Ancillary Consequences of Targeted Policy Interventions in the Presence of Disease-Based Poverty Traps: Evidence from Uganda

Authors

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Abstract

Feedback loops between income dynamics and disease prevalence affect livelihoods for many communities around the world by reinforcing conditions that can foster poverty traps. We develop a coupled natural-human system model of a local economy integrated with ecological and disease dynamics, which we use to investigate the direct and ancillary consequences of targeted policy interventions in a rural, developing-country setting where household livelihoods are deeply linked to health and the environment. Our model characterizes relationships between labor allocation, ecological sustainability, and disease transmission that are common across a wide range of settings. Our results demonstrate that targeted policy interventions can produce both intuitive and counterintuitive consequences. Productivity-enhancing interventions can produce economic, ecological, and public health benefits, while interventions that target ecological objectives may inadvertently prop up conditions that underlie disease-based poverty traps. We also consider how market structure may exacerbate or mitigate the trade-offs resulting from stand-alone and concurrently implemented policy interventions.

Introduction

Despite decades of investments by governments, donors, and NGOs, Neglected Tropical Diseases (NTDs) continue to persist in many parts of the world (Ogongo et al., 2022; World Health Organization, 2015). Schistosomiasis (hereafter, "Schisto") is the second most widespread NTD after malaria and is often associated with conditions of persistent poverty (Centers for Disease Control, 2018; Grimes et al., 2014). Common public health-centered approaches to combat Schisto, such as mass drug administration (MDA) and public investment in water, sanitation, and hygiene (WASH) infrastructure, face critical limitations, including limited coverage, imperfect compliance, reinfection risk, and behavioral constraints linked to household livelihood activities (King, Kittur, et al., 2020; Gurarie et al., 2018; Torres-Vitolas et al., 2023). These limits underscore the need for holistic approaches to combat disease and poverty that recognize the complex coupled natural-human systems in which NTDs are prevalent (Inobaya et al., 2014), including how human behavior sustains disease transmission.

Previous economic-epidemiological studies have emphasized feedback loops between income and disease prevalence. Poor health outcomes, especially those resulting from chronic parasitic infection, reduce labor productivity, increase vulnerability to economic shocks, and may limit long-term asset accumulation (Barrett and Carter, 2013; Gallup and Sachs, 2001; Cole and Neumayer, 2006). At the same time, lower income levels reduce access to treatment, reinforce exposure to diseases, and may delay or prevent recovery from infection (King, 2010). These patterns are consistent with disease-based poverty traps in which income and disease dynamics evolve jointly, highlighting the role of diseases as significant liabilities for poverty alleviation (Bonds et al., 2010; Ngonghala, De Leo, et al., 2017). NTDs often play a critical role in these dynamic relationships, particularly in settings with underdeveloped public health infrastructure, thereby sustaining chronic poverty and undermining development gains across generations (Ngonghala, Pluciński, et al., 2014).

In many rural, natural resource-dependent settings with waterborne parasites like Schisto, transmission risks are determined in part by labor allocation decisions, particularly in activities requiring prolonged contact with infested surface water, such as fishing and rice cultivation (Rinaldo et al., 2021). Driven by relative wages across the different sectors, these labor allocation decisions, in turn and along with levels of effective effort (e.g., hours worked), determine household income and health status. It follows then that policy interventions that alter relative wages across sectors, or that directly target exposure pathways, can shift household behavior in ways that drive changes in disease prevalence and income levels. For example, a public health intervention, such as MDA, could reduce the overall prevalence of the disease and simultaneously increase economic productivity and relative wages of some sectors (inducing labor to switch into those sectors). Whether the consequences of the labor reallocation lead to lower disease prevalence and greater economic activity is an open question, depending on the particulars of the local economy. For instance, treated households might allocate more labor to sectors that have higher disease prevalence, such as fishing and rice, and this could offset the effects of the MDA intervention. Similarly, an intervention targeting economic growth, such as increasing the productivity of an agricultural crop, will also impact household labor decisions that could increase or decrease exposure to the disease and potentially decouple economic growth with lower levels of disease burden.

At the same time, in many rural, natural resource-dependent settings, household labor allocation decisions lead to overexploited natural resources and degraded ecosystems. For example, overfishing on Lake Victoria is a decades-old problem that reduces future returns to fishing effort and contributes to the degradation of the environment (Witte et al., 1992; Kolding et al., 2014; Nyamweya et al., 2022). One of the few options available to policymakers seeking to regulate fishing effort and achieve sustainable, healthy ecosystems (Purcell and Pomeroy, 2015; Gilliland et al., 2022) in developing country settings is to limit access (e.g., number of fishing boats). In settings such as Lake Victoria, fishing exposes households to waterborne pathogens, and therefore, policies to conserve the fishery could have ripple effects in terms of disease prevalence in the region. It is possible, for instance, that a conservation policy that reduces fishing labor could lead to lower disease prevalence, which in turn could improve economic productivity while also simultaneously improving the ecosystem. Whether improving health, economic, and ecological outcomes simultaneously (a win-win-win outcome) is possible is an open question depending on the type of intervention and the interdependencies and interaction effects over time across income generation, labor allocation, ecological processes, and disease dynamics.

