Twenty-year economic impacts of deworming

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Estimating the impact of child health investments on adult living standards entails multiple methodological challenges, including the lack of experimental variation in health status, an inability to track individuals over time, and accurately measuring living standards and productivity in low-income settings. This study exploits a randomized school health intervention that provided deworming treatment to Kenyan children, and uses longitudinal data to estimate impacts on economic outcomes up to 20 y later. The effective respondent tracking rate was 84%. Individuals who received two to three additional years of childhood deworming experienced a 14% gain in consumption expenditures and 13% increase in hourly earnings. There are also shifts in sectors of residence and employment: treatment group individuals are 9% more likely to live in urban areas, and experience a 9% increase in nonagricultural work hours. Most effects are concentrated among males and older individuals. The observed consumption and earnings benefits, 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.

deworming | child health | long-run impacts | Kenya

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 (1, 2), 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.*

This study contributes 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 y to 3 y of additional deworming relative to the 25 control group schools. Second, we estimate impacts on individual living standards up to 20 y later, using data from the Kenya Life Panel Survey (KLPS), which we designed to follow a representative sample of PSDP participants (5). Specifically, we use 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-y follow-up (round 4, 2017–2019), the effective respondent survey rate was 84% among those still alive, with rates balanced across treatment arms; rates were similarly high in the 10-y (round 2, 2007–2009) and 15-y (round 3, 2011–2014) 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.

As background, intestinal helminth infections are widespread, infecting one in five people worldwide (6), and have adverse health and nutritional consequences for children, including stunted growth, weakness, and anemia (7–11). The infections also may have broader immunological effects, for instance, by making individuals more prone to other infections such as malaria (12, 13) and altering the gut microbiome (14, 15); worm infections in pregnant mothers may also reduce child birth weight (16). 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% (17, 18). 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 (19). The appropriateness of this recommendation has been actively debated following a survey article that claimed few population-wide child gains from mass treatment (20). However, a recent metaanalysis incorporating more studies finds larger positive and significant impacts on child weight, height, and mid upper arm circumference (21). There is little evidence regarding long-run

Significance

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 developing countries. This study contributes evidence that addresses leading methodological concerns, by using variation in child health via a randomized health intervention that provided deworming treatment to Kenyan children. We estimate impacts on individual living standards up to 20 y later among a representative sample of participants, and find those in the deworming treatment group experience meaningful gains in adult living standards and earnings, and shifts in sectors of residence and employment.

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Competing interest statement: M.K. works with US Agency for International Development, which supports deworming, and was formerly a board member of Deworm the World, a 501(c)3 organization.

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*A notable exception is the 35-y follow-up (3) of the four villages in the Guatemala Instituto de Nutrición de Centro América y Panamá nutritional intervention for pregnant women and young children (63% respondent tracking rate). Ref. 4 finds few studies of development interventions with more than a 7-y follow-up.

economic impacts, with the exception of ref. 22, which finds that deworming in the US South in the early 20th century led to higher adult educational attainment and income. (See ref. 23 for a critique of ref. 22 that reaches different conclusions.)

Several studies analyze the PSDP experiment. Ref. 24 finds improvements in child school participation in treatment schools over the first 2 y of the program, with absenteeism falling by one-quarter. They also estimate sizable 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.[†] Ref. 30 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 10 y later, equivalent to 0.5 y of schooling on average. The current study most directly builds on ref. 31, which documented deworming impacts 10 y later, including improved self-reported health, educational attainment (by 0.3 y on average), test scores, and secondary schooling attainment (concentrated among females), as well as higher incomes among wage earners (20% gains), and more meals eaten, hours worked, and manufacturing employment (concentrated among males).

Ref. 31 was subject to several limitations that the current study was designed to address. First, because many respondents were still in school at the 10-y 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 were not available for that round, leading to a reliance on a proxy (meals eaten). The current paper makes several contributions. The analysis uses two additional survey rounds to estimate impacts at 15 y and 20 y after deworming treatment—an unusually long timeframe for experimental studies (4)—when most respondents were between 29 y and 35 y old, allowing us to estimate impacts during individuals' prime working years. The measurement of economic outcomes was also improved: KLPS round 4 (KLPS-4) incorporates a detailed consumption expenditure questionnaire (modeled on the World Bank Living Standards Measurement Survey; see ref. 32) for all respondents, and round 3 collected this for a representative subsample. Both KLPS-3 and KLPS-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.

