Worms at Work: Long-run Impacts of Child Health Gains*

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We use data from a survey of young Kenyan adults who participated in a deworming program as children to calibrate a version of the Grossman (1972) model, in which investments in health increase future endowments of healthy time. Mean hours worked increase by 12% in the treatment group, or 1.8 more hours each week on a base of 15.2. There is also evidence that deworming generated positive externalities in work hours.. Furthermore, both the direct and externality effects are even larger in our preferred subsample analysis on out-of-school youth. Gains are concentrated outside of traditional agriculture, among small business owners and those working for wages. Among wage earners no longer in school, the treatment group earned over 20% more, with manufacturing employment tripling. These results suggest health improvements may increase labor supply and facilitate structural transformation. A calibration of the model combining data on the impacts of deworming and the price responsiveness of deworming take-up suggests that fully subsidizing deworming yields greater welfare than partial subsidies or laissez-faire. From the point of view of a public policymaker, deworming also appears to pay for itself by generating more in future government revenue than it costs.

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1. Introduction

We use data on the impact of child deworming on adult outcomes to calibrate a model of health investment along the lines of Grossman (1972), in which health investments expand future endowments of healthy time. Taking advantage of a field experiment, Miguel and Kremer (2004) found that children who were dewormed are healthier and spend substantially more time in school. We follow participants a decade later, when most were 19 to 26 years old. In the full sample, self-reported health improves and mean hours worked increase by 12% in the treatment group, or 1.8 more hours each week on a base of 15.2. Among those no longer enrolled in school, deworming improves self-reported health and increases mean hours worked by 17% on a base of 18.5 hours per week. Living standards improve as well, with treatment respondents eating one-tenth of a meal more per day. Both effects are found not only in the treatment group, but among their neighbors, consistent with substantial positive externalities from reduced disease transmission. The analysis is based on a new longitudinal data set with an effective tracking survey rate of 84% over roughly ten years.

A calibration of the model combining these results with estimates of the responsiveness of deworming drug take-up to price from Kremer and Miguel (2007) suggest that full subsidies for deworming generate greater social welfare than either zero or partial subsidies over a wide range of plausible estimates of the deadweight loss of taxation. From the point of view of a public policymaker, our estimates indicate that deworming pays for itself by generating more in future government revenue than it costs, a striking measure of cost-effectiveness.

We find differential impacts across economic sectors. Among those engaged only in agriculture, there is a small increase in hours worked, consistent with theories in which the marginal product of labor in traditional agriculture is small (Lewis 1954). There is suggestive evidence of modest increases in the use of improved agricultural practices (e.g., fertilizer) and a shift to cash crops. In contrast, among those working for wages or operating small businesses, average work hours increase by nearly five hours in the treatment group, on a base of 45 hours. Earnings increase among out-of-school wage workers by more than 20%, and although estimates are imprecise, point estimates suggest higher profits for owners of small non-agricultural businesses. Work days lost to illness fall by a third among wage earners. Treatment group members are three times more likely to work in manufacturing (albeit on a relatively low base), and less likely to do casual labor or work in domestic service, consistent with the hypotheses that the physical ability to do regular, full-time work allows people to get better jobs.[1] Manufacturing jobs are among the most demanding in our dataset, with long average work weeks. In an Oaxaca-style decomposition, these shifts in employment occupation account for much of the earnings gains in the treatment group.

We cannot distinguish the extent to which we are observing the direct impact of health as opposed to the indirect impact of health through endogenous changes in education (or other behaviors and attitudes). There is some evidence that, among those currently out of school, test scores rose and students were more likely to have graduated from primary school.

The increase in work hours we document helps shed light on the determinants of labor supply, an understudied issue in development economics. While there is considerable discussion about how work hours in wealthy countries differ with tax rates or labor market institutions (Prescott 2004, Costa 2000), differences in labor hours associated with economic development across space and time have been less studied, despite the fact that they are often larger than differences across wealthy countries.

Many historians see a move to a work life governed by long, regular hours and factory discipline as an important aspect of the industrial revolution (Clark 1994). While factory workers in less developed countries put in long work days,[2] work hours are low in some rural low-income contexts. For example, in Sahelian Burkina Faso Fafchamps (1993) finds that people only work an

[1] Our finding that the respondents who received health investments as children work significantly more hours as adults echoes existing evidence on the link between disease and work absenteeism in other African settings (Schultz and Tansel 1997), and is consistent with other work that finds that moderate increases in morbidity affect labor supply (Ichino and Moretti 2009, Hanna and Oliva 2011).

[2] http://www.nytimes.com/2008/01/05/business/worldbusiness/05sweatshop.html

average of two to three hours per day on their farms. One classic explanation for low work hours is that the marginal productivity of additional labor in agriculture is low (Lewis 1954). Indeed, Fafchamps (1993) argues that the low levels of labor supply he observed among peasant farmers are due to low marginal products of labor in the traditional rain-fed agricultural sector, with farmers in rainy areas working nearly twice as many hours as those in drier and less productive areas. Others have advanced cultural theories. Colonial observers advanced racial or ethnic theories of Africans' "laziness", love of leisure and lack of ambition (see Abudu 1986 for a discussion of colonial accounts in Africa). A growing body of work in labor economics emphasizes cultural (though not racial) differences across groups as key drivers of labor supply decisions (Fernandez and Fogli 2009). Finally, some have advanced efficiency wage accounts in which low incomes limit investments in nutrition and health, and this in turn constrains labor supply (Dasgupta and Ray 1986).

The results also contribute to the debate on government subsidies for prevention of infectious disease. While some child public health investments, such as immunization, are routinely provided for free by governments, others – such as deworming or water treatment – are not. There has been a lively debate over subsidies, with evidence accumulating that many people who will utilize these measures when they are free will not pay to use them (Kremer and Miguel 2007, Kremer and Holla 2009, Cohen and Dupas 2010, Ashraf, Berry and Shapiro 2010, Dupas 2011, Kremer, Snyder and Williams 2011). However, to determine whether public investments are worthwhile, it is essential to understand both the direct and externality impact of these investments.

Advocates of public health spending in low-income countries often argue that, even setting aside the immediate utility benefits of improved health, such programs have high rates of return as investments because of their impact on adult living standards.[3] Yet assessing the long-run causal

[3] The INCAP experiment in Guatemala (Hodinott *et al.* 2008, Maluccio *et al.* 2009, Behrman *et al.* 2009) provided nutritional supplementation to two villages while two others served as a control, and finds gains in male wages of one third, improved cognitive skills among both men and women, and positive intergenerational effects on the nutrition of beneficiaries' children. Beyond the small sample size, a limitation of these studies is their 40% attrition

impacts of public health measures has been problematic given the relative lack of both panel data sets tracking children into adulthood, and convincing causal identification from experimental variation. Many existing studies track production within a firm, examining the impact of contemporaneous health on plantation workers' productivity (e.g., Fox et al. 2004). Our evidence suggests this approach misses important gains, in particular on how health investments may lead to shifts across employment occupations and sectors.

While many studies argue that early childhood health gains *in utero* or before age three have the largest impacts (World Bank 2006, Hodinott *et al.* 2008, and Almond and Currie 2010 are but a few examples), our findings show that even health investments made in school-age children can have important effects. These gains do not appear to be mediated by improved cognitive ability alone but rather also by increased healthy hours, both at school and at work, with their potential impact on learning as well as non-cognitive outcomes.

Finally, our results also contribute to the debate over the nature of labor markets in less developed countries. Many have argued that they are largely inflexible, consisting of a formal sector with institutionally determined wages in which jobs are rationed (and allocated through a mix of personal connections and credentialism), as well as a large informal sector with queuing for formal sector jobs (Harris and Todaro 1970). In such a model, an increase in individual human capital or labor supply would not necessarily translate into better employment outcomes. Our finding that an investment in human capital leads to a tripling of manufacturing employment suggests that labor markets (outside of agriculture) are better able to recognize and reward individual productivity differences than is commonly imagined. The finding of much larger gains in work hours in wage

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rate over the 35 years of follow-up. Other studies have studied long-run economic impacts of child health, including effects of war-induced famine in Zimbabwe (Alderman *et al.,* 2006a) and economic shocks driven by rainfall variation in Indonesia (Maccini and Yang, 2009). Other noteworthy micro-empirical contributions on nutrition, health and productivity include Glewwe *et al.* (2001), Alderman *et al.* (2003), Schultz (2005), Jukes et al. (2006), Alderman (2007), Thomas *et al.* (2008), and Pitt, Rosenzweig and Hassan (2011). Related U.S. work includes Currie et al. (2002), Currie (2009), Smith (2009), and Case and Paxson (2010).

employment and non-agricultural small business than in traditional agricultural work is consistent with the hypothesis that land and labor markets in agriculture remain highly imperfect, but that resources are allocated more efficiently between manufacturing and other non-agricultural work.

The rest of the paper is organized as follows. Section 2 presents a simple model of health as human capital investment related to Grossman (1972). Section 3 discusses the Kenyan context, the deworming project, and the survey. Section 4 lays out the estimation strategy and describes the impacts of deworming on health, education, and labor market outcomes. Section 5 uses the data on price responsiveness and deworming impacts to calibrate the model, and finds that full subsidies for deworming yield greater welfare than partial or no subsidies. The final section concludes, discussing external validity and implications for research and policy.

2. A model of health investment with spillovers

In section 2.1 we first describe a framework related to Grossman's (1972) model of health capital, and in 2.2 discuss the relationship between health investments, endowment of healthy time, and work hours, as well as optimal health subsidies in the presence of externalities, and the possibility that the health investment boosts labor supply and possibly future government revenue. In 2.3 we extend the model to consider a traditional rural economic sectors characterized by land and labor market imperfections, and characterize patterns of mobility across sectors.

2.1 Health investment, work hours and deworming subsidies

In the classic Grossman (1972) model, better health status increases "the total amount of time [one] can spend producing money earnings and commodities" (p. 224). We consider a variant of this model in which health investments may lead to increased endowments of healthy time not just for the individual but also for neighbors through an epidemiological externality, and discuss how optimal subsidies depend on the externality and direct benefit of the health investment, the responsiveness of health behavior to price, and the deadweight loss of taxation. We will then calibrate the model to derive welfare implications using the empirical estimates from the rest of the paper

Suppose there are N individuals in an area, and in each period t, people can spend their time working (L_{it}) for income $Y(L_{it})$, or in leisure l_{it}. Income can be spent on a consumption good, with the amount of consumption denoted c_{it}. In the initial period (denoted period 0) people can also purchase deworming medicine. There is no saving or borrowing. Deworming involves paying a price p for a competitively-provided drug and incurring a one-time disutility. $d_i \sim F$. Let $F(d)$ denote the fraction of individuals with disutility less than or equal to d.

Deworming increases an individual's healthy time endowment by x in future periods. It also creates a positive externality (spillover) for everyone nearby, increasing their time endowment by x_S. Each individual's endowment of healthy time in period t is $E_{it} = 1 + xD_i + x_S N^T$, where N^T is the number of other individuals who have taken deworming medicine, 1 is the time endowment if everyone else was untreated, and D_i is an indicator variable for having been previously dewormed. People are infinitely lived and maximize the discounted sum of utility using discount rate δ. We will also consider the case where wages depend on deworming decisions, $w_i = 1 + \pi D_i + \pi_S N^T$, where π is the gain from deworming oneself and π_S is the externality benefit, to show that the comparative statics are similar to where wages are independent of deworming, though to be conservative we often ignore any wage gains in the calibration.

Each individual i has Cobb-Douglas preferences over consumption and leisure at time t,

(1) $$U_{it}(c,l) = (Y(L_{it}) - pD_{it})^{\alpha}(E_{it} - L_{it})^{1-\alpha} - d_i D_{it}.$$

Individuals maximize the value function:

(2) $$V_{it}(c,l) = \sum_{z=t}^{\infty} \delta^{z-t}((Y(L_{iz}) - pD_{iz})^{\alpha}(E_{iz} - L_{iz})^{1-\alpha} - d_i D_{iz}).$$

There are two production sectors, traditional agriculture (a) and other sectors outside of traditional agriculture (o). Production for individual i in each sector j in period t is Cobb-Douglas:

$A_j K_{ij}{}^{\beta_i} L_{it}^{1-\beta_i}$. Outside of agriculture, capital is available at an international interest rate r. In traditional agriculture, we assume there are no land and labor markets, but people have an endowment of land K_{ia} which they can use if they choose to work in agriculture.

We first consider a complete-market, non-agricultural setting. We then consider an agricultural setting without land and labor markets. Finally, we consider a setting in which everyone has the same endowments, talents, and access to jobs, but people have heterogeneous disutilities of moving out of agriculture into the non-agricultural sector, $m_i \sim G$ (with $G(m)$ representing the fraction of people with mobility disutility less than or equal to m), which are independent of the disutility from deworming, d_i.

2.2 Complete Markets Case

***Lemma 1*: For those who work outside traditional agriculture, the fraction of the time endowment spent working is α in every period after the initial period.[4]**

Note that this implies that if we observe that deworming increases work time by z hours, we can infer that deworming increases the endowment of healthy time by $\frac{1}{\alpha} z$ hours.

Since capital flows freely, individuals earn a wage $w = (A_o - r)\left(\frac{A_o}{r}\right)^{\frac{1}{1-\beta_o}}$, so for simplicity of notation we denote earnings as wL for labor outside of agriculture.

***Proposition 1:* If there are competitive capital markets, so $Y(L_t) = \mathrm{wL_t}$, then the proportion of the population that deworms at a given price of deworming medicine $\hat{p}$ is $F\Big(((\mathrm{w\alpha})^{\alpha}(1 - \alpha)1 - \alpha\delta 1 - \delta x - pw$.**

[4] To see this, note that for a given amount of labor, the optimal amount of capital (from the first-order condition) is $\mathrm{K} = \mathrm{L_{it}}\left(\frac{A_o}{\mathrm{r}}\right)^{\frac{1}{1-\beta_o}}$. Plugging back into utility and taking the derivative with respect to capital gives that $\mathrm{L_{it}} = \alpha \mathrm{E_{it}}$. □

Proof: Conditional on buying deworming medicine, agents choose L in the initial period (t = 0) to maximize $U_o = (wL_o - p)^{\alpha}(E_0 - L_0)^{1-\alpha}$. The FOC simplifies $(wL_0 - p)(1-\alpha) = \alpha w(E_0 - L_o)$, implying $L_t = \alpha E_t + \frac{p - \alpha p}{w}$. This implies that utility in the initial period conditional on taking deworming medicine is $(w\alpha E_o - \alpha p)^{\alpha}((1-\alpha)E_o - \frac{p-\alpha p}{w})^{1-\alpha} - d_i = (1 - \frac{p}{E_o W})(w\alpha E_o)^{\alpha}((1 - \alpha)E_o)^{1-\alpha} - d_i$, whereas the utility in the initial period conditional on not deworming is $(w\alpha E_o)^{\alpha}((1-\alpha)E_o)^{1-\alpha}$.Therefore, initial period utility for those who deworm is reduced by $p * \frac{(w\alpha)^{\alpha}((1-\alpha))^{1-\alpha}}{W} + d_i$.

After the initial period, deworming increases healthy time by x per period. Let $\underline{E_t}$ be the time endowment if someone has not taken deworming medicine. Utility conditional on deworming in each period after the initial period is therefore $\left(w\alpha\left(\underline{E_t} + x\right)\right)^{\alpha}((1-\alpha)\left(\underline{E_t} + x\right))^{1-\alpha}$

$$= (1 + \frac{x}{\underline{E_t}})\left(w\alpha\underline{E_t}\right)^{\alpha}(1-\alpha)\underline{E_t})^{1-\alpha}.$$

As a result, the per-period increase in utility from deworming is equal to $x * (w\alpha)^{\alpha}((1-\alpha))^{1-\alpha}$.

Individual i will deworm if the discounted value of increased time in future periods exceeds the price of the medicine and the utility costs of deworming, or $\frac{\delta}{1-\delta} x * (w\alpha)^{\alpha}\left((1-\alpha))^{1-\alpha} - \hat{p} * \frac{(w\alpha)^{\alpha}((1-\alpha))^{1-\alpha}}{w}\right) \geq d_i$. Aggregating over all individuals completes the proof. □

Since the utility gain from an increase in time of *x* in a given period is equivalent to the utility gain from a cash transfer of *xw*, and is equal to $x(w\alpha)^{\alpha}(1-\alpha)^{1-\alpha}$, a cash transfer of $\frac{wd_i}{(w\alpha)^{\alpha}(1-\alpha)^{1-\alpha}}$ increases agent *i*'s utility by exactly d_i.

It is straightforward to compute deworming take-up and social welfare in an extension in which deworming also increases labor productivity per hour of work, where the wage is increasing in past health investments and spillovers. While for simplicity below we will continue to focus on the case in which deworming increases work hours but not wages, all qualitative insights are equivalent.

Corollary 1: **If $\boldsymbol{w_i = 1 + \pi D_i + \pi_S N^T}$, then the proportion of the population that deworms at a given price of deworming medicine $\boldsymbol{\hat{p}}$ is $\boldsymbol{F\left(((\alpha)^{\alpha}(1-\alpha)^{1-\alpha})\left\{\frac{\delta}{1-\delta}(x + \pi(1 + x + x_S N^T)(1 + \pi_S N^T) - \frac{\hat{p}}{w}\right\}\right)}$, which is also decreasing in $\boldsymbol{\hat{p}}$.**

Proof: Analogous to Proposition 1, taking into account that wages are also affected by deworming treatment and externalities. □

Consider policy for a government that seeks to maximize social welfare (the sum of utility of all *N* members of the population) but only has access to distortionary taxation, or equivalently faces constraints leading to wasteful expenditures. Let $\overline{s_i}$ denote the disutility of deworming for someone who is indifferent to treatment at a price of $p - s_i$. That is to say, $\overline{s_i} = \left(\left(\frac{\delta}{1-\delta}x - \frac{p-s_i}{w}\right) * (\mathrm{w}\alpha)^{\alpha}(1-\alpha)^{1-\alpha}\right)$. Furthermore, suppose government deworming programs incur fixed costs at the national, school, and individual level (η_N, η_S, η_I, respectively, and there are *M* schools) as well as inefficiencies of raising public funds and delivering subsidies of $\lambda > 0$**.** In other words, for each dollar of spending, λ dollars are misspent, wasted, or otherwise lost from aggregate output.

