Final Report: Schistosomiasis, Agriculture and Migration in Africa: a joint Economic and Ecological Analysis

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1 Abstract of the executive summary

Irrigation schemes are one of the most important policy responses designed to reduce poverty, particularly in sub-Saharan Africa. Concomitantly, they facilitate the propagation of schistosomiasis, a water-based debilitating disease that is endemic in many developing countries. We study the economic impact of schistosomiasis in Burkina Faso using new data and new methods, and estimate that the elimination of the disease would increase average crop yields by 7%, rising to 32% for high infection clusters. Poorer households engaged in subsistence agriculture bear a far heavier disease burden than do richer ones: we show that schistosomiasis is both a driver and a consequence of poverty. We show that the returns to water resources development are significantly reduced once its health effects are taken into account.

2 Executive summary

2.1 Introduction

Schistosomiasis (*Bilharzia*) is a water-based debilitating neglected tropical disease that affects an estimated 250 million people, more than 85% of whom live in sub-Saharan Africa (Walz et al., 2015). Claiming 3 million disability-adjusted life years per year in the past decade, its global burden ranks second only to malaria among parasitic diseases (James et al., 2018). Severe morbidity due to schistosomiasis results from the accumulation of eggs laid by flatworms of genus *Schistosoma* in the tissues of the human host, leading to a chronic inflammatory response. The parasite species that cause the two main forms of the disease (intestinal and uro-genital) present a complex life cycle involving two reproduction phases, the first asexual in specific species of aquatic snail intermediate hosts, followed by sexual in the human host. Infection occurs through skin penetration by water-motile schistosome larvae, which, once matured, mate and secrete eggs that, exiting the human host through urine or feces, perpetuate the parasite's life-cycle. A large fraction of these eggs remains trapped in the tissues surrounding the bladder or the intestine, eliciting the chronic inflammation that constitutes the root of schistosomiasis-induced morbidity (Colley et al., 2014). When untreated, advanced forms of schistosomiasis lead to kidney failure, bladder cancer, liver fibrosis (Richter, 2003), as well as heightened risk of HIV transmission (Mbabazi et al., 2011). The highest parasite burden is usually borne by school-age children and the disease has been linked to anemia, stunting and cognitive deficits, leading to poor school performance and higher drop-out rates (King, 2010; Ezeamama et al., 2018; Miguel and Kremer, 2004). Due to these life-long impacts, schistosomiasis exerts large health, social and financial burdens on infected individuals and households (King, 2010).

Water resources development aimed at alleviating poverty in rural schistosomiasis-endemic communities in sub-Saharan Africa has been shown to exacerbate disease transmission (Steinmann et al., 2006). Dams and irrigation schemes expand the suitable habitat for the aquatic snails that serve as the intermediate hosts of schistosomes, and also increase the frequency and density of human-water contacts during which infection can occur (Diakité et al., 2017). This effect is particularly marked in water-constrained regions, possibly due to the concentration of human-water contacts in the few available water points (Steinmann et al., 2006). In developing countries, the sector which one would naturally expect to be the most affected by the disease is agriculture, particularly in its subsistence form (De Janvry and Sadoulet, 2010; Christiaensen et al., 2011). This is because populations that rely heavily on agricultural production are the ones that are the most exposed to infection and ultimately suffer the highest disease burden. Schistosomiasis may thus induce "poverty traps". However, its net economic impact and the underlying tradeoffs between water resources development and public health concerns have yet to be rigorously quantified.

General results concerning the relationship between diseases and economic development can be found in Acemoglu and Johnson (2007); Bloom et al. (2004); Bleakley and Lange (2009); Audibert (2010). Despite extensive evidence concerning the long-term health effects of endemic diseases in developing countries, there have been few attempts to quantify their economic impact. This is particularly true of parasitic diseases such as schistosomiasis. Attempts have been sparse and either focused on specific mechanisms of small scale, albeit of great importance, or lacked results of significant strength (Baldwin and Weisbrod, 1974; Weisbrod et al., 1974; Foster et al., 1967; Audibert and Etard, 1998; Audibert, 1986). Despite extensive evidence concerning the long-term health effects of various diseases, there have been few attempts to quantify their economic impact. This is particularly true of parasitic diseases such as schistosomiasis. St. Lucia was one of the first countries studied in an effort to ascertain the impact of schistosomiasis on labour productivity (Baldwin and Weisbrod, 1974; Weisbrod et al., 1974): very little was detected, but mismeasured variables and lack of data hindered the effort. The effect of schisosomiasis on agricultural production was first studied by Foster et al. (1967): again, only small negative effects were found. The quasi-experiment carried out by Audibert and Etard (1998) in Mali found no direct effects on rice production, but did find effects on the use of labour and other resources within households. Conversely, Audibert (1986) found a negative effect of schistosomiasis on rice production for infected households in the Cameroon. In Miguel and Kremer (2004), the authors evaluate a deworming project that includes schistosomiasis and establish the former's large health benefits, although without evidence of treatment effects on academic performance.

