

Methods and Applications

Exploration for the Priority of HIV Intervention: Modelling Health Impact and Cost-Effectiveness — Six Cities, Eastern China, 2019–2028

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ABSTRACT

Introduction: In order to enhance the effectiveness of resource allocation, regions must tailor their responses to their specific epidemiological and economic situations.

Methods: Utilizing Spectrum software, we projected the cost-effectiveness of 10 chosen HIV interventions in six cities in eastern China from 2019 to 2028. We assessed three scenarios — Base, Achievable, and Idealized — for each city. The analysis included the projected number of HIV infections and deaths averted, as well as the incremental cost-effectiveness ratios for each intervention in the six cities.

Results: In Shijiazhuang, Wuxi, Yantai, and Zhenjiang, cities with initially low antiretroviral therapy (ART) coverage, ART showed significant effectiveness, especially for males. Conversely, in Foshan and Ningbo, where ART coverage was notably high, oral pre-exposure prophylaxis (PrEP) for men who have sex with men (MSM) proved effective in the Idealized scenario. MSM outreach, ART for males, and ART for females demonstrated cost-effectiveness across all six cities in both Achievable and Idealized scenarios at the predefined thresholds for each city.

Discussion: Maintaining an appropriate coverage rate for outreach to MSM can lead to cost-effectiveness. In cities with low ART coverage, scaling up ART remains a crucial intervention. In regions with high ART coverage, consideration may be given to the utilization of oral PrEP for MSM individuals, requiring budget allocation.

To effectively implement customized interventions, each region and country must address their unique

epidemiological and economic situations and establish key actions to enhance local human immunodeficiency virus (HIV) responses. Creating tailored financial strategies for sustainability is crucial to guarantee universal access and better health results. Progress evaluation should encompass a comprehensive spectrum of HIV interventions to benefit all demographic groups.

Studies using Spectrum modules have shown that HIV intervention programs are cost-effective in regions like sub-Saharan Africa, Asia, and the Caribbean (1–4). Nonetheless, due to the significant variability in HIV prevalence and intervention coverage in eastern China, it is challenging to extrapolate these results to that specific area.

This study aims to forecast the health outcomes and cost-effectiveness of scaling up HIV interventions, and to prioritize life-saving HIV interventions in six cities in eastern China, utilizing the Spectrum modules.

METHODS

Five cities in eastern China, namely Foshan, Ningbo, Shijiazhuang, Wuxi, and Yantai, were chosen based on the following criteria: each city had a total population exceeding three million and reported over 200 new cases of HIV infection annually. To simultaneously assess the cost-effectiveness discrepancies between two cities within the same province and provide insights for subsequent spatiotemporal distribution studies, Zhenjiang — an additional city in Jiangsu Province like Wuxi, boasting a population of three million and approximately 50 newly reported HIV cases each year — was included in the analysis (5).

A standardized data collection tool was developed following the Spectrum framework to calculate costs and model healthcare payer perspectives. Data from

public and service sectors in six cities between 2015 and 2019 were collected. This study investigates the cost-effectiveness of 10 key HIV interventions (Table 1) and presents the HIV intervention priorities across sampled cities for the period 2019–2028.

Three scenarios were simulated to project the outcomes of scaling up interventions in each city, under the assumption of an unlimited budget.

Scenario 1: Base Scenario

In the Base scenario, from 2020 to 2028, all interventions maintain the same coverage as in 2019.

Scenario 2: Achievable Scenario

Enhance the scope of specific interventions by double up to 99.90% by 2028, with the exception of oral pre-exposure prophylaxis (PrEP) for high-risk heterosexual (HRH) individuals and men who have sex with men (MSM) due to the absence of prior testing and coverage in the studied cities. Simultaneously, escalate the coverage of oral PrEP for HRH and MSM from 0% in the starting year to 5% by 2028. Linear interpolation was utilized to project the coverage rates between 2020 and 2027, while the coverage for other interventions remained constant from 2019.

Scenario 3: Idealized Scenario

In this case, it was assumed that the coverage rate of the 10 chosen interventions would reach 99.90%. Linear interpolation was used to simulate the coverage rates for the years 2020–2027. The coverage rates of the remaining interventions were held constant at 2019 levels.

Definitions of the 10 selected intervention coverage and the remaining interventions's coverage all displayed in the Supplementary Table S1 (available at <https://weekly.chinacdc.cn/>). The Coverage assumptions for 10 selected HIV interventions in the target year 2028 were displayed in Supplementary Table S2 (available at <https://weekly.chinacdc.cn/>). Unit costs for each intervention were based on local data from six cities in 2019 and kept constant in the model, as outlined in Supplementary Table S3 (available at <https://weekly.chinacdc.cn/>).

Initially, the model simultaneously expanded the coverage of ten selected interventions to determine the total infections and deaths prevented, as well as the costs for each scenario in each city. Subsequently, each intervention was individually scaled up per scenario in every city to analyze the outcomes of each intervention.