Data and Estimation Strategy

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 3 y), 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 ref. 33, who argue that child health gains in low-income, "brawn-based" economies may translate into greater labor market gains for males.

In 1998, a nongovernmental 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 (24). (Rates this high are also found in some other African settings.) 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 subunit (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 refs. 24 and 31 and *SI Appendix*, Fig. S1 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 ref. 31. Drug take-up rates were high, at approximately 75% in the treatment group, and under 5% in the control group (24).

The KLPS was launched in 2003 to track a representative sample of approximately 7,500 respondents enrolled in grades 2 to 7 in the PSDP schools at baseline, where the KLPS subsample was selected using a computer random number generator. 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 (*SI Appendix*, Fig. S2). 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 (*SI Appendix*, Table S1).[‡] In KLPS-4, 87% were found and 83.9% surveyed among those still alive (*SI Appendix*, Table S1, KLPS-4 E+ module, column 1). Rates are similar and not statistically significantly different across the treatment and control groups, and the same holds by gender (*SI Appendix*, Table S1, columns 4 to 6) and among those above and below median age (specifically, baseline age 12 y; *SI Appendix*, Table S2). Notably, rates are similarly high and balanced in earlier rounds.[§] In all, 86% of the KLPS sample was surveyed at least once during the 10-, 15-, or 20-y 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% (*SI Appendix*, Fig. S1); group 3 schools received free deworming treatment in 2001. In 2002–2003, the NGO again provided free deworming in all 75 schools (36). We estimate the effect of this temporary reduction in deworming on later

[†]For discussions of the original school participation cross-school externalities estimates, see refs. 25–29; the current analysis employs a new dataset.

[‡]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 US Moving To Opportunity study (34, 35), and ref. 31.

[§]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 (76.0%, *SI Appendix*, Table S1, KLPS-3 E Module), although rates are balanced across treatment arms. The survey rate among those still alive in KLPS-2 is 83.9% (*SI Appendix*, Table S1, KLPS-2).

outcomes. Second, in early 2009, approximately 1,500 individuals in the KLPS sample additionally took part in a vocational training voucher randomized control trial (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.[¶] The randomly assigned voucher and cash control group (nonrecipient) individuals are retained throughout, and given greater weight in the econometric analysis, to maintain the representativeness of the original PSDP sample.

Estimation Strategy. The analytical approach builds on ref. 31 and follows our preanalysis plan (PAP) (37). 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 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 (24), complicating estimation of treatment effects on the treated within schools.

The analysis focuses on two main approaches, namely, 1) pooled regressions that use data from KLPS-2, KLPS-3, and KLPS-4 to estimate the overall long-run deworming effects 10 y to 20 y after treatment and 2) regressions using only KLPS-4, the longest-term follow-up. These two approaches, as well as the main outcome measures, were prespecified in ref. 37 prior to conducting any analyses on the KLPS-4 data. The first approach has the advantage of using 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 our focus here, with the KLPS-4 only results presented in *SI Appendix*.

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

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

The outcome is a function of $T_j \in \{0, 1\}$, the assigned deworming program treatment status of the individual's school. The prespecified 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 ref. 31.[#]

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, *SI Appendix*, section 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. Ref. 31 analyzed interactions between treatment and local saturation, and nonlinearities 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.[‖]

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

Main Results

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

Impacts on Living Standards. All KLPS-4 (20-y follow-up) respondents and a representative subset of one-sixth of KLPS-3 (15-y) 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 purchasing power parity terms (PPP, which accounts for price differences across countries), and trim the top 1% of observations (as prespecified) to reduce the influence of outliers. We present real values below that account for urban–rural price differences, based on regular

[¶]Specifically, vocational training voucher winners are dropped from both KLPS-3 and KLPS-4 analysis, and cash grant winners are dropped from KLPS-4; those interventions are studied in separate work. The results below are robust to including these voucher and grant winners in the analysis; see *SI Appendix*, Tables S5 and S6.

