Technical Appendix

Methods for sexually transmitted disease prevention programs to estimate the health and medical cost impact of changes in their budget

Harrell W. Chesson[*]

Jennifer A. Ludovic

Andrés A. Berruti

Thomas L. Gift

All authors are with the National Center for HIV/AIDS, Viral Hepatitis, STD, and TB Prevention, Centers for Disease Control and Prevention, Atlanta, GA

*Corresponding author: CDC Mailstop E-80, 1600 Clifton Road, Atlanta, GA, 30329. Fax: 404-639-8622. Phone: 404-639-8182. Email: hbc7@cdc.gov

Contents

Overview

The main manuscript describes two distinct approaches for estimating the effect of an increase or decrease in sexually transmitted disease (STD) prevention resources: a historical formula approach and a disease intervention specialist (DIS) approach. In this technical appendix, we provide additional details of these two approaches, along with documentation of the key assumptions used in the calculations. We also provide additional details about the methods used to estimate the changes in direct medical costs associated with changes in the number of STD infections and STD-attributable HIV infections.

Method 1: The historical formula approach

This approach adapted a published mathematical formula on the relationship between prevention funding and STD incidence rates.[1] This formula was based on a published analysis of state-level gonorrhea case rates and federal funding for STD prevention from 1981 to 1998.[2]

Previously-published regression analysis of prevention funding and gonorrhea rates

The published regression analysis of historical gonorrhea and funding data used the following regression model specification, in which the dependent variable was the log of the reported gonorrhea rate in state i in year t:

$$\log(GONORRHEA_{i,t}) = \beta_0 + \beta_1\, FUNDING_{i,t} + \beta_2 \log(GONORRHEA_{i,t-1}) + \beta_{3i}\, STATE_i + \beta_{4t}\, YEAR_t + \beta_{5i}$$
$$(STATE_i \times TREND) + \beta6_i\, (STATE_i \times TREND^2) + B_7 Z_{i,t} + \varepsilon_{i,t},$$

where the independent variable of interest ($FUNDING_{i,t}$) was the average amount of funding (in 1998 dollars per capita allocated by the CDC) for STD and HIV prevention in state i in the previous three fiscal years; STATE and YEAR were dummy variables for state and year; TREND was a linear time trend, set to 1 in 1981, 2 in 1982, and so on; and Z was a vector of explanatory variables (AIDS mortality rate, percentage of the population aged 15 to 24, robbery rate, per capita cigarette consumption, per capita income, and poverty rate).

Interpreting the published regression analysis coefficient (β_1)

The published regression analysis included 6 different model specifications. The β_1 coefficient was negative and significant in all six, indicating that higher amounts of prevention funding were associated with subsequent reductions in gonorrhea case rates. The β_1 coefficient in the six model specifications was: -0.025, -0.054, -0.181, -0.090, -0.243, and -0.244. We focused on the results from the final two

specifications, which used generalized least squares, included the additional Z vector of covariates, and included the TREND variables.

The regression analysis used 1998 dollars; when adjusted to 2016 dollars using the Personal Consumption Expenditures Index the -0.244 coefficient was -0.1762. Given that the dependent variable was the log of the gonorrhea case rate, the -0.1762 coefficient suggests that each one-dollar increase in STD prevention funding is associated with decreases in the gonorrhea case rate of about 16%.

Issues with applying the regression analysis coefficient (β_1)

The model equation in the original study included additional explanatory variables

The original regression model of gonorrhea incidence and state-level STD appropriations included state and year variables and a range of demographic variables, thereby attempting to estimate the effect of funding on gonorrhea rates while controlling for a wide range of other factors. In our application of the model results, we focus on the estimated effect of additional funding and do not include the additional variables. Instead, to isolate the estimated effects of funding changes, we assumed that a jurisdiction's STD incidence rates would be the same from one year to the next in the absence of changes to the jurisdiction's funding. In doing so, we assumed that all other factors related to STD rates (such as socio-economic factors) would be unchanged over time and could be therefore be incorporated into the CONSTANT term.