Because of the complexity of the dynamics of schistosomiasis and its interlinkages with a large set of socioeconomic and environmental variables (Gurarie and Seto, 2009), identifying the relationship between the disease and economic development via its effect on productivity requires the use of detailed agricultural and household datasets, as well as precise information on disease prevalence on a large spatial scale. Recent developments in disease mapping allow us to obtain high resolution prevalence maps which have been used in a variety of public health contexts (Lai et al., 2015) but have not hitherto been paired with household and plot-level data. We contribute to the literature by the novel use of high-resolution disease maps coupled with econometric methods in the estimation of an agricultural production function. In order to address various estimation biases and establish causality of the effect of schistosomiasis, we use the density of the aquatic snails that serve as intermediate host of the disease as an instrumental variable (henceforth, IV). The upper panel of Figure 1 shows a schematic representation of the mechanisms that we estimate in the paper: (1) the effect of schistosomiasis on agriculture; (2) the spatial densities of freshwater snails as instrumental variables; (3) poverty trap mechanics, where poverty and disease burden reinforce each other; (4) the feedback effects of water resources development and disease dynamics on agricultural yield.

We focus on Burkina Faso, a country where schistosomiasis is endemic both in its intestinal and uro-genital forms (Poda et al., 2004; Lai et al., 2015). Burkinabé agriculture is the main component of the country's economy, employing roughly 80% of the population, and is mostly of the subsistence variety, with low crop and livestock productivity and high levels of inefficiency (World Bank Results, 2017; Udry, 1996). Diversification in the sector is low, although increasing, with cotton being the most important cash crop. Large- and small-scale water resources development projects have been completed in the past 30 years to support agricultural activities and reduce climate vulnerability (Fig. 1b), which have however exacerbated the prevalence of malaria and schistosomiasis (Boelee et al., 2010). Mass drug administration campaigns, initiated by the Schistosomiasis Control Initiative in 2005, have been successful in reducing morbidity in most regions with a national mean prevalence of around 5% in school-age children in 2010 (Fig. 1d) (Ouedraogo et al., 2016).

Survey data were obtained from the National Institute of Statistics and Demography (INSD) in Ouagadougou. The annual plot-level agricultural dataset provides detailed information on crops, yields, inputs and pesticides, plot characteristics and labor type for the 2003-2017 period (details are provided in the Supplementary Material, henceforth SM). Surveyed villages were distributed relatively uniformly across the country (Fig. 1a). The household survey data cover the 1996-2017 period and include detailed information on household characteristics and demographics. We first merge and synchronize both survey datasets, and geolocalize the villages. We include a a comprehensive set of climatic remote-sensing data including precipitation, temperature, and vegetation indices. Full information on the dataset, summary statistics and details concerning the covariates used in the analysis can be found in the supplementary material (henceforth, SM) that is available upon request.

We then merge the dataset with two high-resolution maps of schistosomiasis prevalence estimates in school-aged children at a pixel resolution of 5×5 km. This combined dataset is one of the major contributions of this paper. The first map applies up until 2010 (Fig. 1c), the second thereafter (Fig. 1d). The estimated prevalence is a joint measure of both uro-genital and intestinal schistosomiasis, caused by *S. haematobium* and *S.*