To investigate the impacts of targeted policy interventions on public health, economic, and ecological outcomes, we construct a coupled natural-human system model of a local economy in a developing country context that includes ecological and disease dynamics (see Figure 1). We use a rich one-of-a-kind data set on household consumption and production, and local businesses in the Lake Victoria region of Uganda, a setting where household livelihoods are deeply linked to health and the environment (Fiorella et al., 2017) to formulate the model. Specifically, we estimate and calibrate a computable general equilibrium (CGE) model of a local economy that is integrated with an epidemiological model of Schisto transmission and a ecological model of fish stock dynamics.

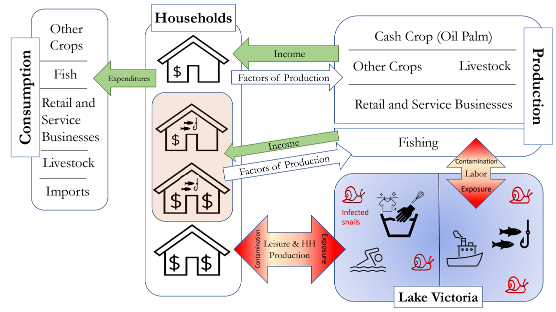

Figure 1: Conceptual framework of the natural-human environment. Four representative households engage in six consumption and six production activities within the local economy. The local fishing sector operates in Lake Victoria. Fishing labor time is a primary, time-varying source of exposure to Schisto.

We use the model to measure the direct and ancillary impacts of one-off sector-specific policies designed for outcomes within a single policy domain (economic, public health, ecological) and the concurrent implementation of multiple policy interventions to capture potential interaction and synergistic effects. Concurrent–rather than coordinated–implementation more accurately reflects the setting in our study area where efforts to coordinate across policy domains in many developing country settings are often limited by institutional capacity constraints, fragmented program delivery, and weak integration of data and planning functions (Requejo et al., 2024). Evidence from multi-sector growth models suggests that the welfare impact of layered interventions can exceed the sum of their individual effects (Bergquist et al., 2022). Our model thus provides a structured framework to explore how concurrent policies may reinforce or counteract each other through economy-wide spillover effects and cross-domain ancillary effects, aspects that are difficult to observe in isolated intervention studies. Our coupled model complements ex-post methods of policy evaluation, such as randomized control trials (RCTs) and quasi-experimental designs. While such methods can deliver credible causal estimates of targeted interventions' effects, they often analyze outcomes in partial equilibrium and within limited spatial or sectoral scopes, which can result in missing spillovers through local markets, wider economy-wide interactions, and policy effects across adjacent domains (Rodrik, 2015).

Our results demonstrate that targeted policy interventions can produce both intuitive and counterintuitive consequences. Interventions that target productivity in non-exposure-intensive economic sectors can produce increases in aggregate output alongside beneficial ecological outcomes while drawing labor away from high-exposure activities, thereby reducing contact time with infected water and lowering disease prevalence over time. Similarly, targeted reductions in disease prevalence can generate small but sustained economic gains by improving labor productivity, with minimal ecological antagonisms. When implemented concurrently, such interventions can partially offset tradeoffs that arise across policy objectives, although market structures can shape the extent to which antagonistic impacts are mitigated. At the same time, our results reveal less intuitive consequences. In particular, interventions that target ecological objectives can work against short-term economic objectives, as well as short- and long-run public health objectives, by incentivizing labor allocation decisions that sustain infection, highlighting how important and powerful trade-offs can exist between efforts to manage natural resources and efforts to reduce disease prevalence.

Our approach builds on and extends recent modeling efforts that explore how coupled natural-human systems can generate reinforcing feedback loops between economic behaviors, environmental change, and health outcomes (Ferraro et al., 2019; Doruska et al., 2024). While bio-economic CGE models have been used to study local general equilibrium effects of policy interventions (Gilliland et al., 2022; Lindsay et al., 2020; Manning et al., 2018), the integration of endogenous disease dynamics contributes to the literature by permitting us to consider policy interactions in complex environments with disease-based poverty traps. While our model is empirically based on a particular lake-region setting in Uganda, our modeling approach is designed to capture dynamics that are relevant in a broader class of low-income, resource-dependent economies where health, livelihoods, and environmental conditions are interdependent. We therefore interpret our findings as illustrative of general patterns, rather than predictive of precise outcomes in other locations.

Results

Our coupled model of the natural-human environment in a small Ugandan economy consists of four key linkages between the three model domains.[1] First, two epidemiological parameters (i.e., recovery rate and parasite-snail mortality rate) are functions of aggregate income in the local economy (Garchitorena et al., 2017), thereby capturing how public investment can affect disease prevention and treatment. Aggregate income in our model is endogenously determined through a general equilibrium framework that incorporates labor allocation, sectoral productivity, and relative wages in the local economy, providing a unique opportunity to trace the effects of targeted policy interventions within the local economy and resulting changes in the epidemiological and ecological components of the coupled model. Second, we introduce a novel, household-specific measure of exposure time in the disease dynamics stemming from the intensity of fishing labor. Third, we model the supply of effective labor as a function of household infection rates, thus characterizing the impact of the disease on labor productivity. Fourth, the fish stock evolves over time as a function of population growth and total catch, linking ecological outcomes to economic activity and labor allocation.

