PrEP and Moral Hazard*

Scott Delhommer† Nir Eilam ‡

March 26, 2020

Abstract

PrEP is a drug introduced in 2012 that reduces the risk of contracting HIV if exposed to the virus. Since its introduction, the drug has become popular amongst gay men, who are responsible for the majority of new HIV infections. Given the reduced risk of contracting HIV, men on PrEP might be more likely to engage in risky sexual behavior, specifically multiple sexual partners and non-protected sex; these might lead to increases in other STIs. In this paper, we examine this empirically, by applying several difference-in-difference analyses, comparing the evolution of STIs in states with different PrEP adoption rates and between men and women. In addition, we exploit cross-state variation in the gay male population before PrEP was introduced as a treatment intensity measure. We show that STI rates were parallel in high and low PrEP states before the introduction of PrEP, but began to diverge afterwards. We estimate that one additional male PrEP user increases male Chlamydia incidences by 0.73 and male Gonorrhea incidences by 0.83, a sizeable effect. We also conduct back of the envelope calculations to estimate the costs associated with the additional STIs due to the introduction of PrEP and create a counterfactual distribution of STIs, estimating that male STI rates would have been XX% lower in the absence of PrEP. This informs an open question regarding the increases in STDs in recent years, as well as the unintended consequences of the rollout of a major drug.

Keywords: Moral Hazard, LGBT, PrEP

JEL Codes: I12, I18, D62

*We want to thank X,X,X,X, and X for

†University of Texas at Austin; sdelhommer@utexas.edu

‡University of Texas at Austin; nir.eilam@gmail.com

1 Introduction

HIV and AIDS have devastated lives by cutting them short, hitting the gay community hardest. At the start of AIDS epidemic in the early 1980s, an HIV or AIDS infection sentenced one to death, but as investment in medical interventions and treatments improved, so did health outcomes. One potential concern with new medical treatments is the potential of unintended consequences of people adjusting their behavior to new medications, attenuating the effect of an intervention. Researchers have shown significant moral hazard responses to HIV medical breakthrough, wherein people adjust their behavior and engage in riskier sex practices if the consequence of that behavior becomes less dangerous (Lakdawalla, Sood and Goldman (2006); Chan, Hamilton and Papageorge (2015)).

We examine the effect of a new HIV treatment, Pre-exposure prophylaxis (PrEP), a drug that effectively prevents HIV infections, on aggregate STIs and HIV infections. Approved nationally in 2012, PrEP has the potential to save lives but also carries a potential risk of moral hazard with it. PrEP has been clinically shown to be effective at preventing new HIV infections in the medical literature, and it has steadily gained use and popularity among men who have sex with men (MSM). Users of PrEP may rationally adjust their sexual behavior and may have sex with more partners and may stop wearing condoms given the drastically decreased likelihood of contracting HIV. PrEP may reduce the number of HIV infections but may give a trade off of increased STIs. However, PrEP could possibly have no effect on HIV infections if all PrEP users used condoms and safer sex practices before PrEP, underlying the importance of examining the effect of PrEP on STIs and HIV.

We are the first to examine the relationship between the roll out of PrEP and aggregate STI and HIV levels. We contribute to the medical literature that has examined PrEP, but they have not viewed the drug in the context of aggregate STI levels, focusing on the people that actively take PrEP. However, this approach could underestimate the effect that PrEP has on aggregate level since STIs can spread to people who are not taking PrEP. We also add to the literature on moral hazard as well as contributing to an open question on increasing

STI rates.

We obtained data on state level PrEP usage per 100,000 for 2012 to 2017 from AidsVU, an organization created by Emory University's Rollins School of Public Health and Gilead Sciences Inc., the company that manufacturers PrEP. We paired that data on STI rates from the Center for Disease Control (CDC) from 2008 to 2017 for chlamydia, gonorrhea, syphilis and HIV infections. PrEP usage and STI rates are broken down by sex and by age, heterogeneity that we exploit in our analysis.

A basic OLS analysis regressing STI rates on PrEP rates show significant associations between male PrEP rate and male STIs. However, there are potential issues of endogeneity where states with increasing STI or HIV rates are most likely to adopt PrEP. We cannot estimate the effect of PrEP in a traditional difference-in-differences framework because it was introduced nationally in 2012. To ameliorate these endogeneity concerns, we exploit a pre-treatment measure of the intensity of PrEP exposure in a difference-in-differences framework. Specifically, we follow Alpert, Powell and Pacula (2018), which examines a nation-wide reformulation of OxyContin making abuse of the pills more difficult. They use the pre-treatment abuse of opioids before the national change to and show those states had the largest increase in heroin abuse following the OxyContin reformulation.

Following their strategy, we use pre-treatment variation in the gay male population, which we show are the areas that use PrEP the most. Given that PrEP is targeted and mostly used by MSM, we use female STIs as an additional control group for male STIs. We show that prior to the introduction of PrEP in 2012, the rate of male and female STIs are parallel in low and high PrEP states, and after 2012, STI rates diverge with male STIs increasing. However, we find that HIV rates are consistently declining before the introduction of PrEP in states with a large gay population with no break when PrEP is introduced, making it difficult to estimate the casual effect of PrEP on aggregate HIV levels. Given that HIV infections are declining faster in states, our estimates on HIV infections will likely be downwardly biased, overstating the effect of PrEP on HIV infections. Specifically, we find that a 1 additional

PrEP user results in 0.73 additional cases of male chlamydia and 0.83 additional cases of male gonorrhea and 0.1 fewer cases of male HIV[1].

Next, we explore age heterogeneity, exploiting that people aged 25-45 take PrEP at a higher rate than other age groups. We show that the largest increases in male STIs occur in the age group that take PrEP the most. We then conduct several robustness checks. First, we replace our measurement of pre-treatment PrEP intensity with HIV prevalence instead of the gay population. While these measures are correlated, one may think that exposure to HIV would make a better measure of pre-treatment PrEP intensity. We show our results hold in that context as well. Next, we look at STI testing to see if our effect is due to increased reporting of STIs. We find no significant change in the number of HIV tests administered following the rollout of PrEP. Then, we conduct a simple counterfactual analysis where we subtract the number of PrEP users multiplied by the estimates of the effect of PrEP on that STI. We show that without PrEP in 2017, male chlamydia rates would be 7-16% lower in our counterfactual estimate than what was observed.

Finally, we conclude our analysis with basic back of the envelope calculations assessing the costs and benefits of PrEP. While PrEP may increase STIs like gonorrhea and chlamydia, the relative cost of treating HIV is much higher. We take lifetime cost estimates of chlamydia, gonorrhea, syphilis, and HIV and examine the costs and benefits of these STIs caused or prevented by PrEP. Given that HIV infections are downwardly trending before and after PrEP's introduction, our estimates of the effect of PrEP on HIV infections are likely overstated, making it difficult to get an accurate cost-benefit analysis. Alternatively, we will look conduct a break-even calculation. We find that in 2017, PrEP increased male chlamydia and gonorrhea rates to a level that cost approximately $9 million. Given the lifetime cost of treating HIV is about $300,000, the 88,151 male PrEP in 2017 would need to prevent only 31 cases of HIV to offset the costs of the additional STI treatment.

We show in the first analysis that PrEP has a significant, causal effect on aggregate STIs,

[1]Again, the HIV estimate is likely overstating the effect of PrEP on HIV

costing millions of dollars for treatment. However, given the relative cost of STI treatments, PrEP can still be an effective public health tool. Our research suggests an increased need of condom usage and education for people who are using PrEP.

2 Literature Review

The medical literature has studied PrEP usage for several years, examining the effectiveness of PrEP along with examining potential moral hazard factors of the HIV-prevention drug. We are the first in the social science literature to examine PrEP and the potential moral hazard consequences of increased risky behavior and corresponding STIs. There are several reasons why one may want to examine this question through the lens of social science. First, the medical literature has not examined the effect of PrEP on aggregate STI levels. They have mostly been confined to looking at the people who are taking PrEP, and it seems plausible that there are potential spillovers of STIs to the non-PrEP community. Second, there is the potential of the Hawthorne effect where enrolling PrEP takers into a study may impact their behavior (Adair, 1984). Enrolling someone into a study has been shown to alter behavior and the medical literature on PrEP is not immune to those concerns. By using observational data on PrEP and STIs, we can circumvent this concern. Finally, the medical literature has found varying effects on how PrEP affects sexual behavior.

The medical literature varies in their approach and findings in examining the effect of PrEP on increased risky behavior. Even the meta-analyses differ in their findings of the effect of PrEP on STIs. Traeger et al. (2018) examines 8 studies on STI incidence and 13 studies on condom usage, and they find significant increases in rectal chlamydia and any STI diagnosis with a stronger association in the later studies. They also find that condomless sex increases in most studies. However, Freeborn and Portillo (2018) conducts a different meta-analysis and found no conclusive evidence on increased STIs.

Some studies focus mostly on surveying MSM before and after administering PrEP while

taking regular HIV and STI tests. Volk et al. (2015) used administrative data and surveys of MSM in San Francisco and found that after a year 50% had any STI, 33% had a rectal STI with 33% having chlamydia, 23% having gonorrhea, and 6% having syphilis. Volk et al. (2015) also found condom use decreased for 41% and number of sexual partners increased for 11%. Marcus et al. (2016) found similar results with total of 771 STI diagnoses for 972 PrEP users with many people having multiple STIs. They found that after a year, 42% had any STI, 27% had a rectal STI, 26% had chlamydia, and 23% had gonorrhea. There were significant increases over the baseline for chlamydia and gonorrhea diagnoses.