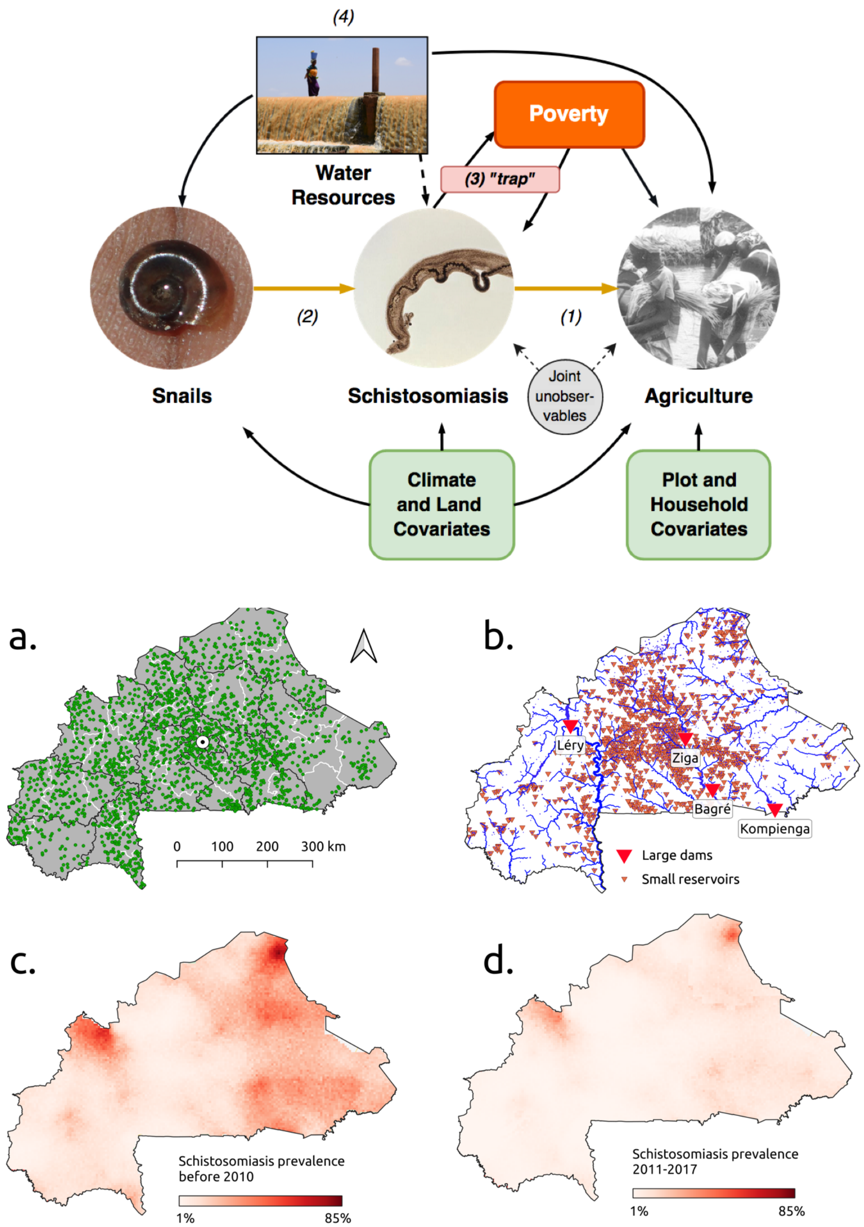

Figure 1: **Mechanisms studied in the paper and data overview**. (Upper Panel) Our main interest lies in estimating (1), the causal effect of schistosomiasis on agriculture. To achieve identification we use a set of variables (instruments) that influence disease intensity without directly affecting agriculture: we use the densities of the different snail species that act as intermediate hosts for the disease parasites (2). Poverty is shown to have a reinforcing effect on the burden the disease exerts on agricultural production, as well as being its consequence: this loop is akin to a "poverty trap" (3). Water resources development (4) is shown to boost agriculture and development, but also to increase the adverse effects of schistosomiasis via both the increase of snail habitat and human-water contact. (Lower Panel) (a) Villages included in the agricultural surveys, the capital Ouagadougou (white point) and level 1 (regions, black lines) and level 2 (provinces, white lines) administrative subdivisions. (b) River network (blue lines, width proportional to upstream area) and water resources infrastructure in the country. (c) Estimated schistosomiasis prevalence up to 2010. (d) Estimated schistosomiasis prevalence for 2011-2017.

mansoni, respectively, and is obtained by means of Bayesian geostatistical analysis. For details concerning the techniques utilized in the creation of the prevalence maps, we refer to Lai et al. (2015) for all details of the first map, which apply equivalently for the second one. Because of resolution of the disease maps, prevalence is constant within each village: households belonging to the same village will be assigned the same level of schistosomiasis prevalence. Given that health consequences of schistosomiasis are more directly linked to infection intensity (measured by egg-output) than to prevalence (Audibert, 1986; King and Dangerfield-Cha, 2008), we translate estimated prevalence into a joint measure of schistosomiasis infection intensity in terms of the average number schistosome egg-output per person. This was done by assuming a negative binomial distribution of egg counts in urine and stools fit to parasitological data. All our results continue to hold when disease prevalence obtained directly from the maps is used in place of our intensity measure. Model-based estimates of spatial snail density were derived from malacological surveys collected in two field sites located along the South-North climatic gradient between the Sudanian and Sahelian regions (Perez-Saez et al., 2016).