The original study included HIV prevention funding

The published regression analysis focused on the association between gonorrhea rates and prevention funding for STD and HIV.[2] However, subsequent analyses of the data indicated that the results were generally consistent when focusing on STD funding only.[3] In fact, the regression analysis coefficient (β_1) suggested an even greater marginal impact of prevention funding when focused on STD funding only, which is not surprising given that HIV prevention funding is geared towards HIV-related outcomes and not specifically focused on bacterial STDs like gonorrhea.

The original study focused on gonorrhea only

As described above, the published regression analysis suggested each one-dollar increase in STD prevention funding was associated with decreases in the gonorrhea case rate of about 16%. For simplicity, we assumed this reduction of 16% could be applied not only for the gonorrhea incidence rate but also for the incidence rates of syphilis and chlamydia. This 16% value could be extremely

conservative for syphilis, in light of an analysis of the impact of changes in syphilis elimination funding at the state level from 1997 to 2005.[4] This previous analysis suggested that each dime of syphilis elimination funding per capita was associated with subsequent reductions in syphilis case rates of about 30%.[4] To our knowledge, no studies have estimated the direct association between STD prevention funding and changes in chlamydia case rates. However, as noted elsewhere, the estimates obtained for gonorrhea could be generalizable to some degree to other STDs.[2]

The original analysis included a three-year moving average of funding

As noted above, the published regression analysis used the average funding in years t-3, t-2, and t-1 to predict gonorrhea rates in year t. For simplicity, in our application of the model we assumed the funding in year t could be used to predict gonorrhea rates in year t.

Method 2: The Disease Intervention Specialist (DIS) approach

Change in the number of DIS

The first step of the DIS approach is to calculate the change in the number of DIS that would result if the entire change in the STD prevention allocation were to be achieved through changes in DIS staff. Programs can use their own data regarding the annual cost per DIS, or can apply a national estimate of $73,600. This national estimate reflects a salary of $45,677 (based on the federal general schedule level 9, step 3 salary as of January 2016[5]), multiplied by 1.61 to account for fringe benefits and other costs,[6] and rounded to the nearest $100. When applying this national estimate, the change in DIS staff (ΔDIS) due to a change in funding of $X ($\Delta$X) can be calculated as ΔDIS =ΔX/$73,600.

Percentage change in the number of DIS

The second step of the DIS approach is to estimate the percentage change in the number of DIS.   The percentage change in DIS activities (%DIS) can be approximated as %DIS = ΔDIS/N, where N is the number of DIS employed by the STD program before the change in budget. For consistency, a program's reduction in the number of DIS should be capped so that a program cannot lose more DIS than they actually had before the budget change. Similarly, the increase in the number of DIS should be capped so that the increase in number of STD patient interviews cannot exceed the number of STD cases that are currently not being interviewed. Methods to estimate the number of STD cases interviewed (and to approximate N when no data are available) are described in the section below on intermediate outcomes.

Approximating the percentage change in STD incidence as a function of the percentage change in the number of DIS

The third step of the DIS approach is to estimate the percentage change in STD incidence that results from the percentage change in the number of DIS. To do so, we assume that each 10% change in the number of DIS results in subsequent change of 2% in the incidence of these STDs. This assumption is based on an analysis of a decade of historical records of gonorrhea incidence and partner notification services in New York State (excluding New York City), which indicated that each 10% increase in DIS activities could reduce gonorrhea case rates by 2% to 6%.[7] Specifically, a 10% increase in the number of index patients interviewed was estimated to reduce gonorrhea case rates by 2%, and a 10% increase in the number of partners provided epidemiologic treatment was estimated to reduce gonorrhea case rates by 6%.

Rather than focus on specific DIS activities, we assumed that a 10% increase in DIS activities in general would reduce gonorrhea incidence rates by 2%. We used 2% instead of 6% because the 2% estimate is more conservative. Further, the 2% estimate is consistent with results from ecological analyses conducted in the 1970's and 1980's of the effect of DIS activities on gonorrhea incidence.[8-10] See the subsection below ("Notes on the assumed impact of DIS activities on STD rates") for additional discussion regarding this assumption. As noted above, we assumed that the percentage changes in DIS activities could be approximated by the percentage change in the number of DIS (%DIS). The percentage change in STD incidence rates attributable to the change in budget can thus be estimated as -%DIS/5, where the division by 5 is applied because each 10% change in DIS activities is assumed to produce a 2% change in STD incidence rates.