[#]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.

[‖]Note that the bound proven in ref. 31 is still valid, albeit looser, if the geographic spread 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 km by 40 km can definitively be considered a "pure control," making meaningful long-run cross-school spillover effects less likely.

[**]Ref. 31 shows that those older than 12 y at baseline experienced larger gains in terms of hours worked, meals eaten, and nonagricultural earnings, a finding they attribute to the fact that these individuals—who were at least 22 y old 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 less than 2% of the sample was still enrolled in school then. We show that there remain meaningful cohort differences in treatment effects in KLPS-3 and KLPS-4, and discuss explanations below.

[††]Ref. 38 prespecifies other outcome domains that are the subject of ongoing data collection, for example, health, marriage, and fertility, and will be the focus of future research.

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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 and 20 y after treatment: Pooling KLPS-3 and KLPS-4, the estimated effect is USD PPP 305 (SE 159, P value < 0.10), a 14% increase relative to the control mean of USD PPP 2156 (Table 1, A: annual per capita consumption, column 1). A shift to the right in the distribution of consumption is visually apparent (Fig. 1*A*). Estimated effects by round are presented in *SI Appendix*, Fig. S3*A*. In the 20 y data, treatment group individuals report a 10% increase in consumption (USD PPP 199, SE 130; *SI Appendix*, Table S3, column 1). We find positive point estimates on subcategories, including both food and nonfood consumption (see ref. 39).

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 (Table 1, A: annual per capita consumption, columns 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. Gender differences in reporting or household structure could also potentially contribute to these gaps. Consumption effects are also far larger for older individuals (those older than 12 y at baseline, who were typically 32 y to 36 y old by KLPS-4), at USD PPP 886 (Table 1, column 4, P value < 0.01), an effect that remains significant at traditional levels accounting for the false discovery rate (FDR) adjustment (40).[‡‡] Note that average living standards (in the control group) are considerably higher for younger than older individuals (Table 1, column 5), which likely at least partially reflects rapidly rising schooling levels in western Kenya in the years following the launch of the PSDP (*SI Appendix*, Table S10, education and labor market outcomes summary statistics).

Impacts on Earnings and Other Labor Outcomes. The second prespecified main outcome measure, total individual earnings, includes the sum of earnings in the past year in wage employment (across all jobs), nonagricultural 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-y follow-up rounds, individual earnings are USD PPP 80 (SE 76) higher in the deworming treatment group (Table 1, B: annual individual earnings, column 1). This estimate corresponds to a 6.5% increase in earnings. The estimated treatment effect is quite stable across KLPS-2 (USD PPP 87), KLPS-3 (USD PPP 83), and KLPS-4 (USD PPP 85; see *SI Appendix*, Fig. S3), 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 CI surrounding estimates from KLPS-2 through KLPS-4 also appears 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; Table 1, B: annual individual earnings, columns 2 and 3), although this difference is also not significant. Average individual earnings are nearly 3 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 sizable deworming effect on total household earnings per capita (only collected in KLPS-4), at USD PPP 239 (P value < 0.10, Table 1, C: annual per capita household earnings, column 1), and this effect is reassuringly similar in magnitude to the estimated impact on total household consumption per capita in KLPS-4 (USD PPP 199; *SI Appendix*, Table S3). Total household earnings gains are again concentrated among males (USD PPP 439, P value < 0.10, Table 1, column 3) and older individuals (USD PPP 565, P value < 0.05, column 4).[§§]

There are meaningful changes in other labor market outcomes. Log annual earnings increase by nine log points among those with nonzero earnings, and the likelihood that individuals have nonzero earnings rises by two percentage points (P value < 0.10; Table 2, A: earnings and wealth, column 1). Gains in both wage earnings and self-employed profits appear to be contributing to the overall effect, and individual earnings per hour also increase, by USD PPP 0.14 (P value < 0.10), or 13%. Patterns are similar in the KLPS-4 data (*SI Appendix*, Table S4). 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 (Table 2, columns 2 and 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 h, SE 0.66, Table 2, B: labor supply, occupation, and sectoral choice, column 1), there is a significant increase in hours worked in nonagricultural employment (1.91 h, P value < 0.01), concentrated among males (2.77 h, P value < 0.01, column 2) and older individuals (2.24 h, P value < 0.05, column 3). Some of this shift is likely related to the substantial increase in urban residence, which rises by four percentage points on a base of 45% (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. (Urban residence was included as an outcome in the later (38) PAP, as we collect a more detailed migration history as part of ongoing survey modules relative to the data used in this paper.) In

