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Research Paper

## Sharing the costs of structural interventions: What can models tell us?

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## ABSTRACT

**Background:** The global HIV response needs to both integrate with the broader health system and tackle the structural drivers of HIV. Cross-sectoral financing arrangements in which different sectors agree to co-finance structural interventions – have been put forward as promising frameworks to address these concerns. However, co-financing arrangements remain rare for HIV, and there is no consensus on how to distribute costs.

**Methods:** We use case studies to investigate how structural interventions can be incorporated within three quantitative decision-making frameworks. First, we consider cost-benefit analyses (CBA) using an opioid substitution therapy (OST) program in Armenia; second, we construct a theoretical example to illustrate the lessons game theory can shed on the co-financing arrangements implied by CBA; and third we consider allocative efficiency analyses using needle-syringe programs (NSPs) in Belarus.

**Results:** A cross-sectoral cost-benefit analysis of OST in Armenia demonstrates that the share of that should be funded by the HIV sector depends on the willingness to pay (WTP) to avert an HIV-related DALY, the long-term cost-benefit ratio, and the HIV risk reduction from OST. For reasonable parameter values, the HIV sector's share ranges between 0–48%. However, the Shapley value—a game-theoretic solution to cost attribution that ensures each sector gains as much or more as they would from acting independently—implies that the HIV sector's share may be higher. In Belarus, we find that the HIV sector should be willing to co-finance structural interventions that would increase the maximal attainable coverage of NSPs, with the contribution again depending on the WTP to avert an HIV-related DALY.

**Conclusion:** Many interventions known to have cross-sectoral benefits have historically been funded from HIV budgets, but this may change in the future. The question of how to distribute the costs of structural interventions is critical, and frameworks that decision-makers use to inform resource allocations will need to take this into account.

## Introduction

The global response to the HIV epidemic is often praised for its profound effects, not only in curtailing the spread of HIV, but also on the management and understanding of public health responses generally (WHO, 2017). In particular, the early stages of the HIV response highlighted the power of distinct, often donor-driven funding streams, novel service delivery channels involving civil society and community-based organizations, and new programmatic management models (Linda-Gail *et al.*, 2018). To a large extent, these innovations were made possible by the fact that the global HIV response was largely siloed from national health systems. However, as the HIV epidemic started to mature from a crisis to a manageable chronic disease (WHO, 2017) and

HIV-specific donor funding began to stagnate (Kates, Wexler & Lief, 2018), the nature of the HIV response also began to evolve. More and more countries have integrated HIV services with other health services (especially maternal, child health, reproductive and sexual health services), and a 2018 report published by the International AIDS Society and the *Lancet* concluded that “the future of the HIV response will depend on finding opportunities for integrating HIV services more closely within health systems” (Linda-Gail *et al.*, 2018).

The maturing HIV epidemic has also led to increased recognition of the need to address broader socioeconomic factors such as stigma, violence, poverty, and gender inequality, all of which place people at greater risk of encountering circumstances such as unsafe or unwanted sex or drug use (Seeley *et al.*, 2012). The global HIV response has long

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recognized the need to provide services for groups at greater risk of HIV, but less attention has been given to addressing the structural drivers that have led to this increased risk. Reorienting the response to address elements higher up in the causal chain calls for interventions that go beyond the traditional domain of HIV responses. Examples include programs to reduce school drop-out rates, extended microfinance and livelihood programs, taxes on alcohol, and increased community mobilization (STRIVE Research Consortium, 2019; Vassall, Remme & Watts, 2011). Evidence on the efficacy of these types of interventions, whilst historically scarce, is growing (STRIVE Research Consortium, 2019).

In this context—that is, driven by the dual demands on the global HIV response to both integrate with the broader health system and to tackle the structural drivers of HIV—cross-sector financing models have been put forward as a promising framework (Claxton, Sculpher & Culyer, 2007; Remme, Vassall, Lutz, Luna & Watts, 2014). The idea behind such models is that structural interventions benefit multiple sectors, and that the costs of funding these interventions should be distributed between all benefiting sectors according to some allocation rule. This idea fits in with the agenda outlined by the Sustainable Development Goals, which promote an interconnected, systematic approach to development. However, despite the theoretical appeal of a systematic and cross-sectoral approach, it remains uncommon in practice (STRIVE Research Consortium, 2019), meaning that the most common funding model for interventions that have cross-sectoral benefits is for one sector to take on the financial burden of operating the intervention in isolation. Possibly the most clear-cut example of this is seen in the financing of opioid substitution therapy (OST) programs. It is well-established that OST is effective in enabling people to reduce or cease injecting drug use, and that this not only greatly reduces the risk of HIV infection, but also has wider health, economic, psychological and social benefits, including reducing the risks of hepatitis C infection or opioid overdose, improving access to healthcare, alleviating financial and other stresses, and reducing crime (UNAIDS, 2016). However, despite its many cross-sectoral benefits, OST has been almost exclusively funded out of HIV budgets. If the future of the HIV response is indeed dependent on integrating HIV services within health systems, this siloed funding model will not be able to continue.

In this paper, we explore methods for incorporating structural interventions like OST within the suite of quantitative approaches typically employed for helping decision-makers prioritize health service delivery. We consider three quantitative frameworks: cost-benefit analyses (CBA), allocative efficiency analyses (AEA), and game theoretic analyses. A brief introduction to each of these is given in Table 1.