Notes on the assumed impact of DIS activities on STD rates

The study by Du and colleagues[7] cites several published studies that show an association between intensification of partner notification activities and subsequent declines in the burden of disease in the population.[8-12]

Wigfield (1972)[10]

The Wigfield assessment of 27 years of regional data from northeast England concludes that the establishment of effective contact tracing can reduce the burden of STDs in the population by 20%.[10] If so, then a 100% reduction in these activities (i.e., elimination of these activities) would result in an increase in the disease burden of about 20%. When this relationship is applied linearly, a 10% reduction

in these activities would be associated with a 2% increase in burden, which matches the assumption described above in which a 10% change in DIS results in a 2% change in STDs.

Woodhouse et al., 1985[8]

Enhanced casefinding measures were applied in the Colorado Springs, Colorado area from 1980 through 1982. Gonorrhea case numbers from 1980 to 1982 were compared to those from 1977 to 1979. In the study period vs. the comparison period, civilian cases declined by 20% in Colorado Springs compared to a decline of 6.6% for the rest of Colorado. This 13.4% additional decline in gonorrhea cases can be examined along with the changes in the number of interviews of gonorrhea cases in the study period vs. the comparison period. The number of civilian gonorrhea cases interviewed increased by 39.3% and the percentage of these cases interviewed increased by 74.2%. These changes suggest that each 10% increase in the number of cases interviewed was associated with decreases in gonorrhea of 3.4%, and each 10% increase in the percentage of cases interviewed was associated with decreases in gonorrhea of 1.8%. Both of these extrapolations are consistent with the assumption described above in which a 10% change in DIS activity results in a 2% change in STDs.

Talbot and Kinghorn (1985)[12]

From 1977 to 1982, gonorrhea rates in Sheffield, England declined by about 50% compared to a decline of about 11% nationally.[12] Talbot and Kinghorn conclude that contact tracing in Sheffield was likely the most important factor contributing to the dramatic decline. Given that the decline in Sheffield exceeded the national decline by about 40 percentage points, and assuming that contact tracing accounted for half of this impact, then contact tracing would be credited with a decline in gonorrhea of about 20%. It is difficult to relate this 20% decline to a specific degree of change in DIS activities, however, because the declining case numbers led to declines in the number of contacts to trace. Over this time, however, the percentage of contacts who were brought to the clinic increased from about 60% in 1974 to over 90% in 1982.

Rather than try to determine the degree to which DIS activities increased over this period, a simple and conservative approach would be to ascribe the 20% reduction in gonorrhea rates to the entirety of the DIS activities. This approach would prevent having to assess the marginal increase in the DIS activities. In doing so, one could then calculate that the establishment of contract tracing activities reduces gonorrhea rates by at least 20%. As noted above in the discussion of the Wigfield study, when this relationship (in which the entirety, or 100%, of DIS activities result in a 20% decline in gonorrhea) is applied linearly, a 10% reduction in these activities would be associated with a 2% increase in burden.

This association matches the assumption described above in which a 10% change in DIS results in a 2% change in STDs.

Han et al. (1999)[11]

Han and colleagues examined the impact of targeting partner notification activities in geographic core areas and noted that such targeting can yield additional reductions in gonorrhea compared to non-targeted partner notification efforts.

Of note, this study also examined the impact of a syphilis initiative, which required the temporary diversion of some DIS from gonorrhea activities to syphilis control activities. During this reduction in DIS activities for gonorrhea, gonorrhea incidence increased by about 16%. This study's finding, that a partial reduction in DIS activities for gonorrhea is associated with an increase in gonorrhea of 16%, is consistent with our "2%" assumption, which as noted above suggests that a 100% reduction in DIS activities would increase gonorrhea rates by 20%.

Phillips et al (1980)[9]

Between August 1976 and March 1978, enhanced casefinding services were conducted for women with gonorrhea in Colorado Springs who were identified as potential "core" group members. In the assessment by Phillips et al.,[9] gonorrhea incidence was noted to decline by 22% following these activities. As the authors note, however, study limitations make it difficult to attribute this decline to the enhanced casefinding efforts. However, this study is consistent with the others discussed above in which population-level decreases in gonorrhea rates were noted after the initiation of enhanced DIS activities.