[‡‡] Following the PAP, the FDR adjustment in Table 1, column 1 is carried out across the two λ_1 coefficient estimates from A: annual per capita consumption and B: annual individual earnings in column 1. The FDR adjustment in Table 1, columns 2 and 3 are carried out across the four λ_1 estimates from A: annual per capita consumption and B: annual individual earnings in columns 2 and 3. Similarly, the FDR adjustment in Table 1, columns 4 and 5 are carried out across the four λ_1 estimates from A: annual per capita consumption and B: annual individual earnings of those columns.

[§§] The FDR adjustment is not presented in Table 1, C: annual per capita household earnings since the total household earnings measure was not one of the two prespecified primary outcomes. If the FDR adjustment is carried out across the six λ_1 coefficient estimates in Table 1, columns 4 and 5 across the three outcomes, all three estimates for the older subgroup are significant with q value < 0.05.

Table 1. The 10- to 20-y deworming treatment effects on consumption and earnings, KLPS-2, KLPS-3, and KLPS-4

	(1) Full sample	(2) Female	(3) Male	(4) Older	(5) Younger
A: Annual per capita consumption (KLPS-3 and KLPS-4)					
Treatment (λ_1)	305*	89	513*	886***	−179
	(159)	(134)	(304)	(223)	(185)
Control mean	2,156	1,715	2,594	1,908	2,381
Treatment effect (%)	14.15	5.21	19.76	46.44	−7.52
Treatment *P* value	0.058	0.505	0.096	0.000	0.337
FDR q value	0.132	0.630	0.623	0.001	0.290
Number observations	4,794	2,473	2,321	2,402	2,341
B: Annual individual earnings (KLPS-2, KLPS-3, and KLPS-4)					
Treatment (λ_1)	80	41	118	258**	−75
	(76)	(62)	(133)	(108)	(100)
Control mean	1,218	674	1,728	1,177	1,242
Treatment effect (%)	6.53	6.02	6.84	21.93	−6.07
Treatment *P* value	0.297	0.515	0.376	0.019	0.451
FDR q value	0.175	0.630	0.630	0.030	0.292
Number of observations	13,624	6,826	6,798	6,791	6,780
C: Annual per capita household earnings (KLPS-4)					
Treatment (λ_1)	239*	36	439*	565**	−22
	(129)	(107)	(252)	(232)	(171)
Control mean	1,296	973	1,623	1,082	1,501
Treatment effect (%)	18.44	3.68	27.06	52.17	−1.48
Treatment *P* value	0.069	0.738	0.086	0.017	0.897
Number of observations	4,074	2,099	1,975	2,039	1,982

Annual per capita consumption is 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 mo, divided by the number of household members. The consumption/expenditure module was administered to a subset of the sample during KLPS-3 and the full sample during KLPS-4. Consumption is adjusted for urban–rural price differences for respondents living in Nairobi and Mombasa. Annual individual earnings are calculated as the sum of wage employment across all jobs; nonagricultural self-employment profit across all business; and individual farming profit, defined as net profit generated from noncrop and crop farming activities for which the respondent provided all reported household labor hours and was the main decision maker within the last 12 mo. Wage earnings and self-employment profits were collected in KLPS-2, KLPS-3, and KLPS-4; agricultural profits were collected in KLPS-3 and KLPS-4. Annual per capita household earnings are 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 one for PSDP worm groups 1 and 2, which received an additional 2.4 y of deworming, on average, compared to group 3. Columns 2 through 5 report estimates separately by gender and age at baseline (older than 12 y, 12 y 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 y at baseline and analogous interaction terms to columns 2 and 3. The 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 annual per capita consumption and annual individual earnings of column 1. The FDR adjustment in columns 2 and 3 are carried out across the four λ_1 coefficient estimates from annual per capita consumption and annual individual earnings 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 annual per capita consumption and annual individual earnings of columns 4 and 5. Covariates follow ref. 31 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 examinations, total primary school pupils within 6 km, and a cost-sharing school indicator. Those treated in a separate vocational training intervention (Technical and Vocational Vouchers Program, VocEd) which occurred prior to KLPS-3 are dropped from the KLPS-3 and KLPS-4 samples. Those treated in a separate small grant intervention (Start-up Capital for Youth, 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. * denotes significance at 10%, ** denotes significance at 5%, and *** denotes significance at 1%.