Within this study, we apply these three frameworks to case studies based on real-world health modeling applications (where possible). First, we consider how an OST program in Armenia could be modeled within a CBA framework, basing our analysis on a 2015 study of the country's HIV response (The World Bank, 2015a). To do this, we adapt with the cross-sectoral funding model proposed by Remme *et al.* (2014), in which the costs of funding an intervention to keep girls in school are divided between three different sectors according to willingness-to-pay. Second, we consider structural interventions from the perspective of

game theory, and construct a theoretical example based on the Armenian case to illustrate some of the lessons that game theory sheds on the CBA framework. Finally, we consider a case study of how structural interventions to improve the enabling environment in Belarus can be modeled within an AEA framework, basing our analysis on an allocative efficiency study (The World Bank, 2015b).

## Methods

### *Modeling OST programs in Armenia in a cross-sectoral cost-benefit analysis*

The first step to incorporating OST in a cross-sectoral cost-benefit analysis (following the framework outlined by Remme *et al.* (2014)) is to obtain estimates from the literature on the long-term benefit-to-cost ratios. Economic evaluations of OST programs have been undertaken in several countries, and have estimated benefit-cost ratios of between 2:1 and 15:1, largely driven by the interventions' cost-reducing effects on crime and criminal justice expenditures (Fischer, 2003; Frei, Greiner & Mehnert, 2000; National Institute on Drug Abuse, 1999; Simoens, Ludbrook, Matheson & Bond, 2006; WHO, UNODC & UNAIDS, 2004). Most of these studies do not disaggregate how much of the benefits accrue to different sectors, although one report specifies that the benefit-cost ratio is between 4:1 and 7:1 for non-health, and 12:1 including health (WHO *et al.*, 2004). We will use the average of the benefit-cost ratios reported in these studies (5.5:1) as the base case for representing the benefit-cost ratio for sectors excluding HIV, and explore alternatives (ranging between 2:1 and 15:1) in a sensitivity analysis.

Next, we need to estimate the monetary benefits of OST programs to the HIV sector—this will enable us to determine what share of the costs should be paid by the HIV sector under a “fair” cost-sharing model, i.e. a model under which each sector's contribution to funding the scheme represented the share of benefits they receive. To do this, we multiply the expected reduction in HIV DALYs by the willingness-to-pay (WTP) to avert a DALY:

- To estimate the expected reduction in HIV DALYs, we begin with the effect of OST programs in reducing the risk of HIV infection. A systematic review found that OST was associated with a 54% reduction in risk of HIV infection among people who inject drugs (rate ratio 0.46, 95% confidence interval 0.32 to 0.67;  $P < 0.001$ ) (MacArthur *et al.*, 2012). We will use the 54% reduction as our base case, and investigate the 95% confidence interval endpoints in a sensitivity analysis. We estimate the expected reduction in DALYs from the reduction in infections, calculating from the onset of infection and using an annual discount rate of 3%.
- There are various methods available to estimate the willingness-to-pay to avert an HIV-related DALY. Previous guidance to use 1–3 times gross domestic product (GDP) per capita has since been criticized as not being based on an empirical assessment of health opportunity costs, not reflecting countries' revealed preferences, and not being affordable in many contexts (Ochalek, Lomas & Claxton, 2018), and alternative methods exist to address these issues

**Table 1**

An overview of the three quantitative decision-making frameworks discussed in this paper. Notes: (1) We consider CBA instead of cost-effectiveness analyses (CEA) despite the fact that the latter are more commonly used for informing investment decisions, because CBA allows sectors to “explicitly factor in the costs and benefits of their resource allocation decisions to other sectors” (Remme *et al.*, 2014), and thus is better suited to the cross-sectoral funding problem.

Framework	Summary
Cost-benefit analysis	Evaluates an intervention by expressing both the costs and the resulting benefits in monetary terms. <sup>1</sup>
Allocative efficiency analysis	Investigates how resources can be allocated among different interventions so as to maximize communal welfare. Now the workhorse for use within the investment case framework promoted by UNAIDS (Schwartländer <i>et al.</i> , 2011).
Game theoretic analysis	Conceptualizes how stakeholders will behave given the particular conditions they are faced with; by focusing on individual motivations, it can shed light on why stakeholders defect from strategies that would lead to the best communal outcome and what incentives would need to be provided to prevent this.

