PrEP and Moral Hazard*

Nir Eilam †   Scott Delhommer‡

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Abstract

PrEP is a drug introduced in 2012 that essentially eliminates the risk of contracting HIV. Since its introduction, it has become popular amongst gay men, who are responsible for the majority of HIV infections. Given the reduced risk of contracting HIV, users might be more likely to engage in risky sexual behaviors that might lead to increases in other STIs. In this paper, we examine this empirically. In our main specification, we proxy for PrEP use in a given state using the predetermined share of the population that is gay in that state, a measure that is highly predictive of PrEP use. We then exploit this pre-treatment cross-state variation in the concentration of gay men to estimate difference-in-difference and triple-difference event studies. We estimate that one additional male PrEP user increases male chlamydia, gonorrhea and syphilis cases by 0.66, 0.51, and 0.04, respectively. Counterfactual distributions suggest that male STI rates would have been between 17.9% and 25.6% lower in the absence of PrEP. This paper adds to the literature on moral hazard by examining the behavioral response to a medical innovation that is cheap, accessible, and confers substantial reduction in risk that is highly salient to users. In addition, it informs an open question regarding the increases in STIs in recent years.

Keywords: Moral Hazard, LGBT, PrEP

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

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

1 Introduction

Sexually transmitted infections (STIs) have been increasing rapidly in recent years. The number of chlamydia, gonorrhea and syphilis cases, the three most common STIs[1], reached a record high of 2.4 million in 2018. The rise in STIs has been described by the CDC[2] as a "hidden epidemic of tremendous health and economic consequence" (Bowen et al., 2019). In this paper, we suggest that the introduction of a medical innovation that greatly reduces the risk of HIV infection, altered individuals' sexual behavior, resulting in significant increases in male STIs.

Pre-exposure prophylaxis, or "PrEP", was approved for HIV prevention in 2012. When taken daily by HIV-negative individuals, PrEP is highly effective at preventing HIV, if exposed to the virus. In addition to its efficacy, it is safe and well tolerated; it has therefore been touted as a "miracle drug" that could eradicate HIV (Stern, 2014). PrEP has been targeted to and adopted by gay men, who are responsible for the majority of HIV infections in the United States. We estimate that by 2018, between 10% to 15% of gay men aged 18-45 used PrEP; among some sub-populations of gay men, the share of users is even higher.[3]

PrEP has the potential to save lives by reducing HIV infections, but carries a moral hazard risk. By essentially eliminating the risk of contracting HIV - the single biggest risk associated with sex without condoms - PrEP decreases the expected costs of sex without condoms, potentially pushing some PrEP users to engage in this or other risky sexual behaviors that have become less costly. These behaviors increase users' risk of contracting other STIs that are perceived as easily curable.

In this paper we examine this empirically by asking whether the introduction of PrEP led to increases in STIs other than HIV. We begin by showing that PrEP take-up was associated with increases in STIs. Male STI rates in states with low and high PrEP take-up trended

[1] Of the STIs that are annually tracked by the CDC. Other STIs such as Herpes and HPV are more common, but are not annually tracked.

[2] Centers for Disease Control and Prevention.

[3] In a 2018 CDC survey of a large sample of gay men (CDC, 2019c) in cities with large gay populations, the share of PrEP users among HIV-negative respondents was around 25%.

similarly prior to the introduction of PrEP, but diverged afterwards, differentially increasing in states with high PrEP take-up. Exploiting the temporal and spatial variation in PrEP take-up, we estimate a difference-in-difference model that compares the evolution of STI rates in states with different PrEP take-up before and after the introduction of PrEP. We then estimate a triple-difference model, that adds females as a control group. The fact that females had very low take-up, as well as the similar evolution of male and female STI rates prior to the introduction of PrEP, suggests that female STI trends could provide a suitable counterfactual for male STI trends. The triple-difference specification has the advantage of controlling for time-variant factors that affect both male and female STI rates in a given state-year, such as local public health campaigns. We find that the introduction of PrEP is associated with 8.9% 24.5% and 16.2% increase in male chlamydia, gonorrhea and syphilis cases, respectively.

We then turn to our main specification in which we proxy for PrEP use in a given state using the predetermined share of the population that is gay in that state. This addresses the potential concern that PrEP take-up may be correlated with factors that also affect STIs. Because PrEP is almost exclusively used by gay men, this measure is highly predictive of PrEP use (i.e. states with larger gay populations, had higher prep take-up). We exploit this pre-treatment cross-state variation in the concentration of gay men to estimate difference-in-difference and triple-difference event studies, comparing the evolution of STI rates between states with different gay population shares, before and after the introduction of PrEP, and between males and females.

We find that each additional male PrEP user increased male chlamydia, gonorrhea and syphilis cases by 0.66, 0.51 and 0.04, respectively. These are sizeable effects that encompass both the direct effect of PrEP on users' STI rates, but also the spillover effect from PrEP users to non-PrEP users with whom they engage in sexual contact. Part of the effect could also stem from a change in sexual behavior norms among gay men driven by the increase in risky sexual behavior of PrEP users. In particular, as more PrEP users engaged in risky sexual behavior, such behavior became more acceptable, thus, spread among non-PrEP users as well. We construct counterfactual distributions of male STI rates in the absence of PrEP and conclude that PrEP was responsible for 204,091 male STI cases in 2018 alone, and that male chlamydia, gonorrhea and syphilis rates would have been 17.9% to 25.6% lower in the absence of PrEP.

Increases in male STI due to PrEP suggest an increase in risky sexual behavior among gay men. Using data from two government surveys, we show that the share of gay men who engage in sex without condoms was steady before the introduction of PrEP, but increased considerably after the introduction of PrEP. The share of HIV-negative gay men who have sex with HIV-positive or HIV-unknown partners, another form of risky sexual behavior, also increased after the introduction of PrEP.

These results identify changes in sexual behavior of the aggregate gay population. In order to directly link the increase in risky sexual behavior to PrEP users specifically, we conduct a survey of young sexually active gay men, both PrEP and non-PrEP users. We find that condom use decreased considerably among PrEP users since going on PrEP, whereas it remained steady among non-PrEP users over a similar period. The majority of PrEP users also admitted that they are less likely to use condoms specifically because of PrEP.

We conduct a series of additional analyses that support our main findings. For example, we explore heterogeneity by age, showing that the age groups that took-up PrEP the most, were also the age groups for which we find the largest treatment effects. In addition, we show that increased testing among PrEP users is unlikely to account for the increase in STI diagnoses.