Proposition 2: **Consider two different levels of subsidies, s_1 and s_2 where $s_2 > s_1 > 0$. If the government faces the costs outlined above, it prefers subsidy s_2 to s_1 if:**

(3) $\int_{\tilde{d}_i=\overline{s_1}}^{\overline{s_2}} \left(\frac{\delta}{1-\delta}(xw + x_S(N-1)w)\right) dF(\tilde{d}_i) - (s_2 - s_1)\lambda \int_{\tilde{d}_i=0}^{\overline{s_1}} dF(\tilde{d}_i) - \int_{\tilde{d}_i=\overline{s_1}}^{\overline{s_2}} [s_2\lambda + \eta_I + p + \tilde{d}_i] dF(\tilde{d}_i) \geq 0$.

Proof: Each person who is induced to deworm, personally benefits by $\left(\frac{\delta}{1-\delta}xw\right)$ from increased time and others benefit by $\left(\frac{\delta}{1-\delta}\mathrm{w}x_S(\mathrm{N}-1)\right)$ from the externality benefits of increased time. However, those dewormed also incur personal costs of $\tilde{d}_i$ from the disutility of medicine and *p* from the price of the medicine, and there are also social costs of the program in terms of both the deadweight loss incurred with greater subsidies and the fixed cost of program administration of η_I per capita. The middle integral captures the deadweight loss from having to further subsidize people who would have dewormed with the lower subsidy. Aggregating over all of the individuals who are induced by the higher subsidy represents the monetary-equivalent impact of increased deworming. □

Corollary 2: **The government prefers a level of subsidy s to no subsidy at all if**

(4) $\int_0^{\bar{s}} \left(\frac{\delta}{1-\delta}(xw + x_S(N-1)w)\right) dF(\tilde{d}_i) - \int_{\tilde{d}_i=0}^{\bar{s}} [s\lambda + \eta_I + p + \tilde{d}_i] dF(\tilde{d}_i) - M\eta_S - \eta_N \geq 0$.

Proof: Same as above, but including the fixed costs. □

Corollary 3: **If the government faces no costs from implementation, subsidizing the price of medicine by the per capita magnitude of the externality benefit, $\frac{\delta}{1-\delta}wx_S(\mathrm{N}-1)$, maximizes social welfare.**

Proof: With no implementation costs, the government optimization problem maximizes $\int_{d_i=\overline{s_1}}^{\overline{s_2}} \left(\frac{\delta}{1-\delta}\left(x + x_S(N-1)\right)w - p - \frac{wd_i}{(w\alpha)^{\alpha}(1-\alpha)^{1-\alpha}}\right) dF(d_i)$, since all of the other terms are 0. The solution is such that, for the marginal user, $\left(\frac{\delta}{1-\delta}x - \frac{p-\frac{\delta}{1-\delta}wx_S(\mathrm{N}-1)}{w}\right) - \frac{wd_i}{(w\alpha)^{\alpha}(1-\alpha)^{1-\alpha}} = 0$, since for lower subsidies the integrand is (weakly) positive, and for higher subsidies it is (weakly) negative. This implies that the social planner solution is to subsidize deworming by the amount of its externality. □

Furthermore, if the only implementation costs are at the national or school levels, then if the program is subsidized, it should be subsidized at this optimal level. However, if $\lambda > 0$ and demand for medicine is perfectly inelastic with respect to price between two price levels, the government will not want to subsidize medicine to the lower level.

Even if the government is not looking to maximize social welfare but only its own revenues, it is still possible that subsidizing deworming is desirable, since the government gains from the greater tax revenue generated by expanding the labor supply. Intuitively, this argument is closely related to the idea that there is a fundamental difference in the deadweight loss incurred from taxing commodities that are complements for labor supply (such as deworming drugs) versus substitutes (Kaplow 2009).[5] In this setup, the government receives a fraction τ of increased earnings generated by the program, for instance, through income or consumption taxes.

***Corollary 4*: If the government only seeks to maximize tax revenue, it prefers subsidy s_2 to subsidy s_1 where $s_2 > s_1 > 0$ if:**

(5) $\tau \int_{\tilde{d}_i=\overline{s_1}}^{\overline{s_2}} \left(\frac{\delta}{1-\delta}(xw + x_S(N-1)w)\right) dF(\tilde{d}_i) - (s_2 - s_1)\lambda \int_{\tilde{d}_i=0}^{\overline{s_1}} dF(\tilde{d}_i) - \int_{\tilde{d}_i=\overline{s_1}}^{\overline{s_2}} [s_2\lambda + \eta I + p + di] dF di \geq 0.$

Proof: Similar to that of Proposition 1. □

2.3 Traditional Agriculture Case

We next consider a traditional agriculture setting in which people have a fixed plot of land and produce with access to neither land nor labor markets. We then consider a setting in which people can choose to stay in traditional agriculture or pay a fixed cost to switch out of the sector.

[5] The connection was drawn to our attention by Glen Weyl.

Proposition 3: **In the absence of land and labor markets, agriculturalists will work a constant fraction of their time $\boldsymbol{\alpha\frac{1-\beta_a}{1-\alpha\beta_a} \leq \alpha}$, regardless of their total stock of time or land.**

Proof: Agriculturalists produce $A_a K_{ia}{}^{\beta_a} L_{it}^{1-\beta_a}$, and thus choose to maximize utility $\left(A_a K_{ia}{}^{\beta_a} L_{it}^{1-\beta_a}\right)^{\alpha} (E_t - L)^{1-\alpha}$. The FOC implies that $\alpha(1-\beta_a)(E_t - L) = (1-\alpha)L$, so $L = \alpha\frac{1-\beta_a}{1-\alpha\beta_a} E_t$, which is smaller than α, the fraction of working time outside traditional agriculture. □

This implies that extra time is worth relatively less to those in agriculture due to the decline in returns to agricultural labor. Agriculturalists with an initial utility of *u* who receive *x* extra units of time have utility of $u\left(1+\frac{x}{E_t}\right)^{1-\alpha\beta_a}$, whereas if their wage were flat (as in the non-agricultural sector in our model) their utility would be $u\left(1+\frac{x}{E_t}\right)$, which is larger. However, if one were to estimate the change in total time endowment by taking the change in work hours and multiplying by $\frac{1}{\alpha}$, as one would in the non-agricultural sector, one would understate the benefits from extra time in agriculture.

Corollary 5: **Suppose agent *i* with utility u without deworming works z more hours with deworming. If *α<0.5*, a lower bound on the increase in individual utility is provided by the utility gain associated with $\boldsymbol{\frac{z}{\alpha}}$ extra healthy hours.**

Proof: For $\beta = 0$ or $z = 0$, $u\left(1+\frac{z}{\alpha E_t}\right) = \left(1+\frac{z}{\alpha E_t}\frac{1-\alpha\beta_a}{1-\beta_a}\right)^{1-\alpha\beta_a}$. For $\beta_a > 0$, if we assume perfect labor markets, the derivative of estimated utility with respect to increases in work hours is $\frac{u}{\alpha E_t}$. However, since people are adjusting work hours less in traditional agriculture than in the complete markets case, the true marginal increase in utility is actually $\frac{u}{\alpha E_t}\frac{(1-\alpha\beta_a)^2}{1-\beta_a} * \left[\left(1+\frac{z}{\alpha E_t}\frac{1-\alpha\beta_a}{1-\beta_a}\right)^{-\alpha\beta_a}\right]$. The term in brackets is strictly greater than 1 for $\beta_a > 0$, and the coefficient outside the brackets is greater than one as long if $2\alpha - 1 < \alpha^2\beta_a$, which implies that the true utility multiplier is greater than the imputed one for any positive change of hours. □

Proposition 4: **If people can choose their sector, increasing deworming subsidies (weakly) increases participation in non-agricultural work.**

Proof: This follows from the fact that the marginal product of labor is decreasing in agriculture and constant in non-agricultural work. Specifically, people leave traditional agriculture if

(6) $\max_{D_i}\left\{\sum_{z=t}^{\infty}\delta^{z-t}\left(w\alpha(1+xD_i+x_SN^T)\right)^{\alpha}(1+xD_i+x_SN^T-L_z)^{1-\alpha}\right\}-d_iD_i-m_i\Big\}>$
$\max_{D_i}\left\{\sum_{z=t}^{\infty}\delta^{z-t}\left(A_aK_{ia}{}^{\beta_a}\left(\alpha\frac{1-\beta_a}{1-\alpha\beta_a}(1+xD_i+x_SN^T)\right)^{1-\beta_a}\right)^{\alpha}\left((1+xD_i+x_SN^T)\left(1-\alpha\frac{1-\beta_a}{1-\alpha\beta_a}\right)\right)^{1-\alpha}\right\}$. [INCOMPLETE PROOF] □

Some individuals may work in multiple sectors in practice. If someone has a plot of land where they can choose to do agriculture as well as the ability to work outside of agriculture, then increasing their healthy time endowment should increase the time spent working outside of agriculture, where there are no diminishing returns to labor. The model does not predict that such people should necessarily reduce their work hours in agriculture to zero, since the returns to the first units of labor in the sector could be high.

3. Study Background

This section describes the context, the deworming program, and the follow-up survey, including our respondent tracking approach, and sample summary statistics.

3.1 The context

The health problem we examine, intestinal worm infections, is among the world's most widespread, with roughly one in four people infected with hookworm, whipworm, roundworm, or schistosomiasis (Bundy 1994, de Silva *et al*. 2003). Although light worm infections are often asymptomatic, more intense infections can lead to lethargy, anemia and growth stunting. Schistosomiasis can also have more severe consequences including enlargement of the liver and spleen. Disease burden estimates suggest that schistosomiasis alone accounts for up to 70 million disability-adjusted life years lost annually with thousands of deaths annually in Africa (Hotez and Fenwick 2009).

Treating worm infections (once to twice per year) can improve child appetite, growth and physical fitness (Stephenson *et al.* 1993), and reduce anemia (Guyatt *et al.* 2001, Stoltzfus *et al.* 1997). It also can strengthen children's immunological response to other infections, potentially producing broader health benefits, such as reduced infection prevalence with *Plasmodium*, the malaria parasite (Kirwan *et al.* 2010). Chronic parasitic infections in childhood are known to generate inflammatory (immune defense) responses and elevated cortisol levels that lead substantial energy to be diverted from growth, and there is mounting evidence that this can produce adverse health consequences throughout the life course, including atherosclerosis, impaired intestinal transport of nutrients, organ damage, and cardiovascular disease (Crimmins and Finch 2005).

Geohelminth eggs are spread when children defecate in the "bush" surrounding their home or school, while the schistosomiasis parasite is spread through contact with infected fresh water. Treatment externalities for schistosomiasis are likely to take place across larger areas than geohelminth externalities due to the differing modes of disease transmission, since the water-borne schistosome may be carried considerable distances by stream and lake currents, and the snails that serve as its intermediate hosts are themselves mobile.

Previous work in our Kenyan sample shows that deworming treatment led to large medium-run gains in school attendance and health outcomes. Due to worms' infectious nature, sizeable externality benefits also accrued to the untreated within treatment communities and to those living near treatment schools (Miguel and Kremer 2004), as well as to younger children in the treatment communities. Ozier (2010) shows that children who were 0-3 years old when the deworming program was launched and lived in the catchment area of a treatment school experienced large cognitive gains ten years later. Among those who were less than one year old when their communities received mass deworming treatment, average test score gains were 0.4 standard deviation units, equivalent to 0.5-0.8 of a year of school learning in his sample.

Bleakley (2007, 2010), examines the impact of a large-scale deworming campaign in the U.S. South during the early 20th century, by comparing heavily infected versus lightly infected regions over time in a difference-in-difference design. He finds that deworming raised adult income by roughly 17%, and, extrapolating these findings to the even higher worm infection rates found in tropical Africa, estimates that deworming in Africa could lead to income gains of 24%, similar to our estimated earnings gains for wage workers below.[6]

We study the impact of a school-based deworming program in Busia district, a densely-settled farming region of rural western Kenya adjacent to Lake Victoria that is somewhat poorer than the Kenyan average.[7] Survey respondents originally attended rural schools and at the time of the data collection were young adults mainly in their early twenties, with roughly one quarter still enrolled in school. Agriculture in Busia is rain-fed with two cropping seasons per year, and there are few draft animals. Unlike other parts of Kenya, where many farmers have turned to growing vegetables for local markets or flowers, coffee or tea for international markets, there is little intensification of agricultural production with only 1.3% of respondents growing cash crops, as discussed below.

The Lewis (1954) model assumption that young adults working in traditional family agriculture receive a share of output rather than their marginal product is plausible in this context. Markets for agricultural land and labor exist in this area but are not highly developed. Young adults have the option of staying on their parents farms or leaving home, to seek paid work, to start

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[6] There has been a debate in public health and nutrition about the cost-effectiveness of deworming (see Taylor-Robinson *et al.* 2007). Early work by Schapiro (1919) using a first-difference research design found wage gains of 15-27% on Costa Rican plantations after deworming. Weisbrod et al (1973) document small correlations between worm infections and labor productivity and test scores in St. Lucia. Bundy *et al*. (2009) argue that many studies understate deworming's benefits since they fail to consider externalities by using designs that randomize within schools; focus almost exclusively on biomedical criteria and ignore cognitive, education and income gains; and do not address sample attrition. The current paper attempts to address these three concerns. Beyond Miguel and Kremer (2004) and the current paper, Alderman *et al.* (2006b) and Alderman (2007) also use a cluster randomized controlled design and find large positive child weight gains from deworming in Uganda.

[7] The 2005 Kenya Integrated Household Budget Survey found 62% of Busia households fall below the poverty line compared to 41% nationally, and 75% of Busia adults were literate versus 80% nationally. Given that Kenyan per capita income is somewhat above the Sub-Saharan African average (excluding South Africa), the fact that Busia is slightly poorer than the Kenyan average probably makes the district more representative of rural Africa as a whole.

businesses, or, if female, to marry. Sons typically inherit land from their parents, with many receiving inter-vivos land transfers. Daughters typically co-locate with their husbands at marriage (Government of Kenya 1986). Note that if adult children are entitled to share food if living at home but not otherwise, then moving away from home could create positive or negative externalities for their family depends on how their marginal productivity at home compares to what they consume.

At the time of survey, just over half of the sample (53% of the control group) work on family farms, primarily for subsistence, and one-quarter are still in school. Nearly 17% of study participants are employed in the wage labor sector and 10% in non-agricultural self-employment.

3.2 The Primary School Deworming Program (PSDP)

In 1998, the non-governmental organization (NGO) ICS launched the Primary School Deworming Program (PSDP) to provide deworming medication to children enrolled in 75 primary schools. The schools participating in the program consisted of 75 of the 89 primary schools in Budalangi and Funyula divisions in southern Busia (with 14 town schools, all-girls schools, geographically remote schools, and program pilot schools excluded), containing 32,565 pupils at baseline.

Parasitological surveys conducted by the Ministry of Health indicated that these divisions had high baseline helminth infection rates at over 90%. Using modified WHO infection thresholds (described in Brooker *et al.* 2000a), over one third of children in the sample had "moderate to heavy" infections with at least one helminth at the time of the baseline survey, a high but not atypical rate in African settings (Brooker *et al.* 2000b, Pullan et al. 2011). The 1998 Kenya Demographic and Health Survey indicates finds that 85% of 8 to 18 year olds in western Kenya were enrolled in school at that time, indicating that our school-based sample is broadly representative of children in the region.

The 75 schools involved in this program 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), listed alphabetically by zone, and were then listed in order of pupil enrollment within each zone, and every third school was assigned to a given program group; Supplementary Appendix A contains a detailed description of the experimental design. The three groups are well-balanced along baseline demographic and educational characteristics, both in terms of mean differences and distributions, where we assess the latter with the Kolmogorov-Smirnov test of the equality of distributions (Table 1).[8] The same balance is also evident among the subsample of respondents no longer enrolled in school – the main sub-sample for analyzing labor market outcomes – and among those currently working for wages (see supplementary appendix tables A1 and A2, respectively).

Due to the NGO's administrative and financial constraints, the schools were phased into the deworming program over the course of 1998-2001 one group at a time. This prospective and staggered phase-in is central to this paper's econometric identification strategy. Group 1 schools began receiving free deworming treatment in 1998, Group 2 schools in 1999, while Group 3 schools began receiving treatment in 2001; see appendix Figure A1. The project design implies that in 1998, Group 1 schools were treatment schools while Group 2 and 3 schools were the control schools, and in 1999 and 2000, Group 1 and 2 schools were treatment and Group 3 was control, and so on.

The NGO typically requires cost sharing, and in 2001, a randomly chosen half of the Group 1 and 2 schools took part in a program in which parents had to pay a small positive price to purchase the drugs, while the other half of Group 1 and 2 schools received free treatment (as did all Group 3 schools). Kremer and Miguel (2007) show that cost-sharing led to a sharp drop in deworming treatment, by 60 percentage points, introducing further exogenous variation in deworming treatment that we exploit. In 2002 and 2003, all sample schools received free treatment.