**Table 2**  
inputs required to conduct a cross-sectoral cost-benefit analysis of the OST program in Armenia.

	Formula	Value	Source/Notes
<b>COUNTRY-SPECIFIC INPUT DATA</b>			
OST program cost (2013 US\$, 2013 data)	$D_1$	283,074	The World Bank (2015a)
Number of people on OST (#, 2013 data)	$D_2$	301	The World Bank (2015a)
HIV prevalence in PWID (% , 2012 data)	$D_3$	6%	The World Bank (2015a)
ART coverage (% of eligible PWID on ART, 2013 data)	$D_5$	5%	The World Bank (2015a)
ART unit cost (2013 US\$, 2013 data)	$D_6$	987	The World Bank (2015a)
<b>KEY PARAMETERS</b>			
Reduction in risk of HIV infection among PWID (relative risk)	$P_1$	0.46 [0.32–0.67]	MacArthur <i>et al.</i> (2012)
Benefit-cost ratio of OST to sectors other than HIV	$P_2$	5.5 [2–15]	See text
<b>OTHER PARAMETERS</b>			
Duration until treatment eligible (years)	$P_3$	5	Assumption
Expected duration of life after ART initiation (years)	$P_4$	35	Assumption
Expected duration of life without ART (years)	$P_5$	10	Assumption
Discounting rate (%)	$P_6$	3%	Assumption
Average age at HIV infection (years)	$P_7$	30	
<b>PRELIMINARY CALCULATIONS</b>			
Average duration of disease (years)	$C_1 = (P_3 + P_4) * D_5 + P_5 * (1 - D_5)$	12	Calculation
Lifetime discounted ART costs (2013 US\$)	$C_2 = (D_6 * P_4) * (1 + P_6)^{P_4}$	12,282	Calculation
HIV incidence rate, PWID (per 100 person years)	$C_3 = D_3 / (1 - D_3) * C_1$	0.58	Calculation
HIV incidence rate, PWID on OST (per 100 person years)	$C_4 = C_3 * P_1$	0.27 [0.19–0.39]	Calculation
HIV infections averted by program (#)	$C_5 = D_2 * (C_4 - C_3)$	0.95 [0.58–1.20]	Calculation
HIV DALYs averted by program (#)	$C_6 = C_5 * DALY / infection$	18 [11–23]	Calculation

(Marseille, Larson, Kazi, Kahn & Rosen, 2015; Meyer-Rath, van Rensburg, Larson, Jamieson & Rosen, 2017; Woods, Revill, Sculpher & Claxton, 2016). Rather than selecting one particular threshold, in this work we will treat the WTP to avert an HIV-related DALY as a variable parameter to highlight the dependency between WTP and cost attribution.

Finally, we will determine the proportion of total monetary benefits for OST attributable to HIV as the fraction of HIV benefits to HIV benefits and other benefits across other sectors. Sensitivity analyses are conducted by varying the values of key parameters: specifically, the long-term benefit-cost ratio (to range between 2:1 and 15:1) and the HIV risk reduction associated with OST (to range between 0.32 and 0.67).

Table 2 summarizes the inputs required for modeling the OST program in Armenia in a cross-sectoral cost-benefit analysis. From these inputs, we will calculate:

- the net costs of the OST programs: derived by subtracting the monetary value of HIV treatment costs averted by the program (calculated as number of HIV infections averted by the program multiplied by the lifetime discounted ART cost, listed as  $C_2$  and  $C_5$  in Table 2) from the cost of implementing the program (listed as input  $D_1$  in Table 2);
- the net benefits of the OST programs: derived by adding the benefits for the HIV sector to the long-term benefits ex-HIV; the first is calculated by multiplying the number of HIV DALYs averted by program (listed as input  $C_6$  in Table 2) by the WTP to avert an HIV-related DALY, while the second is equal to the cost of implementing the program (listed as input  $D_1$  in Table 2) multiplied by the benefit-cost ratio of OST to sectors other than HIV (listed as input  $P_2$  in Table 2).

#### Structural interventions in a game-theoretic framework

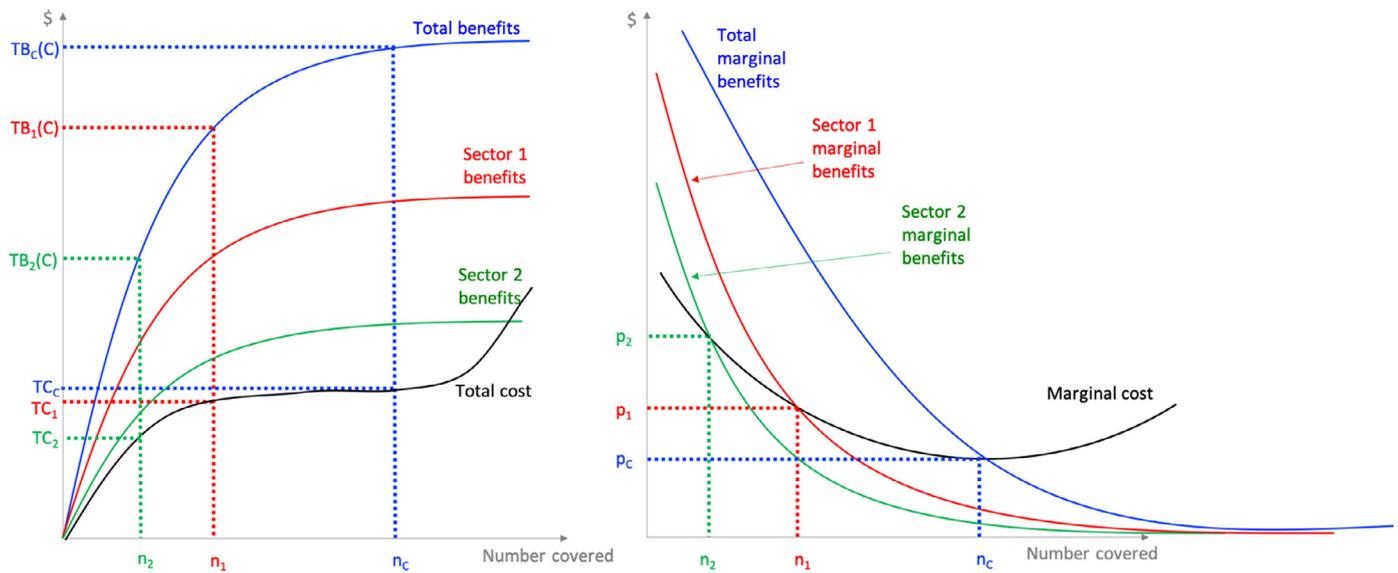
We will consider an example in which two sectors are considering how much funding to allocate to a particular program. Standard economic theory stipulates that the optimal level of funding is at the point where the marginal costs are equal to the marginal benefits. To derive the program's cost curve, we assume economies of scale in the early stages of program scale-up, which are then replaced by diseconomies of scale as the program reaches higher coverage levels. These assumptions