Our findings do not imply that PrEP use should be curtailed. We conduct a cost-benefit analysis that suggests that the direct costs associated with the additional STIs were likely to have been offset by the savings from the reduction in HIV infections. Nonetheless, action could be taken to mitigate the unintended consequences of PrEP that are likely to grow as the number of PrEP users increases rapidly, generating social costs that are harder to quantify stemming from the growing STI epidemic. One such action is ensuring high HIV risk individuals use PrEP. We provide suggestive evidence that a large share of PrEP users were low HIV risk before going on PrEP; thus, they were unlikely to have contracted HIV even in the absence of PrEP. For these, PrEP did not reduce HIV risk, but did encourage risky sex practices. While on the other hand, some individuals of high HIV risk, for whom PrEP would have reduced HIV risk without generating increases in risky sex practices are not using PrEP.

This is the first paper to estimate the causal effect of PrEP on STIs using state-level STI diagnoses data that encompasses all PrEP users. It contributes to two strands of literature. First, we contribute to the medical literature that has previously examined the effect of PrEP on STIs. However, their analyses cannot be interpreted as causal. Specifically these studies suffer from one or more of the following limitations that inhibits the external and internal validity of their findings: lack of a control group, use of self-reported STI responses, analysis of self-selected high-risk PrEP users in one specific location and no account for potential spillover effects from PrEP to non-PrEP users (Traeger et al. (2018) and Freeborn and Portillo (2018) list papers on the topic). More broadly, this paper adds to the literature on the recent rise of STIs, providing evidence that PrEP could be one of the most important culprits (Carmona-Gutierrez, Kainz and Madeo, 2016; Bowen et al., 2019; Clement and Hicks, 2016; Tanne, 2018).

Second, this paper adds to the literature on moral hazard in medical innovations (e.g. Doleac and Mukherjee (2018); Lakdawalla, Sood and Goldman (2006); Chan, Hamilton and Papageorge (2015)). The strength of analyzing PrEP relative to other medical innovations that have been discussed in the literature, is that we demonstrate a significant moral hazard response in a context that is straight forward. PrEP is easily available, inexpensive, and essentially eliminates the risk of contracting HIV. Importantly, the reduction in risk is highly salient to users. This unique context supports the plausibility of the considerable moral hazard response that we document.

The paper proceeds as follows: Section 2 provides background on PrEP and STIs and reviews the related literature. Section 3 outlines our identification strategy. Section 4 details the data sources, the identifying variation, and provides descriptive statistics. Section 5 presents the results. Section 6 explores mechanisms. Section 7 investigates additional analyses. Section 8 provides a discussion and Section 9 concludes.

2 Background and Related Literature

2.1 Background on PrEP

PrEP refers to the use of antiviral drugs for HIV prevention. In 2012, Truvada became the first drug approved for PrEP. It is a combination of 2 drugs that are used for the treatment of HIV[4]. In 2019, a second drug, Descovy, was approved for PrEP. When taken as indicated (1 daily pill) studies have shown that PrEP reduces the risk of contracting HIV from sex by about 99% (CDC, 2020a). Even if adherence is not perfect, PrEP has been shown to be highly effective; for example, Anderson et al. (2012) and Grant et al. (2014) find that individuals who take PrEP only four days a week, appear to maintain a 96% HIV risk reduction. That makes PrEP considerably more effective in preventing HIV in gay men than condoms. Those have been shown to only be ≈70% effective in a comprehensive recent study in gay men who reported that they "always" used condoms (Smith et al., 2015). PrEP confers maximum protection after about 7 days of daily use (CDC, 2020b), therefore, assuming that patients are informed of this, in case PrEP use affects sexual behavior, the effect is likely to be contemporaneous.

In addition to being highly effective, PrEP is also well tolerated. In studies, PrEP has not raised any serious short or medium-term safety concerns[5] (CDC, 2020b). Before

[4] Tenofovir and Emtricitabine

[5] Starting PrEP sometimes involves minor side effects such as upset stomach and headache, but these are usually resolved within the first month of use. Some might experience reduced kidney function and bone density, but these can be managened whilte on PrEP, and are usually resolved after stopping PrEP (Mascolini, 2012).

starting PrEP, patients must undergo HIV, Hepatitis B and renal function testing. Patients then return for follow-ups approximately every 3 months, in which it is recommended that they undergo HIV testing; it is also recommended that they undergo testing for other STIs (chlamydia, gonorrhea, syphilis) as well as renal function testing every 6 months (CDC, 2018)[6]. PrEP users who are at "high risk"[7] are recommended to undergo STI testing every 3 months. Sexually active gay men who are not on PrEP are recommended to undergo all STI testing every 12 months, and in case they are considered "high risk"[8], every 3-6 months (Workowski and Bolan, 2015). Therefore, some PrEP users might be undergoing more frequent STI testing after starting PrEP. Since STIs are asymptomatic in some individuals, more frequent testing could entail increases in reported STI cases without a change in the underlying number of STI cases. We address this issue in Subsection 8.1.

Most insurance plans and state Medicaid programs cover PrEP (CDC, 2020a). For uninsured individuals, PrEP costs $20,000 per year. However, some individuals can get PrEP for free through Gilead's Medication Assistance Program for PrEP, State PrEP Assistance Programs, and through various state, city and private public health organizations that have enthusiastically embraced PrEP and provide it for free. Gilead also covers the copay for PrEP for privately insured users through their Advancing Access Program (NASTAD, 2020). In the survey we conduced, 79% of PrEP users answered "easy" or "moderately easy" to the question: "Once you decided you want to start taking PrEP, how difficult was it to get prescribed and to purchase PrEP?". For 55% of users, the out-of-pocket monthly cost of acquiring PrEP was $0. For the rest, the median out-of-pocket cost was $32.5. Nonetheless, among non-PrEP users who were familiar with PrEP, 27% included "high cost" as one of

[6]Contracting HIV while on PrEP could make the virus resistant to future treatment since PrEP contains only low dosages of the 2 HIV treatment drugs. It is therefore important to make sure that PrEP users remain HIV-negative while on PrEP.