2.2 Schistosomiasis and Agriculture

In order to estimate the burden of schistosomiasis on agricultural production (relationship (1) in Figure 1), we rely on a specification that fully exploits the wealth of information available in our dataset at both plot and household levels. We identify the burden of the disease as a shock to overall productivity in an agricultural production function, which does not directly affect the amount of labor or physical inputs needed for production but instead influences their effectiveness. In the SM we report the complete mathematical framework and show how this interpretation of schistosomiasis as a productivity shock is not rejected by the data, and is compatible with a household optimization model. Since the "real" effect of the disease on household members is unobservable, we approximate it by the measure of infection intensity in terms of mean egg-output per person, as discussed earlier. Furthermore, our measure of schistosomiasis intensity is obtained at a village-level resolution, whilst our estimations exploit a substantially finer granularity in the data. This implies that plot-level estimation is likely to be affected by biases stemming from endogeneity issues, and we address these with the use of an IV strategy. This requires the choice of a set of variables (instruments) that are strongly related to the presence of schistosomiasis, and affect agricultural yield only via the disease burden. A natural choice is constituted by the densities of the snails that act as intermediate hosts of the disease parasites. The presence of either kind of aquatic snail is directly linked to the prevalence of both forms of schistosomiasis, whilst not having any direct detrimental effect on agricultural yields. In order to control for any effects that might jointly determine the presence of snails and agricultural production, we include a plethora of covariates that account for climate, precipitations and land characteristics. Once these variables are controlled for, snail densities are likely to constitute ideal instruments, and allow us to estimate the causal effect of interest. This corresponds to relationship (2) in the upper panel of Fig.1.

We present results for households and plots observed in 2009 and 2011. These years are chosen to maximize the number of observations and provide the best fit and associated model diagnostics. Furthermore, these years cover the sharp decrease in disease burden in school-aged children through Burkina Faso's schistosomiasis control program observed between 2008 and 2013 (Ouedraogo et al., 2016). All results instrument schistosomiasis intensity with our snail density measures. Results are similar for other combinations of years for which there are enough repeated households. All estimates include a measure of malaria prevalence in order to account for co-morbidity which, interestingly, does not significantly affect yield at conventional levels of confidence. In no way does this imply that malaria has no adverse effect on households: this simply reflects the fact that malaria exerts a burden of an entirely different nature, possibly more compatible with a shock to labor supply. Details of this specification, as well as the complete description of the models, the covariates and the estimation methods as well as all additional tables, results and robustness checks, are reported in the SM. The upper panel of Figure 2 reports the main estimates of the paper, which quantify the loss of agricultural yield due to schistosomiasis. The point estimate represents the marginal percentage impact of one additional worm egg per person on yield, and the labels indicate the percentage loss of agricultural yield due to schistosomiasis, both on average and in the top 5% infection intensity clusters.

The topmost estimate in the upper panel of Figure 2 results from a multiplicative (Cobb-Douglas) form for the production technology, which results in a log-linear model. The point estimate shows that schistosomiasis causes an average loss of agricultural yield of 8.9% (95% CI: 1.1%-16.5%), rising to 43.5% for the households in the top 5% quantile of disease intensity. The second estimate is agnostic concerning the functional form of the production technology: we absorb all the non-linear confounding effects stemming from the large matrix of inputs by means of various adaptive machine learning methods. By doing so, point estimates of the disease intensity's marginal effect fall, and precision improves. For our 2009-2011 sample, our preferred method is given by tuned random forests, and results in a mean loss of yield caused by schistosomiasis of 6.6% (95% CI: 2.2%-12.02%), increasing to 32.2% for the household at the top 5% infection quantile. All plot-level estimates control for time, household and crop unobservables, and in the SM we show how the endogeneity bias is likely to result from measurement errors. Aggregating the data to the village level yields similar results. Non-linearities in the impact of schistosomiasis are significant, as illustrated in the lower panel of Fig.2. The adverse effect of the disease is concentrated in villages that experience mid- to high levels of disease intensity, with the negative effect on yield appearing at intensities above 30 worm eggs/person. The upshot from the policy perspective is that the adverse impact of schistosomiasis on economic development is substantial, and control efforts aiming at reducing disease morbidity would produce substantial gains in agricultural productivity.