However, there are some studies that find no change in relative STI rates. Liu et al. (2016) surveyed MSMs before and after PrEP and found that the proportion of those having condomless receptive sex stayed constant at 65% with an insignificant increase in STIs. McCormack et al. (2016) conducted an RCT in the UK. They randomized their sample into people who received PrEP immediately and those who would receive it after 1 year. However, they cut the study short as some participants in deferred PrEP group began to contract HIV and felt ethically obliged to give people in the control group PrEP. Those who immediately received PrEP reported more condomless anal receptive sex and had higher incidences of STIs, but the significance of the increased STIs went away after controlling for additional STI screenings.

Even though the medical literature may have different findings on whether STIs increased or decreased as a result of PrEP, they consistently find that the STI incidence at the baseline was already high before administering PrEP (Volk et al. (2015); Liu et al. (2016); McCormack et al. (2016); Hosek et al. (2017)). Hosek et al. (2017) surveyed young MSM on PrEP and found that 80% reported condomless sex and 58% reported condomless receptive sex. The MSM population that would be taking PrEP already engages in relatively risky sexual behavior that by some studies becomes even riskier following PrEP.

This research also contributes to the robust economics literature on moral hazard. Economics has a long literature on moral hazard and unintended consequences with seminal

work by Peltzman (1975), which suggested that innovations in driving safety would be muted through increased risky behavior. Cohen and Einav (2003) found small changes in behavior from seat belts relative to what Peltzman hypothesized. However, Cohen and Dehejia (2004) found that automobile insurance incentivized riskier driving through moral hazard and caused an increase in traffic fatalities.

Moral hazard is not limited to instances of insurance though. There is a growing literature on medical breakthroughs having unintended consequences. In particular, broadening naloxone access, a drug preventing opioid led to more opioid related emergency room visits and opioid related crime with no decrease in opioid deaths (Doleac and Mukherjee, 2018). The same study showed that broadening naloxone access also increased fentanyl use, a more potent opioid than heroin (Doleac and Mukherjee, 2018).

In a context closer to our own, Lakdawalla, Sood and Goldman (2006) consider the moral hazard effects of HIV treatment breakthroughs on risky sexual behavior. They find that treating HIV-positive individuals more than doubles their number of sexual partners and contributed to a large increase in HIV incidence during the same period. Chan, Hamilton and Papageorge (2015) provide a dynamic model of this behavioral response to the availability of life-saving HIV treatment. They show that both HIV-negative and HIV-positive men increase their risky sexual behavior when the cost of contracting HIV falls.

We contribute to the literature in multiple ways. First, we are the first non-medical study examining the moral hazard impacts of PrEP. Second, we are the first to document the affect of PrEP on aggregate STI levels, which is critically important given that diseases can have spillovers and infect those that are not on PrEP. Third, while the medical literature has documented that PrEP is effective at preventing HIV infections, it is unclear if that finding translates to the aggregate level of HIV diagnoses as people may be substituting away from condom use in replace of PrEP. We also contribute more broadly to the economics literature on moral hazard and unintended consequences and to the epidemiology literature on increasing STI rates.

3 Data

Data on four of the most common STDs: chlamydia, gonorrhea, HIV, and syphilis[2] comes from the CDC National Center for HIV/AIDS, Viral Hepatitis, STD, and TB Prevention (NCHHSTP) database. It contains information on the number of cases of each STD at the state, year, sex, age group and ethnicity level; it also contains the population of each respective group. Using the number of cases and the population we construct our outcome variable – the STD rate per 100,000 population. Data is available for all of the 50 states and the District of Columbia. Our main sample includes male and female (separately) aged 20 and up for the years 2008-2017. Additional analyses use different age and race groups.

For our main sample, we use persons aged 13 and up. The CDC reports STDs in broad age bins, where the earliest age bins are 13-24. During our sample years, PrEP was only approved for persons aged 18 and up, although it was occasionally prescribed off-label for younger persons (Highleymen, 2018). Due to lack of awareness, no insurance coverage, or stigma, older adolescents also under use PrEP. Magnuson et al. (2018) reports that only 2,324 males aged 12-19 started using PrEP over the years 2012-2017 across the United States, compared to 16,739 males aged 20-24. For older males, PrEP usage is even higher, as will be detailed in section XX. Additional analyses using other age groups is detailed in section XX.

Our PrEP use data comes from AIDSVu, an online source for HIV related data. AIDSVu reports the number of PrEP users and rate per 100,000 at the state, year, and sex level as well as separately by the state, year, and age level. The AIDSVu PrEP data was obtained by AIDSVu by researchers at the Rollins School of Public Health at Emory University in conjunction with Gilead Sciences, Inc., the manufacturer of PrEP. The data is based on Symphony Health patient-level prescription data from a sample of pharmacies, hospitals,

[2]CDC reports 3 types of Syphilis - primary and secondary, early latent and congenital. We use primary and secondary as that is what is a typical syphilis case with symptoms appears as. Latent syphilis has no symptoms, so one would be unlikely to seek treatment for it, and congenital syphilis is when a mother passes syphilis to a newborn child, which is not a relevant mode of transmission for this study.

outpatient facilities, and physician practices across the United States. It encompasses all prescription payment types (Including Medicare Part D and Medicaid). Since the prescriptions were for Emtricitabine/Tenofovir Disoproxil Fumarate, which besides PrEP is also used for other indications (such as HIV treatment), Gilead used a stringent algorithm to identify those prescriptions which were indeed PrEP. Prescriptions that could not be attributed to a specific indication were removed, although a certain share of those were PrEP. In addition, prescriptions from certain closed healthcare systems that did not share data with Symphony Health were not included. Therefore, the PrEP use data slightly underestimates the number of PrEP users. A minimum duration of 30 days was required for an individual to be considered a PrEP user, and to be considered a user in a given year, at least one day of that 30-day minimum period was required to fall within that calendar year.

Given that this drug is targeted toward gay men, we want to examine how this treatment differentially affects states with a higher gay male population. Unfortunately, there is little data on the distribution of the LGBT population, so we use data on same-sex partnerships from the 2000 Census. The 2000 Census asks about household composition, which we use to infer sexual orientation. We proxy for the gay male population in each state with data on male same sex partnerships from the 2000 Census. Measuring the gay male population using the Census would likely underestimate the amount of gay men since it is only capturing gay men in committed relationships. However, it should give an approximation of the relative ranks of states with respect to the size of their gay male population, i.e. California has a higher percentage of same-sex partnerships than Wyoming even if both are underestimated. We calculate the share of male same-sex partnerships by dividing the number of male same-sex partnerships and dividing that by the total number of partnerships in a state.

Additional demographic and economic covariates at the state and year level are derived from the yearly American Community Surveys for 2008-2016. These include the racial makeup of the state, the natural logarithm of state GDP, the percent on Supplemental Nutritional Assistance Program, the unemployment rate, the poverty rate, and the state minimum

wage.

As will be explained in Section X, the FDA recommends increased STD testing for persons on PrEP, which could potentially confound our results. In order to tackle this, we proxy for STD testing by analyzing HIV testing data from the Behavioral Risk Factor Surveillance System (BRFSS). The BRFSS data is obtained through telephone interviews that ask participants regarding their health-related risk behaviors, chronic health conditions, and use of preventive services. More than 400,000 adult interviews are conducted yearly in all 50 states and the District of Columbia. Participants were asked the month and year of their last HIV Test. In 2016 for example, the variable was available for 21.2% of participants [3]. Although the variable is not available for the majority of participants, it is likely that participants who had testing done in the months preceding the interview will remember it. Thus, recent testing data could be more complete, and that is the data we are interested in. From that variable, we construct the share of male participants aged 18-45 in each state that had HIV testing in the 6 months preceding the interview for the years 2008-2016.

Table 1 provides summary statistics for states that had the lowest and highest PrEP expansion. States were ranked according to their male PrEP rate in 2017. States labeled as "low" are states that are in the lowest quartile of PrEP take-up, whereas states labeled as "high" are states that are in the highest quartile of PrEP take-up. Statistics are provided for the period before (2008-2011) and after (2012-2017) the introduction of PrEP. All summary statistics are weighted by population.

First, the table details the two treatment variables - male PrEP rate per 100,000 and the share of male same-sex partnerships. In the period after the introduction of PrEP, high PrEP take-up states had an average male PrEP rate that is more than four times that of low take-up states (47.8 versus 11.8 users per 100,000) and had a share of male same-sex partnerships that is almost twice as high (0.7% versus 0.42%). Second, the table details the dependent variables. Before the introduction of PrEP, high and low take-up states had similar male

[3]The rest of the participants were either not sure, didn't know, refused to answer, were not asked or their data is missing

chlamydia and gonorrhea rates; 298 versus 293 cases per 100,000 for male gonorrhea and 110 versus 121 cases per 100,000 for male chlamydia in high and low take-up states, respectively. whereas high take-up states had much higher rates of male syphilis (12.4 versus 5.7 cases per 100,000) and male HIV (34.3 versus 17.1 cases per 100,000). With respect to socioeconomic measures, which we average over the whole period, high take-up states were richer, had a lower share of white males and a higher share of Hispanic and Black people.