Output Indicators

The number of infections and deaths prevented by scaling up interventions from the Base scenario to the Achievable or Idealized scenarios was directly derived from the model calculations. Costs for each scenario, presented in 2019 Chinese Yuan (CNY) with a 3% annual discount rate and an exchange rate of 1 USD=6.90 CNY (6), were calculated. Incremental cost was manually determined by comparing intervention costs under the Achievable or Idealized scenarios with those under the Base scenario. The incremental cost-effectiveness ratio (ICER) was calculated as the ratio of incremental costs to infections averted. To account for economic variations across cities, cost-effective interventions in each city were classified as those with an ICER below the 2019 per capita GDP

TABLE 1. Coverage of 10 selected interventions in six cities in 2019.

Selected interventions (% per year)	Foshan	Ningbo	Shijiazhuang	Wuxi	Yantai	Zhenjiang
VCT	0.22	0.31	0.40	0.14	0.41	0.49
Condoms for adult population	0	25.41	18.75	39.09	20.48	0
SSTT	99.90	95.00	2.50	3.00	0.00	1.40
FSW outreach	99.90	72.00	28.34	99.90	92.00	94.00
MSM outreach	79.32	59.20	70.00	29.94	92.70	4.80
MSM receiving lubricants	79.32	0	11.21	9.98	7.20	3.90
Oral PrEP for HRH	0	0	0	0	0	0
Oral PrEP for MSM	0	0	0	0	0	0
ART for males	99.90	99.90	50.86	86.14	38.61	79.48
ART for females	99.90	99.90	16.93	42.58	10.75	49.90

Abbreviation: VCT=voluntary counseling and testing for adult population; SSTT=secondary students with teachers trained in AIDS; FSW=female sex worker; MSM=men who have sex with men; PrEP=pre-exposure prophylaxis; HRH=high risk heterosexual; ART=antiretroviral therapy.

(Supplementary Table S4, available at <https://weekly.chinacdc.cn/>) for that city per infection averted.

Sensitivity Analysis

A one-way sensitivity analysis was performed by adjusting the unit cost of selected interventions by +/- 50% of the original values to assess the model's stability.

RESULT

Table 2 illustrates the comprehensive costs and cost-effectiveness of two distinct scenarios across six cities from 2019 to 2028. During this period, under the Achievable scenario with Shijiazhuang reaching optimal impact, a total of 1,580 HIV infections and 550 deaths were prevented. In contrast, the Idealized scenario showed even greater impact, with 2,608 HIV infections and 796 deaths averted. The least impact was noted in Foshan and Ningbo. As anticipated, the costs per infection and death averted in the Idealized scenario were considerably higher compared to those in the Achievable scenario across all six cities. In municipalities with high initial antiretroviral therapy (ART) coverage, like Foshan and Ningbo, the ICERs were significant, yielding 0.47 million yuan per infection averted in the Achievable scenario and exceeding 100 million yuan in the Idealized scenario, indicating poor cost-effectiveness when scaling up interventions. Conversely, in the other four cities with lower initial ART coverage, such as Shijiazhuang and

Yantai, escalating current intervention coverage proved to be highly cost-effective, adhering to the cost-effectiveness thresholds established for these cities within the Achievable scenario.

Figure 1 and Table 3 display the cost-effectiveness of HIV interventions in six cities under Achievable and Idealized scenarios. In cities like Shijiazhuang, Wuxi, Yantai, and Zhenjiang, ART, especially for males, showed high effectiveness in averting infections. The most impactful strategy was ART for males in Shijiazhuang, projected to prevent 1,367 infections from 2019 to 2028. The majority of prevented deaths were attributed to ART based on the Spectrum framework (Supplementary Table S5, available at <https://weekly.chinacdc.cn/>). In Foshan and Ningbo, with high ART coverage, oral PrEP for MSM in the Idealized scenario demonstrated significant effectiveness.

At the cost-effectiveness threshold of each city, interventions such as outreach to MSM, ART for males, and ART for females were found to be cost-effective across six cities in both scenarios. Among these, MSM outreach was identified as the most cost-effective, with a range between 0.39 to 42.48 thousand yuan per infection averted. However, the effectiveness of MSM outreach may plateau with expanded coverage, as depicted in Figure 1. For instance, in Zhenjiang and Wuxi, the number of HIV infections averted through MSM outreach increased significantly from Achievable to Idealized scenarios, while the impact in the other four cities did not show a further increase with scaled-up coverage.

TABLE 2. Overall costs and cost-effectiveness in the Achievable Scenario and the Idealized Scenario among six cities from 2019 to 2028.