We first present results from single-domain policy interventions that target public health (MDA), ecology (FMP), or economic growth (TFP), highlighting the synergies and antagonisms that emerge across domain goals. We are implementing example policies in each domain, and are not trying to find the optimal single or multiple sector policy. While that is an interesting question and one that the model could be used to find, our approach better represents the realities of policy-making in developing countries. We also distinguish between year-1 and year-10 outcomes, revealing dynamic feedback between the domains over time. We track the impacts of the policies on public health indicators (infection rates and R_0), an ecological indicator (fish stock level), and economic indicators (fishing labor time, aggregate output, and fishing harvest) (see, e.g., Figs. 2 and 3 and Table S19 in the supplementary materials). The simulated responses over ten years demonstrate that even well-targeted interventions can generate unintended consequences–both positive and negative–across economic, ecological, and public health systems. We then analyze how concurrent policy implementation can mitigate or exacerbate these effects.

Under our preferred specification that best depicts the setting of Lake Victoria, fishing sector output is traded with the rest of the world (RoW), implying that fish prices are not responsive to fish catches. Using the model, we also measure outcomes when fishing sector output prices are endogenous, which means that as fish catches go down, prices go up, and labor is pulled back into the fishing sector (increasing disease susceptibility). These results demonstrate the model's capability to capture other local-economy characteristics, providing insights into how places similar to Lake Victoria but differing in market linkages might respond to various interventions. Additionally, results presented in our paper assume that a unit of labor time is 15% less productive due to Schisto infection (i.e., $\alpha = 0.15$). The relationship between Schisto and labor productivity is a critical link between the public health and economic domains of the human-natural environment. Given the range of estimates from previous studies (Audibert and Etard, 1998; Audibert and Etard, 2003; Fenwick and Figenschou, 1972; Barbosa and Costa, 1981; Kamel et al., 2002), we explore the sensitivity of our results to changes in the value of α in the supplementary materials.

Single-Domain Policy Interventions

We simulate the implementation of an annual community-based mass drug administration (MDA) to reduce Schisto prevalence in the local human population. MDA is a widely used method for combating Schisto in many countries because of the low cost of the drug *Praziquantel*. MDA programs are often conducted in

[1] The use of "domain" follows conventions in the coupled human and natural systems (CHANs) modeling literature, where domains are understood as interlinked components of complex systems, and each is characterized by its own logic, constraints, and feedback structures (Ferraro et al., 2019; Liu, Dietz, et al., 2021; Ostrom, 2009).