4 Empirical Framework

In order to estimate the effect of PrEP on STDs we employ two specifications, both of which have a difference-in-difference variant as well as a a triple-difference variant. In the first, we exploit the temporal and spatial variation in PrEP adoption, by employing the following difference-in-difference specification:

$$STD_{st} = \beta PrEP_{st} + \gamma X_{st} + \mu_s + \tau_t + \epsilon_{st} \tag{1}$$

Where s indexes state and t indexes the year. STD_{st} is the STD rate (Chlamydia, Gonorrhea, Syphilis or HIV) per 100,000; $PrEP_{st}$ is the PrEP rate per 100,000. We include state fixed effects, μ_s to control for time-invariant differences across states that might affect STD rates, such as differences in sexual norms; and year fixed effects, τ_t, to control for nationwide factors that affect STD rates over time, such as common health shocks and changes in STD testing technology. In addition, we include a set of demographic and economic variables, X_{st}; these include the share of the population that is either White, Hispanic, Black, Asian, Native American or other; log GDP; log of the population; and the unemployment rate. Since both the STD and the PrEP rates are per 100,000 population, the coefficient of interest, β, measures the change in STD incidences as a result of one additional PrEP user. As we include state and year fixed effects, the effect is identified from the changes in PrEP rates within the same state over time - and relative to the corresponding changes in other states.

We run the regression separately for each STD and for male and female. The regressions are population weighted and the errors are clustered at the state level.

The identifying assumption is that absent of PrEP, STDs in states with different PrEP rates, would have evolved in parallel. Although untestable, we provide evidence that prior to the introduction of PrEP, Chlamydia and Gonorrhea rates have generally evolved similarly in states that would later adapt PrEP at different rates. First, graphically, as detailed in the next subsection, and second, through an event study design, detailed in Section X, that enables us to estimate a coefficient for the difference in STD rates between states with different PrEP rates (as proxied by the gay male population) for each of the years prior to the introduction of PrEP; these coefficients are statistically insignificant. As noted in the previous section, for HIV it does not seem these STDs have evolved in parallel prior to the introduction of PrEP, therefore, Chlamydia and Gonorrhea and Syphilis will be the main focus of this paper.

Another variant of this specification is a triple difference specification. As detailed in Section X, women were barely treated, as only a small share of PrEP users are women. This, combined with the similar evolution of women and male STD rates prior to the introduction of PrEP, as illustrated in Figure X, makes women a suitable additional comparison group in a triple-difference specification. This difference controls for time variant factors that affect STD rates at the state-year level, for example, if certain states experienced targeted STD reduction campaigns during some of the years. The triple-difference equation we estimate is the following:

$$STD_{stg} = \beta_1 PrEP_{st} + \beta_2 Male_g + \beta_3 Male_g * PrEP_{st} + \gamma X_{st} + \mu_s + \tau_t + \epsilon_{stg} \qquad (2)$$

where all the variables are as defined in (1) and $Male_g$ is an indicator for male obser-

vations. The coefficient of interest β_3, identifies the the differential effect of one additional PrEP user on men compared to women, whereas $\beta_1 + \beta_3$ identifies the effect of one additional PrEP user on male STDs.

The identifying assumption is that absent of PrEP, the differences between STDs of male and female in states with different PrEP rates, would have evolved in parallel. As mentioned above, the DDD event study design, detailed in Section X, would provide evidence this.

Our second specification stems from a unique feature of PrEP. As PrEP is mainly marketed towards (as well as adapted by) the gay male population, it is likely that the higher the gay male population in a state, the higher the number of male PrEP users. More specifically, the higher the *share* of the male population that is gay in a state, the higher the male PrEP rate (i.e. the higher the exposure to treatment). Therefore, we exploit the variation in the gay male population across states as a treatment intensity measure that proxies for the states' differential PrEP use in the following event-study design:

$$STD_{st} = \sum_{\substack{t=2008 \\ t \neq 2011}}^{2017} \beta_t * MaleSSP_s + \gamma X_{st} + \mu_s + \tau_t + \epsilon_{st} \tag{3}$$

where the measure we use for the share of the male population that is gay, $MaleSSP_s$, is the percentage of partnerships that are male same-sex partnership in state s from the 2000 census; the construction of the variable is detailed in Section X. We then interact the variable with year fixed effects, β_t. The year 2011, the year prior to the introduction of PrEP, is used as the baseline year. The other variables are as previosuly described. Therefore, β_ts are interpreted as the additional cases per 100,000 of a STD (i.e. the STD rate) in year t, compared to the baseline year, that occur with a 1 percentage point increase in partnerships that are male same-sex. Similar to the previous specification, year and state fixed effects, as well as controls are included. Hence, the coefficient of each year is identified by the difference

in STDs in comparison to the baseline year, and relative to the difference in other states that were had a higher or lower gay male population. We run the regression separately for each STD and for male and female. The regressions are population weighted and the errors are clustered at the state level. The identifying assumptions are similar to the ones mentioned in the previous specification, where the share of the population that is gay substitutes the PrEP rate. As before, the event studies would provide evidence of this.

Following the same logic as detailed previously, we also estimate a variant of this specification that includes women as a third difference. Specifically, we estimate the following equation:

$$\begin{aligned} STD_{stg} = &\sum_{\substack{t=2008 \\ t\neq 2011}}^{2017} \beta_t^1 \cdot MaleSSP_s + \sum_{\substack{t=2008 \\ t\neq 2011}}^{2017} \beta_t^2 \cdot Male_g + \\ &\sum_{\substack{t=2008 \\ t\neq 2011}}^{2017} \beta_t^3 \cdot MaleSSP_s \cdot Male_g + \gamma X_{st} + \mu_s + \tau_t + \epsilon_{stg} \end{aligned} \tag{4}$$

where all the variables are as defined in (3) and $Male_g$ is an indicator for male observations. The β_t3s are interpreted as the additional cases per 100,000 of a male STDs (i.e. the STD rate) compared to female STDs in year t, compared to the baseline year, that occur with a 1 percentage point increase in partnerships that are male same-sex.

The identifying assumptions are similar to the ones mentioned in the previous specification, where the share of the population that is gay substitutes the PrEP rat; the event studies would provide evidence of this.

4.1 Identifying Variation

We are interested in examining whether the adoption of PrEP coincides with increases in STDs. Specifically, we conjecture that the more persons use PrEP in a given state - year, the higher the incidences of STDs. Identifying the effect stems from the temporal variation

in PrEP adoptions within a state, as well as the differential adoption of PrEP across states which will be illustrated in this section.

First, Figure X illustrates the overall number of PrEP users per 100,000 population (PrEP rate) separately for male and female. Since its introduction in 2012, the number of users, specifically male, grew rapidly. By 2017, there were 94,146 male users and 6,045 female users which corresponds to a PrEP rate of 70.6 for male and 4.3 for female. While the female PrEP rate remained rather constant over time, the male PrEP rate grew 23 fold since its introduction. Given heavy marketing brought by the warm endorsement of various public health organizations, the introduction of generic PrEP and the plan to eradicate HIV infections by 2030, the fast adoption of PrEP is unlikely to halt.

Second, we show that while in some states users barely adapted PrEP, in other states users users heavily adapted PrEP. Figure X, the male PrEP rate across states in 2017, illustrates this spatial variation. As the figure shows, states where users are more likely to adapt PrEP are states in the Northwest and in the West Coast as well as some states along the southern coast and the Midwest. Unsurprisingly, these are states with high gay populations, as will be discussed below.

4.2 Descriptive Evidence on the Evolution of STDs

Next, we plot the evolution of male STD rates for states with different PrEP takeup. We do so by ranking states according to their male PrEP rate in 2017 and dividing them into quartiles pertaining to their PrEP takeup. We then plot the evolution of average male STD rates for each quartile of states for the four STDs separately. Quartile 1 is the quartile of states that had the highest PrEP takeup, whereas quartile 4 is the quartile of states that experienced the lowest PrEP takeup. This is illustrated in Figure 4.

As the figure shows, male STD rates, with the exception of HIV, were trending upwards in all states during the past few years, at a faster pace than previous years, to reach record highs each year. In just 5 years, during the year 2012 to 2017, male Chlamydia, Gonorrhea and

Syphilis rates have increased on average by approximately 36%, 106% and 91%, respectively, compelling the CDC to call for urgent action.

Specifically, the figure shows that the states that experienced the fastest increases in recent years in male Gonorrhea and Chlamydia rates were states with the highest PrEP takeup (1st quartile). Although the rates in these states were trending similarly to the rates in states with lower PrEP takeup before the introduction of PrEP, after its introduction, rates started increasing more rapidly in states with the highest PrEP takeup. Whereas, in 2011, just before PrEP was introduced, male Gonorrhea rates were similar in all states, by 2017, states with high PrEP takeup had rates that were higher by approximately 22% from the rates in states with lower PrEP takeup. Similarly, in 2008, male Chlamydia rates in states with high PrEP takeup were only higher than in states with lower PrEP takeup, but by 2017, they were approximately 20% higher. With respect to male Syphilis, rates began increasing at a faster pace in states with high PrEP takeup 2 years prior to the introduction of PrEP, but increased at a faster rate after. The triple-difference specification will be able to control for some male STD differential pretrends.