Cost and health impact		Foshan	Ningbo	Shijiazhuang	Wuxi	Yantai	Zhenjiang
Total cost of Base Scenario (Million CNY)		141.05	203.55	443.48	202.16	156.53	82.36
Total cost of Achievable Scenario (Million CNY)		145.16	212.53	473.88	222.13	171.50	86.70
Total cost of Idealized Scenario (Million CNY)		375.62	1,054.31	866.18	684.72	915.93	444.30
Total number of infections averted	AS	9	19	1,580	335	618	284
	IS	118	131	2,608	477	1,618	401
Total number of deaths averted	AS	0*	0*	550	132	469	61
	IS	1	1	796	156	775	61
Incremental cost per infection averted (Million CNY)	AS	0.47	0.47	0.02	0.06	0.02	0.02
	IS	1.98	6.51	0.16	1.01	0.47	0.90
Incremental cost per death averted (Million CNY)	AS	105.62	103.20	0.06	0.15	0.03	0.07
	IS	436.82	1,432.25	0.53	3.10	0.98	5.89

Abbreviation: AS=Achievable Scenario; IS=Idealized Scenario; CNY=Chinese Yuan.

* indicates that the numbers provided are rounded integers. The total deaths averted in Foshan and Ningbo were 0.039 and 0.087, respectively.

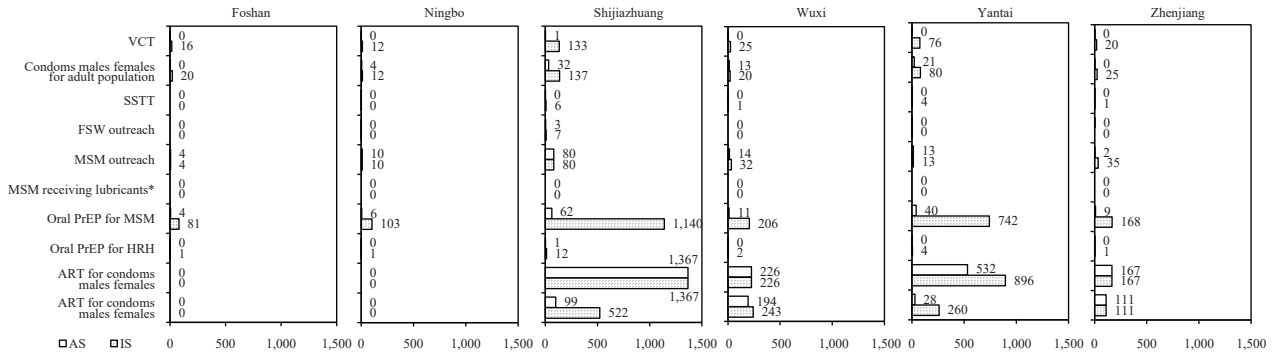


FIGURE 1. Total HIV infections averted by 10 selected HIV interventions in Achievable and Idealized Scenarios in six cities from 2019 to 2028.

Abbreviation: VCT=Voluntary counseling and testing for adult population; SSTT=Secondary students with teachers trained in AIDS; FSW=Female sex worker; MSM=Men who have sex with men; PrEP=Pre-exposure prophylaxis; HRH=High risk heterosexual; ART=Antiretroviral therapy; AS= Achievable Scenario; IS=Idealized Scenario.

* indicates that the impact of MSM receiving lubricants was modeled as 0 in six cities.

TABLE 3. Incremental cost per HIV infection averted for 10 selected HIV interventions in two scenarios across six cities from 2019 to 2028 (thousand CNY).

Selected interventions	Foshan		Ningbo		Shijiazhuang		Wuxi		Yantai		Zhenjiang	
	AS	IS	AS	IS	AS	IS	AS	IS	AS	IS	AS	IS
VCT	53,976.14	9,265.54	60,648.14	62,654.05	1,697.46	1,756.36	15,228.19	15,783.12	8,355.87	8,588.52	105,931.86	16,552.63
Condoms for adult population	1,242.07	1,537.69	237.21	241.46	265.94	272.39	564.35	571.22	47.04*	48.05*	9.05*	28.91*
SSTT	-	-	3,941.67	3,941.67	253.34	263.72	1,376.34	1,491.83	488.55	501.79	1,814.65	1,661.12
FSW outreach	-	-	2,271.00	2,271.00	36.64*	37.49*	-	-	40.63*	40.63*	11.85*	11.85*
MSM outreach	33.06*	33.06*	42.48*	42.48*	0.39*	0.39*	19.76*	19.99*	1.70*	1.70*	6.27*	6.49*
MSM receiving lubricants	-	-	-	-	-	-	-	-	-	-	-	-
Oral PrEP for HRH	68,969.20	67,956.75	115,145.91	114,166.19	9,481.25	9,505.91	35,247.30	35,593.72	18,679.28	18,630.42	27,134.91	27,549.97
Oral PrEP for MSM	147.08*	159.14*	181.99	194.71	15.40*	17.94*	57.63*	64.17*	16.22*	18.59*	33.65*	37.78*
ART for males	-	-	-	-	9.75*	9.75*	19.09*	19.09*	12.30*	12.13*	4.26*	4.26*
ART for females	-	-	-	-	8.66*	12.53*	15.27*	17.89*	18.51*	22.34*	2.61*	2.62*

Note: “-” indicates that the impact was 0 and cannot be divided.