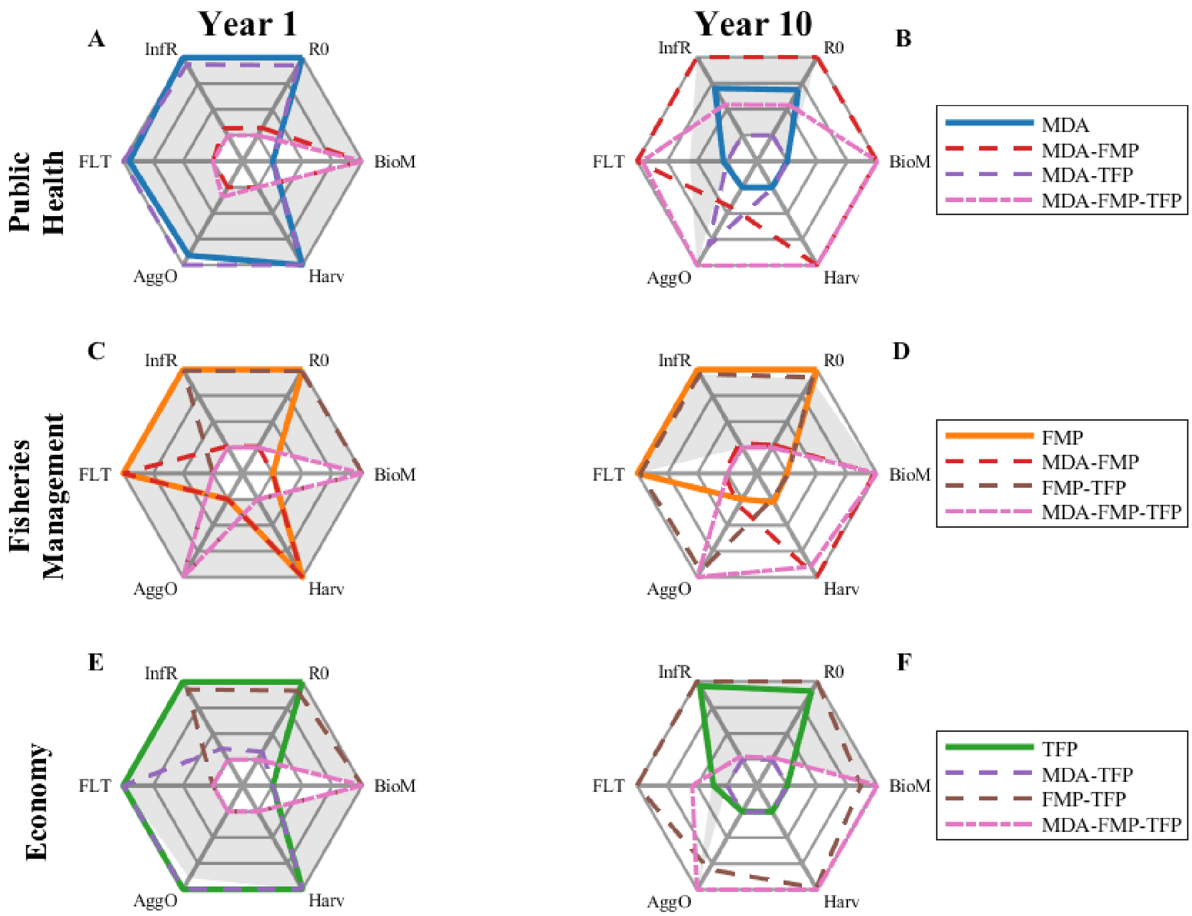

Figure 2: Initial and Year-10 effects of individual and concurrent policy interventions. Fishing sector output prices are *exogenous* to changes in the local economy. Shaded regions represent negative changes from baseline. Each axis is scaled separately and represents percent changes relative to baseline values. Each row presents results from a policy domain perspective. Axes abbreviations are: InfR (household infection rate), BioM (size of fish stock by weight), Harv (harvest by fishers by weight), AggO (aggregate output in the local economy), and FLT (fishing labor time). The combined policies are identical across the panels, for example, MDA-FMP is the same outcome in Panels A and B and in Panels C and D. We illustrate the run twice for comparison purposes within each of the relevant domains. The same holds for the other pairs of policies and the run with all three policies being implemented simultaneously.

schools to achieve program cost savings and to target children, who are often the focus of treatment efforts (King, Sturrock, et al., 2006). We characterize the impact of an effective MDA program as an increase in the rate at which the household transitions out of the infected classification (Castonguay et al., 2020). We assume that, *ceteris paribus*, implementation of the MDA program will produce an annual reduction in infection rates of 19.3% for all households in the local economy (King, Kittur, et al., 2020). Further details on the methodology can be found in the supplementary materials.

We find that the MDA policy intervention successfully meets its primary goal of reducing disease prevalence (Fig. 2 Panels A and B (blue solid line)). The intervention produces large, sustained gains in the public health domain, with household infection rates and R_0 falling consistently over the ten-year period. The ancillary effects create a strong synergy between public health and economic goals. The reduction in disease burden translates to an increase in the effective labor supply, leading to a slight rise in aggregate output (<1%). However, the small increase in fishing effort resulting from improved health exerts marginal pressure on the fishery, causing the fish stock to decline over ten years (<1%) (Fig. 2 Panel B (blue solid line)). Overall, the MDA intervention achieves its intended health benefits with positive economic spillovers and minimal negative impact on the fish stock.

We simulate the introduction of a Fisheries Management Policy (FMP) limited entry program in the fishing sector, which we model as an immediate 25% reduction of the fishing capital stock from its baseline level that is sustained over the ten-year study period. The FMP intervention decisively achieves its ecological goal of increasing the size of the fish stock. Fish stocks increase by 17.7% in the first year and are nearly 43% above the baseline after ten years (Fig. 2 Panels C and D (orange solid line)). However, the FMP intervention introduces a stark short-term trade-off between ecological and economic goals. The restriction on fishing capital causes aggregate output to fall by 6% in year one. Over the long term, the recovered fish stock boosts fishing productivity, with aggregate output eventually recovering to 2.3% above baseline (Fig. 2 Panel D (orange solid line)).

The FMP intervention, however, has a more complex relationship with the public health domain. Initially, as fishing activity contracts, disease exposure declines, and infection rates fall by 2.2%. But as the fish stock recovers, labor flows back into the fishing sector as returns to fishing increase. Since capital is fixed, the renewed demand for fishing effort is met entirely by labor, which results in an increase in exposure time. By year 10, infection rates and R_0 rise above baseline levels, revealing a long-term trade-off between fishery recovery and public health (Fig. 2 Panel D (orange solid line)).

Agricultural extension services have been used in many developing countries as a strategy for improving the quality and productivity of the human capital input in the production process (Anderson and Feder, 2007). Because of the importance of extension services in agricultural development efforts, we simulate a policy intervention in the form of an annual increase of 1% in total factor productivity (TFP) for cash crop-producing households (which in our study is oil palm). The TFP represents the results of agricultural extension services that provide education and recurrent training for cash-crop producing households. We simulate this policy intervention by increasing the value of the shift parameter in the oil-palm production functions by 1% annually for oil-palm producer households.[2]

The simulated TFP intervention successfully meets the primary goal for the economic domain. Aggregate output rises steadily, increasing by 9.3% over the study period as all sectors except fishing expand. This policy generates powerful synergies across all three domains. For example, labor reallocates away from the fishing sector due to the expanding oil palm sector, which directly benefits public health, as reduced fishing labor time lowers disease exposure, causing household infection rates to fall by 3.6% and R_0 by 5% by year