With respect to male HIV rates, the figure shows that rates were declining throughout the period for states in the top 3 quartiles of PrEP takeup. Moreover, the higher the PrEP takeup, the faster the decline in rates. This could be a result of efforts of numerous public health organizations groups that began in the early 200's to combat HIV; these efforts were concentrated in states with high male HIV rates, which were the states that had large gay populations, which are also the states that had higher PrEP takeup. These efforts to reduce HIV could have been coupled with efforts to combat other public health concerns such as STDs. This does not seem the case, since although the reduction in HIV occurred throughout the period, most male STD rates were quite flat at the beginning of the period. Moreover, in case the HIV reduction campaigns had spillovers to other STDs, it would downward bias out estimates. The fact that male HIV rates were trending differently prior to the introduction of PrEP across states with different PrEP takeup, also evident in the event studies (Figures

6 and 7), provides a challenge for the identification of the effect of PrEP on male HIV rates as states with lower PrEP takeup do not provide a valid counterfactual for male HIV rates in states with higher PrEP takeup; a negative effect could just pickup the downward trends of states with high PrEP takeup that existed before the introduction of PrEP. Therefore, this paper will focus on the effects of PrEP on other STDs. Nonetheless, we will show the result of a specification that includes state-specific linear time trends that could control for those differential pre-trends.

5 Results

5.1 Male PrEP Rate Specifications

Table 2 reports the results from estimating the first specification, where the male PrEP rate is the treatment variable (equations (1) and (2)). Columns 1 through 3 detail the respective estimates from separate regressions where the dependent variables are chlamydia, gonorrhea, and syphilis rates defined as cases per 100,000 people. Table 3 reports the results for HIV rates. For each STD, sub-column (1) details the estimates from difference-in-difference described in equation (1) for male and sub-columns (2a) - (2c) detail the estimates from triple-difference Equation (2). Specification (2a) does not include controls; specification (2b) adds the controls discussed in the Data section; and specification (2c) adds state-specific linear time trends. All specifications include state and year fixed effects and are weighted by population. Standard errors are clustered at the state level.

Starting with sub-column (1), the table reports the coefficient on the variable of interest – male PrEP usage. Results are statistically significant at the $\alpha = 0.05$ level for chlamydia and gonorrhea but not for syphilis. It is estimated that each additional male user of PrEP increases the incidences of male chlamydia and gonorrhea by 0.431 and 0.337, respectively.

Column (2b) details the estimates from our preferred specification – triple-difference with controls. We report the estimates for the main effect coefficients and the interaction term

Male*PrEP. We also report the overall effect of the male PrEP rate on male STDs, calculated as the sum of the coefficient on PrEP and Male*PrEP.

The coefficient on PrEP, which identifies the effect of the PrEP rate on women, is negative which suggests that female STD rates are negatively correlated with PrEP. The coefficient on Male is negative for chlamydia and gonorrhea, indicating that males have lower rates for these STDs, which is reasonable given that women are biologically more susceptible to contracting these STDs (Wong, et al 2004). With respect to syphilis, gay men generally experience higher rates as the majority of cases with 63% of cases in 2018 have been found amongst gay men [CITATION NEEDED].

The coefficients on the interaction terms, which identify the differential effect of the male PrEP rate on men compared to women are positive and statistically significant at the $\alpha = 0.01$ level. Adding these to the coefficients on PrEP provides the effect of the male PrEP rate on men compared to women. This effect is also positive and statistically significant at the $\alpha = 0.01$ level. We estimate that each additional male user of PrEP increases the incidences of male chlamydia, gonorrhea and syphilis by 0.744, 0.629 and 0.071 cases, respectively. These estimates are higher than the difference-in-difference estimates. These estimates may be more believable though because comparing men and women within the same state may be a better comparison than comparing men across states. There is the potential of differential trends in STDs between the two specifications that may explain these differences. We explore that later in the XXXXX Section.

Column (2a) details the estimates of specification (2) without controls. Comparing columns (2a) and (2b) suggests that the coefficients are stable to the addition of controls, although for gonorrhea, the inclusion of controls decreases the magnitude of the coefficients, suggesting that there could be socioeconomic variables that were changing over time and were responsible for both a change in the PrEP rate and STDs.

Column (2c) details the estimates from the addition of state-specific linear time trends.

Table 3 details the results for HIV. As noted previously, due to differential trends before

the roll out of PrEP, the estimated effect on HIV will likely be biased downward, making any potential negative effect appear larger. We will note that while the specifications that do not include state-specific linear time trends produce a significant negative coefficient, when time trends are included, the coefficient of interest becomes insignificant.

5.2 Gay Population Specifications

Figures 5-8 plot the event-study estimates from the second specification, where the share of partnerships that are male same-sex is the treatment variable (equations (3) and (4)). Tables X-X detail the corresponding estimates.

Figure 5 and 6 plot the yearly coefficients on MaleSSP from difference-in-difference equation (3) where separate regressions are estimated for men and women and for Chlamydia, Gonorrhea Syphilis and HIV rates, as well as the male PrEP rate; the regressions include the controls mentioned in the Data section.

First, we demonstrate that our measure of PrEP takeup is indeed predictive; e.g. that states with a larger male gay population are states where PrEP takeup was higher. We do so by estimating equation (3) with the dependent variable being the male PrEP rate ("first stage"). The results are plotted in Figure 5. The positive coefficients for men in the years after the introduction of PrEP indeed show that the larger the male gay population, the larger the PrEP takeup. The increase in the coefficient over the years corresponds to the pattern of increase in male PrEP users over time (see Figure 1). By 2017, a 1 percentage point increase in partnerships that are male same-sex is associated with an increase in the male PrEP rate of 136.

Figure 6 plots the estimation results for the STDs. It shows that male and female STDs were trending downward in states with larger gay male population before the introduction of PrEP. For chlamydia and HIV the pre-trends are statistically significant, whereas for Gonorrhea and Syphilis they are not. These could be stemming from different public health efforts that were concentrated in states with larger male gay populations. After the introduction

of PrEP, the coefficients for men start increasing (with the exception of Syphilis) in a pattern that is consistent with the rollout of PrEP (see Figure 1). Nonetheless, due to these pre-trends, we will focus on the triple-difference specification which mitigates the pre-trends. It is important to note that in addition to the low PrEP takeup amongst women, the fact that male and female STD rates were trending similarly before the introduction of PrEP justifies the use of women as an additional control group in the triple-difference specification (equation (4)).

Figure 7 and 8 plot the yearly coefficients on MaleSSP*Male from triple-difference equation (4) where separate regressions are estimated for Chlamydia, Gonorrhea Syphilis and HIV rates, as well as the male PrEP rate; the regressions include the controls mentioned in the Data section. The estimates can be thought of as the differences between the green (male) and orange (female) coefficients in figures 5 and 6, where we are "deducting" womens' STD rates from mens.

As before, we first estimate equation (4) with the dependent variable being the male PrEP rate ("first stage"). The results (Figure 7) mirror the difference-in-difference results that were explained previously (Figure 5). By 2017, a 1 percentage point increase in partnerships that are male same-sex is associated with an increase of 150 in the male PrEP rate.

Figure 8 plots the estimation results for the STDs. It shows that there are no longer statistically significant pre-trends, with the exception of HIV. Therefore, we cannot claim to identify the effect of male PrEP on HIV in our specifications. As before, after the introduction of PrEP, the coefficients start increasing (with the exception of Syphilis, where the coefficients remain rather steady, or even slightly decline until 2015) in a pattern that is consistent with the rollout of PrEP (Figure 1). In addition to the increase in number of male PrEP users, which increases the number of individuals who engage in risky sexual behavior, the pattern could also be partly explained by the natural evolution of an infectious disease (that would have developed in a similar pattern even without an increase in the number of male PrEP users).

By 2017, a 1 percentage point increase in partnerships that are male same-sex, is associated with an increase of 129, 137 and 9.2 in the male Chlamydia, Gonorrhea and Syphilis rates.

As these effects are hard to interpret, we also scale estimate the full IV, in make the results interpretable as well as comparable to the results from the other specification.

5.3 Results by Age

Our PrEP data reveals that PrEP takeup was different amongst age groups. This could be due to different health coverage, awareness, different risk aversion, etc. We estimate our main triple-difference specification (equation (4)) for separately for different age groups, and demonstrate that the largest increases in STDs were amongst the age groups that had a higher PrEP takeup.

6 Robustness Checks

6.1 HIV Prevalence as a Treatment Intensity Measure

We repeat the analysis that used partnerships that are male same-sex but use HIV prevalence amongst the gay population at the treatment variable as men are more likely to use PrEP in states where the risk of contracting HIV is higher.

7 Discussion

7.1 Recommended STD Testing

The FDA recommends screening all patients for HIV infection before initiating PrEP and at least once every 3 months while taking PrEP (FDA, 2018). For the broader gay male population, it recommends screening for all STDs at least every 6 months. Although the

FDA doesn't recommend a schedule of screening for STDs other than HIV while taking PrEP, doctors and STD clinics sometime couple HIV infection screenings with screening for other STDs. If this is the case, persons taking PrEP might undergo more frequent STD screenings (about every 3 months versus every 6 months for gay male that are not taking PrEP). However, it is unclear whether medical practitioners indeed administer more frequent STD screening other than HIV for persons taking PrEP, since it is at their discretion. Furthermore, it could be the case that persons who take-up PrEP already screen for STDs more often than gay male that are not taking PrEP (for example, if persons taking PrEP are more risk averse). In any case, if more frequent STD screening is practised by persons taking PrEP, it could have an ambiguous effect on STD incidences. On the one hand, since Chlamydia, Gonorrhea and Syphilis infections are sometimes asymptomatic, increased STD screening could pick up STD incidences that would have not been picked up without regularly scheduled screening. Thus, the differential increases in STDs that we are picking up in states where the PrEP rate grew more, could have partially been increases in STD diagnoses, not increases in the underlying distribution of STDs. On the other hand, increased screening that result in increased diagnoses of asymptomatic STDs could decrease the incidences of STDs since patients become aware of their infection and were likely getting treated for it, preventing its spread to others.