Issues with applying the DIS approach

The source study by Du and colleagues focused on gonorrhea only

As noted above, the DIS approach estimates the effect of changes in DIS activities based on a published analysis of historical records of gonorrhea incidence and partner notification services in New York State by Du and colleagues.[7] To our knowledge, there are no studies that specifically examine historical syphilis data and DIS services, nor are there studies that examine historical chlamydia data and DIS services.   Given the lack of STD-specific data, and for simplicity, the proposed methodology is to assume that for each 10% change in the number of index patients interviewed for three STDs (syphilis, gonorrhea, and chlamydia), the incidence of these three STDs will change by 2%.

Applying caps to the DIS calculations

To make sure the results of the DIS methodology are plausible, we suggest that the calculations be capped so that in the event of a budget decrease, the decrease in DIS staff does not exceed 100%.

Estimating intermediate effects of a budget change

Programs might also want to know the effect of budget changes on intermediate outcomes, such as DIS activities performed. Here, we describe methods to estimate the change in the number of index STD patient interviews conducted. Programs can apply similar methods to examine other intermediate outcomes of interest.

For this exercise, we assumed the change in the number of DIS can be calculated as $\Delta DIS = \Delta X / \$73,600$, as described above. We then estimated the change in the number of index STD patient interviews (and associated contact tracing) conducted each year due to the change in the number of DIS. The key piece of information needed for this estimation was the number of index patient interviews that the average DIS performs in a year. Programs without data on the number of index patient interviews conducted per year can approximate this value based on their number of reported STD cases, multiplied by published estimates of the average percentage of these cases that are interviewed. Specifically, a multi-site study estimated that 89% of syphilis cases, 17% of gonorrhea cases, and 12% of chlamydia cases are interviewed.[13] Thus, the number of STD index case interviews (INT) can be approximated as INT = 0.89(S) + 0.17(GC) + 0.12(CT), where S is the reported number of primary, secondary, and early latent syphilis cases, and GC and CT are the reported number gonorrhea and chlamydia cases, respectively. Alternatively, programs can apply a literature-based estimate that each DIS can perform about 400 index patient interviews per year.[14-16] Using the estimate of 400, the change in the number of index STD patient interviews per year can be expressed as $400\Delta DIS$.

For consistency, in the event of a budget increase, the increase in the number of index STD patient interviews conducted should not exceed the number of index STD patients who are currently not followed up (i.e., the increase in the number of interviews cannot exceed S + GC + CT − INT, where S, GC, CT, and INT are as described above).

For those without data on the number of DIS working on STD prevention, this number can be estimated as N = INT/400. As described above, N is the number of DIS, INT is the number of STD index patient interviews, and 400 is the estimated number of interviews per DIS per year.

Programs might also want to examine other intermediate outcomes, using their own data or national data to inform estimates. For example, an estimated 1 in 4 DIS interviews identifies a new STD case.[17] Thus, programs can estimate the increase or decrease in the number of people with syphilis, gonorrhea, or chlamydia who will become aware that are infected by dividing the change in number of DIS interviews by 4.

Other key assumptions

Disease burden assumptions

The number of STD infections that occur in the US population each year exceeds the number of reported cases.[18] We assumed that the number of new infections each year in the US would be 55,400 for syphilis, 820,000 for gonorrhea, and 2,860,000 per year for chlamydia.[19] In contrast, the reported number of cases in 2015 was 23,872 for primary and secondary syphilis, 395,216 for gonorrhea, and 1,526,658 for chlamydia.[18] In the absence of program-specific estimates on disease incidence, programs will have to make their own approximations. One method of approximation is to assume that one's share of the national number of new infections each year (reported cases plus unreported infections) is equal to one's share of the national number of reported cases.