give rise to a standard S-shaped total cost curve and a U-shaped marginal cost curve. To derive the benefit curves of the program, we assume that the benefit of the program to each sector decreases as the number of people covered by the program increases. Intuitively, this assumption may be thought to represent contagion effects or herd immunity; the idea is that reaching a critical proportion of the population already delivers most of the benefits. By combining the benefit curves for each individual sector, we can form a total benefit curve. Fig. 1 depicts illustrative total and cost and benefit curves for two sectors.

In the example depicted in Fig. 1, a cost-benefit analysis undertaken by Sector 1 would imply that  $n_1$  people should be covered (i.e., choosing the point at which Sector 1's marginal benefits are equal to the marginal costs), at a total cost of  $TC_1$  and with total benefits equal to  $TB_1(C)$ . However, a cross-sectoral cost-benefit analysis would imply that  $n_C$  people should be covered at a total cost of  $TC_C$  and with total benefits equal to  $TB_C(C)$ . Crucially, each sector derives greater benefit from co-operating than they do by acting alone. Furthermore, even though Sector 1 would not be willing to pay more than  $TC_1$  for the program, if Sector 2 would contribute the difference  $TC_C - TC_1$  then both sectors would be better off. The natural questions arising from this example are: firstly, under what conditions would the two sectors co-operate and conduct a cross-sectoral cost-benefit analysis? And secondly, if they were to conduct such an analysis and agree to co-finance the program to cover  $n_C$  people at a cost of  $TC_C$ , how should they then split the costs between them?

There is a wealth of research in game theory that sheds a great deal of light on co-financing arrangements. The situation described above resembles the stag hunt, a well-studied type of game. Broadly speaking, solutions to co-financing problems are divided into two categories: cooperative and non-cooperative.

- The *cooperative framework* assumes that the various possible sectors will form a coalition, and jointly decide upon the level at which to fund the intervention. Under this framework, a fair distribution of costs can be derived according to a concept known as the Shapley value (roughly defined as the average expected marginal contribution of each sector). In the example illustrated in Fig. 1, we will derive the share of total net benefits that accrue to the HIV sector by solving the Shapley values. Sector 1's Shapley value is given by the formula:



**Fig. 1.** Schematic illustration of the total benefit and cost curves (left) and the marginal benefit and cost curves (right) for a given structural intervention that benefits two sectors. The marginal cost and benefit curves in the right-hand panel are the derivatives of the total cost and benefit curves in the left-hand panel. If acting in isolation, each sector would set the coverage level of the intervention such that the marginal benefit of covering 1 additional person was equal to the marginal costs—these coverage levels are illustrated in the right-hand panel as  $n_1$ ,  $n_2$ , and  $n_c$  for the number of people covered under Sector 1’s cost-benefit analysis, Sector 2’s cost-benefit analysis, and a combined cost-benefit analysis, respectively. The total benefits and costs for each sector under Sector 1’s cost-benefit analysis are indicated on the left-hand panel in red, and the total benefits and costs for each sector under a combined cross-sectoral cost-benefit analysis are indicated on the left-hand panel in blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

$$\frac{1}{2}((TB_1(C) - TC_1) + ((TB_C(C) - TC_C) - (TB_2(C) - TC_2)))$$

where the first term is the marginal contribution of Sector 1 if it acts alone, and the second bracketed term is the marginal contribution of Sector 1 if it joins a coalition with Sector 2 (equal to the value of the two sectors acting together minus the value of Sector 2 acting alone). By symmetry, Sector 2’s Shapley value will be calculated as:

$$\frac{1}{2}((TB_2(C) - TC_2) + ((TB_C(C) - TC_C) - (TB_1(C) - TC_1))).$$

- The *non-cooperative framework* assumes that each sector commits to a funding level for the intervention without any cross-sectoral discussions. The best model for representing this scenario—known as the Cournot model—argues that the sector that gets the greatest marginal benefit from the intervention will fund it up to the point where the marginal cost is equal to the marginal benefit, and none of the other sectors will contribute any funding.