Children in Group 1 and 2 schools thus were assigned to receive 2.41 more years of deworming than Group 3 children on average (Table 1, Panel A), and these early beneficiaries are what we call the deworming treatment group below. We focus on a single treatment indicator rather than separating out effects for Group 1 versus Group 2 schools since this simplifies the analysis and

[8] Miguel and Kremer (2004) present a fuller set of baseline covariates for the treatment and control groups.

because we sometimes lack statistical power to distinguish effects across these groups, although we also present some results taking into account the Group 1 versus Group 2 differences. The fact that the Group 3 schools eventually did receive deworming treatment will tend to dampen any estimated treatment effects relative to the case where the control group was never phased-in to treatment. In other words, a program that consistently dewormed some children throughout childhood while others never received treatment might have even larger impacts. Note, however, that several cohorts "aged out" of Group 3 primary schools (i.e., graduated or dropped out) before treatment was phased-in.

Deworming drugs for geohelminths (albendazole) were offered twice per year and for schistosomiasis (praziquantel) once per year in treatment schools.[9] We focus on intention-to-treat (ITT) estimates, as opposed to actual individual deworming treatments, in the analysis below. This is natural as compliance rates are high. To illustrate, 81.2% of grades 2-7 pupils scheduled to receive deworming treatment in 1998 actually received at least some treatment. Absence from school on the day of drug administration was the leading reported cause of non-compliance. The ITT approach is also attractive since previous research showed that untreated respondents within treatment communities experienced significant health and education gains (Miguel and Kremer 2004), complicating estimation of treatment effects on the treated.

3.3 Kenya Life Panel Survey (KLPS)

The Kenyan Life Panel Survey (KLPS-2) was collected during 2007-2009, and tracked a representative sample of approximately 7,500 respondents who had been enrolled in primary school grades 2-7 in the 75 PSDP schools at baseline in 1998.[10]

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[9] Following World Health Organization recommendations (WHO 1992), schools with geohelmith prevalence over 50% were mass treated with albendazole every six months, and schools with schistosomiasis prevalence over 30% mass treated with praziquantel annually. All treatment schools met the geohelminth cut-off while roughly a quarter met the schistosomiasis cut-off. Medical treatment was delivered to the schools by Kenya Ministry of Health public health nurses and ICS public health officers. Following standard practices at the time, the medical protocol did not call for treating girls thirteen years of age and older due to concerns about the potential teratogenicity of the drugs.

[10] A midterm round (KLPS-1) was conducted in 2003-05. We focus on the KLPS-2, rather than KLPS-1, since it was collected at a more relevant time point for us to assess adult life outcomes: the majority of respondents are

Survey enumerators traveled throughout Kenya and Uganda to interview those who had moved out of local areas.[11] As time progressed and the pace of locating respondents slowed, a representative (random) subsample containing approximately one quarter of still-unfound target respondents was drawn. Those sampled were tracked "intensively" (in terms of enumerator time and travel expenses) for the remaining months, while those not sampled were no longer actively tracked. We re-weight those chosen for the "intensive" sample by their added importance to maintain the representativeness of the sample. As a result, all figures reported here are "effective" tracking rates (ETR), calculated as a fraction of those found, or not found but searched for during intensive tracking, with weights adjusted appropriately. This is analogous to the approach in Moving To Opportunity (Kling *et al.* 2007, Orr *et al.* 2003).The effective tracking rate (ETR) is a function of the regular phase tracking rate (RTR) and intensive phase tracking rate (ITR) as follows:

$$ETR = RTR + (1 - RTR)*ITR \quad (7)$$

Overall, the RTR in KLPS-2 is 65.0% and the ITR is 62.1%, which implies that 86% of respondents were effectively located by the field team, with 82.5% surveyed while 3% were either deceased, refused to participate, or were found but were unable to be surveyed (Table 1, Panel B). The effective survey rate among those still alive is 84%. These are high tracking rates for any age group over a decade, and especially for a highly mobile group of adolescents and young adults, and they are on par with some of the best-known panel survey efforts in less developed countries, such as the Indonesia Family Life Survey (Thomas *et al*. 2001, 2010), and several recent African surveys.[12] Reassuringly, survey tracking rates are nearly identical and not significantly different in the treatment and control groups.

adults by 2007-09 (with median age of 22 years versus 18 in KLPS-1), most have completed school, many have married, and a growing share have wage employment or non-agricultural self-employment (appendix figure A3).

[11] See supplementary appendix table A6. Baird, Hamory and Miguel (2008) further discusses the tracking approach.

[12] Other successful longitudinal data collection efforts among African youth are Beegle *et al*. (2010), Lam et al (2008), and Duflo et al. (2011). Pitt, Rosenzweig and Hassan (2011) document high tracking rates in Bangladesh.

4. Deworming impacts on health, education and labor market outcomes

This section presents the estimation strategy and impacts on health, education and labor outcomes.

4.1 Estimation strategy

The econometric approach relies on the PSDP's prospective experimental design, namely, the fact that the program exogenously provided individuals in treatment (Group 1 and 2) schools two to three additional years of deworming treatment. We also adopt the approach in Miguel and Kremer (2004) and estimate the cross-school externality effects of deworming. Exposure to spillovers is captured by the number of pupils attending deworming treatment schools within 6 kilometers; conditional on the total number of primary school pupils within 6 kilometers, the number of treatment pupils is also determined by the experimental design.

The dependent variable is a labor market outcome (such as hours worked in the last week), $Y_{ij,2007\text{-}09}$, for individual i from school j, as measured in the 2007-09 KLPS-2 survey:

(8) $$Y_{ij,2007\text{-}09} = a + bT_j + c_1N_j^T + c_2N_j + X_{ij,0}'d + e_{ij,2007\text{-}09}$$

The labor market outcome is a function of the assigned deworming program treatment status of the individual's primary school (T_j), and thus this is an intention to treat (ITT) estimator; the number of treatment school pupils (N_j^T) and the total number of primary school pupils within 6 km of the school (N_j); a vector $X_{ij,0}$ of baseline individual and school controls; and a disturbance term $e_{ij,2007\text{-}09}$, which is clustered at the school level.[13] The $X_{ij,0}$ controls include school geographic and demographic characteristics used in the "list randomization" for the PSDP, the student gender and grade characteristics used for stratification in drawing the KLPS sample, the pre-program average school

[13] Miguel and Kremer (2004) separately estimate effects of the number of pupils between 0-3 km and 3-6 km. Since the analysis in the current paper does not generally find significant differences in externality impacts across these two ranges, we focus on 0-6 km for simplicity. The externality results are unchanged if we focus on the proportion of local pupils who were in treatment schools as the key spillover measure (i.e., N_j^T / N_j, results not shown). Several additional econometric issues related to estimating externalities are discussed in Miguel and Kremer (2004).

test score to capture school academic quality, the 2001 cost-sharing school indicator, as well as controls for the month and wave of the interview.

The main coefficients of interest are b, which captures gains accruing to deworming treatment schools, and c_1, which captures spillover effects of treatment for nearby schools. Bruhn and McKenzie (2009) argue for including variables used in the randomization procedure as controls in the analysis, which we do, although as shown below, the coefficient estimates on the treatment indicator are robust to whether or not we do, as expected given the research design. Results are also robust to accounting for the cross-school spillovers. In fact, accounting for externalities tends to increase the b coefficient estimate; in other words, a failure to account for the program treatment "contamination" generated by spillovers dampens the "naïve" difference between treatment and control groups (and also leads the researcher to miss a second dimension of program gains, the spillovers themselves). Certain specifications explore heterogeneity by interacting individual demographic characteristics with the deworming treatment indicator.

Theoretically, the sign of the interaction of treatment with the local level of serious worm infections is ambiguous, and the effect of the program at higher levels of initial disease prevalence need not be monotonic. This is because areas with higher prevalence will typically have conditions more conducive to transmission of the disease; re-infection is thus likely to occur more quickly in these areas and hence the impact of treatment could potentially be smaller in these areas than in areas where it takes longer for re-infection to occur. Given this theoretical ambiguity, and the lack of strong evidence in the data that interaction terms or higher order polynomial externality terms are justified, we focus on specifications in which T_j and N_j^T are additively separable.

The interpretation of coefficient estimates on the externality term (N_j^T) is complicated by the fact that the communities (and individuals) who benefit from cross-school spillovers (in terms of reduced infection intensity) themselves generate positive spillovers for others, as a result of the reduction of their worm burden. While in the short-run (as in the analysis in Miguel and Kremer

2004) the cross-school spillovers are likely to fairly accurately capture the magnitude of these externality impacts, over time the infection "feedback" effects generated across nearby communities would lead us to understate the magnitude of cross-school externality magnitudes as they converge to a common local infection rate (as predicted by standard epidemiological models such as those in Anderson and May 1991). This is a form of "contamination" of the externality "treatment". As a result, it is reasonable to interpret the c_1 coefficient estimate as a lower bound on the true magnitude of long-run cross-school externality effects.

4.2 Impacts on health and education

We first document that deworming led to large reductions in moderate-heavy worm infections during the original project, using the parasitological stool sample data from 1999 and 2001 (Table 2, Panel A). As in the earlier study, there are large direct impacts on moderate-heavy worm infections of being assigned to a treatment school (-0.245, s.e., 0.030) as well as externality benefits for those living within 6 kilometers of treatment schools (-0.075, s.e., 0.026).[14] There is weak evidence of improved hemoglobin status (1.03, s.e. 0.81). In a 1999 survey conducted among a representative subsample of pupils, there is also a significant reduction in self-reported "falling sick often", by 3.7 percentage points (s.e. 1.5). In addition to these health findings, the original study also found gains in primary school participation on the order of 0.127 of a year of schooling (s.e. 0.064, significant at 99% confidence).[15] However, little evidence was found in the original study to suggest improvements in academic test scores associated with treatment (while the impact of deworming on primary school academic test score performance in 1999 is positive, it is not statistically significant),

[14] The time pattern of moderate-heavy worm infections across treatment groups is presented in Appendix Figure A4.
[15] This school participation measure is defined as being found present in school by survey enumerators on the day of an unannounced attendance check. This is our most objective measure of actual time spent at school, and was a main outcome measure in Miguel and Kremer (2004), but two important limitations are that it was only collected during 1998-2001, and only at primary schools in the study area; the falling sample size between 1998 to 2001 (shown in appendix Table A3) is mainly driven by students graduating from primary school.

Adult health also improved as a result of deworming: respondent self-reported health (on a normalized 0 to 1 scale) rose by 0.041 (s.e. 0.018, significant at 95% confidence, Table 2, panel B). Many studies have found that self-reported health reliably predicts actual morbidity and mortality even when other known health risk factors are accounted for (Idler and Benyamini 1997, Haddock *et al.* 2006, Brook *et al.* 1984), making this an important measure to consider. Note that it is somewhat difficult to interpret the channels of impact since effects may partially reflect health gains driven by the higher adult earnings detailed below, in addition to the direct health benefits of earlier deworming. Yet the fact that there were similarly positive and statistically significant impacts on self-reported health in earlier periods, namely, in the 1999 survey before nearly any sample individuals were working, suggests that at least part of the effect is directly due to deworming.

Deworming did not lead to detectable height gains, even when we restrict attention to younger individuals (those in grades 2-4 in 1998, regression not shown). The height result is reassuring since the deworming beneficiaries were already of primary school age when the program started, and thus beyond the age at which we would expect nutritional and health improvements to translate into permanent anthropometric gains.

We next examine impacts on the total number of pregnancies and miscarriages/stillbirths for female respondents. There is no impact on pregnancies through 2007-2009 for the full sample, but we do find a sizeable impact on the rate of miscarriages, with a reduction of 2.8 percentage points (s.e. 1.3) on a base of 3.9 percent, for a large reduction of nearly three quarters (Table 2, Panel B). In the out-of-school sample (where we later focus the labor market analysis) there is a marginally significant reduction in the number of pregnancies, with a reduction of 0.136 (s.e. 0.082), a finding that can perhaps help explain the work hours results we discuss below. The reduction in the miscarriage rate is 2.7 percentage points (significant at 95% confidence), similar to the full sample. Since miscarriage rates are known to be highly sensitive to general maternal health and nutritional status (Hotez 2009), this finding is further evidence that the deworming treatment group experienced some persistent health benefits from the intervention, consistent with the improvements in self-reported improved health status.

A number of education outcomes also improved. For the period 1998-2007, we collected self-reported school enrollment data by year, using an indicator which equals one if the individual was enrolled for at least part of a given year. These annual indicators show consistently positive effects from 1999 to 2007 both on the deworming treatment indicator and the externalities term, and the total increase in school enrollment in treatment relative to control schools over the period is 0.279 years (s.e. 0.147, significant at 90% confidence – Table 2, Panel C). The treatment effect estimates are largest during 1999-2003 before tailing off during 2004-07 (appendix table A4). By the time of the 2007-09 survey, there are no differences in contemporaneous school enrollment, and the treatment and control respondents no longer in school have comparable observable characteristics (appendix table A1). Given that the school enrollment data misses out on attendance impacts, which are sizeable, a plausible lower bound on the total increase in time spent in school induced by the deworming intervention is the 0.129 gain in school participation from 1998-2001 plus the school enrollment gains from 2002-2007 (multiplied by average attendance conditional on enrollment), which works out to nearly 0.3 additional years of schooling.

Despite the sizeable gains in years of school enrollment, there are no significant impacts on total grades of schooling completed (0.153, s.e. 0.143). A likely explanation is that the increased time in school is accompanied by increased grade repetition (0.060, s.e. 0.017, significant at 99%). To summarize, deworming treatment respondents attended school more and were enrolled for more years on average, but do not attain more grades in part because repetition rises substantially.

Test score performance is another natural way to assess human capital impacts. As shown in Table 2, Panel C, there is some evidence that the passing rate did improve on the key primary school graduation exam, the Kenya Certificate of Primary Education (point estimate 0.048, s.e. 0.031), and that English vocabulary knowledge (collected in 2007-09) is higher in the treatment group (impact of 0.076 standard deviations in a normalized distribution, s.e., 0.055).

If we focus on the subsample of respondents who are no longer in school – the natural sample of interest in the analysis of labor market impacts to follow – we find much larger and statistically significant impacts of deworming treatment on test scores, with an average gain in the English vocabulary test of 0.107 s.d. units (s.e. 0.052), and associated significant externality gains of 0.149 (s.e. 0.047). We also see an increase of 6.1 percentage points in the rate at which students pass the KCPE primary-school leaving exam, on a base of 41.3%.[16] It is also possible that the increase in actual time spent in school might yield some labor market returns through improved social or other non-cognitive skills (Heckman, Stixrud, and Urzua 2006), such as greater ability to follow rules or show up regularly and on time, beyond the test score gains documented here.

4.3 Deworming Impacts on Labor Supply

As we note above, at the time of survey, approximately 53% of control group individuals perform subsistence agriculture on small family farms, and one quarter are still in school, nearly 17% are employed in the wage labor sector, and 10% are engaged in non-agricultural self-employment.[17] Approximately 60% of women in the control group have had at least one child.

We find substantial impacts of deworming treatment on labor supply. In particular, among all individuals surveyed in KLPS-2, mean hours worked increased by 1.76 hours (s.e. 0.97 hours, Table 3, Panel A) on a control group mean of 15.2 hours, a 12% increase significant at 90% confidence. However, approximately 25% of our sample was still enrolled in school at the time of survey, and few of these individuals participate in wage labor or non-agricultural self-employment. When assessing labor supply impacts in the remainder of Table 3 and the analysis that follows, we focus on

[16] Note that we cannot reject the hypothesis that the treatment impacts for those in and out of school on these two test score measures are equal (results not shown).
[17] Note that there is some overlap among these groups, so percentages sum to more than 1.

those respondents who are no longer enrolled in school as the relevant population. As noted above, nearly identical proportions of respondents in the treatment and control groups are no longer enrolled in school, at roughly 75%, and we cannot reject that observable characteristics are the same across the two groups in this subsample (appendix Table A1).

Among individuals who are enrolled in school, participation in traditional agriculture, wage- or self-employment is far lower (appendix Table A4); for example, only 0.5% of the sample is both enrolled in school and working for wages. However, there is considerably more overlap across some of the employment sectors, as roughly one quarter of wage workers, and half of those who identified as being self-employed in a non-agricultural business, also engaged in at least some agricultural work. Overall, 0.3% of the sample both work for wages and are in self-employment (outside of agriculture) and 4% of the sample both work for wages and are in agriculture. Among control group individuals in the out-of-school subsample, 54% work on small family farms, 21% work in wage employment and 13% in non-agricultural self-employment. On average, individuals working on family farms work 10 hours per week, those working in wage employment work 47 hours per week, and those in non-agricultural self-employment work over 38 hours per week (Table 3, Panel A).

Among those no longer enrolled in school, hours worked increase substantially in the deworming treatment group. Mean hours worked increased by 3.10 hours (s.e. 1.21, Table 3, Panel A) on a control group mean of 18.5 hours, a 17% increase that is significant at 95% confidence. The coefficient on the cross-school externality term is large though not significant at traditional confidence levels (1.71, s.e. 1.44) but note that the treatment indicator and the externality term are jointly statistically significant at over 95% confidence (p-value=0.026). Much of the increase in hours worked is driven by an increase in full-time work of at least 35 hours per week, which rises by 5.1 percentage points (s.e. 2.3, 95% confidence, not shown) on a base of 21.5% in the control group. In contrast, there is no significant change in the proportion in the treatment group working at all (greater than zero hours in the past week), which is roughly 70% of those not still in school. There is thus a considerable degree of "non-activity" for a young adult population (although some are engaged in home production or child-rearing that is not classified as work here).[18] In the full sample, females are more likely to be classified as non-active (25% vs. 14% for males) which is likely related to the fact that more than three quarters of out-of-school females have had at least one pregnancy.