Cost per case assumptions

The cost per infection assumptions are based on previously published studies and have been updated to 2016 dollars. The cost-per-case estimates for syphilis, gonorrhea, and chlamydia represent the discounted, lifetime medical costs per infection and include the possibility that some infections will not be treated and that some infections will lead to sequelae costs.[20] The cost-per-case estimates for gonorrhea and chlamydia are sex-specific; we applied the average of the male cost per case and the female cost per case. The HIV cost per case also represents the discounted, lifetime cost per new HIV infection and accounts for varying rates of uptake of antiretroviral therapy.[21]

STD-attributable HIV cases

The average number of HIV cases attributable to each new case of chlamydia, gonorrhea, and P&S syphilis in heterosexuals has been estimated at 0.0011, 0.0007, and 0.02386, respectively.[22]   However, it has been recommended that these estimates be adjusted to account for factors that might otherwise result in overestimation, such as the possibility that an estimated HIV case averted might actually be delayed rather than permanently averted.[23] Adjustment factors of 75% and 12.5% have been proposed

for MSM and heterosexuals, respectively,[23] and for this exercise, we suggest using the average of these two values, or 43.75%. When multiplied by 43.75% and rounded to the nearest multiple of 0.0005, the resulting estimated number of STD-attributable HIV cases per new case of chlamydia, gonorrhea, and P&S syphilis in heterosexuals is 0.0005, 0.0005, and 0.0105.

Discounting

Future costs were discounted at 3% annually. The published lifetime costs per infection that we applied reflect the average cost per infection, discounted to the time of infection. Because we examined a 10-year time frame, we also discounted the costs of future infections to year 1. For example, suppose there is an additional syphilis infection in year 10 as a result of a budget cut. The cost per infection we applied for syphilis ($770) reflects the lifetime costs of syphilis, discounted to the time of infection (year 10). We then discounted this lifetime cost to year 1 (that is, we discounted this cost by 3% annually for 9 years by multiplying $770 by 1.03^{-9}), so that the additional lifetime costs would be expressed in present value for year 1.

Phasing in of estimated changes in STD incidence

When STD incidence and prevalence rates are at an equilibrium, these rates do not adjust instantly to a change in one of the factors that influences incidence and prevalence. For example, when there are improvements in the timely delivery of appropriate health care for STDs, the decline in STD incidence (vs. the baseline) can become more pronounced over time as a new equilibrium is reached.[24] To account for gradual changes in STD incidence over time following a change in prevention funding, we assumed that the change in STD incidence in year 2 would be $1+\beta_0$ times that of year 1, that the change in year 3 would be $1+ \beta_0 + \beta_0^2$ times that of year 1, that the change in year 4 would be $1 + \beta_0 + \beta_0^2 + \beta_0^3$ times that of year 1, and so on. A value of 0.7 was applied for β_0, based on the average coefficient of the lagged dependent variable across three regression models used in the analysis of state-level gonorrhea rates and federal funding for STD prevention.[2] The three values from which the average was obtained were 0.857, 0.809, and 0.459. See the technical appendix Table A1 for details on the application of the 0.7 value.

Example of phasing in for the historical formula approach

In the example from the manuscript of the $200,000 reduction in funding for the hypothetical state, the historical formula approach suggested that STD incidence rates in the first year of the budget reduction would be 0.49% higher than they would have been otherwise. This approach was based on a regression

analysis which accounted for the previous year's gonorrhea rate in the estimation of the current year's gonorrhea rate.[2] Thus, an increase in incidence in year 1 would be expected to have an effect on incidence in year 2, and so on. The percentage change in STD incidence in each of the 10 years was estimated by multiplying 0.49% by the corresponding value in the column "Change in STD incidence rate, relative to year 1, when β = 0.7." For example, the increase in year 2 (0.84%) was calculated by multiplying 0.49% by 1.70.

Example of phasing in for the DIS approach

In the example from the manuscript of the $200,000 reduction in funding for the hypothetical state, the DIS approach suggested that STD rates as a result of the budget reduction would be 3.62% higher than they would have been otherwise. The longitudinal analysis on which the DIS approach was based examined changes in partner notification and changes in the gonorrhea rate in New York from 1992 to 2002.[7] Because change was calculated as compared to the baseline year of 1992, [7] we assumed that the 3.62% increase would be the new equilibrium compared to the baseline scenario, and that this new equilibrium would be achieved in year 10. The percentage change in each of the 10 years was estimated by multiplying 3.62% by the corresponding value in the column "Change in STD incidence rate, DIS approach, when β = 0.7." For example, the value of 1.12% for year 1 was calculated by multiplying 3.62% by 0.31.