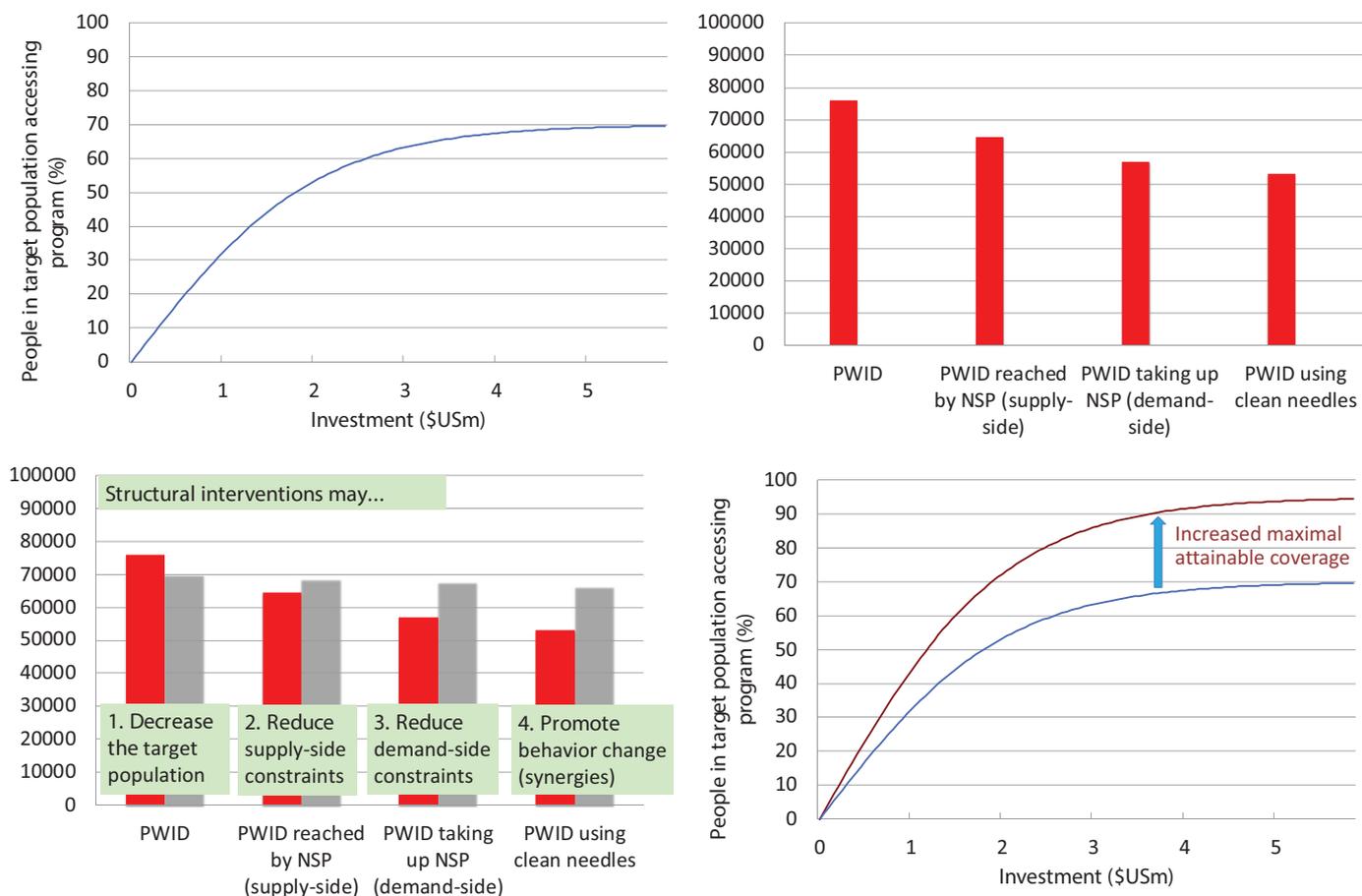
We will illustrate the implications of the game-theory approach by creating a hypothetical scenario around the OST program in Armenia. Since the HIV sector currently funds all of the OST program, we will assume that the coverage level of 301 people represents the result of a single-sector cost-benefit analysis, i.e., that  $n_2 = 301$ ,  $TC_2 = 271,403$ , and  $TB_2(C) = 1556,909 + 18 * WTP$ , and that the marginal cost at this coverage level is equal to the marginal benefits to the HIV sector. Next, we suppose it would be possible to quadruple the coverage of the OST programs with a 50% increase in programmatic funding, thereby reaching a coverage level at which the marginal cost was equal to the total marginal benefit summed across both sectors, and that this would result in a 70% increase to the total benefits for both the HIV and non-HIV sectors. This implies  $n_c = 1204$ ,  $TC_C = 407,105$ ,  $TB_C(2) = 30.6 * WTP$ , and  $TB_C(1) = 2646,745$ . Finally, we assume that if the non-HIV sector conducted a single-sector cost-benefit analysis, the resulting coverage level would be  $n_1 = 600$ , at a total cost of 90% of  $TC_C$  (i.e.,  $TC_1 = 366,395$ ), and with total benefits of 140% of  $TB_2(C)$  (i.e.,

$TB_1(C) = 2179,673 + 25.2 * WTP$ ). We will use these hypothetical numbers to derive the Shapley values for the HIV and non-HIV sectors. This is intended only for illustration purposes, to demonstrate how the game-theoretic approach might give different answers to the CBA approach.

*Incorporating structural interventions in an allocative efficiency model for Belarus*

We illustrate a method for incorporating the effect of structural interventions into the Optima HIV model, which is a compartmental model of HIV transmission and disease progression linked to a programmatic response module capable of estimating the epidemiological impact of interventions (Kerr et al., 2015; Stuart et al., 2017). Like most commonly-used models for assessing the impact of HIV responses, Optima HIV is generally intended to model the effects of targeted programs, i.e., programs that directly target one of the proximal determinants of HIV, and has rarely been employed to assess the impact of structural interventions. Nevertheless, it is possible to adapt the Optima HIV model for this purpose, as shown in this section.