[2] While we use the oil palm sector as an illustrative cash-crop example for our TFP intervention, our findings can be generalized to other sectors (see supplementary materials for a discussion of modeling the environmental impacts of oil palm). Oil palm cultivation has raised environmental concerns—particularly in Southeast Asia—due to its association with deforestation, biodiversity loss, carbon emissions, and water pollution (Meijaard et al., 2020). Nonetheless, oil palm is also exceptionally land-efficient, producing significantly more oil per hectare than soybean, rapeseed, or sunflower (Corley, 2009), which suggests that replacing oil palm with other oils may result in greater land-use impacts overall (Poore and Nemecek, 2018). Furthermore, it is possible that knowledge gained from extension services may be transferable to other sectors that households are active within, including production of other crops. However, as oil palm is a cash crop, its production process may be sufficiently unique to limit such a transfer (Liu, Jiang, et al., 2021). Consequently, we do not model a transfer of knowledge across sectors.

10 (Fig. 2 Panels E and F (green solid line)). This same reduction in fishing effort simultaneously allows fish stocks to rise by 0.4% in year 10 ((Fig. 2 Panel F (green solid line)).

Concurrent Policy Interventions

We now consider the synergistic and antagonistic interactions when (non-optimal) sector-specific policy interventions are implemented concurrently. Simulation of concurrent MDA-FMP interventions reveals a short-term synergy between the ecological and public health domains. The MDA intervention immediately offsets the long-term rise in disease exposure anticipated from the FMP, causing infection rates to fall in year one. However, the underlying trade-off found in the single sector FMP policy persists. As the fish stock recovers due to the FMP intervention, labor is drawn back to the fishing sector, increasing year-10 exposure time and infection rates above what would be seen in an MDA-only scenario. The ecological benefits of the FMP are traded off against the full public health potential of the MDA over time.

When the TFP and MDA interventions are implemented concurrently, we observe strong, reinforcing synergies between the economic and public health domains (Fig. 2 Panels A, B, E, and F (purple dashed line)). The TFP intervention's primary effect of pulling labor out of fishing is amplified by the improvements in health outcomes resulting from the MDA intervention. This leads to larger declines in infection rates and R_0 than either policy could achieve alone. The TFP intervention, however, reduces fishing effort while the MDA intervention slightly increases labor effectiveness. Still, the net effect is a small increase in fish stocks as the TFP intervention-induced labor shift dominates, delivering synergistic gains across all domains.

Concurrent implementation of the FMP-TFP interventions uncovers synergies across the three domains. By pulling labor away from fishing, the TFP intervention counteracts the long-term tendency of the FMP intervention to increase disease exposure, creating a public health synergy. Furthermore, the short-term economic contraction caused by the FMP is overridden by the sustained growth from the TFP intervention, aligning economic and ecological goals for long-term gains.

The simulation of 3-way concurrent interventions produces the most robust and durable positive outcomes. The labor-reallocating effects of the TFP intervention lead to the ecological gain of a greater fish stock ((Fig. 2 all panels). In turn, the economic growth and labor reallocation stemming from the TFP intervention reinforce the public health benefits of the MDA intervention, neutralizing the long-term rebound in disease exposure seen in the FMP-only intervention. The initial economic downturn from the FMP intervention is quickly overcome by economic growth driven by the TFP intervention. Even without explicit coordination, a common attribute in many developing country settings, this concurrent implementation results in multi-domain synergies with minimal antagonisms.

Deviations Under Endogenously Determined Fish Prices

The results above assume that the price of fish is determined on the world market, where the local economy is trading fish globally. In many developing country settings, however, fish markets are local (fish are perishable and refrigeration is not available), and as such, prices are determined locally. Local markets for fish introduce an additional feedback loop that could erode the synergies observed previously (Fig. 3).

Rising incomes from economic growth due to the TFP intervention increase local demand for fish. This drives up fish prices, incentivizing a return of labor to the fishing sector. As a result, the fish stock declines by 3.2% over ten years, which is a reversal from the RoW case where it increased, and the public health gains are smaller. This reveals a key antagonism between income growth and both ecological and public health goals when the fish market is local.

The reduction in fish harvest resulting from the FMP interventions immediately drives up local prices. This price signal pulls labor into the fishing sector more quickly than in the RoW case, making the trade-off with public health more immediate and pronounced, with infection rates rising even in year one. The economic recovery is also slower compared to the RoW case, as higher fish prices mute the reallocation of labor to more productive sectors.

These differences amplify under concurrent interventions. The concurrent FMP-MDA intervention delivers smaller long-term health gains as local price signals continue to attract labor to fishing. Similarly, the powerful synergy observed in the concurrent TFP-MDA intervention is dampened as income growth boosts fish demand, partially offsetting the public health benefits. In nearly every case, endogenous prices introduce or strengthen antagonisms that counteract the synergies seen in the RoW scenario.