Abbreviation: VCT=Voluntary counseling and testing for adult population; SSTT=Secondary students with teachers trained in AIDS; FSW=Female sex worker; MSM=Men who have sex with men; PrEP=Pre-exposure prophylaxis; HRH=High risk heterosexual; ART=Antiretroviral therapy; AS= Achievable Scenario; IS=Idealized Scenario.

* indicates that the intervention in this city was cost-effective at the threshold level of this city.

The results indicate that the epidemiological efficacy of the intervention is influenced by the coverage levels in different scenarios. Supplementary Table S6 (available at <https://weekly.chinacdc.cn/>) presents the cost per HIV infection averted based on varying unit costs of interventions. A direct correlation was observed between unit cost and cost per HIV infection averted; a 50% decrease in unit cost resulted in a similar decrease in the cost per HIV infection averted, and vice versa (Supplementary Table S7, available at <https://weekly.chinacdc.cn/>).

DISCUSSION

Our research conducted using the Spectrum model offers valuable insights for guiding resource allocation. Between 2019 and 2028, Shijiazhuang demonstrated the highest potential impact with the lowest ICER compared to other cities analyzed. Situated in Hebei province, Shijiazhuang stands out due to its large population of 11 million, low ART coverage, and limited HIV resources per capita. In contrast, Foshan

had the lowest estimated potential impact, while Ningbo had the highest ICER. These cities, located in prosperous provinces like Guangdong and Zhejiang, exhibit high ART coverage and ample HIV resources. Therefore, prioritizing funding towards regions with growing economies, low treatment rates, and substantial populations is crucial in shaping the future of HIV intervention strategies (7).

The study showcased that transitioning from an Achievable to an Idealized scenario for a single intervention coverage results in a minor health impact change at a significantly higher cost. For instance, the ICER in the Idealized scenario is estimated to be approximately 4 times (in Foshan) to 45 times (in Zhenjiang) greater compared to the Achievable scenario. Thus, opting for an Achievable scenario is advisable for policymakers with constrained resources across the six cities.

The results guide the development of a ten-year priority intervention plan for six cities, including MSM outreach, ART for males, and ART for females. Prior research has shown that MSM outreach significantly enhances HIV testing rates (8) and encourages prompt treatment (9). However, there is limited data on the cost-effectiveness of MSM outreach (10). Our study indicated that the impact of MSM outreach on health outcomes plateaued at a baseline coverage of around 59.2% (in Ningbo). Beyond this threshold, supplementary interventions are necessary to address remaining gaps due to the saturation of MSM outreach.

ART has proven to be the most effective and economical approach for reducing HIV infections and mortalities in Shijiazhuang, Wuxi, Yantai, and Zhenjiang. In contrast, oral PrEP for MSM has emerged as the strategy of choice in Foshan and Ningbo, areas with high ART coverage, to meet the objectives of decreasing new HIV infections. These findings align with previous oral PrEP modeling studies (11–12). Nonetheless, the adoption of this strategy in Ningbo, where the ICER soared to 181.99 and 194.71 thousand yuan per infection averted, was deemed not cost-effective according to the city's threshold of 146.12 thousand yuan per infection averted. While extensive ART coverage may significantly curb HIV transmission, rendering PrEP redundant and uneconomical in such cases (13), the indirect benefits of enhanced HIV testing and linkage to subsequent treatment attributable to PrEP cannot be overlooked (14). Given the substantial public health challenge posed by the prevalence of HIV among

MSM in China, it is imperative that economically developed areas with high ART coverage continuously evaluate and expand oral PrEP for MSM, ensuring sufficient budgetary provisions. To achieve the ambitious aim of halting the HIV epidemic, strategies must be meticulously tailored and implemented at the local level.

Like all modeling studies, this study is subject to some limitations. First, due to insufficient regional data, we utilized some national-level indicators in the model, potentially impacting the accuracy of projections. Second, the lack of data on mobile populations could lead to underestimation of local epidemics. Third, our models did not consider the impacts of disruptions related to coronavirus disease 2019 (COVID-19) (15). While COVID-19 does not directly influence HIV transmission biologically, it does affect various factors such as awareness, behavior, and healthcare resource availability, as well as resource allocation in response to the sporadic nature of the epidemic.

In conclusion, this study by Spectrum delineated key actions for regions sampled from 2019 to 2028 to improve HIV response and achieve optimal health outcomes in AIDS control. The utilization of Spectrum is crucial for guiding prioritization in cities based on their unique epidemiological, economic, and HIV response characteristics.

Conflicts of interest: No conflicts of interest.