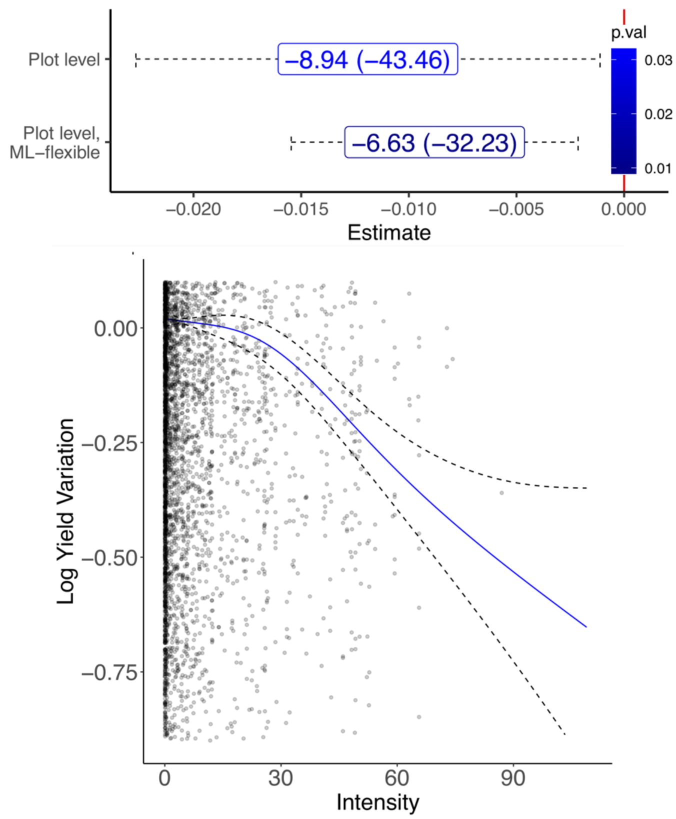

Figure 2: **Estimated burden of schistosomiasis on agricultural yield.** (Upper panel) Estimates of the yield loss (in percent) due to schistosomiasis. Each label reports the average loss and in parentheses the loss at the top 5% infection intensity clusters. 95% error bands are cluster-bootstrapped at the village level. (Lower panel) Nonlinear effect of the disease. Estimation done by fitting an instrumented adaptive spline using a two-stage semiparametric method. Dotted lines represent the 95% confidence interval in function fitting.

2.3 Schistosomiasis and poverty

In Burkina Faso, agricultural households are largely engaged in subsistence farming: shocks to yield therefore affect simultaneously both income and survival probability. Moreover, it is likely that the productivity decrease attributable to schistosomiasis is a function of various household characteristics. Here, we explore two such characteristics: cropping patterns and poverty. We first focus on plots that produce the main cash crop farmed by Burkinabé households, cotton. In the SM we show that such plots are significantly larger and seem to be immune from any deleterious effects of schistosomiasis. A potential reason for this could be that households farming cash crops such as cotton on large plots are on average much richer: they may therefore have readier access to clean running water and enjoy better sanitary conditions. In contrast, households that rely on food crops farm smaller plots and suffer the most from the productivity shock. This is a first sign of how schistosomiasis is effectively a disease of poverty, acting both as its cause and consequence, as indicated in relationship (3) in Figure 1. However, cash crops, particularly GMO-resistant varieties of cotton, are also sometimes farmed by poorer households in order to reduce the risk of adverse shocks. To account for this, we examine the additional burden of the disease for households farming plots that belong to different quantiles of the joint distribution of plot surface and crop weight. Households in the lower reaches of this joint distribution correspond to those who are the most affected by poverty, almost entirely dependent on subsistence agriculture. We interact schistosomiasis intensity with an indicator representing whether a given plot belongs to a specific quantile of the joint plot surface/crop weight distribution. We then estimate the coefficient associated with this interaction variable, while varying the indicator on a grid ranging from the 20th to the 60th percentile of the joint distribution. The coefficients associated with these variables represent the added burden of schistosomiasis linked with the underlying plot characteristics, which are likely to be correlated with poverty at the household level. In the upper panel of Figure 3 we show such plots suffer an additional loss to yield due to schistosomiasis ranging from 5% to 10%. These incremental effects vanish at the 55th percentile (the complete set of results is presented in the SM).

In order to characterize this mechanism in terms of its link to household poverty, we then carry out a similar procedure where the indicator function is defined at the household rather than at the plot level. The cutoffs in this case correspond to the lower 5% and 10% tails of the joint distribution of total harvest weight and plot surface farmed by each household. The lower panel of Figure 3 shows that for such households schistosomiasis exerts a disproportionately higher burden: -32.7% for the households in the bottom 10% and -45% for those in the bottom 5%. Results are unchanged if one carries out the procedure using the joint distribution of harvest and plot yield.

Poverty thus reinforces the negative economic impact of schistosomiasis, with this feedback loop potentially generating a poverty trap phenomenon. Conversely, development interventions that increase agricultural productivity and allow peasants to diversify

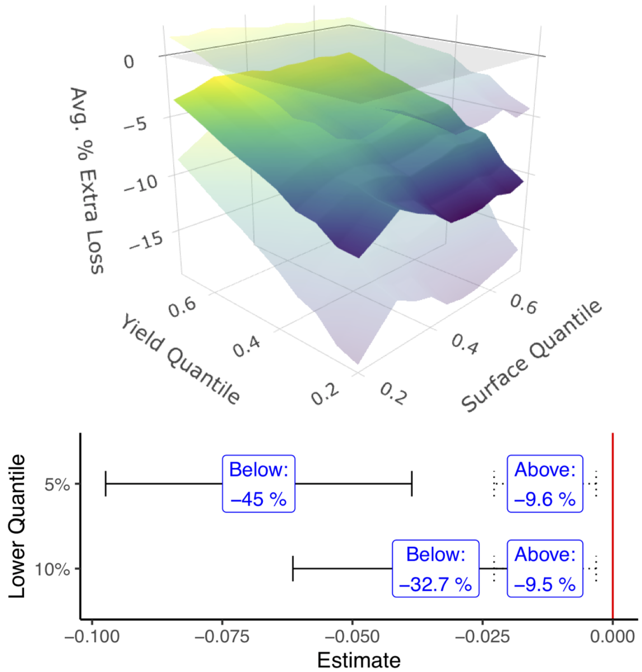

Figure 3: **Schistosomiasis as poverty trap.** (Upper panel) Added schistosomiasis-induced yield loss due to poverty. Each point on the middle surface represents the extra loss due to the disease for plots below the respective crop weight and surface quantiles. The upper and lower transparent surfaces are cluster-bootstrapped 95% confidence intervals. (Lower panel) Losses to yield suffered by households above and below threshold levels of poverty, defined by the left tail of the joint harvest weight and plot surface distribution.

into cash crops will both improve living standards and reduce the burden of the disease.