We next investigate the treatment impact on hours worked in subgroups. We find no significant evidence that deworming impacts on hours worked differ by gender or individual age at baseline (appendix Table A5, columns 2 and 3), nor is there is evidence that gains in hours worked are significantly larger in areas with higher initial infection rates (column 4), although the sign on the interaction term does goes go in the expected positive direction. We use the zonal-level baseline infection rate, rather than individual-level data (which was not collected at baseline for the control group for ethical reasons); using zonal averages is likely to introduce measurement error and attenuation bias, and thus this interaction effect is likely to understate the true extent of differential impacts in high worm infection areas.

We next focus on those who worked at all in the last week, by employment sector. The distributions of hours worked (in all occupations), as represented in kernel densities, for the treatment and control groups are presented in Figure 1, panel A, and by employment sector in panels B through D. There are some visible shifts in the treatment group distribution to the right overall that appear to be driven almost entirely by those not employed in agriculture (either self-employed or wage work). In both the self-employed subsample (panel C) and the wage-earning subsample (panel D), more treatment respondents work approximately full-time (more than 35 hours per week), with fewer working part-time.

The concentration of work hour gains among those in non-agricultural employment is confirmed in the regression analysis in Table 3. Hours in agriculture increase by 1.10 hours (s.e.

[18] Note that "non-activity" is defined here as those not in school or employed in traditional agriculture, wage labor or self-employment.

0.66, significant at 90%) in the treatment group on a base of 9.8 hours per week in the control group. This modest increase is consistent with the idea that the marginal product of labor in traditional agriculture is relatively low (Lewis 1954). The typical person with positive hours in agriculture worked less than ten hours in the last week, echoing earlier studies (e.g., Fafchamps 1993), and even in peak planting and harvest months, where average weekly hours never exceed 12.2. Among those working outside of agriculture, the deworming treatment group worked 5.0 more hours (significant at 95% confidence), an increase of 11% on a base of 44.6 hours. There are even larger increases in hours worked in non-agricultural self-employment in the last week, at 6.7 hours (s.e. 3.0) on a base of 38.2 hours, or 18%. There are similarly large gains among wage earners, at 4.53 hours (s.e. 2.67) on a base of 47.3 hours. However, we cannot reject the hypothesis that the change in labor hours *in percent terms* is equal across the three sectors (agriculture, wage employment, and non-agricultural self-employment, p-value=0.92). Note that the impact magnitude in the wage earning sector (4.5 hours) is similar to the difference between average weekly work hours in the United States versus France (OECD 2010).

Point estimates suggest externalities for schools neighboring treatment schools, and some of the coefficients are statistically significant. Among those working outside of agriculture, there are statistically significant spillovers on total hours (3.51 hours, s.e. 1.58). The externality effects are large in magnitude: an increase of one standard deviation in the local density of treatment school pupils (917 pupils), equivalent to treating 20% of the local primary school population, which Miguel and Kremer (2004) found led to large drops in worm infection rates, is associated with an increase of three work hours per week.

An interesting methodological question is the extent to which the results we present here would differ had the survey data collection not included efforts to track respondents living outside the original study district. While individuals found in the “intensive” tracking phases do differ significantly on mean observable characteristics (see supplementary appendix Table A6), we cannot reject that treatment effect estimates are the same if we exclude this subsample (results not shown).

4.4 Impacts on employment sector, occupation, and migration

Treatment does not lead to significant shifts in rates of employment in agriculture on the one hand versus non-agricultural (small business and wage) employment on the other. However, within these sectors, treatment leads respondents to shift from food crops to cash crops, and from less remunerative occupations where part-time work is common to better-paid, full-time jobs in fields such as manufacturing.

The rates of agricultural, non-agricultural self-employment and wage earning work are nearly identical across the deworming treatment and control groups (Table 4, Panel A). The most common employment sector is farming (53.6% in the control group), as expected in rural Kenya. 21.0% of respondents worked for wages in the last month[19] (and 31.1% at some point since 2007), while 13.3% of respondents were currently self-employed outside of farming.

Among those who work primarily on their own farm, there is evidence that deworming led to a shift towards cash crops (e.g., cotton, sugar, or tobacco) and away from traditional staple crops: the effect is 1.7 percentage points (s.e. 0.9) on a low base of 1.3 percent in the control group, for a doubling of the proportion in the control group.

Treatment also leads to pronounced shifts in the occupation of employment among wage earners, out of relatively low-skilled and low-wage sectors into better paid and higher work intensity sectors (Table 4, Panel B). Deworming treatment respondents are three times more likely to work in manufacturing from a low base of 0.031 (coefficient 0.067, s.e. 0.025). The gains among males are particularly pronounced at 0.082 (s.e. 0.033). Survey responses indicate that the two most common

[19] A small proportion (2%) of those who work for wages do so in agriculture. We do not classify these people as working in traditional agriculture.

types of manufacturing jobs in our sample are in food processing and textiles, with establishments ranging in size from small local corn flour mills up to large blanket factories in Nairobi. On the flip side, casual labor employment falls significantly (-0.041, s.e. 0.019), as does domestic service work for females (-0.190, s.e. 0.113). Not surprisingly given these shifts in occupation of employment, a somewhat larger proportion of treatment group wage earners live in urban areas (not shown).

Manufacturing jobs tend to be quite highly paid, with average real monthly earnings of 5,311 Shillings (roughly US$68), compared to casual labor (2,246 Shillings) and domestic services (3,047 Shillings). Manufacturing jobs are also characterized by longer work weeks than average at 53 hours per week, in contrast to 43 hours for all wage earning jobs, indicating that these are high work intensity jobs. Workers in manufacturing jobs also tend to have relatively few work days missed due to poor health, at just 1.1 days (in the control group), compared to 1.4 days in the last month among all wage earning jobs. One explanation for this pattern that ties into our earlier labor supply findings is that health investments improve individuals' capacity to carry out physically demanding jobs, characterized by long work weeks and little tolerance of absenteeism, and thus allow them to access higher paid jobs such as those in manufacturing. Casual laborers typically do not have to commit to work a certain number of days in a week in advance, so the significant reduction in casual work is also consistent with the hypothesis that deworming helps people obtain jobs that require regular attendance.

4.5 Impacts on production and living standards

Just as we decompose the increase in overall hours into changes in hours in agriculture, non-agricultural self-employment, and hours working for wages, it is useful to separately estimate treatment impacts on output and productivity in each sector.

The impact on wage earners is perhaps easiest to measure. Here point estimates of the increase in earnings are larger than those of the increase in hours, consistent with the hypotheses that certain jobs require higher numbers of work hours, worked on a regular schedule, and that these jobs are better paying. It is also consistent with the idea that people adjust their work effort along intensive as well as extensive margins, as we find some evidence for wage gains.

Treatment shifts the distribution of log wage earnings sharply to the right (Figure 2, Panel A).[20] In the regression analysis, we find that deworming treatment leads to higher log earnings (Table 5, Panel A), with a gain of 30.1 log points (s.e. 9.1, 99% confidence). The earnings result is robust to several alternative specifications. It changes little in response to trimming the top 1% of earners, so the result is not driven by outliers; to including a full set of gender-age fixed effects; to including fixed effects for each of the "triplets" of Group 1, Group 2 and Group 3 schools from the list randomization, and considering cross-school cost-sharing externalities (appendix Table A7).

A decomposition along the lines of Oaxaca (1973) indicates that over 75% of the increase in labor earnings for the treatment group (Table 5, Panel A), and nearly 13% of the increase in hours worked (Table 3), can be explained by the occupational shifts documented in Table 4. While there are standard errors around these estimates and thus the exact figures should be read cautiously, they indicate that the bulk of the earnings gains can be accounted for by such shifts. While not ruling out that per hour labor productivity also rises (as we found above), this is consistent with the hypothesis that an increase in labor supply allows people to take jobs that require regular, full-time work and that this in turn allows them to earn more per hour.

There is suggestive evidence for positive deworming externalities on earnings. While the coefficient estimate on the local density of treatment pupils is not significant at traditional confidence levels (22.8 log points, s.e. 16.3, in Table 5, Panel A), it reassuringly has the same sign as the main deworming treatment effect, and a substantial magnitude: an increase of one standard deviation in the local density of treatment school pupils, or roughly 20% of the local primary school pupils, would

[20] Here and below we present real earnings measures that account for the higher prices found in the urban areas of Nairobi and Mombasa. We collected price surveys in both rural western Kenya and in urban Nairobi during KLPS-2, and base the urban price deflator on these data. Results are unchanged without this price adjustment, however.

boost labor earnings by roughly (917/1000)*(22.8 log points) = 20.9 log points. The coefficient estimate on deworming treatment and this externality term are jointly significant at 95% confidence.

Log wages computed as earnings per hour worked rise 20.3 log points (s.e. 11.1) in the deworming treatment group, and the effect is significant at 90% confidence (Table 5, Panel A). These results are also robust to trimming the top 1% of wages and to including a full set of gender-age fixed effects (not shown).

Positive wage earnings impacts are similar in the larger group of respondents who have worked for wages at any point since 2007, where we use their most recent monthly earnings if they are not currently working for wages. The mean impact on log earnings is 0.211 (s.e. 0.072), and there is once again suggestive evidence of positive externality effects (0.170, s.e. 0.116, Table 5, Panel B).

We find no significant evidence that deworming impacts on labor earnings differ by gender or individual age at baseline, nor are gains in labor earnings are significantly larger in zones with higher baseline worm infection rates (Appendix Table A8).[21]

Point estimates of the percentage increases in profits among owners of non-agricultural businesses are similar to the percentage increases in earnings among wage earners, but are estimated with less precision, partly because fewer people work in the sector and partly because the underlying variance of reported profits is higher than that of reported wages (presumably due to a combination of stochastic variation and measurement error). The estimated deworming treatment effect on the

[21] Deworming does not seem to affect the likelihood that people become wage earners or the process by which observable characteristics influence the likelihood of becoming a wage earner. In Table 4, we found no evidence that deworming treatment respondents are more likely to be working for wages or in-kind payments in the last month (Panel A, estimate -0.006, s.e. 0.022). There is similarly no differential selection into the subsample who have worked for wages at any point since 2007 by treatment group (Table 5, Panel B). We further confirm that we cannot reject that the observable characteristics of wage earners, including academic performance measures, are the same in the treatment versus control groups (appendix Table A2). These factors all point towards an interpretation of the difference in labor earnings between the deworming treatment and control groups primarily reflecting causal treatment rather than a selection effect. Further evidence is provided by a Heckman (1979) approach explicitly modeling the process of selection into wage earning. We use a marital status indicator and marital status interacted with gender as variables that predict selection into earning but are excluded from the earnings regression; marital status is strongly positively (negatively) correlated with any wage earning among males (females). Keeping in mind the standard caveats to selection correction models, this approach yields an almost unchanged estimated impact on log wage earnings (results not shown).

monthly profits of the self-employed (as directly reported in the survey) is positive at 409 Shillings (s.e. 313, Table 5, Panel C), although this 23% gain is not significant at traditional confidence levels.[22] Trimming the top 5% of self-reported profits results in a similarly sized but statistically significant treatment effect of 407 Shillings (s.e. 176, significant at 95% confidence). We also find impacts on the total number of employees hired (0.641 additional employees on a base of 0.189, s.e. 0.374, significant at 90%)..

We next construct a measure of total monthly non-agricultural earnings by summing wage earnings and self-employed profits (among all those not still in school), and estimate a treatment effect of 245 Shillings (s.e. 136, significant at 90%, Table 5 Panel D) on a base of 974 shillings in the control group, for a 25% increase; impacts are unchanged with a measure that trims that top 5% of profits. The majority of this sample either works solely in agriculture or is idle and thus has zero non-agricultural earnings, making this a particularly stringent test.

Unfortunately, we do not have a concrete measure of agricultural yield or output analogous to the wages or profits of those working in other sectors. In any case, measuring the on-farm productivity of an individual worker in the context of a farm where multiple household members (and sometimes hired labor) all contribute to different facets of the production process is difficult. We also lack sufficiently detailed information on farming choices to compute a reliable yield measure, and thus rely on several proxies for agricultural productivity. There is no indication that deworming led to higher crop sales in the past year (Table 5, Panel E). The failure to find increased crop sales may, in part, be due to the fact that households are consuming more of the grain they produced, as suggested by the increase in meals eaten (discussed below). We do find suggestive evidence of increased adoption of "improved" agricultural practices including fertilizer, hybrid seeds, or irrigation, with an increase of 4.7 percentage points (s.e. 2.7) on a base of 29.5 percent, suggesting

[22] There are large, positive but not statistically significant impacts on a monthly profit measure based directly on revenues and expenses reported in the survey (553 Shillings, s.e. 940) and reported profits in the last year (2,515 Shillings, s.e. 2,332). We focus here on self-reported profits in the last month, which appear to be less noisy.

somewhat greater agricultural productivity. While these results should be taken with a grain of salt, together with the finding that there was a doubling in the cultivation of cash crops, they suggest there were modest improvements in agricultural productivity, consistent with the finding of small increases in hours worked in agriculture (Table 3).

Just as deworming treatment does not appear to affect broad sources of income (i.e., agriculture versus non-agriculture), but does lead to shifts within each sector, treatment does not affect overall migration rates but there is some evidence that it leads respondents to migrate further from their homes. As illustrated in Table 6, Panel A (and the map in appendix Figure A2), roughly 30%, of respondents resided outside of Busia District in 2007-09, with rates roughly balanced between the treatment and control groups.[23] However, treatment group respondents are somewhat more likely to live at least 500 km away from Busia, primarily due to greater likelihood of moving to Mombasa, Kenya's main port, with an increase of 1.7 percentage points (s.e. 1.0) on a base of 3.1 percent in the control group. This tendency for treatment group respondents to live farther away from the home district may capture greater effort exerted in the job search process. While the point estimates are not significant at traditional confidence levels, there is suggestive evidence that treatment individuals are somewhat more likely to move to a city for a job or to look for work.

Consumption is commonly used to assess living standards in rural areas of less developed countries, where many households engage in subsistence agriculture rather than wage work. We do not have complete data from a consumption module[24], but did collect data on the number of meals consumed. Deworming treatment respondents consume 0.096 more meals per day (s.e. 0.028, 99% confidence, Table 6, Panel B) than the control group, and the externality impact is also large and

[23] Since the individuals we did not find, and thus typically did not obtain residential information for, are plausibly even more likely to have moved out of the region, these figures are almost certainly lower bounds on true out-migration rates.

[24] A consumption expenditure module was collected as a pilot for roughly 5% of the KLPS-2 sample during 2007-2009, for a total of 254 complete surveys. The estimated treatment effect for total consumption is near zero and not statistically significant (-$14, s.e. $66), but the confidence interval is large and includes substantial gains, since average consumption levels are $580.

positive (0.080, s.e. 0.023, 99% confidence). Among those not still enrolled in school, the gains are nearly identical, at 0.103 additional meals (s.e. 0.029) with an externality gain of 0.101 (s.e. 0.032).

There are statistically significant improvements in meals eaten for those working in all employment sectors, and mirroring the hours worked and productivity results, the gains are largest outside of agriculture. Deworming led to an increase of 0.205 meals eaten (s.e. 0.059) among wage earners and the non-agriculturally self-employed, with large externality effects of 0.180 (s.e. 0.067) meals. There was a smaller, though still significant, gain of 0.076 meals (s.e. 0.035) among those engaged in agriculture. This suggests that the labor market gains documented for respondents in the non-agricultural sector (relative to agriculture) translate into higher living standards, as well. It is worth noting that some of the additional calories may be required to allow for the by increased physical effort at work (given the gains in labor hours), as suggested by Deaton and Drèze (2008).

5. Socially Optimal Subsidies for Deworming

We first calibrate a Grossman (1972) style model in section 5.1, using changes in the observed hours worked in our data to compare the social welfare under full deworming subsidies, partial subsidies, and no subsidies, under the model from section 2, which assumes fully informed rational agents. We also assess whether the additional government revenues generated by increased labor supply are greater or less than the direct costs of implementing the deworming program. We then consider a "health planner" perspective, setting aside traditional welfare economics based on revealed preference, and calculate the social rate of return to deworming as a human capital investment in section 5.2. Using parameter values directly obtained in the empirical analysis, we conclude that large subsidies for deworming are justified, and that the future revenue generated by deworming is likely to outweigh the initial program outlays.

5.1 Calibrating the health investment model

It is possible to calibrate the model with our data on the impact of deworming on hours worked and data from Kremer and Miguel (2007) on price responsiveness, and solve for the lower bound on inefficiencies of spending needed for a higher subsidy to be preferred. Re-writing equation (3), we have that, for two levels of subsidy for which $s_2 > s_1$, the government prefers subsidy s_2 to s_1 if

$$(3) \quad \lambda \leq \frac{\int_{\tilde{d}_i=\overline{s_1}}^{\overline{s_2}} \left(\frac{\delta}{1-\delta} (xw + x_S(N-1)w) - p - \tilde{d}_i - \eta_I \right) dF(\tilde{d}_i)}{(s_2 - s_1) \int_{\tilde{d}_i=0}^{\overline{s_1}} dF(\tilde{d}_i) \; + s_2 \int_{\tilde{d}_i=\overline{s_1}}^{\overline{s_2}} dF(\tilde{d}_i)}$$

if both subsidies are larger than zero, and a positive subsidy to no subsidy if

$$(4) \quad \lambda \leq \frac{\int_{\tilde{d}_i=\bar{0}}^{\bar{s}} \left(\frac{\delta}{1-\delta} (xw + x_S(N-1)w) - p - \tilde{d}_i - \eta_I \right) dF(\tilde{d}_i) - \eta_N - M\eta_S}{s \int_{\tilde{d}_i=0}^{\bar{s}} dF(\tilde{d}_i)}$$

In order to be conservative, we impose that those who do choose to deworm are making weakly optimal decisions but set their net benefits from treatment to zero, so that $\frac{\delta}{1-\delta} xw - \tilde{d}_i - (p - s_i) = 0$. By assuming that those who take deworming themselves do not personally benefit, this procedure abstracts from credit market imperfections, behavioral issues, and failures of intra-household bargaining, all of which could plausibly lead households to further under-consume deworming, and instead bases gains on deworming's externality benefits.