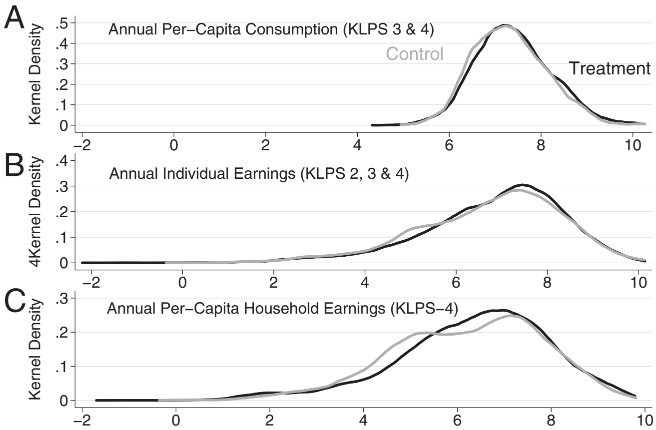

Fig. 1. Kernel densities of (log) consumption and earnings, KLPS-2, KLPS-3, and KLPS-4. This figure plots the smoothed (Epanechnikov) kernel densities of (*A*) log per capita annual per capita consumption, (*B*) log annual individual earnings, and (*C*) log annual per capita household earnings of the full sample (2017 USD PPP, top 1% trimmed). See Table 1 for additional details on outcome construction. Household earnings are only available in KLPS-4. The gray line represents the control group, and the black line represents the treatment group. Observations are weighted to be representative of the original PSDP sample, and account for KLPS population weights, SCY and VocEd control group weights, and KLPS intensive tracking weights.

contrast to ref. 31, 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 KLPS-2, KLPS-3, and KLPS-4 (Table 2, B: labor supply, occupation, and sectoral choice) or KLPS-4 alone (*SI Appendix*, Table S4).

Heterogeneous Effects and Mechanisms. The concentration of deworming effects among males and those older than 12 y 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 (ref. 31 and *SI Appendix*, Table S11, education and labor market outcomes). 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 (41). 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 nonagricultural labor force is far lower (*SI Appendix*, Table S10, education and labor market outcomes summary statistics).

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 (*SI Appendix*, Table S10, baseline summary statistics). 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 reflecting the rapid increase in schooling over the decade following the start of PSDP (*SI Appendix*, Table S10, education and labor market outcomes summary statistics), but the deworming effect for the older group is +0.45 y of schooling (SE 0.18, P value < 0.05; *SI Appendix*, Table S11, education and labor market outcomes), while, for younger individuals, it is closer to zero (+0.04 y). 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-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; *SI Appendix*, Table S11), 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 (*SI Appendix*, Table S10), the distributions are different, and, in particular, the average years of assigned treatment in the control group is far higher among younger individuals (*SI Appendix*, Table S11), as many older control group students graduate from (or leave) primary school before receiving any deworming (*SI Appendix*, Fig. S4 *A* and *B*). 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 y (*SI Appendix*, Fig. S4*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 *SI Appendix*, section 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 (*SI Appendix*, Tables S10 and S11). Nor did ref. 31 estimate significant differences in impacts as a function of baseline local area infection levels, although this latter analysis is somewhat statistically underpowered. 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 (*SI Appendix*, Table S9). 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 (*SI Appendix*, Table S8).