2.4 Schistosomiasis and water resources development

Having established the reinforcing effects of schistosomiasis on poverty, it is of substantive importance to examine whether economic policies aimed at lifting people out of poverty can indirectly increase poverty itself by means of their impact on the spatial distribution of the disease, as indicated by mechanism (4) in Figure 1. Given that schistosomiasis is water-based, we study the feedback effects between the disease and water resources development. We begin by concentrating our attention on Burkina Faso's four main dams (Fig. 1b). To address this question we aggregate the data up to the village level, and we compute the geographical distance of each village from the closest dams and reservoirs. We are interested in whether the presence of a large dam affects the magnitude of the effect of schistosomiasis on agricultural yields, and thus identify villages in provinces that directly benefit from the presence of the four main dams. Interacting the presence of a dam with our measure of disease intensity allows us to disentangle the direct impact of dams, which should increase yields, from the deleterious indirect effects that they

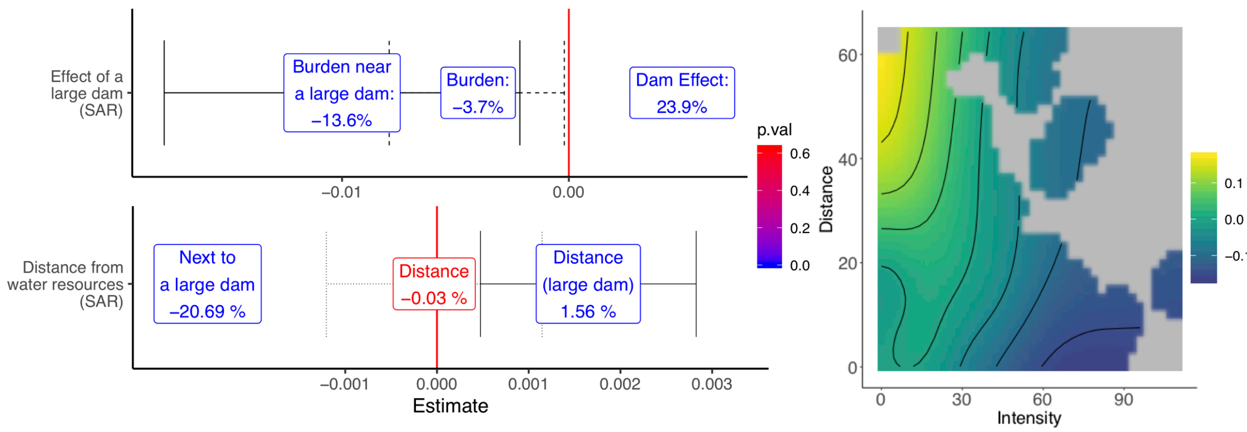

Figure 4: **Feedback effects of disease and water resources on agriculture.** (Top left) Added effect of schistosomiasis on yields caused by the presence of a large dam. (Bottom left) Joint effect of schistosomiasis, distance from water resources networks and dam size. Estimations account for spatial correlation. (Right) Joint effect of schistosomiasis and distance from dams and water networks. Each point in the fitted surface represents the effect of schistosomiasis on yield for a village at the corresponding distance from a dam or a water reservoir: the darker the color, the more negative is the effect.

may produce by facilitating the diffusion of schistosomiasis. The explicit inclusion of the dams, however, generates spatial dependence in the data that does not vanish even when controlling for the highest possible level of unobservables (regions), and therefore for the estimation we rely on a spatial autoregressive specification (SAR). The upper left-hand panel of Figure 4 shows that whilst the presence of a dam increases yield by 23.9%, the average burden due to schistosomiasis increases from a yield loss of 3.7% to 13.6% for villages in proximity to large dams.

We refine the previous results by accounting for each village's distance in km from the nearest dam or water reservoir. The full network of dams and reservoirs is illustrated in panel (b) of Figure 1. The right-hand panel of Figure 4 shows how the deleterious marginal effect of schistosomiasis intensity on yield is mitigated as one moves further away from a dam or a reservoir, as well as how areas with high schistosomiasis intensity are concentrated within 20 km of a dam or reservoir. Households located in these areas suffer from large negative feedback effects between schistosomiasis and water resources development; to make matters worse, the effect of an increase in distance on the marginal effect of schistosomiasis intensity is greater for villages which display lower disease intensity.