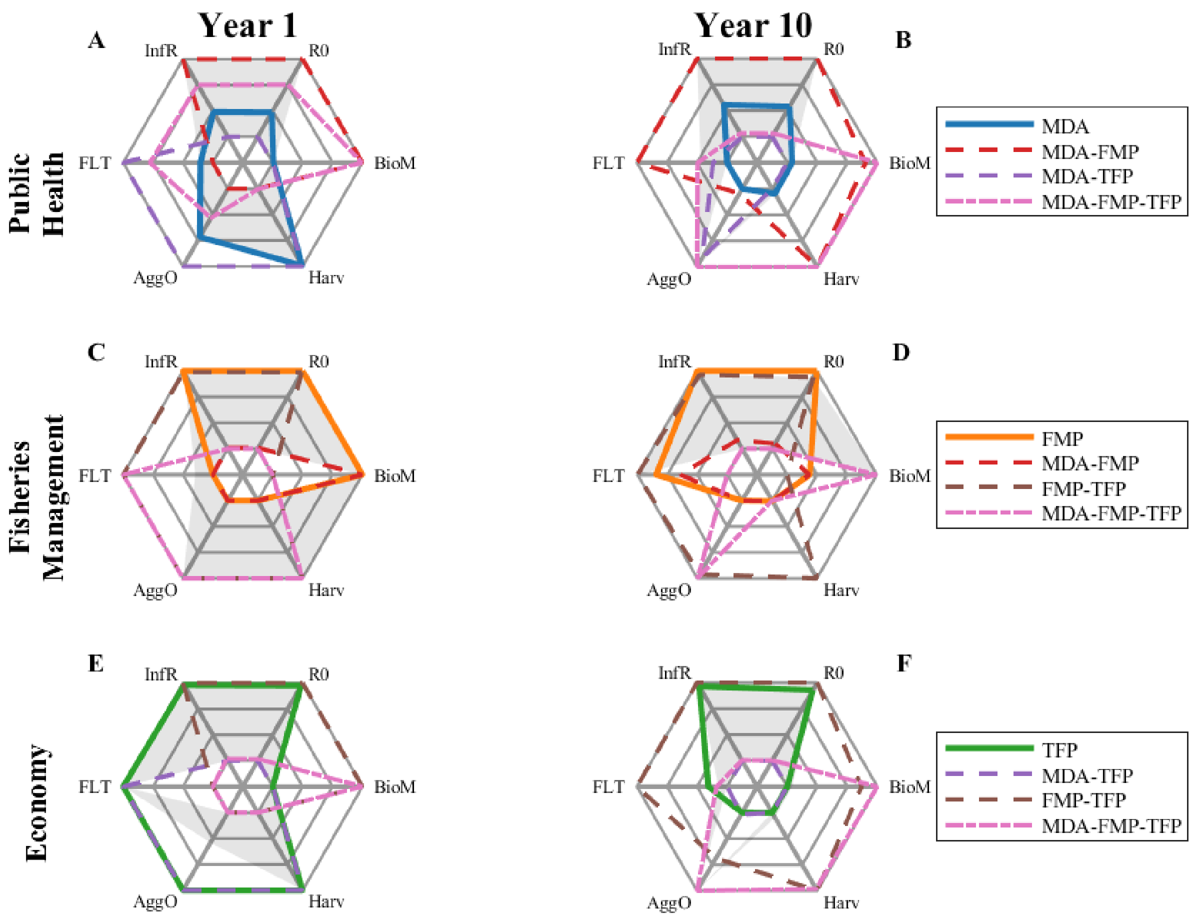

Figure 3: Initial and Year-10 effects of individual and concurrent policy interventions. Fishing sector output prices are *endogenously* determined within the local economy. Shaded regions represent negative changes from baseline. Each axis is scaled separately and represents percent changes relative to baseline values. Each row presents results from a policy domain perspective. Axes abbreviations are: InfR (household infection rate), BioM (size of fish stock by weight), Harv (harvest by fishers by weight), AggO (aggregate output in the local economy), and FLT (fishing labor time). The combined policies are identical across the panels, for example, MDA-FMP is the same outcome in Panels A and B and in Panels C and D. We illustrate the run twice for comparison purposes within each of the relevant domains. The same holds for the other pairs of policies and the run with all three policies being implemented simultaneously.

Discussion

Neglected Tropical Diseases (NTDs), particularly schisto, persist despite decades of public health investment due to limitations in current interventions and the complex interplay between disease transmission and human behavior. For example, in rural, resource-dependent communities, labor decisions—shaped by relative wages and exposure risks—can influence both income and disease prevalence, making the outcomes of health and economic interventions highly context-dependent. To better understand these connections, we developed a novel empirically-based coupled, multi-domain modeling framework for evaluating policy interventions. In general, we find that each policy intervention appears successful in isolation (see solid lines in Figures 2 and 3). Our high-level results beg the question, ”Is it OK to make policy decisions without considering the knock-on effects?” Our results suggest that the answer is no in general, but might be acceptable in some cases when spillovers are qualitatively present but empirically small in magnitude. For example, the MDA-only intervention leads to an increase in the effective labor supply, which results in a (very) slight increase in the pressure on the fish stock. On the other hand, the FMP-only intervention leads to an increase in R_0, revealing a significant trade-off between the ecological and public health domains.