[7]"Conduct STI testing for sexually active persons with signs or symptoms of infection and testing for asymptomatic MSM at high risk for recurrent bacterial STIs (e.g., those with syphilis, gonorrhea, or chlamydia at prior visits or multiple sex partners)" (CDC, 2018)

[8]"More frequent STD testing (i.e., for syphilis, gonorrhea, and chlamydia) at 3–6-month intervals is indicated for MSM, including those with HIV infection if risk behaviors persist or if they or their sexual partners have multiple partners." (Workowski and Bolan, 2015)

the reasons as to why they do not take PrEP, which implies that either some gay men are uninformed of the possibility of getting PrEP at a low cost, or that low-cost PrEP is not available in their area. This suggests some barriers to access that have been noted in the medical literature and in the public arena (Kay and Pinto, 2020; Luthra and Gorman, 2018)

An overwhelming majority of PrEP users are gay men. Gay men are responsible for most HIV infections[9], thus, of the 1.2 million individuals that the CDC estimates to be eligible for PrEP due to high HIV risk, 492,000 are gay men; 15% of the estimated gay population. Of the rest, 468,000 are straight women; 157,000 are straight men, and 115,000 are adults who inject drugs (Siegler et al., 2018). However, these populations had low PrEP take-up. In 2018, we calculate that only 6% of PrEP users were female (AIDSVu, 2019); there is evidence that take-up is low among injection drug users as well (McFarland et al., 2020; Brown, Mullins and Ferguson, 2020). On the other hand, there is abundant evidence that PrEP users are mostly gay men. A quick search in the medical literature, reveals that most PrEP research is done in the context of gay men. In a CDC survey of gay men conducted in 2018 (CDC, 2019b), 25% of gay men were on PrEP; in that survey, also 9 out of 10 gay men were aware of PrEP. Similarly, in the survey that we conducted, 97% of non-PrEP users responded that they were either "very familiar" or "somewhat familiar" with PrEP. In the results section, we show that the share of the population that is gay in a state, is highly correlated with the PrEP rate in that state.

PrEP use grew rapidly in recent years. Figure 1 plots the PrEP rate over time, by sex. As seen in the figure, initial take-up of PrEP, in 2012 and 2013 was slow, but started increasing from 2014 onward. From 2014 to 2018, the male PrEP rate grew 70.7% year to year, reaching 177,765 male users in 2018. PrEP use is likely to continue increasing in the near future. First, cost is likely to decrease due to the recent approval of a generic version of PrEP, which will be introduced later in 2021 (Fitzsimons, 2019). In addition, The U.S. Preventive Services Task Force recently gave PrEP a grade A recommendation, requiring insurers to cover PrEP at no

[9] Gay men accounted for 69% of the 37,968 new HIV diagnoses in the United States in 2018 (HIV.gov, 2020a)

cost to their policyholders (Lovelace, Berkeley Jr., 2019). Second, in the State of the Union Address on February, 2019, the United States president announced the administration's goal to end the HIV epidemic in the United States within 10 years. In December of 2019, the plan, titled "Ending the HIV Epidemic: A Plan for America" was passed in Congress and signed into a law that included an allocation of $267 million for activities as part of the plan in fiscal year 2020 (HIV.gov, 2020b). One of the plan's four pillars (diagnose, treat, *prevent*, respond) entails the distribution of PrEP to individuals in the Unites States who are considered to be of a "significant risk" of contracting HIV. As noted, their number was estimated at 1.2 million in 2017.

PrEP has garnered considerable attention in the medical literature and among public health organizations. Most have embraced PrEP as a main component of a strategy to reduce HIV infections (My PrEP Experience, 2014; Reynolds, 2014). However, a few prominent figures in the HIV/AIDS community, such as Michael Weinstein, head of the AIDS Healthcare Foundation (AHF), the largest nonprofit HIV/AIDS service provider in the nation, have come out against PrEP, highlighting the moral hazard implications of PrEP. He has called PrEP a "party drug" and a "public health disaster in the making", claiming that it will promote sex without condoms, which will increase STIs, and due to lack of adherence, could end up increasing HIV infections as well. The AHF even lobbied the FDA against the approval of PrEP (Spokony, 2011). Still, these views are marginal among public health organizations.

2.2 PrEP and Risky Sexual Behavior

We focus our discussion on sex without condoms, the behavior that has been been the focus of the academic literature on risky sexual behavior. In the decision to have sex without condoms, an individual weighs the benefits versus the expected costs. On one hand, sex without condoms increases sexual pleasure (Randolph et al., 2007; Flood, 2003); some of the reasons mentioned in the literature are increased tactile sensation, decreased physical barriers and less inconvenience. On the other hand, sex without condoms increases the risk of contracting HIV, or other STIs.

Of the objective costs associated with sex without condoms, none is greater than HIV. First, HIV is still prevalent. In 2018, 1.2 million people were living with HIV in the United States, of whom 14% are estimated to not be aware of their status, which makes them highly infectious (HIV.gov, 2020a). Despite a decline in new HIV infections in recent years, in 2018, 30,318 men were newly diagnosed with HIV (CDC, 2019a). Second, HIV is a chronic incurable disease that carries a permanent health burden and social stigma. Although the prospects of HIV-positive individuals have improved since the introduction of the HIV/AIDS cocktail, still, a large number die from the disease each year. In 2018, 11,705 men died of HIV/AIDS in the United States (CDC, 2019a). The other STIs one can contract through sex without condoms are rarely fatal, and are usually curable through a short course of antibiotics. Nonetheless, they impose private and social costs, which people might underestimate, as discussed in the next subsection.

PrEP essentially eliminates the risk of contracting HIV, leaving PrEP users who engage in sex without condoms with only the risk of contracting other STIs that are likely to be considered "minor" relative to HIV. This could push some PrEP users to engage in sex without condoms.

Two other risky sexual behaviors become less costly for PrEP users: increased number of sexual partners and decreased serosorting. The latter is when individuals sort to sexual partners with similar HIV status. As PrEP users are protected from contracting HIV, they might care less about their sexual partner's HIV-status, i.e. decrease serosorting. That could result in higher STIs, since HIV-positive men usually have considerably more STIs (CDC, 2019c). Each one of these behaviors is risky by itself, and more so, if 2 or more of these behaviors are adopted concurrently.

2.3 Background on STIs

STIs are among the most common acute conditions worldwide. The World Health Organization estimated that in 2012, more than a million new STI infections occurred daily[10], calling the rise in STIs a "hidden, silent, dangerous' global epidemic" (Unemo et al., 2017; Walker, 2019). In the United States, STIs have been rising in recent years, reaching an all time high in 2018[11], a situation described by the CDC as a public health crisis that requires "urgent action"" (Bowen et al., 2019). Despite the rise in STIs, it remains a neglected field of clinical and public health research (Unemo et al., 2017; Bowen et al., 2019).

Men who have sex with men (MSM)[12] incur the burden of STIs more than any other group. From reported cases in which the sex of the sexual partner was available, the CDC deduces that around 33%, 61% and 78% of male chlamydia, gonorrhea and syphilis cases were attributable to MSM (Bowen et al., 2019), which implies much higher STI rates in MSM, since their share in the male population is small.

Figure 2 plots the STI rates from 2008 onward, by sex. As seen in the figure, for all 3 STIs, female and male STI rates were trending similarly before 2012, and started diverging after 2012, with male STI rates beginning to increase at a much faster pace from 2014 onward. The divergence is strongest for syphilis and gonorrhea, and to a lesser extent for chlamydia. The fact that male STI rates started diverging from female STI rates after 2012, and at faster pace for those STIs that are mostly attributable to MSM, suggests a shock that altered gay men's' sexual behavior after 2012. In this paper, we argue that the introduction of PrEP is responsible for a large share of the increase in male STIs in recent years.