From a policy perspective, it is important to investigate whether it is only large-scale dams that are the culprits when it comes to the transmission of the disease, or whether smaller scale projects built for livestock and small-scale irrigation can potentially generate as much of an adverse effect. We interact the presence of a large dam with the distance from any water infrastructure as well as with the measure of intensity. Results are presented in the lower left-hand panel of Figure 4. For villages located within 1 km from a large dam, the average estimated loss due to schistosomiasis is 20.7%. An increase of one kilometer in distance from the dam generates an average 1.6% *reduction* of the burden of schistosomiasis on agricultural yield: being further away from large dams is therefore beneficial. The distance effect for villages *not* in proximity of large dams, however, is insignificant at any level of confidence: such dams seem indeed to be the main culprits of the feedback effects. The consequences from the standpoint of poverty and inequality can be substantial: populations that gain the most from such large irrigation projects often do not correspond to those most exposed to their deleterious consequences in terms of health and productivity.

Schistosomiasis therefore imposes a substantial burden on agricultural production, generating losses which range from an average of 6.6% to 32% for households and villages located in areas in high infection clusters. This burden is paradoxically reinforced both by poverty and by poverty-reducing measures such as water resources development. Given that grain output represents roughly 12% of Burkina Faso's gross domestic product, our preferred mean estimate implies that schistosomiasis is associated with economic losses which correspond to around 0.8% of GDP. From a policy perspective, perhaps our most interesting result is that while dams and reservoirs, *ceteris paribus*, increase agricultural yields, they can also induce substantial negative feedback effects by spreading the disease. We show that this feedback is generated entirely by large-scale dams, which account for a significant portion of development finance. Our work highlights how the study of the interactions between disease diffusion and economic development can benefit from the use of high-resolution data, which allows one to control for the numerous confounding factors that data at higher levels of aggregation necessarily miss. While our focus has been on Burkina Faso, in part because it is likely to be a worst-case scenario due to the country's joint economic and epidemiological profile, our approach can be applied to any country in which schistosomiasis is endemic and, indeed, to the economic impact of many other diseases.

References

Acemoglu, Daron and Simon Johnson, "Disease and Development: The Effect of Life Expectancy on Economic Growth," *Journal of Political Economy*, 2007, *115* (6), 925–985.

Audibert, Martine, "Agricultural non-wage production and health status: A case study in a tropical environment," *Journal of Development Economics*, 1986, *24* (2), 275–291.

_ , "Endemic Diseases and Agricultural Productivity: Challenges and Policy," *Journal of African Economies*, 2010, *19* (3), 110–165.

— **and Jean-Francois Etard**, "Impact of Schistosomiasis on Rice Output and Farm Inputs in Mali," *Journal of African Economies*, 07 1998, *7* (2), 185–207.

Baldwin, Robert E. and Burton A. Weisbrod, "Disease and Labor Productivity," *Economic Development and Cultural Change*, 1974, *22* (3), 414–435.

Bleakley, Hoyt and Fabian Lange, "Chronic disease burden and the interaction of education, fertility, and growth," *The Review of Economics and Statistics*, 2009, *91* (1), 52–65.

Bloom, David E., David Canning, and Jaypee Sevilla, "The Effect of Health on Economic Growth: A Production Function Approach," *World Development*, 2004, *32* (1), 1 – 13.

Boelee, Eline, Philippe Cecchi, and André Koné, *Health impacts of small reservoirs in Burkina Faso*, Vol. 136, Iwmi, 2010.

Christiaensen, Luc, Lionel Demery, and Jesper Kuhl, "The (evolving) role of agriculture in poverty reductionAn empirical perspective," *Journal of Development Economics*, 2011, *96* (2), 239–254.

Colley, Daniel G, Amaya L Bustinduy, W Evan Secor, and Charles H King, "Human schistosomiasis," *The Lancet*, 2014, *383* (9936), 2253–2264.

Diakité, Nana R, Mirko S Winkler, Jean T Coulibaly, Négnorogo Guindo-Coulibaly, Jürg Utzinger, and Eliézer K N'Goran, "Dynamics of freshwater snails and *Schistosoma* infection prevalence in schoolchildren during the construction and operation of a multipurpose dam in central Côte d'Ivoire," *Infectious Diseases of Poverty*, 2017, *6* (1), 93.

Ezeamama, Amara E, Amaya L Bustinduy, Allan K Nkwata, Leonardo Martinez, Noel Pabalan, Michael J Boivin, and Charles H King, "Cognitive deficits and educational loss in children with schistosome infectiona systematic review and meta-analysis," *PLoS Neglected Tropical Diseases*, 2018, *12* (1), e0005524.