Accounting for uncertainty

In addition to the qualitative uncertainties in the parameter estimates used in the models (e.g., applicability of parameters based on analyses of gonorrhea cases to other STDs, issues related to whether estimates from older studies are applicable to current and future events), there is quantitative uncertainty around the parameter values. For example, there is a standard error associated with the regression analysis coefficient (β_1) that we used to estimate the effect of a $1 per-capita change in prevention funding. In order to allow jurisdictions to examine the potential importance of this uncertainty, we have provided a range of values for selected parameters (Appendix Table A2).

Description of basic approach to account for uncertainty

Perhaps the simplest way to generate a range of plausible estimates is to examine the two most extreme scenarios possible when all of the parameters in Table A2 are set at their lower or upper bound values. For example, the estimated impact of a budget increase (in terms of the reduction in STIs and

the costs averted) will be highest when applying the upper bound values for all of the parameters in Table A2, and will be lowest when applying the lower bound values for all of these parameters.

Description of ranges suggested for selected parameters

Uncertainty in the percent change in STDs per $1 change in funding per capita

The range for the "percent change in STDs per $1 change in funding per capita" parameter was approximated as 9% to 23% based on the confidence interval estimated from the coefficient and standard error of the regression analysis coefficient (β_1).[2]

Uncertainty in the percent change in STDs per 10 percent change in DIS activities

For the "percent change in STDs per 10 percent change in DIS activities" parameter, the study from which our estimate was obtained suggested a base case value of 2% and a range of 0% to 5%, when DIS activities were assessed in terms of the percentage of cases interviewed.[7]   Instead of 0% for the lower bound, however, we applied a value of 0.5%. We note that our choice of measure of DIS activities (percentage of cases interviewed) was more conservative than a second choice (percentage of partners treated). We could have applied higher values for the base case, lower bound, and upper bound had we used the latter measure. Specifically, the estimated effect of changes in DIS activities based on changes in the percentage of partners brought to treatment suggests a base case value of 6% with a range of 3% to 9%.[7]

Uncertainty in the B_0 parameter used to phase in the estimated changes in STD incidence

The value of the constant term across three regression models used in the analysis of state-level gonorrhea rates and federal funding for STD prevention was 0.857, 0.809, and 0.459. [2] The range we applied represents the minimum and maximum of these three values.

Uncertainty in the average lifetime cost per STI and HIV infection

Following the source study on which the lifetime cost values were obtained per STI, we varied the base case value by ±50%.[20] For HIV, the range of values we applied represents the lower and upper bound values in the source study when the CD4 count at time of diagnosis was varied.[21]

Uncertainty in the probability of an STD-attributable HIV infection

To vary the probability of an STD-attributable HIV infection, the lower and upper bound values were calculated by multiplying the base case value by ±90%.[23]

Uncertainty in other parameters

We did not suggest ranges for other parameters, such as the number of reported STD cases, the annual DIS salary, the number of reported STD cases, the percentage of STD cases interviewed, and the annual number of index patient interviews performed by one DIS. Values for these parameters can vary substantially from one program to the next, making it difficult to propose meaningful, program-specific ranges for these parameter values.