Using the model, we demonstrate that concurrent policy interventions can sometimes produce superior outcomes due to synergistic feedbacks in the local economy (dashed lines in Figures 2 and 3). Our findings suggest that productivity-enhancing investments in non-fishing sectors that pull labor out of sectors with greater disease exposure can be a powerful tool to erode the conditions that foster disease-based poverty-traps. For example, the TFP intervention changes relative wages that draw labor away from fishing, simultaneously reducing disease exposure time and boosting aggregate household income, which can lead to a reduction in poverty. Furthermore, the TFP intervention produces a small, long-term decline in R_0 due to rising aggregate output. This in turn contributes to the long-term goal of disease eradication, a result that is consistent with prior literature (e.g., Bonds et al. (2010) and Garchitorena et al. (2017)).

However, the superior outcomes from concurrent policies are not assured, as unintended consequences are also possible. For example, we find that the FMP intervention, which is designed to reduce overfishing and improve the local ecology, can have the perverse outcome of increasing disease exposure. As the fish stock recovers and returns to fishing increase over time, restrictions on new capital (boats) leave producers with labor as the only source of fishing input that can respond to the improved economic conditions. The intensified reliance on labor directly increases exposure times and, consequently, disease prevalence, revealing that attempts to regulate fisheries may inadvertently prop up disease-based poverty traps. The implication, however, is not all policies to reduce ecosystem degradation will have such a negative feedback loop with disease-based poverty traps. Restoration of coastal habitats in some places might be a way to reduce the prevalence of disease vectors (Sokolow et al., 2015). In our setting, the result is driven by a lack of fishery management institutions combined with households engaging in fishing activities, which led to greater levels of exposure.

Not surprisingly, our results support the idea that there is no one-size-fits-all solution to addressing disease-based poverty traps. Along with an array of socio-ecological factors(citations), local economic conditions matter. We demonstrate that the success of any policy in altering the conditions that underlie these traps depends on underlying market structures, a finding that is relevant for the local economy under study here and for settings where imperfect markets are present. In the RoW scenario, the TFP intervention produces beneficial outcomes across the three domains. When transaction costs and other impediments to trade are present, higher household incomes put upward pressure on fishing sector output prices, incentivizing demand for fishing labor. The resulting increase in exposure time and infection rates work against the public health goal of disease eradication. This result demonstrates how market structures can create a powerful antagonistic effect between the economic and public health domains, sustaining disease-based poverty traps.

While none of the simulated policy interventions, and in particular the MDA intervention, achieve the long-term public health goal of disease eradication (i.e., reducing R_0 below 1), our study offers a nuanced perspective on policy pathways toward that goal that is relevant across developing country settings where similar underlying mechanisms linking labor allocation, disease exposure, ecological processes, and economic outcomes are found. The 3-way concurrent intervention produces the most robust positive outcomes, creating multi-domain synergies that mitigate the antagonistic effects observed in single-policy scenarios. This result suggests that eliminating disease-based poverty traps requires a coordinated approach that simultaneously boosts economic opportunities for non-fishing sectors, directly treats the disease, and carefully manages the unintended changes in behavioral incentives arising from targeted policy interventions.

Our results are directly applicable to other settings where disease exposure is linked to an income-generating activity, such as rice production. In such settings, we would expect qualitatively similar year-one effects across both public health and economic outcomes. However, year-ten effects will diverge due to differences in the underlying ecological processes. Unlike fisheries, which exhibit endogenous ecological stock dynamics that generate feedback effects over time (e.g., depletion of the fish stock and harvest impacting the relative economic returns from fishing), rice production relies on annual planting and harvesting without stock dynamics. As a result, shifts in labor allocation for a rice-based local economy would not be communicated through an ecological stock constraint, but instead would influence exposure times primarily through changes in labor demand. Furthermore, if rice prices are determined locally, our simulation results suggest that higher output prices would draw labor into the rice sector, increasing exposure time to the disease. The mechanisms differ across rice production and fishing owing primarily to the lack of rice stock dynamics, but the potential for market structure to determine exposure time remains.

While our framework is an ex ante policy impact evaluation tool, our approach can complement ex-post evaluation methods in several ways. First, our coupled modeling approach can be used to refine research design to ensure empirically sound estimates of policy impacts (see, e.g., Ferraro et al., 2019 regarding potential SUTVA violations in CHANS). Second, ex-post methods could be used to develop more precise understanding and measures of the parameters central to the links between the component models in our study, including sources of exposure time (τ_h), the relationship between income and exposure rate to the disease (β), and determinants of household risk of exposure and contamination (ϵ_h). Furthermore, ex-post methods can provide insight into how interventions may affect these relationships. For example, an intervention designed to reduce water contact rates by providing protective gear for fishers could shed further light on the value of τ_h. Additionally, information-based campaigns targeting high-risk behaviors associated with exposure and contamination could inform values of β and ϵ_h. With refined values of these and other parameters, coupled models such as ours would be better equipped to evaluate cross-domain synergies and consequences of targeted policy interventions, which can produce spillover effects that may be difficult or infeasible to detect solely with ex-post methods.