The programmatic response module within Optima HIV relies on the construction of cost functions, an example of which is shown in Fig. 2a, for a needle-syringe program in Belarus (The World Bank, 2015b). These cost functions can be nonlinear, allowing for the possibility that programs have a maximum attainable coverage, which incorporates demand- and supply-side constraints. During the course of a 2015 study of the allocative efficiency of the HIV response in Belarus (The World Bank, 2015b), the maximal attainable coverage of needle-syringe programs in the country was determined to be 70% of all people who inject drugs (PWID). Fig. 2b provides a schematic illustrating the types of factors that can determine this maximal attainable coverage, and which were discussed by the analytic team that conducted the study. Fig. 2c then illustrates how different structural interventions might affect the maximal attainable coverage, and Fig. 2d illustrates how structural interventions could shift the cost function for the needle-syringe program that was illustrated in Fig. 2a, with an increase in the maximal attainable coverage from 70% to 95%.



**Fig. 2.** Schematic illustration of the construction of cost functions and how structural interventions may affect these. (A) a typical nonlinear cost function with saturating coverage, indicating that the marginal cost of covering additional people increases as coverage increases; (B) a schematic illustrating how the maximal attainable coverage of a given intervention (in this case, a needle-syringe program) is affected by supply- and demand-side constraints, as well as behavior change limitations; (C) a schematic illustrating how a structural intervention could increase the maximal attainable coverage of a needle-syringe program by alleviating both supply- and demand-side constraints and synergistically promoting behavior change; (D) an illustration of how the cost function for the needle-syringe program might look both with (red line) and without (blue line) the structural intervention. Abbreviations used: PWID = people who inject drugs; NSP = needle-syringe programs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

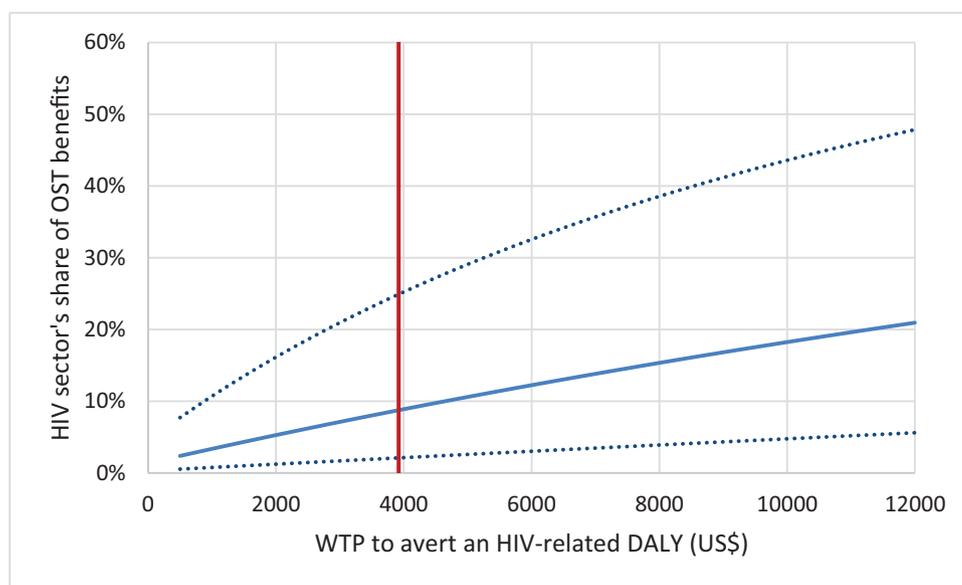
To determine how structural interventions might affect the prioritization of the HIV budget, we compare the results of the allocative efficiency analysis conducted in Belarus (which were derived using the cost function shown in Fig. 2a), with a counterfactual in which we use the cost function shown in red in Fig. 2d. By optimally allocating available resources, the 2015 allocative efficiency study in Belarus determined that 7% of new HIV infections and 25% of AIDS-related deaths could be averted over 2014–2020. This could be achieved by reducing expenditure on management programs (from 52% to 34% of the annual budget), and then doubling investments in antiretroviral therapy and programs targeting key populations – in particular, increasing the annual expenditure on needle-syringe programs from US \$1.2 m to US\$2.4 m. We will compare these outcomes to the outcomes obtained assuming that structural interventions could increase the maximal attainable coverage of the NSP program, meaning that each dollar spent on the NSP program would have more impact. As an illustrative example, we will suppose that structural interventions could increase the maximal attainable coverage of NSPs to 95%. This is an ambitious and arguably unrealistic target, given that ‘high’ coverage has been defined as meaning that at least 60% of the PWID population is in contact with an NSP during a reporting period (Kirwan, Carrotte & Dietze, 2015), and we consider it as strictly hypothetical in order to demonstrate how structural interventions could be incorporated into the allocative efficiency model framework.