For concreteness, in what follows we assume that $\alpha = \frac{1}{3}$, although the magnitudes of the results are not sensitive to changing this value.[25] We calculate the hourly earnings in non-agricultural work (combining wage work and profits from self-employment) as \$0.29 per hour. From Table 3, we conservatively estimate that if an extra person dewormed, those within 6 km of them (and who are not currently in school) are currently working an extra 0.00013 hours a week.[26] Since people only work a third of their total healthy time, this implies a daily increase of 0.0004 hours of healthy time.

[25] To illustrate why this is reasonable, working (40 hours/week) x (50 weeks/year) = 2,000 hours per year corresponds to $\alpha = 0.34$, assuming people are endowed with 16 hours of healthy (non-sleep) time per day.
[26] The estimates are for intent-to-treat externality effects. Using them provides a lower bound on the true benefits due to the fact that any region-wide health and labor market benefits would not be captured in this measure.

This is equivalent to a utility gain in the model of 0.0004 x US$0.29 x (365 days) = US$0.01 in money-metric utility terms in the first year. We assume that earnings first rise and then gradually fall over the life cycle in an inverted-U shaped manner, as documented by Knight, Sabot, and Hovey (1992) for Kenyan labor markets. With a conservative annual discount rate of 10%, and labor force participation for 40 years, we estimate that the NPV of the externality benefit for each person affected is US$0.03 (when we start discounting 10 years before labor earnings start to match our case, since deworming was done in 1998 and we start observing labor earnings a decade later). From Table 1, each person who is dewormed generates externality benefits for an average of at least 4,709 others (those who attended primary school within 6 km, which is a lower bound since benefits for individuals in other age groups are not considered), so under our assumption of additively separable externality effects, the total externality utility benefit per person who actually deworms is US$0.03 x 4,709= US$133.

We use current estimates of per pupil mass treatment costs (provided by the NGO Deworm The World) of US$0.59 per year. This cost incorporates the time of personnel needed to administer drugs through a mass school-based program, and accounts for the fraction of our sample that requires treatment with the more expensive drug for schistosomiasis (praziquantel). The total direct deworming cost then is the 2.41 years of average deworming in the treatment group times US$0.59, or US$1.42. Under partial subsidies (as in the 2001 cost-sharing program), individuals paid an average of $0.27 for the medicines, so the direct cost to the government would be $1.15.

Taken together, these figures allow us to estimate the expected welfare costs and benefits of targeting one additional person for deworming at various subsidy levels, and the level of costs that would make that level of subsidy less socially beneficial than no government intervention (or a lower subsidy level). Table 7, Panel A lays out the results. The first row presents the price for deworming drugs paid by individuals under the three subsidy regimes: no subsidy, partial subsidy and full subsidies for deworming. Drawing on Kremer and Miguel (2007), the third row presents the take-up levels that resulted from these prices, with sharply declining take-up at higher prices, and the next row presents the average subsidy price per targeted student, taking into account that actual spending is low in the case of partial subsidies since take-up is falls. The fifth row presents the total utility benefits generated by deworming externalities (in money-metric terms) under each of the three subsidy regimes, as described above.

The next rows present the inefficiency of government spending (λ) needed in order for the costs of the subsidies to outweigh the social benefits. The first two test for the size of λ given no implementation costs, while the following four isolate the size of fixed implementation costs (either at the targeted-individual or national level) given no inefficiencies in spending. Data on the number of Kenyan school children come from estimates by the US Census[27] (around ten million school-aged children) and from UNICEF[28] (around 80% primary school enrollment rates).

We also present information on the extent of inefficient government spending needed for a purely profit-maximizing government to prefer not to subsidize deworming, looking only at the increased tax revenue (at a 17% tax rate, roughly the average in Kenya over the last 20 years as well as approximately the current rate[29]) coming from the increase in work hours. Given the large increase in work hours and resulting gains in earnings and tax revenues, we find that deworming is a case in which the upfront "investment" cost of treatment is smaller than the later tax revenues generated by rising labor supply. In a context such as this, the concept of deadweight loss is less useful than with other expenditure programs, since the initial costs of deworming could be borrowed by a government and then repaid over time wth the increased tax revenue. We believe the case of deworming in Kenya is among the first to be shown to display this property of having later revenue outweigh initial costs.

Across all specifications in Panel A of Table 7, the costs for deworming subsidies to be inefficient are very large, with a benevolent government needing to waste over 8,000% of

[27] http://www.census.gov/population/international/data/idb/country.php
[28] http://www.childinfo.org/files/ESAR_Kenya.pdf
[29] http://data.worldbank.org/indicator/GC.TAX.TOTL.GD.ZS

expenditure (in other words, for over $80 to be wasted for each $1 in productive government spending, which seems highly implausible in even the world's most corrupt societies), or for the program fixed costs to be on the order of hundreds of millions of U.S. dollars annually, rather than the real-world costs of the 2009 Kenyan national deworming program which were not even 1% of these amounts. Even a "selfish" government that cared only about future government revenues and placed no value on other social benefits of the program would need to waste over 495% of expenditure (nearly $5 wasted for each $1 in actual program spending) in order for it not to want to fully subsidize deworming medicine.

5.2 Deworming as a human capital investment

An alternative approach is to calculate the internal rate of return (IRR) on deworming investments to assess its relative benefits and costs, including for those who took deworming themselves. This approach complements the Grossman-style (1972) model calibration presented above by incorporating both direct benefits to those who take deworming drugs, and the gains due to higher individual wage productivity.

On the benefits side, we consider the earnings gains estimated over 40 years of an individual's work life, making the same assumptions on lifecycle earnings in Kenya as above. We make several assumptions that imply that our rate of return estimates are lower bounds on the true returns to deworming. An important assumption in some calculations is that only those working in non-agricultural employment (34% of those not still in school) will experience improved living standards as a result of deworming. Disregarding living standards gains experienced by those in agriculture is conservative given that the number of meals eaten rose in this subsample. There may also be broader community-wide benefits to deworming among those not of school age, for example, among the younger siblings of the treated (Ozier 2010); we conservatively also ignore these gains.

As outlined above, cost for 2.41 years of treatment is approximately $1.42. Multiplying by the average compliance rate (46% in treatment schools, accounting for cost-sharing years and the fact that some of the sample "ages out" of primary school each year) gives an average cost of $0.65 per treatment pupil and $0.44 per pupil in the full sample (Table 7, Panel B). Auriol and Walters (2009) suggest that deadweight loss is around 20%, so we estimate an average total cost per student in the treatment schools of $0.44 x (1 + 0.2) = $0.53.

Under these assumptions, the average gain in total lifetime earnings (undiscounted) from deworming treatment per pupil in the PSDP sample is $1,001 (Table 7, Panel B). [30]

An estimated IRR of 64.7% is obtained by considering the increase in total earnings, and treating time spent in school as having no net benefits or costs beyond the impact on earnings. The interpretation is that a social planner with an annual discount rate or cost of capital of less than 64.7% would choose to invest in deworming as a human capital investment. For reference, at the time of writing nominal commercial interest rates in Kenya are 10-12% per annum, the rate on long-term sovereign debt is 11% and inflation is 3% (according to the Central Bank of Kenya).[31] Deworming appears to be an attractive investment given the real cost of capital in Kenya.

We have so far focused on those working outside of agriculture because their productivity gains are more accurately measured than those in agriculture. As a growing share of our sample has obtained non-agricultural employment over time (appendix figure A3), this may be a conservative assumption. If we abandon this assumption and assume that the full sample experienced analogous living standard gains, the social internal rate of return would be much larger, with lifetime earnings gains of $2,961 and an estimated IRR of 81.7%.

[30] The other potential component of costs is the opportunity cost of time spent in school rather than doing something else, presumably working. We focus on the case where all of the additional days spent in school were due to an increase in non-sick time, as in the Grossman (1972) framework. An alternative assumption is that all days of additional schooling came at the expense of days worked. This would be an upper bound on the actual opportunity cost of time, if school participation instead increased at least in part because children were simply sick less often. The internal rate of return figures remain large even under this more conservative assumption (not shown).

[31] This figure was obtained at: http://www.centralbank.go.ke/ (accessed November 1, 2010).

6. Conclusion

The Kenya Primary School Deworming Program was experimentally phased-in across 75 rural schools between 1998 and 2001 in a region with high rates of intestinal worm infections, one of the world's most widespread diseases. As a result, the treatment group exogenously received an average of two to three more years of deworming treatment than the control group. A representative subset of the sample was followed up for roughly a decade through 2007-09 in the Kenya Life Panel Survey, with high survey tracking rates, and the labor market outcomes of the treatment and control groups are compared to assess impacts.

There were large increases in average hours worked (by 12%) as a result of deworming. There are sharp shifts in employment towards jobs that require full-time regular work, and have higher wages, notably towards manufacturing sector jobs (especially for males) and away from casual labor and domestic services employment (for females). As a result, among those working for wages average earnings rise by over 20%. These findings complement Bleakley's work on historical deworming programs in the U.S. South in the early 20th century, and the correspondence between the two sets of results – using distinct research designs and data – increases confidence in both findings.

The finding that shifts into different employment sectors account for the bulk of the earnings gains suggests that characteristics of the broader labor market – for instance, sufficient demand for manufacturing workers – may be critical for translating better health into higher living standards. Our finding of considerable labor market impacts (outside of the agricultural sector) suggests that Kenyan labor markets are more flexible than is often believed. We cannot decompose how much of our labor market impacts are working through health versus education without imposing strong assumptions, but both "channels" appear to play a role.

The social returns to child deworming treatment appear high using an approach based on calibration the Grossman (1972) model, or an alternative social planner approach, where the latter generates an annualized social internal rate of return of 81.7%. The estimates suggest that the externality benefits alone justify fully subsidizing school-based deworming. In fact, using parameter estimates from our data and actual Kenyan public finance statistics, and under conservative assumptions, deworming generates more in later government revenue (appropriately discounted) than it costs in upfront subsidies, making it a highly attractive public investment.

It goes without saying that deworming alone, and its associated increase in earnings, cannot make more than a small dent in the large gap in living standards between poor African countries like Kenya and the world's rich countries. Yet that obvious point does not make deworming any less attractive as a public policy option given its extraordinarily high social rates of return, and the fact that boosting incomes by roughly a quarter would have major welfare impacts for households living near subsistence.

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Table 1: Baseline (1998) summary statistics and PSDP randomization checks, and KLPS (2007-09) survey attrition patterns

	All mean (s.d.)	Treatment mean (s.d.)	Control mean (s.d.)	Treatment – Control (s.e.)	Kolmogorov-Smirnov p-value
Panel A: Baseline summary statistics					
Age (1998)	11.9	11.9	12.0	-0.04	0.106
	(2.6)	(2.6)	(2.6)	(0.11)	
Grade (1998)	4.23	4.22	4.25	-0.03	0.162
	(1.68)	(1.70)	(1.66)	(0.05)	
Female	0.470	0.469	0.473	-0.004	--
				(0.019)	
School average test score (1996)	0.029	0.024	0.038	-0.013	0.299
	(0.427)	(0.436)	(0.406)	(0.109)	
Primary school located in Budalangi division	0.370	0.364	0.381	-0.017	--
				(0.137)	
Population of primary school	476	494	436	58	0.405
	(214)	(237)	(146)	(54)	
Total treatment (Group 1, 2) primary school students within 6 km	3,180	3,085	3,381	-296	0.165
	(917)	(845)	(1,022)	(260)	
Total primary school students within 6 km	4,709	4,698	4,732	-34	0.210
	(1,337)	(1,220)	(1,555)	(389)	
Years of assigned deworming treatment, 1998-2003	3.31	4.09	1.68	2.41***	--
	(1.82)	(1.52)	(1.23)	(0.08)	
Panel B: Sample attrition, KLPS					
Found[a]	0.862	0.860	0.867	-0.007	--
				(0.017)	
Surveyed	0.825	0.824	0.827	-0.003	--
				(0.018)	
Not surveyed, dead	0.017	0.018	0.014	0.004	--
				(0.004)	
Not surveyed, refused	0.015	0.014	0.017	-0.003	--
				(0.005)	

Notes: The data in Panel A are from the PSDP, and includes all individuals surveyed in the KLPS2. There are 5,084 observations for all variables, except for Age where N=5,072. All variables in Panel A are 1998 values unless otherwise noted. Years of assigned deworming treatment is calculated using the treatment group of the respondent's school and their grade, but is not adjusted for the treatment ineligibility of females over age 13 or assignment to cost-sharing in 2001. Those respondents who "age out" of primary school are no longer considered assigned to treatment. The average school test score is from the 1996 Busia District mock exam, and has been converted to units of normalized individual standard deviations. The sample used in Panel B includes all individuals surveyed, found deceased, refused participation, found but unable to survey, and not found but sought in intensive tracking during KLPS2, a total of 5,569 respondents (3,686 treatment and 1,883 control). All observations are weighted to maintain initial population proportions. The "Treatment – Control" differences are derived from a linear regression of the outcome on a constant and the treatment indicator, but results are similar if we include further controls. Standard errors are clustered by school. Significant at 90% (*), 95% (**), 99% (***) confidence. The Kolmogorov-Smirnov p-values are only presented for the non-binary variables, where it is informative. [a] The proportion "Found" is the combination of pupils surveyed, found deceased, refused and found but unable to survey.

Table 2: Impacts on health, nutrition and education outcomes

Dependent variable	Control group variable mean (s.d.)	Coefficient estimate (s.e.) on deworming treatment indicator	Coefficient estimate (s.e.) on deworming treatment school pupils within 6 km (in '000s), demeaned
Panel A: Health and education outcomes during 1998-2001			
Moderate-heavy worm infection (1999, 2001 parasitological surveys)	0.321	-0.245***	-0.075***
	(0.467)	(0.030)	(0.026)
Hemoglobin (Hb) level (1999, 2001 parasitological survey samples)	126.1	1.03	0.91
	(14.7)	(0.81)	(0.96)
Falls sick often (self-reported), 1999	0.154	-0.037**	0.001
	(0.361)	(0.015)	(0.014)
Total primary school participation, 1998-2001	2.51	0.127***	-0.115*
	(1.12)	(0.064)	(0.060)
Academic test score (normalized across all subjects), 1999	0.026	0.059	0.158
	(1.000)	(0.090)	(0.101)
Panel B: Health and nutrition outcomes, KLPS (2007-09)			
Self-reported health "very good"	0.673	0.041**	0.028
	(0.469)	(0.018)	(0.022)
Height (cm)	167.3	-0.12	-0.39
	(8.0)	(0.26)	(0.33)
Number of pregnancies	0.98	-0.093	-0.044
	(1.29)	(0.066)	(0.065)
Miscarriage indicator (among females only)	0.039	-0.028**	-0.020*
	(0.194)	(0.013)	(0.010)
Out-of-school sample:			
Number of pregnancies	1.29	-0.136*	-0.127
	(1.34)	(0.082)	(0.086)
Miscarriage indicator (among females only)	0.039	-0.027**	-0.018*
	(0.194)	(0.013)	(0.010)
Panel C: Education outcomes, KLPS (2007-09)			
Total years enrolled in school, 1998-2007	6.69	0.279*	0.138
	(2.97)	(0.147)	(0.149)
Grades of schooling attained	8.72	0.153	0.070
	(2.21)	(0.143)	(0.146)
Indicator for repetition of at least one grade (1998-2007)	0.672	0.060***	0.010
	(0.470)	(0.017)	(0.023)
Enrolled in school in year of 2007-09 survey	0.252	0.003	-0.045*
	(0.434)	(0.022)	(0.026)
English vocabulary test score (normalized), 2007-09	0.000	0.076	0.067
	(1.000)	(0.055)	(0.053)
Passed primary school leaving exam during 1998-2007	0.505	0.048	0.032
	(0.500)	(0.031)	(0.029)
Out-of-school sample:			

English vocabulary test score (normalized), 2007-09	-0.232	0.107**	0.149***
	(0.972)	(0.052)	(0.047)
Passed primary school leaving exam during 1998-2007	0.413	0.061*	0.083***
	(0.493)	(0.032)	(0.028)

Notes: The sample size in Panel A is 2,720 for worm infection, 1,765 for Hb, 3,861 for health self-reports, and 5,057 for school participation, and 3,592 for test scores. Representative subsets of pupils in all schools were surveyed for these 1999 and 2001 pupil surveys. The sample in Panels B and C includes all individuals surveyed in KLPS-2, and the rows underneath "*Out-of-school sample*" further condition on not being enrolled in school in the year of survey. Self-reported health "very good" takes on a value of one if the answer to the question "Would you describe your general health as somewhat good, very good, or not good?" is "very good", and zero otherwise. Each row is from a separate OLS regression except the miscarriage indicator rows, which are marginal probit specifications (in which each observation is a pregnancy, N=3,238 in the full sample and N=3,199 in the out-of-school sample). All observations are weighted to maintain initial population proportions. Standard errors are clustered by school. Significant at 90% (*), 95% (**), 99% (***) confidence. All regressions 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 the cost-sharing school indicator.