Our analysis provides pathways for future research on cross-domain consequences of targeted policy interventions and implications for conditions that foster poverty traps. For example, household domestic production and recreation, which we incorporate into our model as the time-invariant component of τ_h, provide additional transmission pathways for the disease. Future studies that incorporate survey data on these activities and how they relate to labor-leisure trade-off decisions, as well as the value of domestic production for the local economy, are needed. Another fruitful area of future research is to investigate the added value of including a model of household asset accumulation into the coupled modeling framework. Explicitly accounting for asset growth over time in the presence of disease-based poverty traps could provide insights into how targeted policy interventions can affect conditions that underlie either asset-based poverty traps (Barrett, Carter, and Chavas, 2019) or disease-based poverty traps.

The gendered nature of labor is another aspect of disease-based poverty traps, where exposure risks to diseases like Schisto in many settings around the world differ by gender. Social norms around household labor allocation create systematically different patterns of risk of exposure to NTDs across genders (Shomuyiwa et al., 2023). In many settings where Schisto is endemic, including the Lake Victoria region, fishing itself is a highly gendered activity. Men often dominate offshore, boat-based fishing, while women are heavily engaged in shoreline-based tasks such as fish processing, cleaning, trading, and mending nets, in addition to domestic chores like washing clothes and fetching water (Ayabina et al., 2021; Standley et al., 2011; Jul-Larsen et al., 2003). These distinct labor roles produce different exposure profiles, with risks for women often compounded and overlooked. In particular, exposure-based activities dominated by women have been linked to adverse outcomes such as Female Genital Schistosomiasis (FGS), a condition associated with chronic pain, infertility, and increased HIV susceptibility (Rossi et al., 2024). Future studies could disaggregate household labor and water-contact time by gender to capture these differential exposure risks, providing a more nuanced understanding of the intra-household consequences of policy interventions and supporting the design of more equitable and effective interventions.

Methods

We develop a coupled model of the natural-human environment by combining three component models: a computable general equilibrium (CGE) model of the local economy, a system of equations that characterizes the dynamics of the disease Schisto, and a growth equation for the biomass of the fish stock targeted by the local fishing sector. The model is solved using a mixed complementarity problem (MCP) solver using *General Algebraic Modeling System (GAMS)* software v*24.1.3*.

We use originally collected survey data from households and business in the study area to parameterize the CGE model. We classify households into four representative groups according to poverty status and whether they participate in the fishing sector. We identify six productive sectors (oil palm, other crops, livestock, fishing, retail and service businesses) using the survey data. We identify six consumption activities (crops excluding oil palm, livestock, fishing, imports, and retail and service businesses). Prices for oil palm, fish, and imports are determined globally; all other prices are endogenous to the local economy. We assume a fixed capital stock and a fixed population of households over the study period.

Four links between the three component models characterize the interconnectedness of the three policy domains. Firstly, changes in aggregate output affect the capacity for *public* investment in disease prevention and treatment. We represent this relationship in our model by writing two parameters in the disease dynamics, the exposure rate β and the parasite-human host parameter γ, as (decreasing and increasing, respectively) functions of aggregate output from the local economy. Secondly, changes in demand for fishing labor directly affect household exposure time, influencing disease transmission. We include in the disease dynamics a measure of household-specific exposure time, τ_h, that is composed of a fixed component (e.g., water collection) and a variable component (commercial fishing labor time), allowing us to represent the role of *private* decisions in disease transmission. Thirdly, the household supply of effective labor E_h is decreasing in household infection rates I_h, representing the impact that the disease has on an individual's ability to work. Our preferred specification assumes a value of 0.15 for the effect that the disease has on labor productivity. We explore robustness of the results based on this value in the supplementary appendix. Fourthly, total harvest by the local fishing sector depletes future fish stock, as is common in bio-economic modeling.

We identify parameter values and ranges for the disease dynamics and biomass equations from previous studies. For the disease dynamics, the assigned parameter values imply a maximum value of 3.6 for R_0, the basic reproductive number for the disease, based on the assumption of a homogeneous population (Mari et al., 2017). The disease parameters β and γ vary with economic activity and are assigned minimum and maximum values. The exposure time parameter τ_h is normalized to 1 at baseline.

To solve the coupled model, we first establish baseline solutions with the three component models in equilibrium. Consequently, the local economy, disease dynamics, and fish stock are all at steady-state levels at baseline, implying no changes to outcomes without external interventions. Baseline output prices and factor prices are set to 1, permitting evaluation of changes in price levels due to interventions. We assume a value of 3 for elasticity of substitution between consumption goods and a value of 8 for trade elasticity for fish. Endogenous parameter values and solutions for the CGE component are derived from sampled values and model assumptions. The state variables in the disease dynamics component are solved simultaneously with the CGE component to ensure equilibrium across component models. The baseline fish stock is assumed to be at a steady state where natural growth equals harvest.

We simulate policy interventions over a 10-year period in annual time steps. The CGE component reaches equilibrium annually, and the Bio component equation is treated as a step equation. The Epi component's dynamics are assumed to evolve faster than those of the economy or fish stock, allowing it to respond more quickly to changes in other component models. Thus, the steady-state values for the state variables in the disease dynamics are solved for using relevant values from the solutions to the CGE component. The supplementary index includes a complete description of model development, estimation of parameter values, and description of the process used to solve the model.

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