Rate of Return and Fiscal Impacts of Deworming

Here we present deworming cost-effectiveness estimates (see *SI Appendix*, section 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 (31), and economic gains measured via consumption or earnings. Fig. 2 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 (31) by recent Kenyan teacher salary figures (42, 43). On the benefit side, we use λ_{1t} estimates for consumption and earnings generated from our pooled specification across KLPS-2, KLPS-3, and KLPS-4. For earnings, we assume these gains start 10 y after deworming treatment, roughly coinciding with entry into adulthood and KLPS-2. Since we do not have consumption data until KLPS-3, we conservatively assume that the average estimated effect from KLPS-3 and KLPS-4 only pertains during the period from 15 y to 25 y after treatment. We also make the conservative assumption, presented graphically in Fig. 2, that effects last for 5 y, roughly

Table 2. The 10- to 20-y deworming treatment effects on earnings, labor supply, occupation, and sectoral choice, KLPS-2, KLPS-3, and KLPS-4

	Treatment (λ_1)			Full sample	
	(1) Full sample	(2) Male	(3) Older	(4) Control mean	(5) Number of obs.
A: Earnings and wealth					
Log annual individual earnings	0.09	0.06	0.19**	6.73	7,698
	(0.06)	(0.07)	(0.08)		
Wage earnings (annual)	81	138	162*	887	13,628
	(68)	(110)	(89)		
Self-employment profit (annual)	41*	51	70*	212	13,638
	(24)	(48)	(39)		
Individiual farming profit (annual)	−0	1	−3	9	13,707
	(2)	(3)	(3)		
Nonzero earnings	0.02*	0.04**	0.02	0.59	13,794
	(0.01)	(0.02)	(0.02)		
Hourly earnings	0.14*	0.22	0.32*	1.07	6,096
	(0.08)	(0.15)	(0.16)		
Per capita household wealth (KLPS-4)	69	102	253***	522	4,085
	(50)	(97)	(89)		
B: Labor supply, occupation, and sectoral choice					
Urban residence	0.04**	0.06**	0.03	0.45	13,793
	(0.02)	(0.03)	(0.03)		
Total hours worked (last 7 d)	1.04	2.20**	1.79**	24.19	13,807
	(0.66)	(0.92)	(0.91)		
Hours worked—agriculture (last 7 d)	−0.87**	−0.57	−0.46	3.99	13,807
	(0.43)	(0.62)	(0.56)		
Hours worked—nonagriculture (last 7 d)	1.91***	2.77***	2.24**	20.20	13,807
	(0.65)	(0.94)	(1.08)		
Employed—agriculture/fishing	-0.003	−0.001	0.004	0.043	13,768
	(0.008)	(0.013)	(0.012)		
Employed—services/wholesale/retail	0.002	0.012	−0.002	0.230	13,761
	(0.014)	(0.020)	(0.019)		
Employed—construction/trade contractor	0.004	0.011	−0.007	0.033	13,760
	(0.007)	(0.014)	(0.009)		
Employed—manufacturing	−0.001	0.002	0.002	0.026	13,760
	(0.004)	(0.007)	(0.006)		

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 Eq. **1**) for the full sample, while columns 2 and 3 report estimated treatment effects for males and those older than 12 y at baseline, respectively. Columns 4 and 5 report the full sample control mean and number of observations for each outcome, respectively. Variables in earnings and wealth are converted to 2017 USD at PPP and trimmed at the top 1%. Log annual individual earnings are based on annual individual earnings from Table 1. Wage earnings, self-employment profits, and farming profits are annual amounts. Hourly earnings are 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 nonrural area, which includes both towns and cities. Hours worked variables are based on the total hours worked within the last 7 d; 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 h per week. Employed variables are indicator variables coded as "1" for those with wage employment in a given sector. See the PAP report (39) 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. * denotes significance at 10%, ** denotes significance at 5%, and *** denotes significance at 1%. obs., observations.

the time between survey rounds, and fall to zero 5 y after KLPS-4 (at $t = 25$).[¶¶]

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), which can be intuitively thought of as the annual rate of growth that an investment generates. An IRR larger than the real interest rate of 10% would indicate that

[¶¶]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 (30).