Table 3: Deworming impacts on labor supply (out-of-school sample)

Dependent variable	Control group variable mean (s.d.)	Coefficient estimate (s.e.) on deworming Treatment indicator	Coefficient estimate (s.e.) on deworming Treatment pupils within 6 km (in '000s), demeaned	Obs.
Panel A: Hours worked in last week				
Full sample	15.2	1.76*	1.54	5,084
	(21.9)	(0.97)	(1.16)	
Out-of-school sample	18.5	3.10**	1.71	3,873
	(23.8)	(1.21)	(1.44)	
Indicator for hours worked > 0	0.704	0.023	-0.027	3,873
	(0.457)	(0.024)	(0.030)	
Hours worked within sector (conditional on hours>0) by individuals in:				
Wage employment, self-employment, agriculture	26.3	3.23**	3.51**	2,853
	(24.5)	(1.44)	(1.58)	
Traditional agriculture	9.8	1.10*	-0.77	2,187
	(9.1)	(0.66)	(0.62)	
Wage employment and/or self-employment	44.6	5.03**	7.40***	1,120
	(23.0)	(2.19)	(2.39)	
Self-employment	38.2	6.7**	7.7***	528
	(24.0)	(3.0)	(2.9)	
Wage employment	47.3	4.53*	5.06**	605
	(21.3)	(2.67)	(3.11)	
Panel B: Hours worked in all sectors, by individuals with hours>0 in past week in:				
Traditional agriculture	18.4	1.31	2.98**	2,187
	(19.5)	(1.33)	(1.45)	
Wage and/or self-employment	47.7	4.69**	7.00***	1,120
	(22.4)	(2.13)	(2.32)	
Self-employment	44.9	6.90**	7.47**	528
	(24.7)	(2.90)	(2.96)	
Wage employment	50.2	3.16	3.51	605
	(21.2)	(2.73)	(3.02)	

Notes: Each row in Panels A and B is from a separate OLS regression. All observations are weighted to maintain initial population proportions. The sample is restricted to respondents who were not enrolled in school in the year of the survey, except for the first row of Panel A (which is run on the full sample of surveyed individuals). Standard errors are clustered by school. Significant at 90% (*), 95% (**), 99% (***) confidence. All regressions 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 the cost-sharing school indicator.

Table 4: Deworming impacts on employment sector and occupation (out-of-school sample)

	Control group mean	Coefficient estimate (s.e.) on deworming treatment indicator	Coefficient estimate (s.e.) on deworming treatment pupils within 6 km (in '000s), demeaned	Mean (s.d.) hours per week worked in sector, control group	Mean (s.d.) days of work lost to poor health in last month, control	Mean (s.d.) earnings in sector, past month (KSH), control
Panel A: Employment Sector [a]						
Agriculture	0.536	-0.013	-0.006	10	1.6	--
		(0.031)	(0.038)	(9)	(2.9)	
Agriculture–cash crop (cotton, tobacco, sugar)	0.013	0.017*	-0.002	7	1.4	--
		(0.009)	(0.008)	(9)	(3.6)	
Self-Employment (non-agriculture)	0.133	0.023	0.006	34	1.8	--
		(0.016)	(0.016)	(26)	(4.4)	
Wage Employment	0.210	-0.006	-0.002	43	1.4	3,572
		(0.022)	(0.025)	(25)	(2.9)	(3,586)
Mother of child under age two	0.245	-0.010	-0.003	--	--	--
		(0.019)	(0.018)			
Idle / No occupation	0.206	-0.015	0.035	--	--	--
		(0.022)	(0.024)			
Panel B: Occupation within wage employment						
Agriculture	0.022	-0.017	-0.019	13	2.1	618
		(0.014)	(0.023)	(12)	(1.9)	(258)
Casual/Construction laborer	0.031	-0.041**	-0.022	51	0.4	2,246
		(0.019)	(0.018)	(31)	(1.0)	(1,576)
Fishing	0.200	-0.027	-0.014	37	2.1	3,130
		(0.063)	(0.086)	(25)	(4.2)	(1,722)
Manufacturing	0.031	0.067***	0.043	53	1.1	5,311
		(0.025)	(0.032)	(24)	(1.8)	(3,373)
Manufacturing – males only	0.032	0.082**	0.034	49	1.0	6,277
		(0.033)	(0.034)	(20)	(1.9)	(3,469)
Restaurants, cafes, etc.	0.064	-0.032	0.023	53	1.2	4,194
		(0.025)	(0.034)	(21)	(2.5)	(3,567)
Retail and wholesale trade	0.177	-0.001	0.042	43	1.0	2,636
		(0.047)	(0.048)	(25)	(2.0)	(2,373)
Services (all)	0.414	0.040	0.040	50	1.4	4,345
		(0.057)	(0.077)	(22)	(2.7)	(4,837)
Domestic	0.122	-0.015	-0.028	61	1.5	3,047
		(0.033)	(0.039)	(17)	(2.5)	(1,754)
Domestic – females only	0.346	-0.190*	-0.445***	65	1.6	2,795
		(0.113)	(0.154)	(17)	(2.6)	(888)
Trade contractors	0.096	-0.009	0.056	26	0.9	3,191
		(0.030)	(0.045)	(22)	(2.5)	(2,183)

Notes: The sample used in Panel A includes all individuals surveyed in the KLPS2 who were not enrolled in school in the year of the survey. The sample used in Panel B additionally restricts the sample to those respondents who report working for pay (with earnings greater than zero) at the time of the survey. Each row is from a separate OLS regression. All observations are weighted to maintain initial population proportions. Standard errors are clustered by school. Significant at 90% (*), 95% (**), 99% (***) confidence. All regressions 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 the cost-sharing school indicator.

[a] Note that we only have days of work missed in total, not separated by sector, so among those who work in multiple sectors, there is some overlap.

Table 5: Deworming impacts on wage and non-agricultural self-employment earnings

Dependent variable	Control group variable mean (s.d.)	Coefficient estimate (s.e.) on deworming Treatment indicator	Coefficient estimate (s.e.) on deworming Treatment pupils within 6 km (in '000s), demeaned	Obs.
Panel A: Wage earners, out-of-school subsample				
Ln(Total labor earnings, past month)	7.84	0.301***	0.228	687
	(0.84)	(0.091)	(0.163)	
Ln(Wage = Total labor earnings / hours, past month)	2.76	0.203*	0.027	605
	(0.94)	(0.111)	(0.155)	
Panel B: Wage earners since 2007 subsample				
Ln(Total labor earnings, most recent month worked)	7.88	0.211***	0.170	1,175
	(0.91)	(0.072)	(0.116)	
Indicator for worked for wages (or in-kind) since 2007	0.244	0.000	0.040	5,081
	(0.430)	(0.021)	(0.024)	
Panel C: Self-employed (non-agriculture), out-of-school subsample				
Total self-employed profits (self-reported) past month	1,771	409	-53	570
	(2,621)	(313)	(361)	
Total self-employed profits (self-reported) past month, top 5% trimmed	1,224	407**	198	539
	(1,151)	(176)	(212)	
Total employees hired (excluding self), among the self-employed	0.189	0.641*	0.623	616
	(0.625)	(0.374)	(0.530)	
Panel D: Wage earners or self-employed (non-agr.), out-of-school subsample				
Total earnings (wages, self-employed profits), past month (=0 for non-earners)	974	245*	46	3,847
	(2,392)	(136)	(186)	
Total earnings (wages, self-employed profits), past month, top 5% trimmed profits	900	231*	51	3,816
	(2,227)	(130)	(180)	
Panel E: Agriculture, out-of-school subsample				
Total value (KSh) of crop sales past year (if farm household)	578	126	-168	2,732
	(2534)	(198)	(264)	
Uses "improved" agricultural practice (fertilizer, seed, irrigation)	0.295	0.047*	0.035	2,738
	(0.456)	(0.027)	(0.028)	

Notes: The sample includes all individuals who were surveyed in KLPS2 who were not enrolled in school in the year of the survey. Panel A restricts to those who report positive earnings at the time of survey. Panel B instead restricts on reporting positive earnings since 2007. The three profit measures in panel C additionally restrict on having positive profits; this is not too restrictive as no one reports negative profits and only 5% of the sample report zero profits. "Agricultural work" in Panel E includes both farming and pastoral activities. Ln(Wage) adjusts for the different reporting periods for earnings (month) and hours (week), and is missing for those with zero earnings. Each row is from a separate OLS regression. All observations are weighted to maintain initial population proportions. Standard errors are clustered by school. Significant at 90% (*), 95% (**), 99% (***) confidence. All regressions 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 the cost-sharing school indicator.

Table 6: Deworming impacts on migration and meals eaten

Dependent variable:	Control group variable mean (s.d.)	Coefficient estimate (s.e.) on deworming Treatment indicator	Coefficient estimate (s.e.) on deworming Treatment pupils within 6 km (in '000s), demeaned	Obs.
Panel A: Migration (full sample)				
Residence in Busia district	0.740	0.14	-0.019	5,075
	(0.439)	(0.022)	(0.025)	
Residence in a city	0.179	-0.001	0.016	5,075
	(0.383)	(0.019)	(0.024)	
Residence > 500 km from 1998 primary school	0.031	0.017^{*}	0.018	5,046
	(0.174)	(0.010)	(0.013)	
Residence outside of Kenya	0.042	0.011	-0.003	5,075
	(0.202)	(0.011)	(0.016)	
Migrated to city for a job or to look for work	0.319	0.053	0.045	820
	(0.467)	(0.056)	(0.072)	
Panel B: Number of meals eaten				
Number of meals eaten yesterday, full sample	2.16	0.096^{***}	0.080^{***}	5,083
	(0.64)	(0.028)	(0.023)	
Number of meals eaten yesterday, among those not in school	2.16	0.103^{***}	0.101^{***}	3,872
	(0.64)	(0.029)	(0.032)	
Number of meals eaten yesterday, among those in agriculture	2.13	0.076^{**}	0.120^{***}	2,186
	(0.63)	(0.035)	(0.035)	
Number of meals eaten yesterday, among wage earners and self-employed	2.15	0.205^{***}	0.180^{***}	1,263
	(0.65)	(0.059)	(0.067)	
Number of meals eaten yesterday, among wage earners	2.15	0.224^{***}	0.173^{*}	695
	(0.65)	(0.072)	(0.101)	
Number of meals eaten yesterday, among self-employed	2.13	0.149^{*}	0.193^{*}	584
	(0.69)	(0.084)	(0.079)	

Notes: The sample used in Panel A includes all individuals surveyed in the KLPS2 with residential location information. Outcomes are indicators for location of residence at the time of survey. The sample used in Panel B is all individuals who were surveyed in KLPS2. All but the top row in this panel further restrict to those who were not enrolled in school in the year of survey. Each row is from a separate OLS regression. All observations are weighted to maintain initial population proportions. Standard errors are clustered by school. Significant at 90% (*), 95% (**), 99% (***) confidence. All regressions 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 the cost-sharing school indicator.

Table 7: Welfare and Rate of Return Analysis

Panel A: Health investment model calibration results	No subsidy	Partial Subsidy	Full Subsidy
Deworming Price Paid by Individuals (2.41 doses)	$1.42	$0.72	$0.00
Deworming Price Paid by Government (2.41 doses)	$0.00	$0.70	$1.42
Deworming Take-up Rate	0.05	0.19	0.75
Cost (USD) per targeted pupil (Cost per treated * Take-up rate)	$0.00	$0.13	$1.07
Net externality benefit per targeted pupil, in money-metric utility (USD)	$6.65	$25.29	$99.82
Inefficiency of spending (λ) above which subsidy less desirable than no subsidy		14,032%	8,737%
Inefficiency of spending (λ) above which full subsidy less desirable than partial subsidy			12,028%
Size of individual fixed treatment cost (η_I) above which subsidy less desirable than no subsidy		$25.16	$98.76
Size of individual fixed treatment cost (η_I) above which full subsidy less desirable than partial subsidy			$73.60
Size of national fixed treatment cost (η_N) above which subsidy less desirable than no subsidy (with an estimated 8,000,000 school children)		$200,000,000	$790,000,000
λ above which subsidy less desirable than no subsidy, only consider tax revenue (17% tax rate)		795.17%	495.07%
λ above which full subsidy less desirable than partial subsidy, only consider tax revenue (17% tax rate)			681.59%
Panel B: Deworming as a human capital investment	Total benefits (per pupil), USD	Deworming cost and DWL (per pupil), USD	Internal rate of return, per annum
Total lifetime earnings (over 40 years), only current non-agricultural sample gains	$1,001	$0.53	64.1%
Total lifetime earnings (over 40 years), entire sample gains	$2,961	$0.53	81.7%

Notes: The take-up levels and deworming subsidies and prices are taken from Kremer and Miguel (2007). Data on number of school-age children comes from the US census, on enrollment rates from UNICEF, and on tax rates from the World Bank.

Figure 1: The distribution of hours worked in the last week, deworming treatment versus control (if out of school and working 10 to 80 hours)
Panel A (top-left): Full sample; Panel B (top-right): Agricultural work subsample;
Panel C (bottom-left): Self-employed subsample; Panel D (bottom-right): Wage earner subsample.

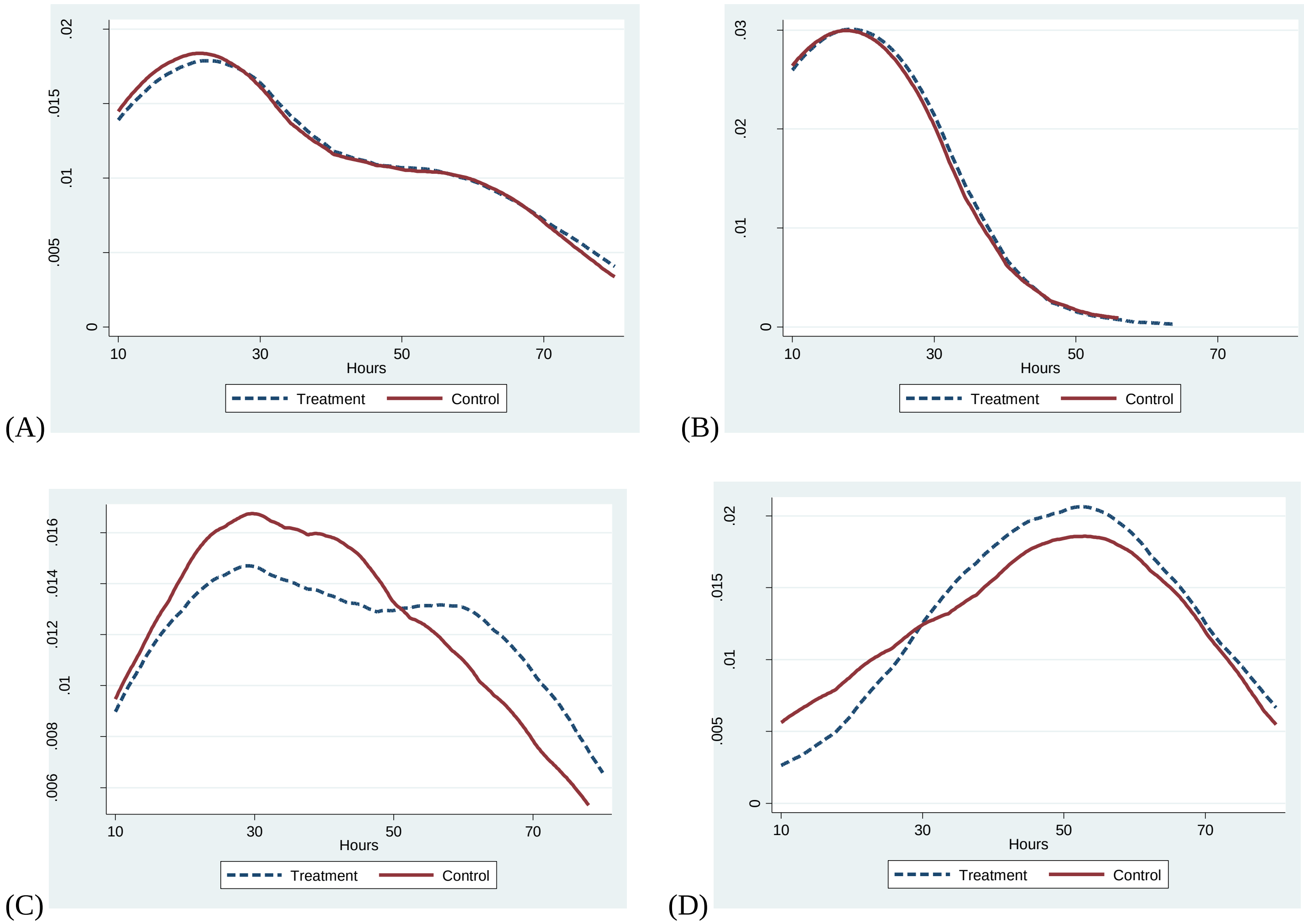
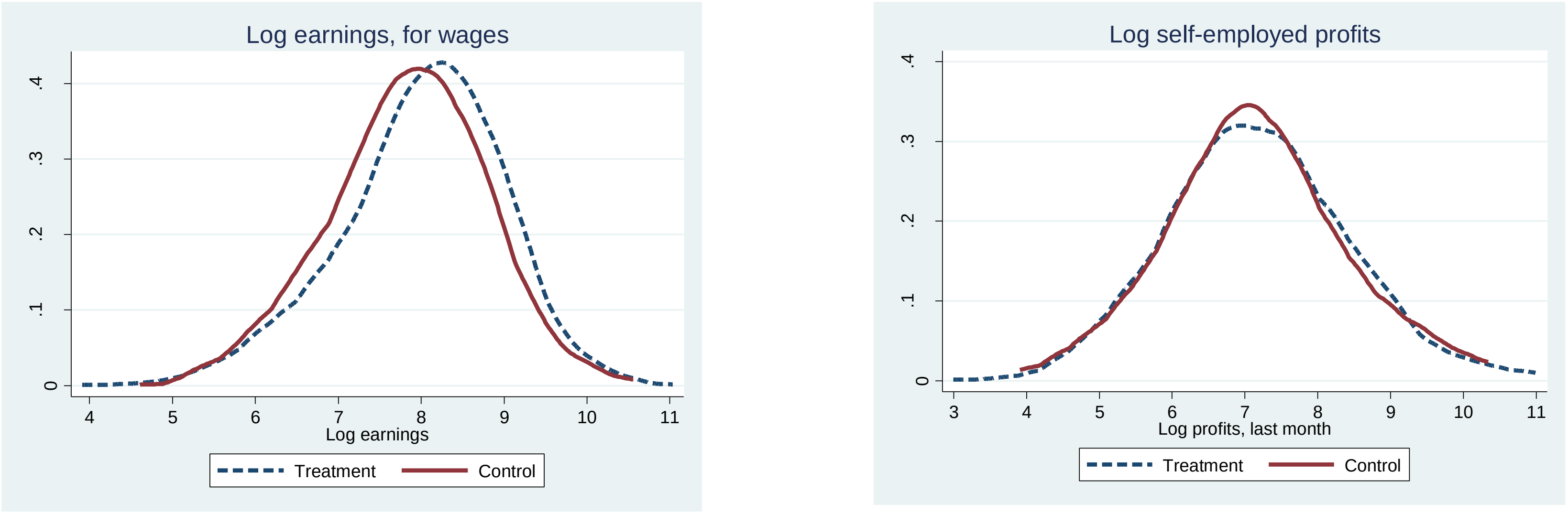


Figure 2: The distribution of log labor earnings and non-agricultural self-employment profits in the last month, deworming treatment versus control (among those with positive labor earnings or profits)



Notes: The sample used here includes all individuals who were surveyed in KLPS-2, were not enrolled in school at the time of survey and reported working for wages or in-kind or for positive profits in the last month. All observations are weighted to maintain initial population proportions.