## Results

### Modeling OST programs in Armenia in a cross-sectoral cost-benefit analysis

We calculate the net cost of the OST program as US\$271,403 [range: US\$268,377 – US\$275,942] and a net benefit of the OST program as 1285,506 + 18\*WTP [range: 290,207 + 11\*WTP to 3977,740 + 23\*WTP], using the inputs listed in Table 2. In Fig. 3 we present the HIV benefits of the OST program in Armenia as a share of total benefits, as a function of how much one is willing to pay to avert an HIV-related DALY. This figure shows that the more one values averting an HIV-related DALY, the more the HIV sector should pay for the OST program (assuming that everything else is held constant). With our baseline assumptions, the HIV sector’s share of OST benefits (and therefore the proportion of the total costs of the OST program they would be willing to pay) ranges from 2.4% [range: 0.5%–7.7%] with a \$500 WTP to avert an HIV-related DALY, up to 20.9% [range: 5.6%–47.9%] with a \$12,000 WTP.

In the 2015 allocative efficiency study conducted in Armenia (The World Bank, 2015a), 10% of the OST cost was included in the optimization analysis, reflecting the results of this cross-sectoral cost-benefit analysis. This assumes that other sectors will pay for the remainder of the program, which may not be a realistic assumption. We will discuss this assumption in the game-theoretic framework section and the discussion sections.



**Fig. 3.** The relationship between the willingness-to-pay to avert an HIV DALY and the HIV sector's share of OST benefits. The solid blue line represents the values corresponding to a 54% reduction in risk of HIV infection among PWID and a long-term cross-sector (ex-HIV) benefit-cost ratio of 5.5:1 of OST. The dotted lines represent the ranges from varying these 2 parameters. The solid red vertical line indicates GDP per capita in Armenia (US \$3936.80). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

### Structural interventions in a game-theoretic framework

Using the hypothetical numbers for the OST program in Armenia, a cross-sector cost-benefit analysis would lead to a coverage level of  $n_C=1204$  with net benefits of  $2,646,745 + 30.6 \cdot \text{WTP} - 407,105 = 2,239,640 + 30.6 \cdot \text{WTP}$ . The Shapley value for the non-HIV sector is  $1,383,706 + 18.9 \cdot \text{WTP}$ , and for the HIV sector it is  $855,934 + 11.7 \cdot \text{WTP}$ . The sum of the Shapley values gives the total net benefits. The ratio  $(855,934 + 11.7 \cdot \text{WTP}) / (2,239,640 + 30.6 \cdot \text{WTP})$  gives the share of total net benefits that accrue to the HIV sector, and for all WTP values from 0 to 10 times GDP per capita in Armenia, this is equal to 38%. This implies that the HIV sector would pay 38% of the costs of the OST program under a cooperative cofinancing model, under the assumptions we imposed for this example.

If the two sectors do not cooperate, we can predict funding outcomes by solving a Cournot model to find the Cournot-Nash equilibrium. In the example illustrated in Fig. 1, Sector 1's best response is to not fund the intervention at all, while Sector 2 covers  $n_2$  people at a total cost of  $\text{TC}_2$ .

### Incorporating structural interventions in an allocative efficiency model for Belarus

We find that, if the maximal attainable coverage of NSP programs could be increased from 70% to 95%, the optimal annual expenditure on NSPs in Belarus would increase by another 2.5% to US\$2.5 m, and the optimal allocation would avert an additional 2740 HIV-related DALYs over 2014–2020 relative to the scenario in which the maximal attainable coverage of NSPs was 70%. The amount that the HIV sector would be willing to pay for such a structural intervention depends on the willingness-to-pay for an HIV-related DALY, as shown in Fig. 4. Again, the more one values averting an HIV-related DALY, the more the HIV sector would pay, ranging from US\$1.4 m with a \$500 WTP to avert an HIV-related DALY, up to US\$32 m with a \$12,000 WTP.

### Discussion

Mathematical models have proven useful for addressing questions related to the prioritization of health service delivery (Eaton *et al.*, 2014; Stuart *et al.*, 2018). However, such models have historically been limited in their capacity to offer decision support regarding the funding of structural interventions. In part this is because structural interventions often have multi-sectoral benefits, while mathematical models

typically only consider one disease at a time; in part it is because evidence on the efficacy of structural interventions has historically been limited; and in part it is because the benefits associated with structural interventions often go beyond the analytic capacity of standard quantitative methods applied in health economics and policy.

In this paper, we examined three possible avenues for addressing the limitations of quantitative methods in analyzing structural interventions. First, we showed how a cost-benefit analysis framework could be applied to an intervention (OST in Armenia) known to have cross-sectoral benefits. This framework also encompasses a possible method for distributing the costs of funding a structural intervention among the sectors that benefit from it. Second, we showed how a structural intervention could be considered within an allocative efficiency analysis in Belarus. The structural intervention that we considered was one that had the capacity to increase the maximal attainable coverage of needle-syringe programs. There is a substantial body of research addressing the physical, social, economic and policy factors that enhance the effectiveness of NSP service provision (Bluthenthal, Kral, Lorvick & Watters, 1997; Lurie & Drucker, 1997; Wood *et al.*, 2003), and while some of these are costly to implement (e.g., addressing poverty, unemployment, homelessness and dependence on social welfare), others are less so (e.g., using network-oriented strategies). In the example we considered, the maximal attainable coverage of NSPs in Belarus was already estimated to be high, thanks to the maturity of these programs. In other contexts—particularly contexts in which injecting drug use is criminalized—the maximal attainable coverage would be much lower.