Although there is no suitable data on STD screening that will enable us to test whether STD screening increases more, the higher the PrEP rate, we are able to provide suggestive evidence that this is likely not the case using suitable data on HIV screening, as STD screenings usually include HIV screening. As explained in Section X, using data from the BRFSS (CDC, 2008-2017), we construct the share of male participants aged 18-45 in each state that had HIV testing in the 3 months preceding the interview for each of the years 2008-2016. We then estimate our preferred triple-difference specification (equation (4)) where the dependent variable is the HIV screening variable we constructed, to examine whether states in which a higher share of the population is gay (i.e. states where the PrEP rate grew more),

experienced higher increases in HIV screening. The event study results appear in Figure X. As the figure shows, the coefficients for each of the years are insignificant for all years, and they do not form an upward trend, as the event studies for the STDs. Therefore, there is no evidence that HIV screening did increased differentially for states with a higher male PrEP rate.

7.2 The Proliferation of Dating Applications

A potential omitted variable in our analysis is the rise of the dating apps, especially Grinder which is targeted at the male gay population and grew in number of users concurrently with the adaption of PrEP. If Grinder increased the availability of sex amongst the gay population, it could lead to an increased number of sexual partners and consequently increased STD incidences in states with a larger gay population. Given that we identify of the share of the population that is gay, our estimates could actually be picking up some of the effect of Grinder on STDs and not of PrEP. Although there is no publicly available data on the adaption of Grinder that would have enabled us to test this hypothesis, it is unlikely that our results are driven by the growth of Grinder. Gridner was introduced in 2009 and by 2011, the year before the introduction of PrEP, it already had an estimated 5 million active users. If indeed the use of Grinder increased STDs, it should show up as positive coefficients in our event study specification (illustrated in Figure X), for the years 2009, 2010, 2012, which is not the case. Nonetheless, we cannot rule out the possibility as Grinder grew its user base, it was responsible for an increase in STDs amongst gay men.

7.3 Counterfactual

We conduct a simple counterfactual analysis to examine how STIs would evolve in a counterfactual world without PrEP. We take our estimated effect of PrEP on STIs and subtract the amount of additional STIs caused by PrEP from aggregate STI numbers. For instance, we find in our IV model that 1 additional male PrEP user results in about 0.9 additional cases of

gonorrhea, so for each PrEP user we subtract out 0.9 cases of gonorrhea for each PrEP user in each year and recalculate the STI rate. The implicit assumption in this analysis is that the marginal effect of an additional PrEP user is constant over time and across states, which could be strong assumptions. However, we believe that this analysis can still be instructive. We plot the new estimates for the STI rate for each year. We present the OLS and IV results together for comparison. We present the counterfactual estimates for chlamydia, gonorrhea and syphilis in Figure X.

In the top left quadrant, we present the counterfactual for the aggregate chlamydia rate in the absence of PrEP with the top right quadrant showing the counterfactual for gonorrhea and the bottom left quadrant showing the counterfactual for syphilis. We also give how large of a decline the total STI rate would be in the absence of PrEP with our different estimates. In the chlamydia figure, our OLS estimates suggest that the chlamydia rate would be about 7% lower in aggregate in the absence of PrEP with the IV estimates suggesting about a 16% decline. For gonorrhea, our estimates suggest that the gonorrhea rate would be 10 to 27% lower in the absence of PrEP. For syphilis, our estimates suggest that the syphilis rate would be 5 to 27% lower in the absence of PrEP. We do not perform the counterfactual analysis for HIV diagnoses as the estimates are likely biased away from zero, and the estimate sizes are likely too large. For each of these STIs, the OLS results are smaller than the IV counterfactuals, which is consistent with Table X. One potential concern with this analysis is that the IV results are likely far too large to plausible. It suggests that the rate for chlamydia would be about 16% lower and the rate for gonorrhea would be about 27% lower. This seems relatively high given that LGBT population is relatively small compared to the non-LGBT population. However, the amount of people that identify as part of the LGBT population is significantly different from the population that engages in sexual behavior with a member of the same-sex. For instance, about 3.5% of the population identifies with the LGBT title but about 8% of the population has engaged in same-sex sexual behavior and about 11% have some same-sex sexual attraction (Gates 2011). These estimates are from surveys though,

and people could be underreporting same-sex attraction or behavior given the stigma around same-sex attraction.

The CDC reports on their website that the majority of male syphilis cases are from MSM at about 78% in 2018[4]. This finding would suggest that our IV estimates of the effect of PrEP on syphilis are potentially plausible. Gonorrhea is also growing specifically among the MSM community. The CDC shows that the rate of gonorrhea among men and women were relatively equal until 2012 when gonorrhea among men starting to shoot up while the rate for women stayed the same, which the CDC suggests is due to increased infections among MSMs who are less likely to have sexual interaction with women[5]. The CDC has a STI surveillance network giving them greater information on STI in certain cities. There's a wide range in the share of gonorrhea attributed to MSM with about 86% of gonorrhea cases in San Francisco attributed to MSM to about 20% in Baltimore. The CDC estimates about 43% of gonorrhea cases are attributable to MSM, 21% are attributable to heterosexual men, and 32% attributable to women in their surveillance cities. The figures for men suggest that about 67% of male cases of gonorrhea are attributable to MSM, suggesting that our estimates are again plausible. The CDC does not present the rate of male chlamydia cases attributable to MSM, making any inference about plausibility of counterfactual estimates difficult. If the prevalence of chlamydia is the same or slightly smaller among MSM as gonorrhea is then our estimates would be plausible.

Overall, our estimates suggest that a large amount of the STIs are potentially attributable to PrEP and the rollout of the new HIV-prevention drug. Importantly, our findings are plausible given how many STIs are attributable to MSM, who are most likely to use PrEP. At the high end of our estimates, chlamydia rates would be 16% lower, gonorrhea rates would be 27% lower, and syphilis rates would be 24% lower in the absence of PrEP in 2017, suggesting that PrEP contributes to a sizeable amount of current STIs.

[4]https://www.cdc.gov/std/stats18/msm.htm
[5]https://www.cdc.gov/std/stats18/gonorrhea.htm

7.4 Back of Envelope Calculations

We conduct back of the envelope calculations that estimate the additional costs relative to the benefits associated with additional STDs that occurred due to the introduction of PrEP using STD costs estimates from the medical literature. Ideally, one would want to do a cost-benefit analysis to compare the costs of PrEP – the additional STDs caused from a moral hazard effect – to the benefits of PrEP – the reduced cases of HIV. However, any benefit we estimate will likely be overestimated due to the differential pre-trends, so to scale the costs of PrEP to any potential benefit, we do a break-even analysis. Since we cannot be confident in identifying the reduction of HIV due to PrEP because of the differential pre-trends in states with high gay populations to those with low gay populations, we then calculate how many cases of HIV should PrEP prevent in order to justify the added costs of the STDs.

8 Conclusion

References

Adair, John G. 1984. "The Hawthorne effect: a reconsideration of the methodological artifact." *Journal of applied psychology*, 69(2): 334.

Alpert, Abby, David Powell, and Rosalie Liccardo Pacula. 2018. "Supply-side drug policy in the presence of substitutes: Evidence from the introduction of abuse-deterrent opioids." *American Economic Journal: Economic Policy*, 10(4): 1–35.

Chan, Tat Y, Barton H Hamilton, and Nicholas W Papageorge. 2015. "Health, risky behaviour and the value of medical innovation for infectious disease." *The Review of Economic Studies*, 83(4): 1465–1510.

Cohen, Alma, and Liran Einav. 2003. "The effects of mandatory seat belt laws on driving behavior and traffic fatalities." *Review of Economics and Statistics*, 85(4): 828–843.

Cohen, Alma, and Rajeev Dehejia. 2004. "The effect of automobile insurance and accident liability laws on traffic fatalities." *The Journal of Law and Economics*, 47(2): 357–393.

Doleac, Jennifer L, and Anita Mukherjee. 2018. "The moral hazard of lifesaving innovations: naloxone access, opioid abuse, and crime." *Opioid Abuse, and Crime (September 30, 2018)*.

Freeborn, Kellie, and Carmen J Portillo. 2018. "Does pre-exposure prophylaxis for HIV prevention in men who have sex with men change risk behaviour? A systematic review." *Journal of clinical nursing*, 27(17-18): 3254–3265.

Gates, Gary. 2011. "How many people are lesbian, gay, bisexual, and transgender?" The Williams Institute.

Hosek, Sybil, Bret Rudy, Raphael Landovitz, Bill Kapogiannis, George Siberry, Brandy Rutledge, Nancy Liu, Jennifer Brothers, Kathleen Mulligan, Gregory Zimet, et al. 2017. "An HIV pre-exposure prophylaxis (PrEP) demonstration project and safety study for young MSM." *Journal of acquired immune deficiency syndromes (1999)*, 74(1): 21.

Lakdawalla, Darius, Neeraj Sood, and Dana Goldman. 2006. "HIV breakthroughs and risky sexual behavior." *The Quarterly Journal of Economics*, 121(3): 1063–1102.