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SUPPLEMENTARY MATERIAL

Structure of the Spectrum Software

Spectrum is a policy module system designed to support the analysis, planning, and advocacy efforts of health programs (1). This system, along with its associated manuals, undergoes regular updates and is accessible in various languages at no cost via <https://avenirhealth.org/software-spectrum.php>. Funding for module development has been primarily provided by the United States Agency for International Development, with additional technical assistance from a group of collaborators including the Joint United Nations Programme on HIV/AIDS, World Health Organization, United Nations Children's Fund, the United Nations Population Division, the United States Census Bureau, United Nations Fund for Population Activities, among others. For this study, we employed four specific modules from the Spectrum suite — namely, the Demographic module (DemProj), the AIDS Impact module (AIM), the Resource Needs module [Chinese yuan (CNY)], and the Goals module — to assess the cost-effectiveness of comprehensive HIV interventions in six eastern Chinese cities. The DemProj module was used to project age- and sex-specific population totals for each city, drawing on fertility and mortality assumptions. The AIM module provided projections of the HIV epidemic's impact, such as the number of people living with HIV, new infections, and age- and sex-specific AIDS mortality. The RNM supplied estimates of the resources required for various interventions, based on coverage data and unit costs previously ascertained in the six cities (2). Finally, the Goals module calculated the costs, infections averted, and deaths prevented as a result of the HIV interventions.

Data Collection

Utilizing the Spectrum framework, our team designed a methodical and scalable data collection instrument from the perspective of healthcare payers to streamline the process of calculating costs and constructing models. We consolidated a comprehensive array of indicators, organizing them into a practical instrument comprising 6 primary and 66 secondary categories (2). The primary indicators encompass demographic statistics, numbers of HIV-positive individuals and those at elevated risk, strategies for preventing mother-to-child transmission (PMTCT), ART, the scope and expenditure per unit of integrated services, and program logistical support. Meanwhile, the secondary indicators offer detailed quantification of these domains. Experts from the national, provincial, and municipal levels with backgrounds in HIV prevention, treatment, maternal and child healthcare, procurement, and finance were solicited to refine this data collection instrument. A preliminary trial for HIV cost estimation was conducted in Shijiazhuang (3). Subsequent data collection in six cities from 2015 to 2019 provided public and service information. Our findings for the comprehensive costs of HIV intervention not only aligned with the realities of the respective locales but also garnered validation from the local expert community.

The CDC in six cities collected data on population size, coverage, unit costs of high-risk populations, and program costs from local demographic, sentinel monitoring, and survey data sources. Data on PMTCT were provided by maternal and child care institutions, while designated hospitals for HIV/AIDS treatment contributed treatment data from hospital information systems. Due to the nature of the study design, personal consent was not deemed necessary. The study received approval from the Ethical Review Committee on Research at the National CDC HIV/STD Center (ID number: X180315504).

Setting Information

To address the lack of regional data, default national-level data for China were utilized in the model, covering aspects like age distribution of fertility, oral PrEP adherence (50%), and PrEP effectiveness (90%). Population mobility was not considered, and the total net migrants per year for each city were set to 0.

After entering all the data into Spectrum, we fitted the model to the epidemic following the software manual.

RESULT

Sensitivity Analysis

Supplementary Table S7 presents remarkable cost-effectiveness results for Shijiazhuang and Ningbo based on selected interventions. The ranking of cost-effectiveness by interventions remained consistent, indicating the

SUPPLEMENTARY TABLE S1. Definitions of all intervention coverage in our study.

Categories	Interventions	Coverage definitions
Selected interventions	VCT	The percentage of the population aged 15–49 years old that receives VCT each year.
	Condoms for adult population	The percentage of the condoms free of charge provided for the population aged 15–49 years old by health institutions each year.
	SSTT	The percentage of secondary school students who have teachers trained in HIV/AIDS education each year.
	FSW outreach	The percentage of female sex workers that is reached by outreach interventions each year.
	MSM outreach	The percentage of MSM that is reached by outreach interventions each year.
	MSM receiving lubricants	The percent of MSM receiving lubricants each year.
	oral PrEP for HRH	The percentage of oral PrEP provided by the health institutions for high-risk heterosexual population each year.
	oral PrEP for MSM	The percentage of oral PrEP provided by the health institutions for MSM each year.
	ART for males	The percentage of males aged 15 years old and above receiving ART to people living with HIV (modeled by Spectrum)each year.
	ART for females	The percentage of females aged 15 years old and above receiving ART to people living with HIV (modeled by Spectrum)each year.
	Community mobilization	The percentage of the population aged 15–49 years old that is reached by community mobilization efforts each year.
	Mass media	The percentage of the population aged 15–49 years old that is reached by mass media campaigns each year.
	Primary school students with teachers trained in AIDS	The percentage of primary school students who have teachers trained in HIV/AIDS education each year.
	Out-of-school youth reached	The percentage of youth not attending school reached by an HIV/AIDS intervention.
Remaining interventions	Cash transfers	The percentage of young women and girls aged 15–24 receiving cash transfers each year.
	Male Sex workers outreach	The percentage of male sex workers that is reached by outreach interventions each year.
	IDUs receiving harm reduction intervention	The percentage of IDUs receiving harm reduction interventions each year.
	IDUs receiving counseling and testing	The percentage of IDUs receiving counseling and testing each year.
	IDUs receiving community outreach and peer education	The percentage of IDUs receiving community outreach or peer education each year.
	IDUs receiving needle and syringe exchange	The percentage of IDUs participating in needle and syringe exchange programs each year.
	IDUs receiving drug substitution	The percentage of IDUs participating in drug substitution programs each year.
	Males with STI receiving treatment	The percentage of males with new and symptomatic STIs that receive treatment each year.
	Females with STI receiving treatment	The percentage of females with new and symptomatic STIs that receive treatment each year.
	Units of blood for transfusion tested	The percentage of blood units tested for HIV each year.
	PEP	The percentage of PEP kits needed that are supplied each year.
	Unsafe injections replaced with AD syringes	The percentage of unsafe injections that are replaced with AD syringes each year.
	Reduction in the number of other injections	The percentage reduction in the number of injections that are not replaced with AD syringes.
	Universal precautions	The percentage of hospital beds that are supplied with universal precautions each year.
Male circumcision	The percentage of adult males that are currently circumcised in a particular year.	