The rise in STIs generates both private and social costs. Although most STIs are not usually fatal, they result in a substantial burden of disease. Privately, STI infections cause

[10]Chlamydia, gonorrhea, syphilis and Trichonomiasis.

[11]As mentioned in the introduction, 2.4 million cases of chlamydia, gonorrhea and syphilis were reported in 2018, in addition to millions of HPV, herpes and other STI cases, which are not annually tracked by the CDC.

[12]The CDC does not distinguish between gay and bisexual men.

various symptoms[13], can lead to long-term complications such as cancer and infertility, and increase the probability of contracting HIV (CDC, 2016). Those infected also incur the shame and stigma associated with STIs (Foster and Byers, 2008; Mulholland and Van Wersch, 2007), as well as the explicit monetary costs of treatment.

Socially, the increase in STIs imposes a burden on the healthcare system. Owusu-Edusei Jr et al. (2013) estimated the yearly direct medical costs associated with the STIs reported in 2008 to be $15.6 billion[14]. However, the most urgent concern associated with rising STIs is that antibiotic-resistant strains of STIs are becoming more common. Gonorrhea specifically has progressively developed resistance to the antibiotic drugs prescribed to treat it. Today, doctors are down to one last recommended treatment option with the CDC claiming that "little stands between us, and untreatable gonorrhea". Concurrent with the increase in drug resistance, the pipeline for new drugs is shrinking (CDC, 2020c). In its latest antibiotic resistance threats report in 2019, the CDC categorized the bacteria that causes gonorrhea as an "urgent threat", one of only 5 bacteria and fungi put in the highest threat category. Currently, more than half of gonorrhea infections are resistant to at least one of the 2 drugs jointly administered to treat it (CDC, 2020d), and there have been cases of "Super-gonorrhea" reported abroad, in which the infection did not respond to conventional treatment (Gallagher, 2019).

2.4 Related Literature

This is the first paper in the economics literature to examine PrEP in general, and specifically its potential moral hazard consequences. The medical literature has studied PrEP for several years, examining its effectiveness in HIV reduction, along with its effect on risky sexual behavior (condom use, number of sexual partners) and STIs.

[13]These could include among others pain, discharge, bleeding and itching, depending on the site of the infection (Eske, 2018).

[14]Costs associated with HIV infections accounted for 81% of the total cost. Although PrEP has likely decreased HIV cases, the increase in STIs associated with PrEP that is reported in this paper, increased the probability of those infected contracting HIV, in case there are spillovers from PrEP to non-PrEP users.

However, the medical literature on PrEP suffers from one or more of the following shortcomings that our paper improves upon. First, most studies examine PrEP user's STIs and sexual behavior before and after initiating PrEP, without having a control group (Montaño et al., 2019; Traeger et al., 2019; Nguyen et al., 2018; Beymer et al., 2018). In a recent meta-analysis of 17 papers on the effect of PrEP on sexual behavior and STIs (Traeger et al., 2018), only 2 had some sort of a control group. Having no control group ignores changing sexual norms. If for example, risky sexual behavior is increasing over time, these studies would overestimate the effect of PrEP. In our specifications,the effect of PrEP is identified not only over time within an observation unit, but also compared to other units that we show are suitable counterfactuals.

Second, studies are done locally, on individuals who sign up to participate. Since the studies are usually conducted in LGBT and public health clinics, participants are more likely be high-risk, and therefore, might be different than PrEP users who get their prescription from their general practitioner for example (Oldenburg et al., 2018; Volk et al., 2015; Montano et al., 2017). This also means small sample sizes; in Traeger et al. (2018), the average sample size across the 17 studies is 392 with a median of 280. Overall, for these reasons, these studies might represent a local effect, but might lack external validity. Our analysis is nationwide, encompassing all PrEP users and uses all reported STI diagnoses. Therefore, our estimated effect is identified from both high-risk PrEP users, but also low-risk PrEP users, who might react differently to PrEP; and, from PrEP users across the country, who might differ from one another.

Moreover, enrolling someone into a study has been shown to potentially alter his behavior, a phenomena known as the Hawthorne effect (Adair, 1984). Therefore, examining the effect of PrEP on sexual behavior and STIs using participants who signed up for these studies, could potentially bias the estimates. Our analysis uses observational data that overcomes this shortcoming.

Third, since these studies only examine PrEP users, or PrEP users plus a small group of non-PrEP users, they are unlikely to account for any spillovers of STIs from PrEP users having sexual encounters with non-PrEP users. Since we study aggregate STI diagnoses, our specification will pick up these spillovers.

The lack of external validity, and potentially internal validity as well, is why the medical literature reports mixed results on the effect of PrEP on sexual behavior and STIs. In a recent meta-analysis (Traeger et al., 2018), out of 10 papers that reported results for STIs, 3 reported significant decreases in at least one STI following PrEP initiation, 7 reported significant increases in at least one STI following PrEP initiation, while in some of these studies, the results were insignificant. Results for sexual behavior are also mixed.

More broadly, this paper adds to the medical literature that discusses potential reasons for the recent rise in STIs. Some of the reasons that have been suggested are - cuts to STI prevention programs at the state and local level, drug use, and decreased condom use among the young people and MSM (without explaining the cause for the decline) (Bowen et al., 2019); lower rate of marriages concomitant with increasing numbers of lifetime sex partners, delayed childbirth and enhanced population movement (Carmona-Gutierrez, Kainz and Madeo, 2016); decline in the attention to some of more "minor" STIs in the shadow of HIV (Clement and Hicks, 2016) and the opioid crisis (Tanne, 2018). This paper suggests that PrEP is responsible for a change in men's sexual behavior that is responsible for a large share of increases in male STIs in recent years.

This paper 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 that treats overdoses led to more opioid related emergency room visits and opioid related crime with no decrease in opioid deaths (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 incidences during the same period. Chan, Hamilton and Papageorge (2015) provide a dynamic model of this behavioral response. They show that both HIV-negative and HIV-positive men increase their risky sexual behavior when the cost of contracting HIV falls.

We believe that the moral hazard story we propose in this paper is more striking. First, PrEP is easily accessible and usually inexpensive. Second, it confers a substantial reduction in risk, by essentially eliminating the the risk of contracting HIV. Lastly, the reduction in risk is known and clear to users.