Liu, Albert Y, Stephanie E Cohen, Eric Vittinghoff, Peter L Anderson, Susanne Doblecki-Lewis, Oliver Bacon, Wairimu Chege, Brian S Postle, Tim Matheson, K Rivet Amico, et al. 2016. "Preexposure prophylaxis for HIV infection integrated with municipal-and community-based sexual health services." *JAMA internal medicine*, 176(1): 75–84.

Marcus, Julia L, Leo B Hurley, Charles Bradley Hare, Dong Phuong Nguyen, Tony Phengrasamy, Michael J Silverberg, Juliet E Stoltey, and Jonathan E Volk. 2016. "Preexposure prophylaxis for HIV prevention in a large integrated health care system: adherence, renal safety, and discontinuation." *Journal of acquired immune deficiency syndromes (1999)*, 73(5): 540.

McCormack, Sheena, David T Dunn, Monica Desai, David I Dolling, Mitzy Gafos, Richard Gilson, Ann K Sullivan, Amanda Clarke, Iain Reeves, Gabriel Schembri, et al. 2016. "Pre-exposure prophylaxis to prevent the acquisition of HIV-1 infection (PROUD): effectiveness results from the pilot phase of a pragmatic open-label randomised trial." *The Lancet*, 387(10013): 53–60.

Peltzman, Sam. 1975. "The effects of automobile safety regulation." *Journal of political Economy*, 83(4): 677–725.

Traeger, Michael W, Sophia E Schroeder, Edwina J Wright, Margaret E Hellard, Vincent J Cornelisse, Joseph S Doyle, and Mark A Stoové. 2018. "Effects of pre-exposure prophylaxis for the prevention of human immunodeficiency virus infection on sexual risk behavior in men who have sex with men: a systematic review and meta-analysis." *Clinical Infectious Diseases*, 67(5): 676–686.

Volk, Jonathan E, Julia L Marcus, Tony Phengrasamy, Derek Blechinger, Dong Phuong Nguyen, Stephen Follansbee, and C Bradley Hare. 2015. "No new HIV infections with increasing use of HIV preexposure prophylaxis in a clinical practice setting." *Clinical infectious diseases*, 61(10): 1601–1603.

Table 1: **Summary Statistics**

	2008-2011		2012-2017	
	Low	High	Low	High
Male PrEP Rate	0	0	11.8	47.8
Share of Male Same-Sex Par.	0.42	0.70	0.42	0.70
Male Chlamyia Rate	293	298	355	386
Male Gonorrhea Rate	122	110	158	183
Male Syphilis Rate	5.7	12.4	8.8	20.9
Male HIV Rate	17.1	34.3	16.6	28.6
	2008-2017			
	Low	High		
Share White	77.9	59.8		
Share Hispanic	3.5	8.4		
Share Black	7.9	14.3		
Unemployment Rate	5.6	7.2		
Gross State Product Per Capita	49,356	68,707		
Poverty Rate	13.6	12.8		

Notes: The table provides summary statistics for states according to their PrEP takeup for the years before the introduction of PrEP (2008-2011) and the years after the introduction of PrEP (2012-2017). States were ranked according to their male PrEP rate in 2017; "Low" are states that are in the lowest quartile of PrEP takeup, whereas "High" are states that are in the highest quartile of PrEP takeup. All summary statistics are population weighted. "Rate" refers to the rate per 100,000.

Tables

Table 2: **PrEP Specification Results - STDs**

	Chlamydia				Gonorrhea				Syphilis			
	(1)	(2a)	(2b)	(2c)	(1)	(2a)	(2b)	(2c)	(1)	(2a)	(2b)	(2c)
PrEP	0.431**	-0.386***	-0.428**	0.384**	0.337**	-0.391***	-0.590***	0.151*	0.015	-0.044***	-0.056***	-0.042***
	(0.131)	(0.136)	(0.205)	(0.149)	(0.136)	(0.058)	(0.120)	(0.087)	(0.009)	(0.007)	(0.011)	(0.008)
Male		-441.48***	-441.44***	-441.44***		-6.59	-6.51	-6.51		9.09***	9.09***	9.10***
		(21.45)	(21.57)	(22.03)		(6.77)	(6.85)	(6.99)		(1.01)	(1.02)	(1.04)
Male*PrEP		1.17***	1.17***	1.17***		1.22***	1.22***	1.22***		0.130***	0.130***	0.130***
		(0.165)	(0.166)	(0.169)		(0.107)	(0.105)	(0.107)		(0.017)	(0.017)	(0.017)
PrEP + Male*PrEP		0.789***	0.744***	1.56***		0.831***	0.629***	1.37***		0.086***	0.071***	0.088***
		(0.164)	(0.153)	0.165		(0.122)	(0.123)	(0.147)		(0.015)	(0.009)	(0.012)
Year F.E.	X	X	X	X	X	X	X	X	X	X	X	X
State F.E	X	X	X	X	X	X	X	X	X	X	X	X
Controls	X		X	X	X		X	X	X		X	X
Linear Time Trend				X				X				X
Dep. Var. Mean	277	277	277	277	117	117	117	117	9.5	9.5	9.5	9.5
Observations	510	1,020	1,020	1,020	510	1,020	1,020	1,020	510	1,020	1,020	1,020
R-Squared	0.949	0.935	0.934	0.940	0.936	0.855	0.874	0.890	0.914	0.833	0.848	0.860

* p<0.1; ** p<0.05; *** p<0.01

Notes: The table provides the results from estimating equation (1) and (2) where the outcomes variables are either Chlamydia, Gonorrhea or Syphilis. For each STD, column (1) are the results of difference-in-difference equation (1), estimated for male. Columns (2a), (2b) and (2C) are the results of triple-difference equation (2) without controls, with controls and with state-specific linear time trends, respectively. All specifications include year and state fixed effects and are population weighted. Controls include the share of the population that is either White, Hispanic, Black, Asian, Native American or other, log GDP, log of the population and the unemployment rate. Robust standard errors clustered at the state level are in parentheses. The dependent variable mean is calculated from the period before the introduction of PrEP (2008-2011).

Table 3: **PrEP Specification Results - HIV**

	HIV			
	(1)	(2a)	(2b)	(2c)
PrEP Rate	-0.119***	-0.089**	-0.090***	0.021
	(0.031)	(0.037)	(0.026)	(0.017)
Male		19.10***	19.10***	19.11***
		(1.62)	(1.63)	(1.67)
Male*PrEP Rate		0.018	0.017	0.017
		(0.017)	(0.016)	(0.017)
PrEP Rate + Male*PrEP Rate		-0.072***	-0.073***	0.038
		(0.023)	(0.014)	(0.030)
Year F.E.	X	X	X	X
State F.E	X	X	X	X
Controls			X	X
Linear Time Trend				X
Dependent Variable Mean	27.7	27.7	27.7	27.7
Observations	510	1,020	1,020	1,020
R-Squared	0.955	0.863	0.867	0.884

* p<0.1; ** p<0.05; *** p<0.01

Notes: The table provides the results from estimating equation (1) and (2) where HIV is the outcome variable. column (1) are the results of difference-in-difference equation (1), estimated for male. Columns (2a), (2b) and (2C) are the results of triple-difference equation (2) without controls, with controls and with state-specific linear time trends, respectively. All specifications include year and state fixed effects and are population weighted. Controls include the share of the population that is either White, Hispanic, Black, Asian, Native American or other, log GDP, log of the population and the unemployment rate. Robust standard errors clustered at the state level are in parentheses. The dependent variable mean is calculated from the period before the introduction of PrEP (2008-2011).

Figures

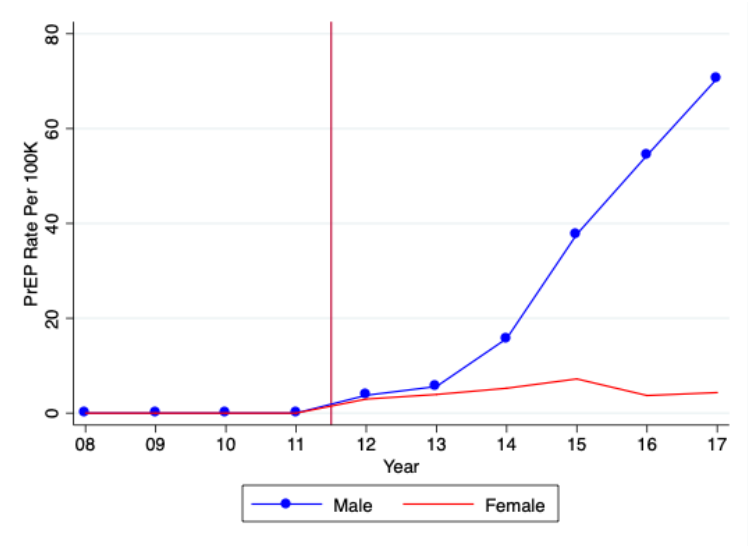

Figure 1: **PrEP Use Over Time**

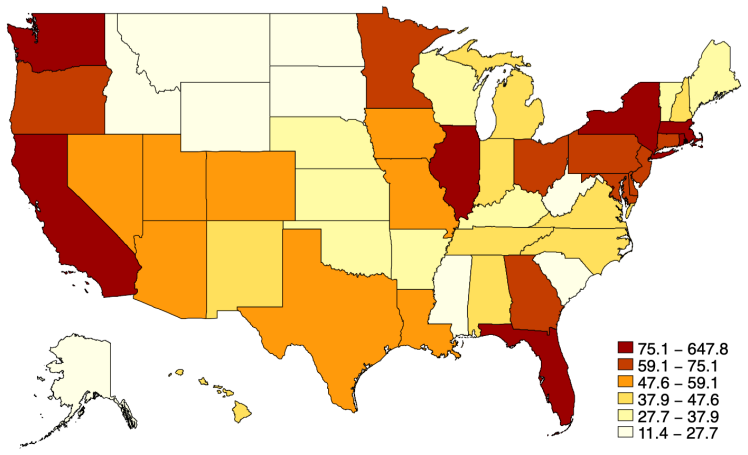

Figure 2: **PrEP Use Across States**

Notes: The figure details the male PrEP rate per 100,000 across states.

