175	.630	.630	.030	.292
Number Observations	13624	6826	6798	6791	6780
Panel C: Annual Per-Capita Household Earnings (KLPS-4)					
Treatment (λ_1)	239	36	439	565	-22
	(129)	(107)	(252)	(232)	(171)
Control Mean	1296	973	1623	1082	1501
Treatment Effect (%)	18.44	3.68	27.06	52.17	-1.48
Treatment p-value	.069	.738	.086	.017	.897
Number Observations	4074	2099	1975	2039	1982

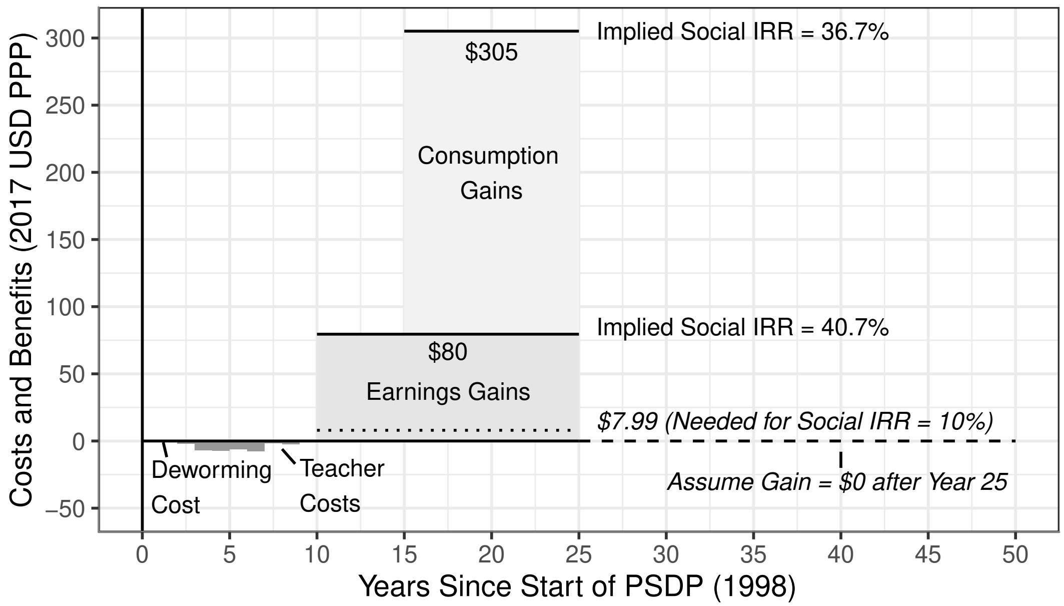
Notes: Panel A reports annual per-capita total consumption, calculated as the sum of the monetary value of goods consumed by the household through purchase, gift, barter, or home production in the last 12 months, divided by the number of household members. The consumption/expenditure module was administered to a subset of the sample during round 3 and the full sample during round 4. Consumption is adjusted for urban-rural price differences for respondents living in Nairobi and Mombasa. Panel B reports annual individual earnings, calculated as the sum of wage employment across all jobs; non-agricultural self-employment profit across all business; and individual farming profit, defined as net profit generated from non-crop and crop farming activities for which the respondent provided all reported household labor hours and was the main decision-maker within the last 12 months. Wage earnings and self-employment profits were collected in KLPS rounds 2, 3 and 4; agricultural profits were collected in KLPS 3 and 4. Panel C reports annual per-capita household earnings, calculated as the sum of wage employment earnings, self-employment profits, and agricultural profits across all household members, divided by the number of household members. Household earnings are only available in KLPS-4. All outcomes are converted to constant 2017 USD at PPP rates, and the top 1% of observations are trimmed. Treatment is an indicator variable equal to 1 for PSDP Worm Groups 1 and 2, which received an additional 2.4 years of deworming on average compared to Group 3. Columns (2) through (5) report estimates separately by gender and age at baseline (older than 12, 12 or younger). Columns (2) and (3) report estimates for Female and Male are constructed from a single regression including treatment-female, cost-sharing-female, and saturation-female interaction terms. Columns (4) and (5) also report results from a single regression, using an indicator for those older than 12 at baseline and analagous interaction terms to Columns (2) and (3). The pre-analysis plan (PAP) specified annual per-capita consumption and annual individual earnings as primary outcomes. Following the PAP, the FDR adjustment in column (1) is carried out across the two λ_1 coefficient estimates from Panels A and B of column (1). The FDR adjustment in columns (2) and (3) are carried out across the four λ_1 coefficient estimates from Panels A and B of columns (2) and (3). Similarly, the FDR adjustment in columns (4) and (5) are carried out across the four λ_1 coefficient estimates from Panels A and B of columns (4) and (5). Covariates follow Baird et al. (2016) and include controls for baseline 1998 primary school population, geographic zone of the school, survey wave and month of interview, a female indicator variable, baseline 1998 school grade fixed effects, the average school test score on the 1996 Busia District mock exams, total primary school pupils within 6 km, and a cost-sharing school indicator. Those treated in a separate vocational training intervention (VocEd) which occurred prior to KLPS-3 are dropped from the KLPS-3 and KLPS-4 sample. Those treated in a separate small grant intervention (SCY) which occurred after KLPS-3 are dropped from the KLPS-4 sample. Observations are weighted to be representative of the original PSDP population, and include KLPS population weights, SCY and VocEd control group weights, and KLPS intensive tracking weights. Standard errors are clustered at the 1998 school level.