3 Identification Strategy

We are interested in estimating the effect of PrEP on STIs. We begin by showing that PrEP take-up is associated with an increase in STIs. Specifically, we exploit the temporal and spatial variation in PrEP adoption, by employing the following difference-in-difference specification:

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

Where s indexes state and t indexes the year. STI_{st} is the STI rate (chlamydia, gonorrhea or syphilis) per 100K; $PrEP_{st}$ is the PrEP rate per 100K. We include state fixed effects, μ_s to control for time-invariant differences across states that might affect STI rates, such as differences in sexual norms; and year fixed effects, τ_t, to control for nationwide factors that affect STI rates over time, such as common health shocks and changes in STI 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 STI and the PrEP rates are per 100K population, the coefficient of interest, β, measures the change in STI 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 a state over time - and relative to the corresponding changes in other states with different PrEP rates. We run the regression separately for each STI 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, STIs in states with different PrEP rates, would have evolved in parallel. Although untestable, we provide evidence that prior to the introduction of PrEP, STI 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 STI 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.

We then add a third difference, by sex, and estimate a triple-difference specification. As detailed in Section 2.1, females had low PrEP take-up; this, combined with the similar evolution of female and male STI rates prior to the introduction of PrEP, as illustrated in Figure 7, suggest that female STI trends are a suitable control group for male STI trends in a triple-difference specification. This difference controls for time variant factors that affect

STI rates of both male and female at the state-year level. For example, if public health campaigns that affected both male and female STIs were implemented in California in 2010, the difference by sex would "deduct" the reductions in female STI from those of male STI, essentially controlling for those factors. The triple-difference equation we estimate is the following:

$$STI_{stg} = \beta_1 PrEP_{st} + \beta_2 Male_g + \beta_3 Male_g \cdot PrEP_{st} + \gamma X_{st} + \mu_{sg} + \tau_{tg} + \epsilon_{stg} \tag{2}$$

Where all the variables are as defined in (1) and $Male_g$ is an indicator for male observations. Also, we now control for state×gender fixed effects, μ_{sg}, as well as time×gender fixed effects, τ_{tg}. The former control for time-invariant differences across states more flexibly, while the latter control for common time shocks more flexibly, as we allow them to vary by gender as well. The coefficient of interest β_3, identifies the the differential effect of one additional PrEP user on male STI incidences compared to females.

The identifying assumption is that absent of PrEP, the differences between male and female STIs in states with different PrEP rates, would have evolved in parallel. As mentioned above, the results of the triple-difference event study design, detailed in Section 5.2, would provide suggestive evidence of parallel pre-trends.

Main Specification: PrEP take-up could potentially be correlated with factors that also affect STIs, therefore, in order to estimate the casual effect of PrEP on STIs, we proxy for PrEP use in a given state using a measure of exposure to treatment that has been predetermined before PrEP was introduced; that is the share of the population that is gay in a state in 2000. Since PrEP was mostly targeted and adopted by gay men, this measure is highly predictive of PrEP use, as our "first stage" will show. Our identification then exploits the variation across states in the gay population to compare states that were differentially exposed to the treatment; states that had larger gay populations were more "exposed" to PrEP than states that had smaller gay populations. This identification is related to the identification used in Bleakley (2007), Alpert, Powell and Pacula (2018), and Beheshti (2019) to examine treatments that were were rolled out at the same time throughout the country using pre-treatment variation.

We begin by estimating the following equation:

$$STI_{st} = \sum_{\substack{t=2008 \\ t\neq 2011}}^{2018} \beta_t \mathbb{1}(Year = t) * MaleSSP_s + \gamma X_{st} + \mu_s + \tau_t + \epsilon_{st} \tag{3}$$

Where the measure we use for the share of the population that is gay in a state, $MaleSSP_s$, is the share of partnerships that are male same-sex in state s from the 2000 census; the construction of the variable is detailed in Section 4.1. $MaleSSP_s$is interacted with year indicators, with 2011, the year prior to the introduction of PrEP, omitted. The other variables are as previously described for equation (1). The coefficients of interest, the β_ts are interpreted as the additional cases per 100K of a STI (i.e. the STI rate) in year t, compared to 2011, that occur with a 1 percentage point increase in partnerships that are male same-sex. For context as to the size of the treatment, the difference in the male same-sex partnerships between North Dakota and New York is about 0.5 percentage points., so $\beta_t/2$ would give the predicted effect between North Dakota and New York. 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 STIs in comparison to the baseline year, and relative to the difference in other states that had larger or smaller gay population. We run the regression separately for each STI 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 specification (1), where the share of the population that is gay substitutes the PrEP rate. The event studies that are presented in the results would provide suggestive evidence of parallel pre-trends.

Following the same logic detailed previously, we then add a third difference, by gender, and estimate the following triple-difference specification:

$$\begin{aligned}STI_{stg} =&\beta_1 \cdot Male_g + \beta_2 \cdot MaleSSP_s \cdot Male_g + \sum_{\substack{t=2008\\t\neq 2011}}^{2018} (\beta_{3t}\mathbb{1}(Year = t) \cdot MaleSSP_s)+ \\ &\sum_{\substack{t=2008\\t\neq 2011}}^{2018} (\beta_{4t}\mathbb{1}(Year = t) \cdot MaleSSP_s \cdot Male_g) + \gamma X_{st} + \mu_{sg} + \tau_{tg} + \epsilon_{stg}\end{aligned} \tag{4}$$

where all the variables are as defined in (3) and $Male_g$ is an indicator for male observations. As detailed for specification (2), we now control for state×gender fixed effects, μ_{sg}, as well as time×gender fixed effects, τ_{tg}. The coefficients of interest, the β_{4t}s, the coefficients on the triple interaction term, are interpreted as the additional cases per 100K of male STIs (i.e. the STI rate) compared to female STIs in year t, compared to the baseline year, that occur with a 1 percentage point increase in partnerships that are male same-sex[15].

The identifying assumption is similar to the one detailed for specification (2), where the share of the population that is gay substitutes the PrEP rate; the event studies detailed below will provide suggestive evidence of parallel pre-trends.

4 Data and Identifying Variation

4.1 Data

STI: Data on HIV, chlamydia, gonorrhea, syphilis[16] come from the CDC NCHHSTP[17] database (CDC, 2019a). The database contains the number of diagnosed cases of each STI

[15]All lower-order terms of the triple interaction term are included in the specification, but some are perfectly co-linear with the fixed effects, and are therefore not written.

[16]The CDC reports 3 types of syphilis cases - primary and secondary, latent, and congenital. When we refer to syphilis, we refer to the primary and secondary syphilis. These are the first two stages after an infection; they usually manifest in various symptoms including a rash that is worst 3-4 months after infection. It is the most common type of syphilis. If the person does not receive treatment, the disease progresses to it latent stage. This stage may last up to 25 years, in which the person is asymptomatic. Therefore, it is not reflective of contemporaneous sexual behavior trends. Congenital syphilis occurs when a mother with syphilis passes the infection on to her baby during pregnancy; not a relevant mode of transmission for this study.