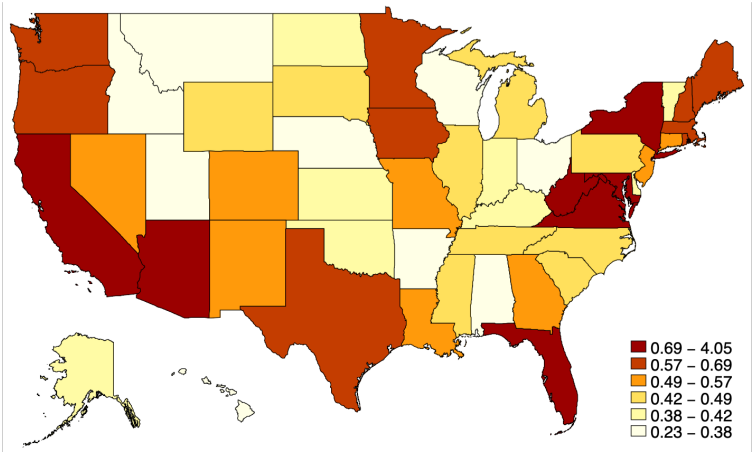

Figure 3: **Gay Male Population Across States**

Notes: The figure details the share of partnerships that are male same-sex across states; this is the measure we use to gauge each state's gay male population.

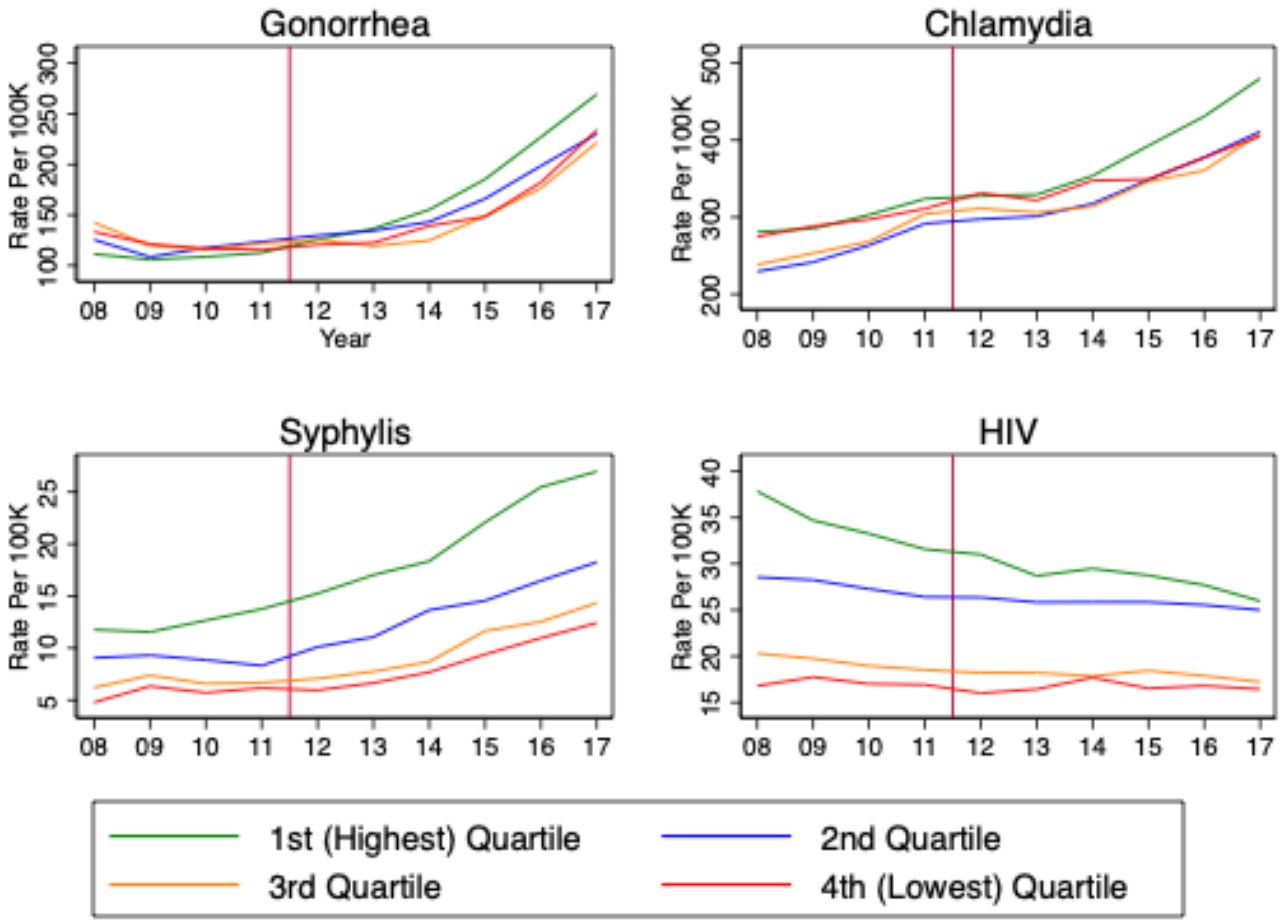

Figure 4: **Evolution of Male STD Rates by Quartile of PrEP Takeup**

Notes: The figure plots the male STD rates per 100,000 over time for states with different PrEP takeup. States were ranked according to their male PrEP rate in 2017 and put into quartiles, where quartile 1 includes states with the highest PrEP rate in 2007, and quartile 4 includes states with the lowest PrEP rate in 2017. The variables are population weighted.

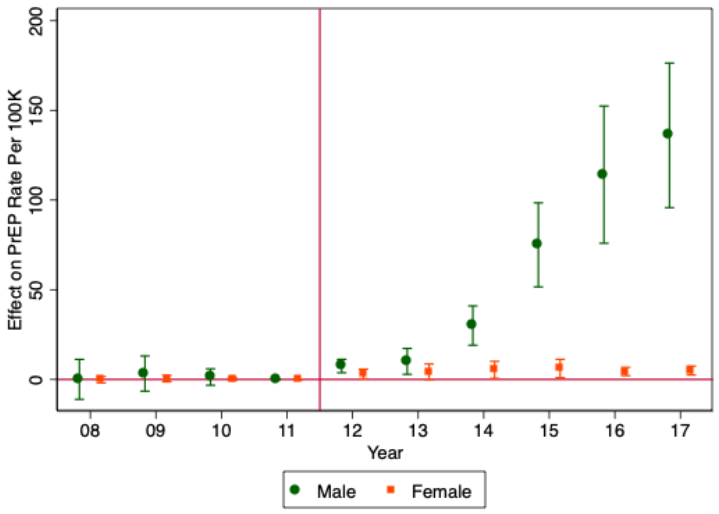

Figure 5: **DD Treatment Intensity Specification Results - PrEP**

Notes: The figure plots the event-study estimates from estimating difference-in-difference Equation (3) separately for male and female. The dependent variable is the PrEP rate per 100K. The year prior to the introduction of PrEP (2011) is omitted. Estimation includes year and state fixed effects and are population weighted. Controls include the share of the population that is either White,Hispanic, Black, Asian, Native American or other, log GDP, log of the population and the unemployment rate.The bands represent the 95% confidence interval, calculated using robust standard error clustered at the state level.