Supplementary Appendix A: Research Design Appendix (not intended for publication)

A.1 Selection of Primary Schools for the PSDP Sample:
There were a total of 92 primary schools in the study area of Budalangi and Funyula divisions, across eight geographic zones, in January 1998. Seventy-five of these 92 schools were selected to participate in PSDP. The 17 excluded schools include: town schools that were quite different from other local schools in terms of student socioeconomic background; single-sex schools; a few schools located on islands in Lake Victoria (posing severe transportation difficulties); and those few schools that had in the past already received deworming and other health treatments under an earlier small-scale ICS (NGO) program.

In particular, four primary schools in Funyula Town were excluded due to large perceived income differences between their student populations and those in other local schools. In particular, Moody Awori Primary School, Namboboto Boys Primary School, and Namboboto Girls School charged schools fees well in excess of neighboring primary schools, and thus attracted the local "elite". Nangina Girls Primary School is a private boarding school, and charged even higher fees, and was similarly excluded.

Four other primary schools in Budalangi division were excluded from the sample due to geographic isolation, which introduced logistic difficulties and would have complicated deworming treatment and data collection. Three of these schools – Maduwa, Buluwani and Bubamba Primary Schools – are located on islands in Lake Victoria. The fourth, Osieko Primary School, is separated from the rest of Budalangi by a marshy area.

Two additional schools were excluded. Rugunga Primary School in Budalangi division served as the pilot school for the PSDP in late 1997, receiving deworming treatment before other local schools, and thus it was excluded from the evaluation. Finally, Mukonjo Primary School was excluded since it was a newly opened school in 1998 with few pupils in the upper standards (grades), and thus was not comparable to the other sample schools.

Seven schools had participated in the ICS Child Sponsorship Program/School Health Program (CSP/SHP). In 1998, it was felt that identification of treatment effects in these schools could be complicated by the past and ongoing activities in those schools, including health treatment (and deworming in particular), and hence they were excluded from the sample. The NGO's earlier criteria in selecting these particular seven schools (in 1994-1995) is not clear.

A.2 Prospective Experimental Procedure:
Miguel and Kremer (2004) contains a partial description of the prospective experimental "list randomization" procedure, and we expand on it here. Schools were first stratified by geographical area (division, then zone)[32], and the zones were listed alphabetically (within each division), and then within each zone they were listed in increasing order of student enrolment in the school. Table 1 shows there is no significant difference between average school populations in the treatment and control groups.

While the original plan had been to stratify by participation in other NGO programs, the actual randomization was not carried out this way. Schools participating in the intensive CSP/SHP program were dropped from the sample (as detailed above), while 27 primary schools with less intensive NGO programs were retained in the sample. These 27 schools were receiving assistance in the form of either free classroom textbooks, grants for school committees, or teacher training and bonuses. It is worth emphasizing that the randomized evaluations of these various interventions did

[32] There are two divisions (Budalangi and Funyula) containing a total of eight zones (Agenga/Nanguba, Bunyala Central, Bunyala North, Bunyala South, Bwiri, Funyula, Namboboto, Nambuku).

not find statistically significant average project impacts on a wide range of educational outcomes.[33] The schools that benefited from these previous programs were found in all eight geographic zones; the distribution of the 27 schools across the eight zones is: Agenga/Nanguba (5 schools), Bunyala Central (1), Bunyala North (4), Bunyala South (2), Bwiri (4), Funyula (5), Namboboto (1), Nambuku (5). The results in the current paper are robust to including controls for inclusion in these other NGO programs (results not shown).

The schools were "stacked" as follows. Schools were divided by geographic division, then zone (alphabetically), and then listed according to school enrolment (as of February 1997, for grades 3 through 8) in ascending order. If there were, say, four schools in a zone, they would be listed according to school enrolment in ascending order, then they would be assigned consecutively to Group 1; Group 2; Group 3; Group 1. Then moving onto the next zone, the first school in that stratum was assigned to Group 2, the next school to Group 3, and so on. Thus the group assignment "starting value" within each stratum was largely arbitrary, except for the alphabetically first zone (in the first division), which assigned the school with the lowest enrolment in its geographic zone to Group 1. Finally, there were three primary schools (Runyu, Nangina Mixed, and Kabwodo) nearly excluded from the original stacking of 72 schools that were added back into the sample for the original randomization, to bring the sample up to 75. These schools were originally excluded for similar reasons as listed above – e.g., Runyu is rather geographically isolated, and Nangina Mixed is a relatively high quality school located near Funyula Town. However, in the interests of boosting sample size, these three schools were included in the list randomization alphabetically as the "bottom" three schools in the list.

Deaton (2010) raises concerns about the list randomization approach, in the case where the first school listed in the first randomization "triplet" is different than other schools (in our case, it has lower than average school enrolment); the same concerns would apply to several other well-known recent field experiments in development economics, most notably Chattopadhyay and Duflo's 2004 paper "Women as policymakers: Evidence from a randomized policy experiment in India" in *Econometrica*.[34] However, this is not a major threat to our empirical approach. Following Bruhn and McKenzie (2009) we include all variables used in the randomization procedure (such as baseline school enrolment) as explanatory variables in our regression specifications, thus controlling for any direct effect of school size, and partially controlling for unmeasured characteristics correlated with school size. Table 7 shows that the estimate on the deworming treatment indicator is unchanged whether or not additional explanatory variables are included, suggesting that any bias is likely to be very small. The difference in average school enrollment between the treatment and control groups is small and not statistically significant (Table 1). Moreover, even if the first school in the first randomization triplet were an outlier along some unobserved dimension (which seems unlikely), given our sample size of 75 schools and 25 randomization triplets, and the fact that school size is not systematically related to treatment group assignment for the other 24 randomization triplets (as discussed above), approximately 96% of any hypothesized bias would be eliminated. Taken together, the prospective experimental design we exploit in the current paper is likely to yield reliable causal inference.

[33] See Glewwe, Paul, Michael Kremer, and Sylvie Moulin. (2009). "Many Children Left Behind? Textbooks and Test Scores in Kenya", *American Economic Journal: Applied Economics*, 1(1): 112-135.

[34] The references are Deaton, Angus. (2010). "Instruments, Randomization and Learning about Development", *Journal of Economic Literature*, 48, 424-455, and Chattopadhyay, Raghabendra, and Esther Duflo. (2004). "Women as policymakers: Evidence from a randomized policy experiment in India", *Econometrica*, 75(2), 1409-1443.

Supplementary Appendix Table A1: Baseline (1998) summary statistics and PSDP randomization checks (out-of-school sample)

	All mean (s.d.)	Treatment mean (s.d.)	Control mean (s.d.)	Treatment – Control (s.e.)	Kolmogorov-Smirnov p-value
Age (1998)	12.7	12.6	12.7	-0.114	0.319
	(2.4)	(2.4)	(2.4)	(0.118)	
Grade (1998)	4.56	4.54	4.61	-0.072	0.207
	(1.64)	(1.66)	(1.59)	(0.063)	
Female	0.500	0.496	0.508	-0.012	--
	(0.500)	(0.500)	(0.500)	(0.022)	
School average test score (1996)	0.013	0.009	0.020	-0.011	0.266
	(0.417)	(0.425)	(0.400)	(0.105)	
Primary school located in Budalangi division	0.386	0.375	0.408	-0.033	--
	(0.487)	(0.484)	(0.492)	(0.139)	
Population of primary school	477	498	433	65	0.370
	(218)	(241)	(148)	(55)	
Total treatment (Group 1, 2) primary school students within 6 km	3156	3071	3335	-264	0.193
	(923)	(845)	(1064)	(271)	
Total primary school students within 6 km	4663	4661	4667	-7	0.243
	(1352)	(1235)	(1571)	(400)	

Notes: The data are from the PSDP, and includes all individuals surveyed in the KLPS2 who had worked for wages in the past month at the time of the interview. All observations are weighted to maintain initial population proportions. Sample size is 3,873, except for age which is missing some information. All variables are 1998 values unless otherwise noted. The average school test score is from the 1996 Busia District mock exam, and has been converted to units of normalized individual standard deviations. The "Treatment – Control" differences are derived from a linear regression of the outcome on a constant and the treatment indicator, but results are similar if we include further controls (for survey wave, 1998 administrative zone of residence, cost sharing school indicator, and baseline 1998 population of the individual's primary school). Standard errors are clustered by school. Significant at 90% (*), 95% (**), 99% (***) confidence. The Kolmogorov-Smirnov p-values are only presented for the non-binary variables, where it is informative.

Supplementary Appendix Table A2: Baseline (1998) summary statistics and PSDP randomization checks, (out-of-school wage earner sample)

	All mean (s.d.)	Treatment mean (s.d.)	Control mean (s.d.)	Treatment – Control (s.e.)	Kolmogorov-Smirnov p-value
Age (1998)	13.3	13.1	13.5	-0.358	0.285
	(2.4)	(2.4)	(2.5)	(0.281)	
Grade (1998)	4.86	4.84	4.90	-0.057	0.477
	(1.61)	(1.63)	(1.57)	(0.142)	
Female	0.235	0.208	0.289	-0.081*	--
	(0.424)	(0.406)	(0.454)	(0.046)	
School average test score (1996)	-0.014	-0.030	0.020	-0.049	0.301
	(0.411)	(0.415)	(0.400)	(0.109)	
Primary school located in Budalangi division	0.412	0.434	0.397	0.037	--
	(0.494)	(0.496)	(0.490)	(0.146)	
Population of primary school	480	506	427	78	0.348
	(220)	(247)	(137)	(57)	
Total treatment (Group 1, 2) primary school students within 6 km	3196	3111	3369	-258	0.168
	(906)	(801)	(1069)	(290)	
Total primary school students within 6 km	4718	4728	4699	29	0.204
	(1331)	(1176)	(1602)	(430)	

Notes: The data are from the PSDP, and includes all individuals surveyed in the KLPS2 who had worked for wages in the past month at the time of the interview and were not enrolled in school during the year of interview. Sample size is 695, except for age which is missing some information (694 observations). All observations are weighted to maintain initial population proportions. All variables are 1998 values unless otherwise noted. The average school test score is from the 1996 Busia District mock exam, and has been converted to units of normalized individual standard deviations. The "Treatment – Control" differences are derived from a linear regression of the outcome on a constant and the treatment indicator, but results are similar if we include further controls (for survey wave, 1998 administrative zone of residence, cost sharing school indicator, and baseline 1998 population of the individual's primary school). Standard errors are clustered by school. Significant at 90% (*), 95% (**), 99% (***) confidence. The Kolmogorov-Smirnov p-values are only presented for the non-binary variables, where it is informative.

Supplementary Appendix Table A3: Impacts on school enrollment and participation

Panel A: Dep. var.: School enrollment indicator	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Total
Deworming Treatment indicator	N/A	0.021*	0.036**	0.047**	0.046**	0.046*	0.028	0.035	0.017	0.003	0.279*
		(0.011)	(0.016)	(0.019)	(0.021)	(0.022)	(0.026)	(0.027)	(0.027)	(0.027)	(0.147)
Deworming Treatment pupils within 6 km	N/A	0.011	0.014	0.024	0.026	0.015	0.008	0.016	0.034	-0.011	0.138
(in ‘000s), demeaned		(0.013)	(0.015)	(0.017)	(0.018)	(0.025)	(0.027)	(0.027)	(0.029)	(0.031)	(0.149)
Mean in the control group		0.924	0.834	0.757	0.696	0.653	0.584	0.474	0.426	0.342	6.690
Observations		5,037	5,037	5,037	5,037	5,037	5,037	5,037	5,037	5,037	5,037
Panel B: Dep. var.: Primary school participation											
Deworming Treatment indicator	0.074***	0.068***	0.013	0.057**	N/A	N/A	N/A	N/A	N/A	N/A	0.129**
	(0.023)	(0.023)	(0.020)	(0.024)							(0.064)
Deworming Treatment pupils within 6 km	0.019	-0.008	-0.019	0.009							0.044
(in ‘000s), demeaned	(0.024)	(0.018)	(0.020)	(0.017)							(0.049)
Mean in the control group	0.839	0.709	0.686	0.586							2.513
Observations	4,900	4,821	4,342	3,831							5,037

Notes: The sample used in Panel A includes all individuals who were surveyed in KLPS2. The sample used in Panel B includes a subset of these respondents who additionally have school participation data from at least one of the years between 1998 and 2001. All regressions include controls for baseline 1998 primary school population, geographic zone of the school, cost-sharing school in 2001 indicator, a gender indicator and pupil grade. The treatment indicator in 1998 is the Group 1 indicator. There is no estimated result for 1998 in Panel A since all respondents were enrolled in school in 1998 (as this was a study inclusion criterion). All observations are weighted to maintain initial population proportions. Standard errors are clustered by school. Significant at 90% (*), 95% (**), 99% (***) confidence.

Supplementary Appendix Table A4: Proportion of Individuals Working in Multiple Sectors (conditional probabilities in brackets)

	In School	Work in Agriculture	Work for Wages	Work in Self Employment	Mother of Child Under Age Two
In School	0.251	0.122	0.005	0.002	0.002
Work in Agriculture		0.519	0.040	0.058	0.112
Work for Wages			0.158	0.003	0.010
Work in self-employment				0.107	0.029
Mother of Child Under Age Two					0.182
None of the above: 0.154					

Notes: This table explores the proportion of individuals working in multiple sectors. The diagonal provides percentage of the overall respondents working in that specific sector. "None of the above" refers to respondents who are not in school, do not work in agriculture, for wages, or for self-employment, and are not a mother of a child under age two.

Supplementary Appendix Table A5: Deworming impacts on total hours worked among subgroups (out-of-school sample)

	Dependent Variable: Total Hours Worked in last week			
	(1)	(2)	(3)	(4)
Deworming Treatment indicator	3.10**	4.55**	2.48*	3.20**
	(1.21)	(1.87)	(1.49)	(1.33)
Female		-7.10***		
		(1.99)		
Female * Treatment		-2.83		
		(2.28)		
Grades 5-7 in 1998			4.00*	
			(2.06)	
Grades 5-7 * Treatment			1.14	
			(2.38)	
Moderate-heavy worm infection rate at the zonal level (1998), demeaned				7.3
				(8.6)
Moderate-heavy worm infection rate*Treatment				8.0
				(9.0)
R^2	0.063	0.064	0.062	0.062
Observations	3,873	3,873	3,873	3,873
Mean (s.d.) in the control group	18.5	18.5	18.5	18.5
	(23.8)	(23.8)	(23.8)	(23.8)

Notes: The sample includes all individuals surveyed in the KLPS2 with data for the relevant dependent variable who were not enrolled in school at the time of survey. All observations are weighted to maintain initial population proportions. Additional controls include a gender indicator, baseline grade fixed effects, geographic zone fixed effects, the mean pre-program school test score, baseline school population, cost-sharing school in 2001 indicator, survey wave indicator, and month of interview fixed effects, as well as both the total number of deworming treatment school pupils and the total number of primary school pupils within 6 km (in '000s), demeaned (coefficient estimates not shown). Standard errors are clustered by school. Significant at 90% (*), 95% (**), 99% (***) confidence

Supplementary Appendix Table A6: Baseline (1998) summary statistics and attrition checks

	Full KLPS Sample	Found: Regular Tracking	Found: Intensive Tracking	Not Found	Found (Regular and Intensive) – Not Found
Age (1998)	12.4	12.4	12.5	12.7	-0.37***
	(2.2)	(2.2)	(2.2)	(2.1)	(0.09)
Grade (1998)	4.26	4.24	4.24	4.32	-0.105
	(1.69)	(1.68)	(1.70)	(1.70)	(0.063)
Female	0.486	0.461	0.495	0.535	-0.072***
	(0.500)	(0.499)	(0.501)	(0.499)	(0.016)
Assignment to the deworming treatment group	0.675	0.681	0.665	0.664	0.006
	(0.468)	(0.466)	(0.473)	(0.472)	(0.020)
Group 1 school	0.357	0.355	0.354	0.362	-0.015
	(0.479)	(0.479)	(0.479)	(0.481)	(0.025)
Group 2 school	0.318	0.326	0.311	0.302	0.021
	(0.466)	(0.469)	(0.463)	(0.459)	(0.021)
Years of assigned deworming treatment during 1998-2003	3.29	3.32	3.25	3.22	0.069
	(1.83)	(1.82)	(1.83)	(1.85)	(0.090)
Primary school located in Budalangi division	0.380	0.361	0.389	0.420	-0.067***
	(0.486)	(0.480)	(0.488)	(0.494)	(0.023)
Population of primary school	484	480	465	496	-20**
	(221)	(223)	(178)	(222)	(8)
School average test score (1996)	0.043	0.035	0.023	0.066	-0.026
	(0.439)	(0.434)	(0.416)	(0.453)	(0.021)
Total treatment (Group 1 and 2) primary school students within 6 km	3171	3182	3174	3149	30
	(910)	(915)	(918)	(900)	(36)
Total primary school students within 6 km	4678	4713	4691	4602	93
	(1340)	(1342)	(1335)	(1334)	(62)
Number of observations [a]	7530	4891	421	2218	7530

Notes: The regression results (Found – Not Found) in column 5 reweights appropriately for intensive tracking. [a] The number of observations is correct except for the Age (1998) variable, which has somewhat more missing data.