Note: Considering the potential underreporting of HIV infections locally, which could lead to an overestimation of ART coverage rates, we have implemented a consistent approach. ART coverage for both males and females was determined by dividing the reported number of individuals on ART from 2015 to 2019 by the annual estimates of people living with HIV derived from Spectrum using local incidence rates from 2015 to 2019.

Abbreviation: VCT=Voluntary counseling and testing for adult population; SSTT=Secondary students with teachers trained in AIDS; FSW=Female sex worker; MSM=Men who have sex with men; PrEP=Pre-exposure prophylaxis; HRH=High risk heterosexual; ART=Antiretroviral therapy; IDU=Injecting drug user; STI=Sexually transmitted infection; PEP=Post-exposure prophylaxis; AD=Auto-destruct.

robustness of the cost-effectiveness assessment even with variations in unit costs. Comparable patterns were observed in the remaining four cities, although not displayed.

SUPPLEMENTARY TABLE S2. Coverage assumptions for 10 selected HIV interventions in the target year (2028).

Categories	Foshan			Ningbo			Shijiazhuang			Wuxi			Yantai			Zhenjiang		
	Base Scenario	Achievable Scenario	Idealized Scenario	Base Scenario	Achievable Scenario	Idealized Scenario	Base Scenario	Achievable Scenario	Idealized Scenario	Base Scenario	Achievable Scenario	Idealized Scenario	Base Scenario	Achievable Scenario	Idealized Scenario	Base Scenario	Achievable Scenario	Idealized Scenario
	2028	2028	2028	2028	2028	2028	2028	2028	2028	2028	2028	2028	2028	2028	2028	2028	2028	2028
VCT	0.22	0.44	99.90	0.31	0.62	99.90	0.40	0.80	99.90	0.14	0.28	99.90	0.41	0.82	99.90	0.49	0.98	99.90
Condoms for adult population	0	5.00	99.90	25.41	50.82	99.90	18.75	37.51	99.90	39.09	78.18	99.90	20.48	40.96	99.90	0	5.00	99.90
SSTT	99.90	99.90	99.90	95.00	99.90	99.90	2.50	5.00	99.90	3.00	6.00	99.90	0	5.00	99.90	1.40	2.80	99.90
Female sex workers outreach	99.90	99.90	99.90	72.00	99.90	99.90	28.34	56.68	99.90	99.90	99.90	99.90	92.00	99.90	99.90	94.00	99.90	99.90
MSM outreach	79.32	99.90	99.90	59.20	99.90	99.90	70.00	99.90	99.90	29.94	59.89	99.90	92.70	99.90	99.90	4.80	9.60	99.90
MSM receiving lubricants	79.32	99.90	99.90	0	5.00	99.90	11.21	22.42	99.90	9.98	19.96	99.90	7.20	14.40	99.90	3.90	7.80	99.90
oral PrEP for MSM	0	5.00	99.90	0	5.00	99.90	0	5.00	99.90	0	5.00	99.90	0	5.00	99.90	0	5.00	99.90
oral PrEP for HRH	0	5.00	99.90	0	5.00	99.90	0	5.00	99.90	0	5.00	99.90	0	5.00	99.90	0	5.00	99.90
ART for males	99.90	99.90	99.90	99.90	99.90	99.90	50.86	99.90	99.90	86.14	99.90	99.90	38.61	77.21	99.90	79.48	99.90	99.90
ART for females	99.90	99.90	99.90	99.90	99.90	99.90	16.93	33.86	99.90	42.58	85.16	99.90	10.75	21.50	99.90	49.90	99.79	99.90

Abbreviation: VCT=Voluntary counseling and testing for adult population; SSTT=Secondary students with teachers trained in AIDS; FSW=Female sex worker; MSM=Men who have sex with men; PrEP=Pre-exposure prophylaxis; HRH=High risk heterosexual; ART=Antiretroviral therapy.

SUPPLEMENTARY TABLE S3. Unit cost of 10 selected HIV interventions in six cities (CNY).