[17]National Center for HIV/AIDS, Viral Hepatitis, STI, and TB Prevention

at the state/county, year, sex and age group level; it also contains the population of each respective group. Using the number of cases and the population we construct our outcome variable – the STI rate per 100K population. Our main sample includes male and female (separately) aged 13 and up for the years 2008-2018. Data is available for all of the 50 states and the District of Columbia. Additional analyses use different age groups, and county level data.

Two points are important to mention with respect to the STI data. First, although we are interested in STIs incurred by gay men, there is no comprehensive data on STI diagnoses by sexual orientation. Nonetheless, as mentioned in Subsection 2.2, the majority of male gonorrhea and syphilis cases are attributable to MSM, as well as about a third of male chlamydia cases. We discuss this further in the results section. Second, certain STIs might by asymptomatic in some men. However, since the overwhelming majority of gay men routinely test for STIs[18], asymptomatic STIs are likely to be detected close to infection. Therefore, gay men's STI diagnoses are likely to be indicative of contemporaneous sexual behavior.

PrEP: Data on PrEP use come from AIDSVu (AIDSVu, 2019), an online source of HIV related data. AIDSVu reports the number of PrEP users and the rates per 100K at the state/county, year, sex and age group level. The AIDSVu PrEP data was constructed 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, 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

[18]For example, in a 2017 CDC survey of gay men, 77% reported that they had been tested for HIV in the 12 months before interview (CDC, 2019c).

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.

Male same-sex partnerships: For our main specification we proxy for PrEP use in a given state using a measure of the share of the population that is gay in that state. There are several surveys from which one can estimate the gay population (e.g. The General Social Survey, The National Survey of Family Growth, etc.). Since the gay population is a small[19], these small sample surveys are likely to produce a noisy measure of its size at the state/county level. We therefore utilize the largest government administered survey, the census, to construct an estimate of the share of the population that is gay in each state; we specifically use the 2000 census (Ruggles et al., 2020a). As part of the census, household members are required to specify their relationship to the head of the household. First, we identify households with 2 adults whose relationship is stated as either partnered or married. Then, we define a household as either a male same-sex household, in case the 2 adults were both male, or other, in all other cases. Then, for each state, we divide the number of male same-sex partnerships by the number of total partnerships (male or other) to attain the share of partnerships that are male same-sex in that state in 2000, our measure of the share of the population that is gay in that state. Although this measure captures a specific subgroup of gay men, those in committed relationships who are therefore older, the gay-friendly locations where these gay men tend to reside, are likely to also be the locations where younger gay men tend to reside. This is substantiated by examining the Gallup estimates of the share of the broad population (i.e. not just those in relationships) that identifies as gay, lesbian,

[19] These surveys produce estimates of the share of men who identify as gay that range from 1.4% to 3.9%

bisexual or transgender in each state (Gates and Newport, 2013); these estimates are highly correlated ($corr = 0.82$) with our estimates.

Sexual behavior: Data on sexual behavior come from 2 government surveys as well as a self-administered survey. The first survey is the NHANES - the National Health and Nutrition Examination Survey (CDC, 2019b). The survey is conducted by the CDC with the objective of assessing the health and nutritional status of adults and children and includes a sexual behavior module. It combines interviews with physical examinations. We use data from 5 rounds (2007/8 - 2015/16)[20]. Each round included ≈10,000 participants, half of which were male. Of those, about a third responded that they either think of themselves as gay (≈2%) or straight to the sexual orientation question[21]. The rest either responded that they don't know, refused to respond, identified as bisexual, or had missing values. In our analysis we compare the sexual behavior of those who think of themselves as gay with those who think of themselves as straight[22]. Although the survey examines a nationally representative sample, given the small size of the gay men sample, it is not necessarily representative of the gay men population. Therefore, it will be indicative of general trends, less so of specific numbers.

The second survey is the NHBS - National HIV Behavioral Surveillance survey (CDC, 2019c). The survey is conducted by the CDC with the objective of monitoring the behavior of individuals who are at high risk for HIV infection (gay men, injection drug users, etc.). For the gay men sample, the CDC samples men who identify as gay in gay "spots" (i.e. restaurants, bars, other venues that gay men tend to frequent) in 20-23 cities with high HIV prevalence. We use data from 4 rounds (2008 - 2017). We present the results for the sample of HIV-negative gay men (≈8,000 in each round). Respondents are interviewed on location at these venues, and the interview includes various questions relating to sexual behavior. Given how

[20] The sexual behavior module is not publicly available for later rounds.

[21] "Do you think of yourself as..."

[22] It is unclear whether bisexual men took-up PrEP, we therefore focus on gay men only and compare them to straight men.

participants are recruited, the survey isn't necessarily representative of all gay men, but of a subset of more "open" gay men.

The third survey was administered by the authors of this paper. We contracted Qualtrics to provide a high impact sample of 500 men who identify as gay, are 25-44 year old, were mostly single in 2019, and had at least 2 sexual partners in 2019. half of the respondents took PrEP, while the other half did not. The survey was conducted online, and administered during October-November, 2020. An online appendix containes the full survey.

HIV testing: Data on HIV testing, our proxy for STI testing come from the BRFSS - Behavioral Risk Factor Surveillance System (CDC, 2019c). 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 across the country. Participants were asked the month and year of their last HIV Test. In 2018 for example, the variable was available for 21.2% of participants[23]. 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 rate per 100K of male participants aged 18-45 in each state that had HIV testing in the 6 months preceding the interview for the years 2008-2018.

Controls: Additional demographic and economic covariates at the state/county and year level for 2008-2018 were derived from the yearly American Community Surveys (Ruggles et al., 2020) as well as from the University of Kentucky Center for Poverty Research National Welfare Data (University of Kentucky Center for Poverty Research, 2020). These include the

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

racial makeup of the state, the natural logarithm of state GDP, the share of the population participating in the Supplemental Nutritional Assistance Program, the unemployment rate, the poverty rate, and the state minimum wage.

4.2 Descriptive Statistics

Table 1 provides summary statistics for states that had the lowest and highest PrEP take-up. States were ranked according to their male PrEP rate in 2018. States labeled as “low” are states that were in the lowest quartile of PrEP take-up, whereas states labeled as “high” are states that were in the highest quartile of PrEP take-up. Statistics are provided for the period before (2008-2011) and after (2012-2018) the introduction of PrEP. All summary statistics are weighted by population.