The implications of the game theoretic analysis are also noteworthy. The first takeaway is that a lack of cooperation between different sectors results in one single sector shouldering the entirety of the funding burden. This could, to some extent, explain the financing arrangements that have tended to prevail to date, whereby interventions known to have cross-sectoral benefits (including opiate substitution therapy or cash transfer programs) are typically funded by HIV. The second takeaway is that if a cross-sectoral funding model could exist, it would likely need to use a more nuanced method for apportioning the costs than a CBA, to avoid a situation where funders have incentives to abandon the cross-sectoral coalition. The Shapley value presents a possible solution for distributing the costs of a cross-sectoral intervention. We provided an illustrative example which would result in the HIV sector paying 38% of the costs of an OST program based on the Armenian case study, and although the numbers used to construct this example were strictly illustrative, it is already clear that the HIV share under a co-financing model might be higher than that implied by a

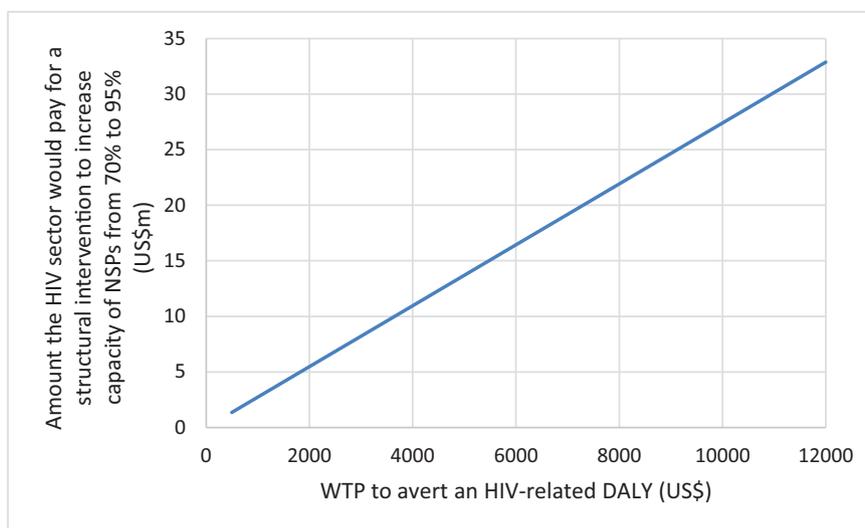


Fig. 4. The relationship between the willingness-to-pay to avert an HIV DALY and the amount that the HIV sector would be willing to pay for an intervention that would increase the maximal attainable coverage of NSP programs from 70% to 95%.

simpler cost attribution framework based on WTP thresholds. This is because the game-theoretic framework (a) allows for a more nuanced negotiation in situations where there is an unequal distribution of benefits across sectors, ensuring that each sector gains as much or more as they would have from acting independently, and (b) gives greater consideration to the trade-offs involved for each sector, with decreasing marginal benefit curves for each sector indicating that scaling up the program beyond a certain level becomes less attractive.

Although we have argued that it is important for quantitative decision-making frameworks to be able to value structural interventions, and have presented three ways of doing so, it is important to note there are still many limitations. First, the data required in order to use any of these three quantitative decision-making frameworks in practice is likely to be scarce or nonexistent, and assumptions may need to be made about fundamentally important parameters, such as the ability of structural interventions to expand the reach of other interventions (needed for evaluating the NSPs in Belarus within the AEA framework), or the marginal cost functions of OST programs (needed for evaluating OST programs in Armenia within the game-theoretic framework). While it is possible to proceed using assumptions and conduct sensitivity analyses around these parameters as we did here, it is still a significant practical limitation to adopting these frameworks. Second, the theoretical underpinnings of all three frameworks are not without flaws: in particular, all three are based on a monetization of welfare which ignores equity. Third, we have not considered the broader funding landscape in these analyses, and it's likely that the relative availability of funding for HIV compared to other health, welfare, and development sectors plays a role in determining co-financing arrangements. This is relevant for the example we considered of the OST program in Armenia, where the HIV sector actually paid 100% of the costs of the program. There are several different possible interpretations of this. If we apply the cross-sectoral cost-sharing framework that we used in this paper, it would imply that the revealed WTP to avoid an HIV-related DALY is very high (in excess of 10 times GDP/capita). In reality, it is likely that HIV budgets are often used to fund structural interventions simply because HIV has historically been well-funded compared to other sectors.

The HIV response has benefitted from (a) dedicated donor funding streams, and (b) a set of peer-reviewed models to help with the allocation of these funds (The HIV Modelling Consortium, 2015). However, these models were mainly developed to support the allocation of siloed funding (as this was the majority of the funding available), and are not well-adapted to valuing interventions that do not have direct, proximal

effects on HIV transmission or progression. Outside of HIV, this problem is much less pronounced: structural interventions are often funded from national government budgets or official developmental assistance projects, in which case funding is already pooled and distributed to interventions known to benefit multiple sectors (such as microfinancing projects, programs to support children remaining in school, or social housing projects, to take just three examples). As the global HIV response moves towards integration with the broader health sector, the methods used to assess the allocation of funds may ultimately need to expand beyond HIV-specific models, in order to capture the many different benefits of cross-sectoral interventions. To maximize health benefits, resource allocations need to be informed by decision frameworks that explicitly take cost-effectiveness into account. It is therefore imperative to ensure that structural interventions can be modelled within such decision frameworks.

### Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.drugpo.2020.102702](https://doi.org/10.1016/j.drugpo.2020.102702).

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