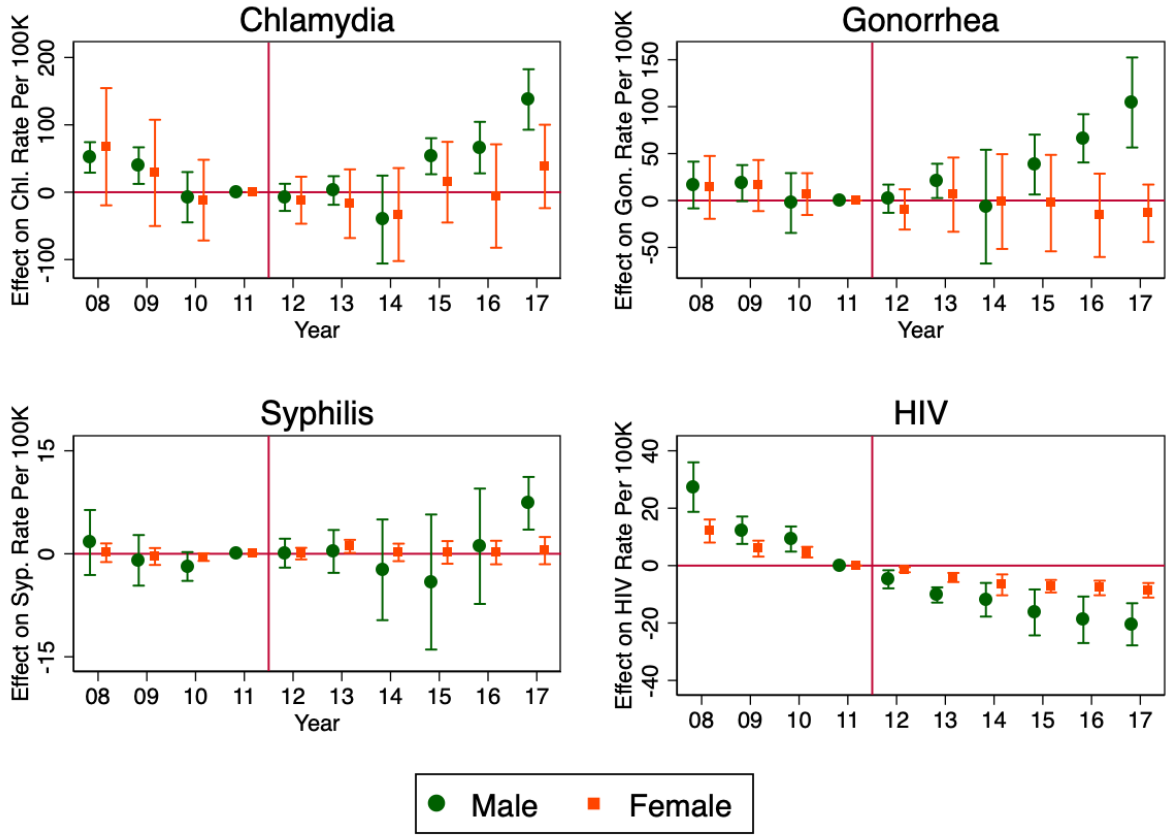

Figure 6: **DD Treatment Intensity Specification Results - STDs**

Notes: The figure plots the event-study estimates from estimating difference-in-difference Equation (3) separately for male and female for the different STDs. The dependent variables are the STD rates per 100K. The year prior to the introduction of PrEP (2011) is omitted. Estimation includes year and state fixed effects and are population weighted. Controls include the share of the population that is either White,Hispanic, Black, Asian, Native American or other, log GDP, log of the population and the unemployment rate. The bands represent the 95% confidence interval, calculated using robust standard error clustered at the state level.

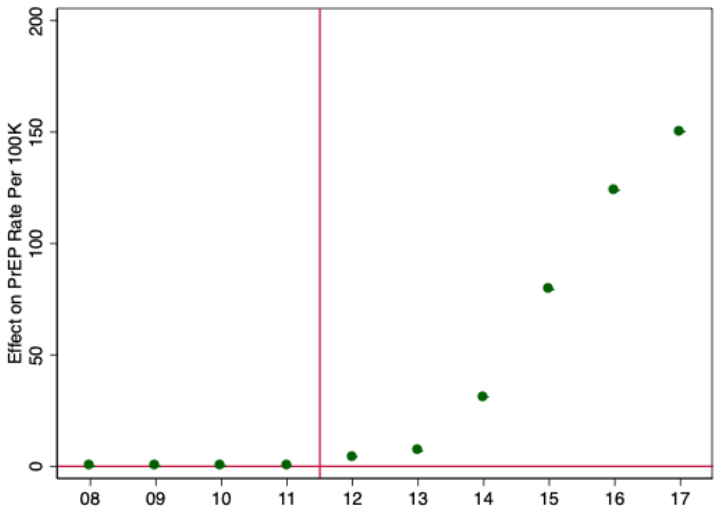

Figure 7: **DDD Treatment Intensity Specification Results - PrEP**

Notes: The figure plots the event-study estimates from estimating triple-difference Equation (4). The dependent variable is the PrEP rate per 100K. The year prior to the introduction of PrEP (2011) is omitted. Estimation includes year and state fixed effects and are population weighted. Controls include the share of the population that is either White,Hispanic, Black, Asian, Native American or other, log GDP, log of the population and the unemployment rate.The bands represent the 95% confidence interval, calculated using robust standard error clustered at the state level.

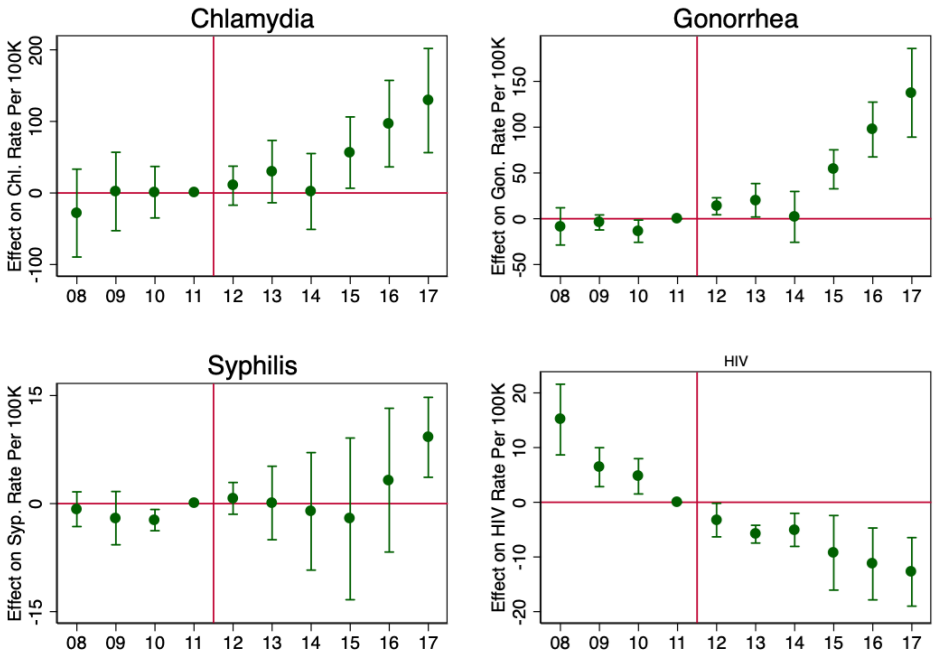

Figure 8: **DDD Treatment Intensity Specification Results - STDs**

Notes: The figure plots the event-study estimates from estimating triple-difference Equation (4) for different STDs. The dependent variables are the STD rates per 100K. The year prior to the introduction of PrEP (2011) is omitted. Estimation includes year and state fixed effects and are population weighted. Controls include the share of the population that is either White,Hispanic, Black, Asian, Native American or other, log GDP, log of the population and the unemployment rate. The bands represent the 95% confidence interval, calculated using robust standard error clustered at the state level.

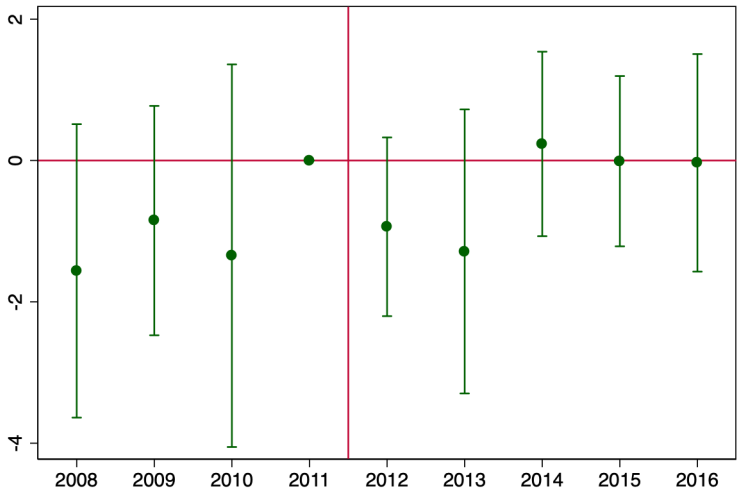

Figure 9: **Event Study - HIV Testing**

Notes: The figure plots the event-study estimates from estimating Equation (4); the dependent variable is the share of individuals tested for HIV in the past 3 months.

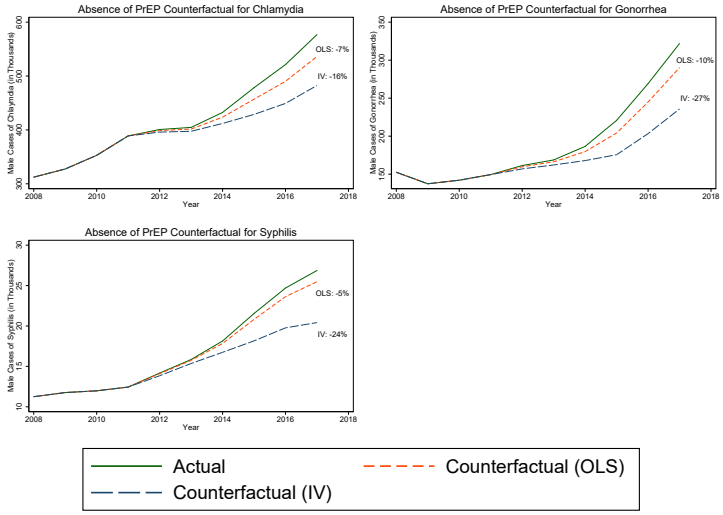

Figure 10: **Counterfactual STI development in absence of PrEP**

Notes: These figures plot how the aggregate STI rate would have developed in the absence of PrEP using two different estimates.