First, the table details the two treatment variables - male PrEP rate per 100K and the share of male same-sex partnerships. In the period after the introduction of PrEP, high PrEP states had a male PrEP rate that is more than three times that of low PrEP states (65.6 versus 19.2 users) and had a share of male same-sex partnerships that is 63% higher (0.67% versus 0.41%). Second, the table provides summary statistics on the dependent variables. Before the introduction of PrEP, high and low PrEP states had similar male chlamydia and gonorrhea rates; 276 versus 287 for male chlamydia and 115 versus 112 for male gonorrhea in high and low PrEP states, respectively. After the introduction of PrEP, the rates in high and low PrEP states began diverging. While the rates increased for both, the increase in high PrEP states was higher; the male chlamydia rate increased by $\approx$ 37% in high PrEP states, while it only increased by $\approx$ 26% in low PrEP states. The male gonorrhea rate increased by $\approx$ 73% in high PrEP states, while it only increased by $\approx$ 40% in low PrEP states. With respect to male syphilis and male HIV, high PrEP states had higher rates of both before the introduction of PrEP (Male syphilis: 11.8 versus 5.1 in high and low PrEP states, respectively; male HIV: 13.4 versus 26.6 in high and low PrEP states, respectively). With respect to socioeconomic measures, which we average over the whole period, high PrEP states were richer, had a lower share of white persons and a higher share of Hispanic and Black persons.

4.3 Identifying Variation

In specification (1) and (2), we are interested in examining whether PrEP take-up coincides with increases in STIs. Identifying the effect stems from the variation in PrEP take-up within a state over time, as well as the differential take-up of PrEP across states. We illustrate this identifying variation in this section.

Figure 1 plots the number of PrEP users per 100K population (PrEP rate), by sex. In the first 2 years after its introduction, in 2012 and 2013, PrEP take-up was rather low, but from 2014 onward, PrEP take-up grew rapidly. By 2018, there were 177,436 male users and 11,931 female users; these correspond to a PrEP rate of 131 for male and 8 for female. While the female PrEP rate remained constant over time, the male PrEP rate grew considerably. As mentioned in Section 2.1, the fast adoption of PrEP is unlikely to stop.

Although PrEP take-up grew over time, the growth was different across states. Figure 3, the male PrEP rate across states in 2018, illustrates this spatial variation; the darker the shade, the higher the PrEP rate. While in some states, the PrEP rate as high as 935, in others, it was as low as 29. States with high PrEP rates are those in the West Coast, in the Northeast, some in the Midwest, as well as Florida and Texas. As we expect, since most PrEP users are gay men, the spatial variation in PrEP take-up is highly correlated with the spatial distribution of the the gay population, as illustrated in Figure 34, discussed below. When controlling for the share of the population that is gay, other factors have been found to be correlated with PrEP take-up, among them income, race (Ya-lin et al., 2018), insurance status (Patel et al., 2017) and whether a state is a Medicaid expansion state (Karletsos and Stoecker, 2020); these could affect STIs as well. As detailed in Section 3, the triple-difference specification attempts to control for these; we control for time-invariant differences across states, shocks that affect all states similarly and shocks that affect both male and female

STIs in specific states. Moreover, we include several socio-demographic controls for factors that might change over time.

In our main specification (equations (3) and (4)) we exploit the variation across states in the gay population. Figure 4, the share of partnerships that are male same-sex across states in 2000, illustrates this spatial variation; the darker the shade, the the larger the share of partnerships that male same-sex. While in some states, this measure was as high as 4.05%, in others, it was as low as 0.23%. The literature has offered a few reasons as to why certain areas have larger gay populations. Black et al. (2002) for example, claim that gay men disproportionately sort into high-amenity locations. Since it is costly for them to have children, their lifetime demand for housing and children's' education is lower, freeing up resources to be allocated for local amenities, while Murray (1996) emphasises the importance of an area's prevailing social and political views.

States with larger gay populations differ from states with smaller gay population, both geographically, as seen in Figure 4, and across various socio-economic characteristics, as detailed in Subsection 4.2. Given our differences-in-difference design, level differences between these states are not required for the identification of the causal effect. The casual identification relies on the assumption that the STI trends across these states would have been similar absent of PrEP. We provide suggestive evidence of that in the next subsection, as well as in the event studies in Section 5.2.

4.4 Descriptive Evidence on the Evolution of STIs

We plot the evolution of male STI rates for states with different PrEP take-up. We do so by ranking states according to their male PrEP rate in 2018 and dividing them into quartiles pertaining to their PrEP take-up. We then plot the evolution of average male STI rates for each quartile of states for the 3 STIs separately. Quartile 1 is the quartile of states that had the highest PrEP take-up, whereas quartile 4 is the quartile of states that had the lowest PrEP take-up. This is illustrated in Figure 5.

As the figure shows, male STI rates were trending upwards in all states during the past few years, and at a faster pace than previous years, to reach record highs each year. In just 6 years, from 2012 to 2018, male chlamydia, gonorrhea and syphilis rates have increased on average by approximately 46%, 102% and 103%, respectively, compelling the CDC to call for urgent action (Bowen et al., 2019).

Specifically, the figure shows that the states that experienced the fastest increases in recent years in male STIs were states in the first quartile of PrEP take-up. Although the STI rates in these states were trending similarly to the STI rates in states with lower PrEP take-up before the introduction of PrEP, after its introduction, STI rates started increasing more rapidly in states with the higher PrEP take-up. Whereas, in 2011, just before PrEP was introduced, male chlamydia rates were somewhat similar across states, by 2018, states with high PrEP take-up had rates that were higher by approximately 22% from the rates in states with lower PrEP take-up. Similarly, in 2011, male gonorrhea rates in states with high PrEP take-up were similar to those in states with lower PrEP take-up, but by 2018, they were approximately 20% higher. With respect to male syphilis, rates began increasing at a faster pace in states with high PrEP take-up 2 years prior to the introduction of PrEP, but increased at a faster rate after. The triple-difference specification will be able to somewhat control for these differential pre-trends in male syphilis rates .

5 Results

5.1 PrEP Rate Specification

Table 2 reports the results from estimating the specifications in which 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 per 100K. For each STI, sub-column (1) details the estimates from the difference-in-difference equation (1) run 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 year×gender and state×gender fixed effects and are population weighted. Standard errors are clustered at the state level.

Starting with sub-column (1), the table reports the coefficient on the variable of interest – PrEP rate. Results are statistically significant at the $\alpha = 0.01$ level for chlamydia and gonorrhea, and at the $\alpha = 0.05$ level for syphilis. It is estimated that each additional male user of PrEP is associated with 0.371, 0.280 and 0.014 additional male chlamydia, gonorrhea and syphilis cases.