Table 2: 10 to 20 Year Deworming Treatment Effects on Earnings, Labor Supply, Occupation, and Sectoral Choice, KLPS Rounds 2, 3 and 4

	Treatment (λ_1)			Full Sample	
	(1) Full Sample	(2) Male	(3) Older	(4) Control Mean	(5) Number Obs.
Panel A: Earnings and Wealth					
Log Annual Individual Earnings	0.09	0.06	0.19	6.73	7698
	(0.06)	(0.07)	(0.08)		
Wage Earnings (annual)	81	138	162	887	13628
	(68)	(110)	(89)		
Self-Employment Profit (annual)	41	51	70	212	13638
	(24)	(48)	(39)		
Individiual Farming Profit (annual)	-0	1	-3	9	13707
	(2)	(3)	(3)		
Non-Zero Earnings	0.02	0.04	0.02	0.59	13794
	(0.01)	(0.02)	(0.02)		
Hourly Earnings	0.14	0.22	0.32	1.07	6096
	(0.08)	(0.15)	(0.16)		
Per-Capita Household Wealth (KLPS-4)	69	102	253	522	4085
	(50)	(97)	(89)		
Panel B: Labor Supply, Occupation, and Sectoral Choice					
Urban Residence	0.04	0.06	0.03	0.45	13793
	(0.02)	(0.03)	(0.03)		
Total Hours Worked (last 7 days)	1.04	2.20	1.79	24.19	13807
	(0.66)	(0.92)	(0.91)		
Hours Worked - Agriculture (last 7 days)	-0.87	-0.57	-0.46	3.99	13807
	(0.43)	(0.62)	(0.56)		
Hours Worked - Non-Agriculture (last 7 days)	1.91	2.77	2.24	20.20	13807
	(0.65)	(0.94)	(1.08)		
Employed - Agriculture/Fishing	-0.003	-0.001	0.004	0.043	13768
	(0.008)	(0.013)	(0.012)		
Employed - Services/Wholesale/Retail	0.002	0.012	-0.002	0.230	13761
	(0.014)	(0.020)	(0.019)		
Employed - Construction/Trade Contractor	0.004	0.011	-0.007	0.033	13760
	(0.007)	(0.014)	(0.009)		
Employed - Manufacturing	-0.001	0.002	0.002	0.026	13760
	(0.004)	(0.007)	(0.006)		

Notes: This table reports treatment effects for numerous outcomes, using data pooled across KLPS-2, KLPS-3, and KLPS-4 unless otherwise indicated. Column (1) reports the overall treatment effect (λ_1 from Equation (1)) for the full sample, while columns (2) and (3) report estimated treatment effects for males and those older than 12 at baseline, respectively. Columns (4) and (5) report the full sample control mean and number of observations for each outcome, respectively. Variables in Panel A are converted to 2017 USD at PPP and trimmed at the top 1%. Log annual individual earnings is based on annual individual earnings from Table 1. Wage earnings, self-employment profits and farming profits are annual amounts. Hourly earnings is calculated by dividing annual individual earnings by 52, divided by the total hours worked across all activities during the last week, among those with at least 10 work hours across all activities. Per-capita household wealth is calculated as the sum of total household durable asset ownership and livestock ownership, divided by the number of household members. Urban residence is an indicator variable coded as "1" for living in a non-rural area, which includes both towns and cities. Hours worked variables are based on the total hours worked within the last 7 days; hours worked in each job, within job categories (i.e., wage-earning, self-employment, and farming), and across all jobs are top-coded at 100 hours per week. Employed variables are indicator variables coded as "1" for those with wage employment in a given sector. See the PAP report (Layvant, Miguel, and Walker 2020) for additional details on variable construction, results for female and younger respondents, and statistical significance levels. Weights and control variables included in the regression are defined in the notes for Table 1. Standard errors are clustered at the 1998 school level.

Figure 1: Deworming Costs, Benefits and Rate of Return



Notes: This figure presents the costs and benefits of deworming over time, and calculated social internal rate of return (IRR). Costs and benefits in the figure are reported in 2017 USD PPP terms. For additional details and alternative assumptions, see Table A.12 and Appendix D.
Costs: Total costs include the direct cost of providing mass school-based deworming from the NGO Deworm the World plus the costs of additional teachers, based on documented educational gains and the approach of Baird et al. (2016). We calculate teacher costs as average educational gains per student per year as a result of deworming (from Baird et al. (2016)) times annual teacher salary costs per pupil (USD PPP 267.88, based on an estimate of annual teacher salary (USD PPP $12,055) from the upper tier of monthly teacher salaries from (Nyanchama 2018) and (Oduor 2017) of and a pupil-teacher ratio of 45, as in Baird et al. (2016)). On average, from 1999 to 2007, students attended school for an additional 0.15 years.
Benefits: We assume no earnings gains in the first 10 years after receiving deworming medication. We use the estimate of treatment effects for annual individual earnings measured 10, 15 and 20 years after the start of deworming and pooled across rounds (λ_{1t} from Table 1, Panel B). We assume no per-capita consumption gains in the first 15 years after receiving deworming medication. As for earnings, we use the estimate of annual per-capita consumption expenditures measured 15 and 20 years after the start of deworming and pooled across rounds from Table 1, Panel A. For both earnings and per-capita consumption, we assume zero gains after the last observed five-year period (25 years after receiving treatment).
Calculations: The dotted line at USD PPP 7.99 shows the average treatment effect (λ_{1t}) needed from year 10 to year 25 in order to generate a Social IRR of 10%. A return of 10% represents the median real interest rate from 1998 to 2018 (based on Kenyan government bond rates and inflation rates). The annualized Social IRR for earnings gains is 40.7% and for consumption gains is 36.7%. Assuming a discount rate of 10%, the net present value (NPV) from observed earnings gains is USD PPP 230.71, and for consumption gains is USD PPP 467.90.