Selected HIV interventions	Foshan	Ningbo	Shijiazhuang	Wuxi	Yantai	Zhenjiang	Sources
VCT (costs per test per year)	91.75	326.00	65.00	200.00	389.00	403.21	
Condoms for adult population (costs per condom)	4.50	0.30	2.60	1.64*	0.58	0.20	
SSTT	92.39*	60.00	70.00	92.39*	92.39*	147.16	
FSW reached by intervention per year	50.00	100.00	20.26	100.00	13.90	4.00	CDC
MSM reached by intervention per year	100.00	100.00	122.61*	168.00	122.61*	122.45	
MSM receiving lubricants	5.00	7.75*	2.76	10.00	1.00	20.00	
oral PrEP (costs per person per year)	1,980.00	1,980.00	1,980.00	1,980.00	1,980.00	1,980.00	
ART							
Adults (costs per patient per year)							
First-line ART drugs	1,134.34*	936.23	1,832.00	715.40	1,136.86	1,051.20	
Second-line ART drugs	4,163.78*	4,343.50	3,577.00	4,526.00	3,846.42	4,526.00	
Additional ART drug costs for TB patients (male)	2,019.46*	2,609.75	1,200.00	4,526.00	1,761.55	0	
Additional ART drug costs for TB patients (Female)	2,029.46*	2,609.75	1,250.00	4,526.00	1,761.55*	0	
Lab costs for ART treatment	2,436.40	1,662.20	1,728.00	3,565.00	3,565.00	1,384.85	
Lab costs for drugs to treat infections	20,000.00	1,000.00	15,000.00	19,459.00	1,1368.77*	1,384.85	
Cotrimoxazole prophylaxis	0.28	120.00	100.00	64.00	80.00	0.10	
TB prophylaxis	0	1,000.00	90.00	200.00	0	15.00	
Nutrition supplements in the first six months	0	0	0	0	0	0	
Children (costs per patient per year)							
Children's ARV drugs	0	6,278.00	0	0	2,656.90	0	Designated hospitals for HIV/AIDS treatment
Children's ART treatment lab costs	0	1,142.20	0	0	1,350.00	0	
Service delivery costs							
Cost per in-patient day	600.00	1,000.00	950.00	1,183.00	550.00	856.6*	
Cost per out-patient visit	200.00	500.00	350.00	284.00	250.00	316.8*	
Service delivery requirements (per patient per year)							
ART: in-patient days	7.00	5.00	8.83*	13.00	12.00	7.15	
ART: out-patient visit	4.00	3.00	5.00	4.00	6.00	5.88	
OI treatment: in-patient days	21.00	25.19*	22.00	15.00	28.00*	42.77	
OI treatment: out-patient days	12.00	6.00	4.00	6.00	11.00*	5.00	
Migration from first to second line (% per year)	5.00	3.40	3.30	5.00	1.43	1.63	

Abbreviation: VCT=Voluntary counseling and testing for adult population; SSTT=Secondary students with teachers trained in AIDS; FSW=Female sex worker; MSM=Men who have sex with men; PrEP=Pre-exposure prophylaxis; ART=Antiretroviral therapy; TB=Tuberculosis; OI=Opportunistic infections; CNY=Chinese Yuan.

* indicates cases where the unit cost significantly differed or was missing compared to other cities; in such instances, the average value from the other cities was used to fill in the missing data.

SUPPLEMENTARY TABLE S4. Per capita GDP of the six cities in 2019.

City	Population size			Per Capita GDP (Thousand yuan)
	Male	Female	Total	
Foshan	2,260,855	2,394,761	4,655,616	230.93
Ningbo	4,149,439	4,052,550	8,201,989	146.12
Shijiazhuang	5,536,927	5,414,696	10,951,623	53.05
Wuxi	3,404,656	3,169,859	6,574,515	180.28
Yantai	3,611,082	3,510,713	7,121,795	107.47
Zhenjiang	1,621,496	1,574,911	3,196,407	129.12

Note: Per capita GDP is calculated by dividing the GDP of each city in 2019 (from *the National Economic and Social Development Statistical Bulletin*) by the total population reported by each city.

SUPPLEMENTARY TABLE S5. Total HIV deaths averted by 10 selected HIV interventions in the Achievable Scenario and Idealized Scenario in six cities from 2019 to 2028.

Item	Foshan		Ningbo		Shijiazhuang		Wuxi		Yantai		Zhenjiang	
	AS	IS	AS	IS	AS	IS	AS	IS	AS	IS	AS	IS
VCT	0	0	0	0	0	0	0	0	0	2	0	0
Condoms for adult population	0	0	0	0	0	0	0	0	0	2	0	0
SSTT	0 [†]	0 [†]	0	0	0	0	0	0	0	0	0	0
FSW outreach	0 [†]	0 [†]	0	0	0	0	0 [†]	0 [†]	0	0	0	0
MSM outreach	0	0	0	0	0	0	0	0	0	0	0	0
MSM receiving lubricants*	0	0	0	0	0	0	0	0	0	0	0	0
oral PrEP for MSM	0	0	0	0	0	0	0	0	0	0	0	0
oral PrEP for HRH	0	0	0	0	0	0	0	0	0	0	0	0
ART for males	0 [†]	0 [†]	0 [†]	0 [†]	453	453	15	15	432	545	9	9
ART for females	0 [†]	0 [†]	0 [†]	0 [†]	102	331	115	134	40	235	48	48

Abbreviation: VCT=Voluntary counseling and testing for adult population; SSTT=Secondary students with teachers trained in AIDS; FSW=Female sex worker; MSM=Men who have sex with men; PrEP=Pre-exposure prophylaxis; HRH=High risk heterosexual; ART=Antiretroviral therapy; AS=Achievable Scenario; IS=Idealized Scenario.