References

1.   Chesson HW. Estimated effectiveness and cost-effectiveness of federally funded prevention efforts on gonorrhea rates in the United States, 1971-2003, under various assumptions about the impact of prevention funding. *Sex Transm Dis.* 2006;33(10 Suppl):S140-S144.
2.   Chesson HW, Harrison P, Scotton CR, Varghese B. Does funding for HIV and sexually transmitted disease prevention matter? Evidence from panel data. *Eval Rev.* 2005;29(1):3-23.
3.   Chesson HW, Pinkerton SD, Holtgrave DR. Distribution of prevention resources and impact on sexual health in the USA. In: Aral SO, Fenton KA, Lipshutz JA, eds. *The New Public Health and STD/HIV Prevention*. New York: Springer; 2013:129-149.
4.   Chesson H, Owusu-Edusei K, Jr. Examining the impact of federally-funded syphilis elimination activities in the USA. *Soc Sci Med.* 2008;67(12):2059-2062.
5.   US Office of Personnel Management. Salary table 2016-GS incorporating the 1% general schedule increase effective January 2016. 2016; https://www.opm.gov/policy-data-oversight/pay-leave/salaries-wages/salary-tables/pdf/2016/GS.pdf. Accessed May 8, 2017.
6.   Bureau of Labor Statistics. Employer costs per hour worked for employee compensation and costs as a percent of total compensation: state and local government workers, by occupational and industry group, December 2016. 2017; https://www.bls.gov/news.release/ecec.t04.htm. Accessed May 8, 2017.
7.   Du P, Coles FB, Gerber T, McNutt LA. Effects of partner notification on reducing gonorrhea incidence rate. *Sex Transm Dis.* 2007;34(4):189-194.
8.   Woodhouse DE, Potterat JJ, Muth JB, Pratts CI, Rothenberg RB, Fogle JS, 2nd. A civilian-military partnership to reduce the incidence of gonorrhea. *Public Health Rep.* 1985;100(1):61-65.
9.   Phillips L, Potterat JJ, Rothenberg RB, Pratts C, King RD. Focused interviewing in gonorrhea control. *Am J Public Health.* 1980;70(7):705-708.
10.   Wigfield AS. 27 years of uninterrupted contact tracing. The 'Tyneside Scheme'. *Br J Vener Dis.* 1972;48(1):37-50.
11.   Han Y, Coles FB, Muse A, Hipp S. Assessment of a geographically targeted field intervention on gonorrhea incidence in two New York State counties. *Sex Transm Dis.* 1999;26(5):296-302.
12.   Talbot MD, Kinghorn GR. Epidemiology and control of gonorrhoea in Sheffield. *Genitourin Med.* 1985;61(4):230-233.
13.   Golden MR, Hogben M, Handsfield HH, St Lawrence JS, Potterat JJ, Holmes KK. Partner notification for HIV and STD in the United States: low coverage for gonorrhea, chlamydial infection, and HIV. *Sex Transm Dis.* 2003;30(6):490-496.
14.   Heumann CL, Katz DA, Dombrowski JC, Bennett AB, Manhart LE, Golden MR. Comparison of In-Person Versus Telephone Interviews for Early Syphilis and Human Immunodeficiency Virus Partner Services in King County, Washington (2010-2014). *Sex Transm Dis.* 2017;44(4):249-254.

15.   Macke BA, Hennessy M, McFarlane MM, Bliss MJ. Partner notification in the real world: a four site time-allocation study. *Sex Transm Dis.* 1998;25(10):561-568.

16.   Macke BA, Hennessy MH, McFarlane M. Predictors of time spent on partner notification in four US sites. *Sex Transm Infect.* 2000;76(5):371-374.

17.   Brewer DD. Case-finding effectiveness of partner notification and cluster investigation for sexually transmitted diseases/HIV. *Sex Transm Dis.* 2005;32(2):78-83.

18.   Centers for Disease Control and Prevention. *Sexually Transmitted Disease Surveillance, 2015*. Atlanta: U.S. Department of Health and Human Services; 2016.

19.   Satterwhite CL, Torrone E, Meites E, et al. Sexually transmitted infections smong US women and men: prevalence and incidence estimates, 2008. *Sex Transm Dis.* 2013;40(3):187-193.

20.   Owusu-Edusei K, Jr., Chesson HW, Gift TL, et al. The estimated direct medical cost of selected sexually transmitted infections in the United States, 2008. *Sex Transm Dis.* 2013;40(3):197-201.

21.   Farnham PG, Holtgrave DR, Gopalappa C, Hutchinson AB, Sansom SL. Lifetime costs and quality-adjusted life years saved from HIV prevention in the test and treat era. *J Acquir Immune Defic Syndr.* 2013;64(2):e15-e18.

22.   Chesson HW, Pinkerton SD. Sexually transmitted diseases and the increased risk for HIV transmission: implications for cost-effectiveness analyses of sexually transmitted disease prevention interventions. *J Acquir Immune Defic Syndr.* 2000;24(1):48-56.