Supplementary Appendix Table A7: Deworming impacts on labor earnings (2007-2009), robustness checks (out-of-school wage-earner sample)

	Dependent variable: Ln(Total labor earnings, past month)			
	(1)	(2)	(3)	(4)
Deworming Treatment indicator	0.311***	0.318***	0.371***	0.386***
	(0.092)	(0.092)	(0.088)	(0.090)
Deworming Treatment pupils within 6 km (in ‘000s), demeaned	0.268*	0.218	0.337***	0.444**
	(0.157)	(0.154)	(0.123)	(0.177)
Total pupils within 6 km (in ‘000s), demeaned	-0.148	-0.188	-0.184**	-0.167
	(0.120)	(0.118)	(0.094)	(0.120)
Cost sharing school (in 2001) indicator	-0.180**	-0.182**	-0.195**	-0.262***
	(0.088)	(0.092)	(0.095)	(0.089)
Cost sharing school pupils within 6 km (in ‘000s), demeaned				-0.273**
				(0.119)
Gender-age indicators	No	Yes	No	No
Randomization triplets	No	No	Yes	No
Additional controls	Yes	Yes	Yes	Yes
R^2	0.071	0.178	0.186	0.187
Observations	687	687	687	687
Mean (s.d.) in the control group	7.84	7.84	7.84	7.84
	(0.85)	(0.85)	(0.85)	(0.85)

Notes: The sample used here includes all individuals surveyed in the KLPS2 who report positive labor earnings at the time of survey and were not enrolled in school in the year of the survey. Labor earnings include cash and in-kind, and are deflated to reflect price differences between rural and urban areas. All observations are weighted to maintain initial population proportions. The top 1% of dependent variable values are trimmed in column 1. Significant at 90% (*), 95% (**), 99% (***) confidence. All regressions include controls for baseline 1998 primary school population, geographic zone of the school, and survey wave and month of interview. Additional controls include a female indicator variable, baseline 1998 school grade fixed effects, and the average school test score on the 1996 Busia District mock exams. Standard errors are clustered by school.

Supplementary Appendix Table A8: Deworming impacts on labor market outcomes among subgroups (out-of-school sample)

	Ln (Total labor earnings, past month)			Number of meals eaten yesterday		
	(1)	(2)	(3)	(4)	(5)	(6)
Deworming Treatment indicator	0.274***	0.260*	0.337***	0.160***	0.060	0.076***
	(0.106)	(0.140)	(0.090)	(0.046)	(0.042)	(0.033)
Female	-0.482***	-0.433***	-0.412***	0.168***	0.092***	0.091***
	(0.157)	(0.103)	(0.095)	(0.058)	(0.029)	(0.030)
Female * Treatment	0.093			-0.112*		
	(0.213)			(0.066)		
Grades 5-7 in 1998		0.372***			-0.046	
		(0.138)			(0.043)	
Grades 5-7 * Treatment		0.057			0.085	
		(0.168)			(0.055)	
Moderate-heavy worm infection rate at the zonal level (1998), demeaned			-0.191			-0.550***
			(0.403)			(0.180)
Moderate-heavy infection rate * Treatment			0.611			0.037
			(0.583)			(0.236)
R^2	0.186	0.174	0.179	0.038	0.037	0.028
Observations	687	687	687	3,872	3,872	3,872
Mean (s.d.) in control group	7.8	7.8	7.8	2.16	2.16	2.16
	(0.85)	(0.85)	(0.85)	(0.64)	(0.64)	(0.64)

Notes: The sample used in columns (1)-(3) include all individuals surveyed in the KLPS2 with data for the relevant dependent variable who were not enrolled in school at the time of survey and additionally restricts to those who report positive labor earnings at the time of survey. The sample used in columns (4)-(6) include all individuals surveyed in the KLPS2 with data for the relevant dependent variable who were not enrolled in school at the time of survey. All observations are weighted to maintain initial population proportions. Additional controls include a gender indicator, baseline grade fixed effects, geographic zone fixed effects, the mean pre-program school test score, baseline school population, cost-sharing school in 2001 indicator, survey wave indicator, and month of interview fixed effects, as well as both the total number of deworming treatment school pupils and the total number of primary school pupils within 6 km (in '000s), demeaned (coefficient estimates not shown). Standard errors are clustered by school. Significant at 90% (*), 95% (**), 99% (***) confidence.

Supplementary Appendix Figure A1: Project Timeline of the Primary School Deworming Program (PSDP) and the Kenya Life Panel Survey (KLPS)

January 1998: 75 primary schools chosen for Primary School Deworming Program (PSDP), and assigned to three groups of 25 schools (Group 1, Group 2, Group 3). Baseline pupil and school survey data collection.

↓

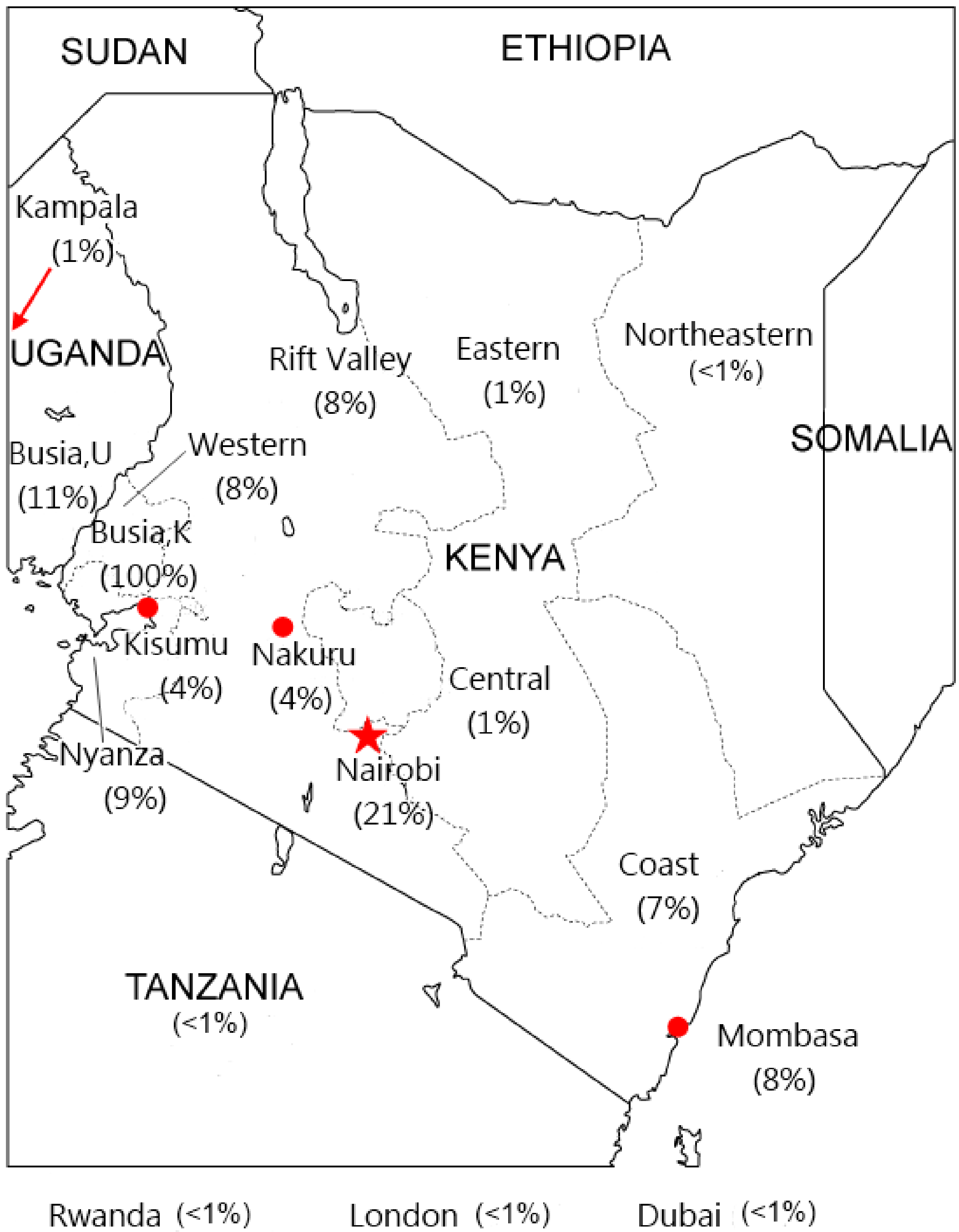
1998-2001: Ongoing unannounced school participation data collection visits

1998: Group 1 receives free deworming	**1998:** Group 2 does not receive deworming	**1998:** Group 3 does not receive deworming
1999-2000: Group 1 receives free deworming	**1999-2000:** Group 2 receives free deworming	**1999-2000:** Group 3 does not receive deworming
2001: A random half of Group 1 receives free deworming, half participate in cost-sharing	**2001**: A random half of Group 2 receives free deworming, half participate in cost-sharing	**2001**: Group 3 receives free deworming
2002-2003: Group 1 receives free deworming	**2002-2003**: Group 2 receives free deworming	**2002-2003**: Group 3 receives free deworming

2003-05: Kenya Life Panel Survey (KLPS) Round 1 data collection (Wave 1 2003-04, Wave 2 2004-05). N=5,211 (82.7% effective survey rate)

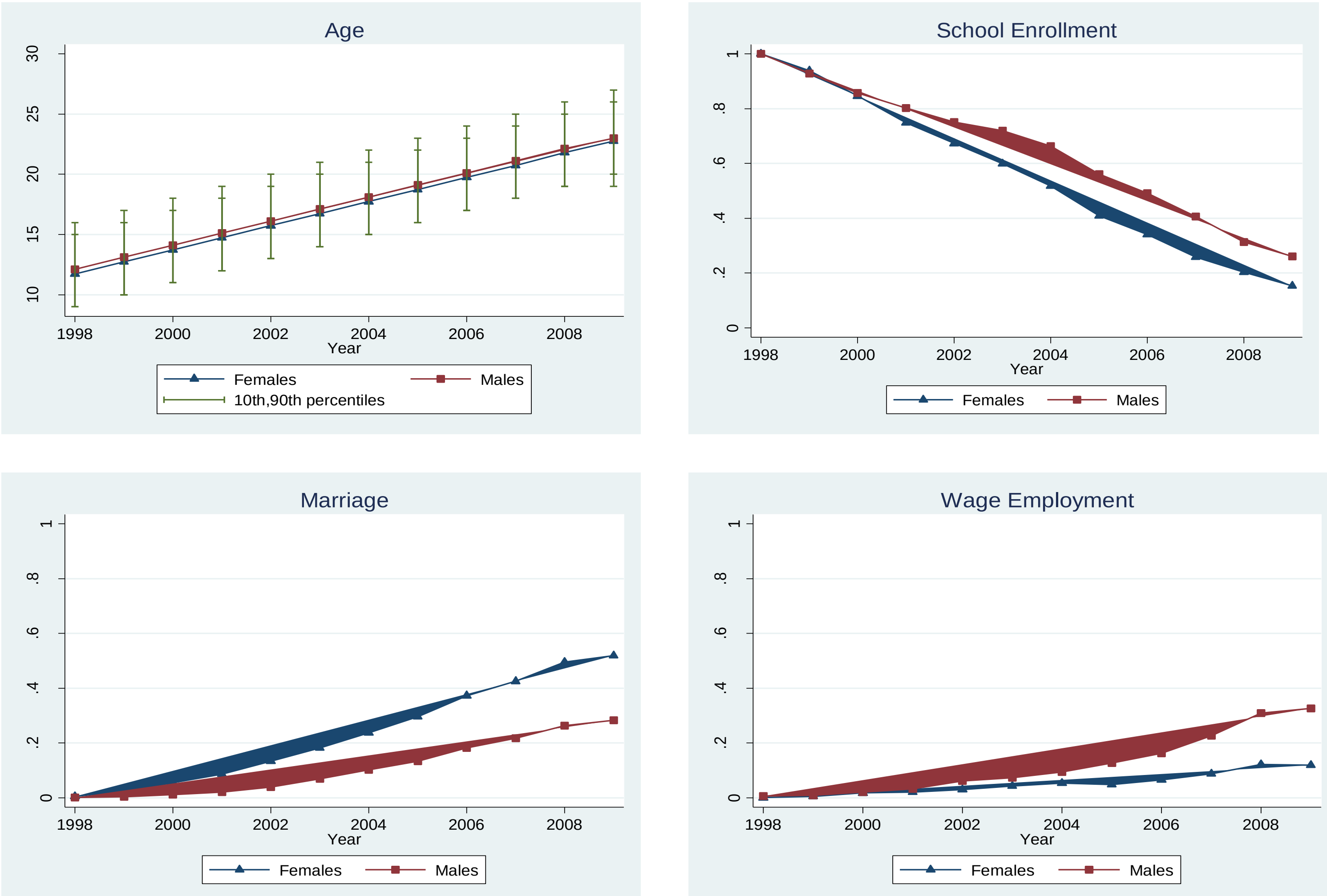
2007-09: Kenya Life Panel Survey (KLPS) Round 2 data collection (Wave 1 2007-08, Wave 2 2008-09). N=5,084 (82.5% effective survey rate)

Supplementary Appendix Figure A2: Migration residential location map

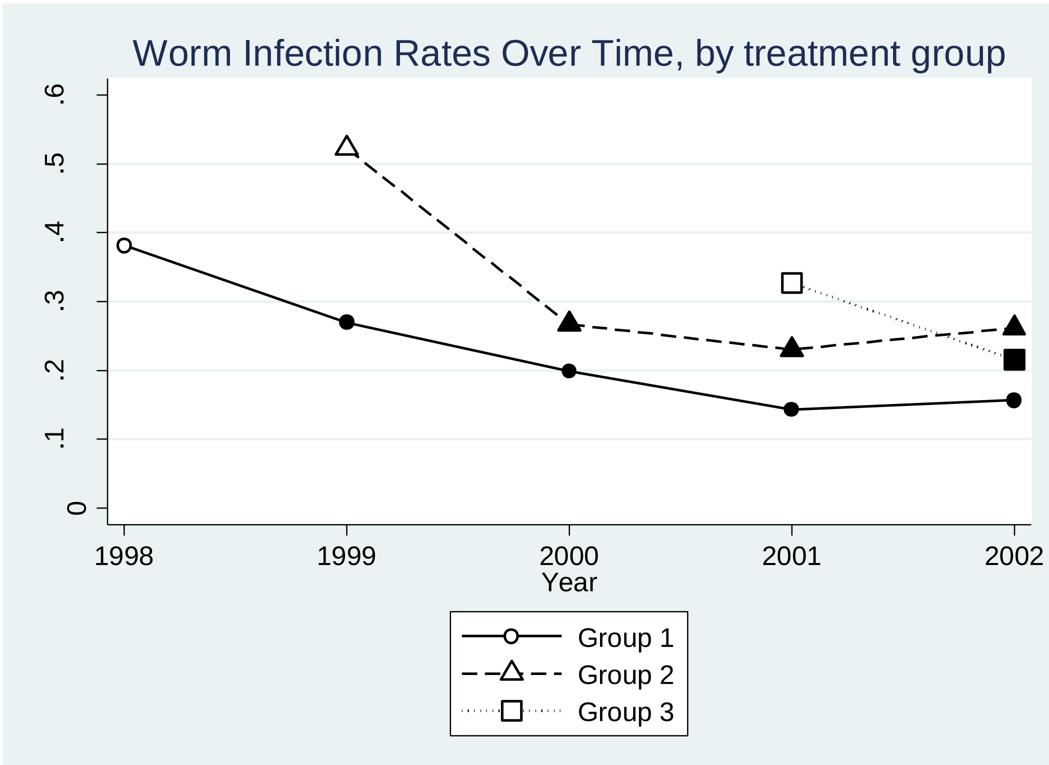


Notes: Percentages sum to greater than one, since they capture residential location (for at least four consecutive months) at any point during 1998-2009.

Supplementary Appendix Figure A3: Age, School Enrollment, Marriage and Employment Patterns over 1998-2009



Supplementary Appendix Figure A4: Moderate-heavy worm infection rates over time by PSDP treatment group



Notes: Hollow symbols (circles, triangles, squares) denote pre-deworming observations (for the group), and filled symbols denote post-deworming. Group 1 and Group 2 schools are jointly considered "treatment" in most of the analysis in the paper. Note that half of the Group 1 and Group 2 schools took part in deworming cost-sharing in 2001, likely accounting for some of the slight rise in infection rates observed in those groups between 2001 and 2002.