* indicates that the impact of MSM receiving lubricants was modeled as 0 in six cities;

[†] indicates that the baseline intervention coverage reported from the city was 99.9% in 2019, with no room for increase. Therefore, the total deaths averted projected by Spectrum in this city were 0.

SUPPLEMENTARY TABLE S6. Sensitivity analysis with adjusted unit costs in six cities from 2019 to 2028.

City	unit cost+50%						unit cost-50%									
	Incremental cost per infection averted (Thousand yuan)		Times compared to the original unit price		Incremental cost per infection averted (Thousand yuan)		Times compared to the original unit price		Incremental cost per infection averted (Thousand yuan)		Times compared to the original unit price					
	AS	IS	AS	IS	AS	IS	AS	IS	AS	IS	AS	IS				
Foshan	712.24	2,975.07	1.5	1.5	158,428.05	656,397.30	1.5	1.5	237.45	992.04	0.5	0.5	52,816.42	218,468.41	0.5	0.5
Ningbo	702.66	9,725.11	1.5	1.5	154,778.00	2,139,229.35	1.5	1.5	234.37	3,297.14	0.5	0.5	51,625.34	725,271.79	0.5	0.5
Wuxi	28.93	243.12	1.5	1.5	83.03	796.85	1.5	1.5	9.79	80.99	0.5	0.5	28.10	265.45	0.5	0.5
Shijiazhuang	89.28	1,517.91	1.5	1.5	226.47	4,647.26	1.5	1.5	29.76	505.92	0.5	0.5	75.50	1,548.93	0.5	0.5
Yantai	36.27	704.36	1.5	1.5	47.78	1,470.50	1.5	1.5	12.11	234.66	0.5	0.5	15.95	489.91	0.5	0.5
Zhenjiang	22.97	1,353.74	1.5	1.5	106.62	8,834.89	1.5	1.5	7.61	451.21	0.5	0.5	35.33	2,944.71	0.5	0.5

Abbreviation: AS=Achievable Scenario; IS=Idealized Scenario.

SUPPLEMENTARY TABLE S7. Sensitivity analysis with unit costs adjusted in Shijiazhuang and Ningbo from 2019 to 2028.

	Ningbo						Shijiazhuang										
	unit cost+50%			unit cost-50%			unit cost+50%			unit cost-50%							
	Incremental cost per infection averted (Thousand yuan)	Times compared to the original unit price	AS	IS	AS	IS	Incremental cost per infection averted (Thousand yuan)	Times compared to the original unit price	AS	IS	AS	IS					
VCT	90,971.60	93,980.45	1.5	1.5	30,324.68	31,327.65	0.5	0.5	2,545.60	2,633.91	1.5	1.5	849.32	878.81	0.5	0.5	
Condoms for adult population	355.20	361.57	1.5	1.5	119.22	121.35	0.5	0.5	398.32	407.96	1.5	1.5	133.56	136.82	0.5	0.5	
SSTT	5,952.32	5,952.32	1.5	1.5	1,931.03	1,931.03	0.5	0.5	389.74	405.18	1.5	1.5	116.94	122.26	0.5	0.5	
FSW outreach	3,405.85	3,405.85	1.5	1.5	1,136.14	1,136.14	0.5	0.5	54.32	55.59	1.5	1.5	18.96	19.39	0.5	0.5	
MSM outreach	63.71	63.71	1.5	1.5	21.25	21.25	0.5	0.5	0.55	0.55	1.4	1.4	0.23	0.23	0.6	0.6	
MSM receiving lubricants	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
oral PrEP for MSM	272.97	292.05	1.5	1.5	91.01	97.36	0.5	0.5	23.07	26.87	1.5	1.5	7.73	9.00	0.5	0.5	
oral PrEP for HRH	172,718.24	171,248.66	1.5	1.5	57,573.59	57,083.72	0.5	0.5	14,221.25	14,258.24	1.5	1.5	4,741.25	4,753.59	0.5	0.5	
ART for males	-	-	-	-	-	-	-	-	14.43	14.43	1.5	1.5	5.07	5.07	0.5	0.5	
ART for females	-	-	-	-	-	-	-	-	13.91	19.00	1.6	1.5	3.42	5.60	0.4	0.5	

Note: "-" indicates that the impact was 0 and cannot be divided.

Abbreviation: VCT=Voluntary counseling and testing for adult population; SSTT=Secondary students with teachers trained in AIDS; FSW=Female sex worker; MSM=Men who have sex with men; PrEP=Pre-exposure prophylaxis; HRH=High risk heterosexual; ART=Antiretroviral therapy; AS=Achievable Scenario; IS=Idealized Scenario.

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