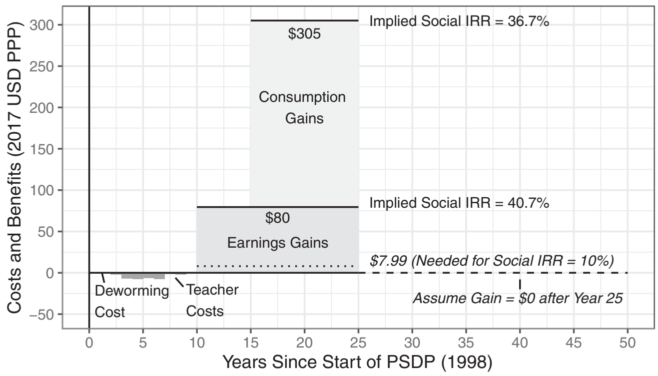

Fig. 2. Deworming costs, benefits, and rate of return. This figure presents the costs and benefits of deworming over time, and calculated social IRR. Costs and benefits in the figure are reported in 2017 USD PPP terms. For additional details and alternative assumptions, see *SI Appendix*, Table S12 and section D. 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 ref. 31. We calculate teacher costs as average educational gains per student per year as a result of deworming (from ref. 31) 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 refs. 42 and 43 of and a pupil–teacher ratio of 45, as in ref. 31). On average, from 1999 to 2007, students attended school for an additional 0.15 y. We assume no earnings gains in the first 10 y after receiving deworming medication. We use the estimate of treatment effects for annual individual earnings measured 10, 15, and 20 y after the start of deworming and pooled across rounds (λ_{1t} from Table 1, annual individual earnings). We assume no per capita consumption gains in the first 15 y after receiving deworming medication. As for earnings, we use the estimate of annual per capita consumption expenditures measured 15 and 20 y after the start of deworming and pooled across rounds from Table 1, annual per capita consumption. For both earnings and per capita consumption, we assume zero gains after the last observed 5-y period (25 y after receiving treatment). 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 NPV from observed earnings gains is USD PPP 230.71, and, for consumption gains, is USD PPP 467.90.

deworming is likely to be a cost-effective policy in Kenya. The dotted horizontal line in Fig. 2 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 (Fig. 2 and *SI Appendix*, Table S12), and are also far larger than the gains needed to attain a fiscal IRR of 10% (USD PPP 29.12 and 48.21, respectively; *SI Appendix*, Table S12). 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 y, the social NPV is USD PPP 230.71, and the fiscal NPV is USD PPP 16.74 (*SI Appendix*, Table S12, NPV). 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 (*SI Appendix*, Table S12, IRR). If we focus on consumption and consider gains out to 25 y, the social and fiscal IRR estimates are 36.7% and 19.6%, respectively. The results imply that even quite limited earnings or consumption gains far smaller than those observed in KLPS could justify subsidies for mass deworming given its very low cost.

Discussion

This study provides 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, nonagricultural employment, and urban residence. These findings add to growing evidence that the PSDP had meaningful positive effects on recipients (24, 31). Even ignoring spillovers and making other conservative assumptions, the social rate of return appears to be very high. Notable strengths of the study include the 84% effective respondent follow-up rate after 20 y, and the use of a PAP for the most recent round of survey data.

The study has several limitations. The main full sample treatment effect estimates for the primary outcomes are not statistically significant at conventional levels, although some estimated effects are significant at such levels among the demographic subgroups mentioned in the PAP. The original experiment was carried out as a stratified list randomization rather than using a computer random number generator; see refs. 24 and 31 for details.

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 US South (44). 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 and flooding 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 intensity and timing of the El Niño event may also have contributed to the heterogeneity of impacts across demographic subgroups that we document.

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.[##] 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 (1). 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 (45). Our findings indicate that even health programs focused on school-age children can yield substantial benefits, consistent with recent US findings (2).

[##] 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.

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 intergenerational benefits would further bolster deworming's cost effectiveness.

Data Availability. Anonymized survey data and code have been deposited in Harvard Dataverse (https://dataverse.harvard.edu/dataverse/KLPS).

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