23.   Chesson HW, Collins D, Koski K. Formulas for estimating the costs averted by sexually transmitted infection (STI) prevention programs in the United States. *Cost Eff Resour Alloc.* 2008;6:10.

24.   White PJ, Ward H, Cassell JA, Mercer CH, Garnett GP. Vicious and virtuous circles in the dynamics of infectious disease and the provision of health care: gonorrhea in Britain as an example. *J infect Dis.* 2005;192(5):824-836.

Technical Appendix Table A1: Explanation of gradual changes in STD incidence rates over time after a change in the STD prevention budget

Year after budget change	Change in STD incidence rate, relative to year 1	Change in STD incidence rate, relative to year 1, when $\beta_0 = 0.7$	Change in STD incidence rate, relative to year 10, when $\beta_0 = 0.7$	Change in STD incidence rate, historical formula approach	Change in STD incidence rate, DIS approach
Year 1	1	1.00	0.31	0.49%	1.12%
Year 2	$1+ \beta_0$	1.70	0.52	0.84%	1.90%
Year 3	$1+ \beta_0 + \beta_0^2$	2.19	0.68	1.08%	2.45%
Year 4	$1+ \beta_0 + \beta_0^2 + \beta_0^3$	2.53	0.78	1.25%	2.83%
Year 5	$1+ \beta_0 + \beta_0^2 + \beta_0^3 + \beta_0^4$, or $1 + \sum_{i=1}^{i=4} \beta_0^i$	2.77	0.86	1.37%	3.10%
Year 6	$1 + \sum_{i=1}^{i=5} \beta_0^i$	2.94	0.91	1.45%	3.29%
Year 7	$1 + \sum_{i=1}^{i=6} \beta_0^i$	3.06	0.94	1.51%	3.42%
Year 8	$1 + \sum_{i=1}^{i=7} \beta_0^i$	3.14	0.97	1.55%	3.51%
Year 9	$1 + \sum_{i=1}^{i=8} \beta_0^i$	3.20	0.99	1.57%	3.58%
Year 10	$1 + \sum_{i=1}^{i=9} \beta_0^i$, or $1+ \beta_0 + \beta_0^2 + \beta_0^3 + \beta_0^4 + \beta_0^5 + \beta_0^6 + \beta_0^7 + \beta_0^8 + \beta_0^9$	3.24	1.00	1.59%	3.62%

The changes in STD incidence as a result of changes in STD budget were phased in over time as shown in the table above. When using the historical formula approach, we applied the estimated change in STD incidence (0.49%) in year 1, and applied greater changes in subsequent years 2-10 according to relative values (ranging from 1.0 to 3.24) in the third column. For example, the final row value of 1.59% was calculated by multiplying 0.49% by 3.24. When applying the DIS approach, we assumed the estimated change (3.62%) represented the final, phased-in result. We therefore applied the 3.62% estimate in year 10, and applied smaller changes in the previous years 1-9 according to the relative values (ranging from 0.31 to 1) in the fourth column. For example, the value 1.12% in the first row was calculated by multiplying 3.62% by 0.31.

Technical appendix Table A2: Proposed ranges of selected parameter values

Parameter	Base case	Range
Percent change in STDs per $1 change in funding per capita (B_1 parameter)	16%	9% to 23%
Percent change in STDs per 10 percent change in Disease Intervention Specialist (DIS) activities	2%	0.5% to 5%
B_0 parameter used to phase in the estimated changes in STD incidence (see text)	0.70	0.46 to 0.86
Average lifetime cost per syphilis infection	$770	$385 to $1,155
Average lifetime cost per gonorrhea infection	$230	$115 to $345
Average lifetime cost per chlamydia infection	$210	$105 to $315
Average lifetime cost per HIV infection (both sexes)	$351,000	$269,000 to $427,000
Probability of STD-attributable HIV infection, per syphilis infection	0.0105	0.001 to 0.02
Probability of STD-attributable HIV infection, per gonorrhea infection	0.0005	0.00005 to 0.001
Probability of STD-attributable HIV infection, per chlamydia infection	0.0005	0.00005 to 0.001

Medical costs were updated to 2016 US dollars using the health care component of the personal consumption expenditures index.