Foster, R et al., "Schistosomiasis on an irrigated estate in East Africa. III. Effects of asymptomatic infection on health and industrial efficiency.," *Journal of Tropical Medicine and Hygiene*, 1967, *70* (8), 185–195.

Gurarie, David and Edmund YW Seto, "Connectivity sustains disease transmission in environments with low potential for endemicity: modelling schistosomiasis with hydrologic and social connectivities," *Journal of the Royal Society Interface*, 2009, *6* (35), 495–508.

James, Spencer L, Degu Abate, Kalkidan Hassen Abate, Solomon M Abay, Cristiana Abbafati, Nooshin Abbasi, Hedayat Abbastabar, Foad Abd-Allah, Jemal Abdela, Ahmed Abdelalim et al., "Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017," *The Lancet*, 2018, *392* (10159), 1789–1858.

Janvry, Alain De and Elisabeth Sadoulet, "Agricultural growth and poverty reduction: Additiona l evidence," *The World Bank Research Observer*, 2010, *25* (1), 1–20.

King, Charles H., "Parasites and poverty: The case of schistosomiasis," *Acta Tropica*, 2010, *113* (2), 95 – 104.

King, Charles H and Madeline Dangerfield-Cha, "The unacknowledged impact of chronic schistosomiasis," *Chronic Illness*, 2008, *4* (1), 65–79.

Lai, Ying-Si, Patricia Biedermann, Uwem F Ekpo, Amadou Garba, Els Mathieu, Nicholas Midzi, Pauline Mwinzi, Eliezer K N'Goran, Giovanna Raso, Rufin K Assae, Moussa Sacko, Nadine Schur, Idrissa Talla, Louis-Albert Tchuem Tchuente, Seydou Toure, Mirko S Winkler, Jurg Utzinger, and Penelope Vounatsou, "Spatial distribution of schistosomiasis and treatment needs in sub-Saharan Africa: a systematic review and geostatistical analysis," *The Lancet Infectious Diseases*, 2015, *15* (8), 927 – 940.

Mbabazi, Pamela Sabina, Olivia Andan, Daniel W Fitzgerald, Lester Chitsulo, Dirk Engels, and Jennifer A Downs, "Examining the relationship between urogenital schistosomiasis and HIV infection," *PLoS Neglected Tropical Diseases*, 2011, *5* (12).

Miguel, Edward and Michael Kremer, "Worms: Identifying Impacts on Education and Health in the Presence of Treatment Externalities," *Econometrica*, 2004, *72* (1), 159–217.

Ouedraogo, Hamado, François Drabo, Dramane Zongo, Mohamed Bagayan, Issouf Bamba, Tiba Pima, Fanny Yago-Wienne, Emily Toubali, and Yaobi Zhang, "Schistosomiasis in school-age children in Burkina Faso after a decade of preventive chemotherapy," *Bulletin of the World Health Organization*, 2016, *94* (1), 37.

Perez-Saez, Javier, Theophile Mande, Natalie Ceperley, Enrico Bertuzzo, Lorenzo Mari, Marino Gatto, and Andrea Rinaldo, "Hydrology and density feedbacks control the ecology of intermediate hosts of schistosomiasis across habitats in seasonal climates," *Proceedings of the National Academy of Sciences*, 2016, *113* (23), 6427–6432.

Poda, J., A. Traoré, and B. K. Sondo, "L'endémie bilharzienne au Burkina Faso," *Societé de Pathologie Exotique*, 2004, *97* (1), 47–52.

Richter, Joachim, "The impact of chemotherapy on morbidity due to schistosomiasis," *Acta Tropica*, 2003, *86* (2-3), 161–183.

Steinmann, Peter, Jennifer Keiser, Robert Bos, Marcel Tanner, and Jrg Utzinger, "Schistosomiasis and water resources development: systematic review, meta-analysis, and estimates of people at risk," *The Lancet Infectious Diseases*, 2006, *6* (7), 411 – 425.

Udry, Christopher, "Gender, Agricultural Production, and the Theory of the Household," *Journal of Political Economy*, 1996, *104* (5), 1010–1046.

Walz, Yvonne, Martin Wegmann, Stefan Dech, Penelope Vounatsou, Jean-Noël Poda, Eliézer K N'Goran, Jürg Utzinger, and Giovanna Raso, "Modeling and validation of environmental suitability for schistosomiasis transmission using remote sensing," *PLoS Neglected Tropical Diseases*, 2015, *9* (11), e0004217.

Weisbrod, Burton A, Ralph L Andreano, Robert E Baldwin, Erwin H Epstein, Allen C Kelley, and Thomas W Helminiak, "Disease and economic development: The impact of parasitic diseases in St. Lucia," *International Journal of Social Economics*, 1974, *1* (1), 111–117.

World Bank Results, "Agriculture as a Powerful Instrument for Poverty Reduction," 2017.