Column (2b) details the estimates from our preferred specification – triple-difference equation (2) with controls. We report the estimates for the main effect coefficients and the the coefficient of interest, of the interaction term $Male * PrEP$.

The coefficient on PrEP, which identifies the effect of the PrEP rate on female, is negative and statistically significant for gonorrhea and syphilis, suggesting that female STI rates were higher in states with high PrEP take-up. This does not imply spillovers from men on PrEP to women (as this would manifest in positive coefficient), nor can it be interpreted as causal given that the female PrEP take-up was very low. If state-specific linear time trends are included (column (2c)), the coefficient becomes statistically insignificant for the 3 STIs, suggesting that differential pre-trends were responsible for the aforementioned estimated effect. The coefficient on Male is negative for chlamydia and gonorrhea, indicating that on average men had lower rates of these STIs during the period. With respect to syphilis, it is "trapped" within the gay community, which manifests in much higher male syphilis rates than female.

The coefficient on the interaction term, which identifies the differential effect of the male PrEP rate on men compared to women is positive and statistically significant at the $\alpha = 0.01$ level for the 3 STIs. We estimate that each additional male PrEP user is associated with 0.512, 0.597 and 0.032 additional chlamydia, gonorrhea and syphilis cases, respectively.

The difference-in-difference estimates understate the effect of PrEP relative to the triple-difference since the pre-period estimates for STIs for both male and female are slightly positive.

Column (2a) details the estimates of specification (2) without controls. Comparing columns (2a) and (2b) reveals that the coefficient of interest barely changes with the addition of controls. This stability suggests that any compositional changes across states did not confound our results.

Column (2c) details the estimates from the addition of state-specific linear time trends. Again, these barely change the coefficient of interest, suggesting that male STI rates did not trend differently across states with different PrEP take-up.

5.2 Gay Population Specification

Figures 6-9 plot the event-study estimates from our main specification, where the share of partnerships that are male same-sex is the treatment variable (equations (3) and (4)). The magnitudes of the estimates are discussed for the triple-difference specification, although we present the results of the difference-in-difference specification as well, as it helps to understand the factors that are controlled for when estimating the triple-difference specification.

Figure 5 and 6 plot the yearl coefficients on MaleSSP from difference-in-difference equation (3) where separate regressions are estimated for male and female and for chlamydia, gonorrhea, and syphilis rates, as well as the male PrEP rate; the regressions include the controls mentioned in the Data Section. First, we demonstrate that our proxy of PrEP take-up is indeed predictive; i.e. that states with larger gay populations, are also states where PrEP take-up was higher. We do so by estimating equation (3) with the dependent variable being the male PrEP rate (our "first stage"), for male and female separately. The results are plotted in Figure 5. The positive coefficients for male (in blue) in the years after the introduction of PrEP indeed show that the larger the gay population, the larger the PrEP take-up. The increase in the coefficient over the years corresponds to the pattern of increase in male PrEP users over time (see Figure 1). The coefficients for female (in red) are small in magnitudes and mostly statistically insignificant.

Figure 7 plots the results from estimating equation (3) with the dependent variable being the 3 STIs. It shows that male and female STIs were trending slightly downward in states with larger gay population before the introduction of PrEP. For chlamydia these pre-trends are statistically significant, whereas for gonorrhea and syphilis they are not. These could be stemming from various public health efforts that were concentrated in states with larger gay populations, or from differential changes in sexual norms in these states. After the introduction of PrEP, the coefficients for male start increasing (with the exception of syphilis) in a pattern that is consistent with the rollout of PrEP (see Figure 1); i.e. PrEP take-up was slow in 2012, 2013 and started increasing from 2014 onward. Also, 2014 exclusively seem to be an anomaly, as both male and female STI rates drop considerably from their trend. This could be a data measurement issue. As it seems to affect both male and female, it will be controlled for in our triple-difference specification. For syphilis, the coefficients start increasing later, and the confidence intervals are larger, consistent with syphilis being a much rarer disease than chlamydia or gonorrhea.

Next, we turn to our main specification. Figures 8 and 9 plot the yearl coefficients on MaleSSP*Male from triple-difference equation (4) where separate regressions are estimated for chlamydia, gonorrhea, and syphilis, 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 blue (male) and red (female) estimates in figures 6 and 7, where we are "deducting" female' STI rates from male STI rates. Table 3 details the corresponding estimates.

As before, we first estimate equation (4) with the dependent variable being the male PrEP rate ("first stage"). The results (Figure 8) mirror the difference-in-difference results that were explained previously (Figure 6). By 2018, a 1 percentage point increase in partnerships that are male same-sex is associated with an increase of 221 in the male PrEP rate, compared to 2011.

Figure 7 plots the results from estimating equation (4) with the dependent variable being the 3 STIs. It shows that there are no longer statistically significant pre-trends, with the exception of syphilis, for which the coefficient for the year 2010 is statistically significant, but small in magnitude. 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). By 2018, a 1 percentage point increase in partnerships that are male same-sex, is associated with an increase of 119, 126 and 10 in the male chlamydia, gonorrhea, and syphilis rates, compared to 2011.

For interpretability, we scale these estimates by PrEP take-up. We find that 1 additional male PrEP user increases male chlamydia, gonorrhea and syphilis cases by 0.66, 0.51 and 0.04, respectively. These estimates are slightly higher than the OLS estimates for chlamydia and syphilis, and slightly lower than the OLS estimates for gonorrhea. The estimates are within 1 standard error of each other, suggesting that the endogeneity in PrEP take-up is not a major concern.

We then multiply the effect of each additional PrEP user by the average number of PrEP users in the post-period (2012-2018) and divide by the pre-period (2008-2011) STI rate and find that on average, over the post-period, PrEP increased chlamydia, gonorrhea and syphilis rates by 11.0%, 20.1% and 19.5%, respectively. The magnitude of the effect for chlamydia versus gonorrhea and syphilis is consistent with the fact that the majority of male gonorrhea and syphilis cases, from which we identify the effect, are attributable to our "treated group", MSM, whereas only about a third of male chlamydia cases are attributable to MSM. Indeed the magnitude of the effect on male chlamydia rates is about half of the effect on male gonorrhea and syphilis rates.

The estimated effect of PrEP on STIs is large, but it is important to remember that it includes both the effect on PrEP users themselves, as they increase their engagement in risky sexual behavior, but also the spillover effects onto non-PrEP users, with whom PrEP users might be in sexual contact. In addition, if an increasing number of PrEP users engage in risky sexual behavior, this could alter sexual norms in the gay community, making risky sexual behavior more socially acceptable, thus amplifying the effect of PrEP. Also, an individual can contract STI more than once, so it is not necessarily the case that every 1 out of 2 PrEP users will contract gonorrhea yearly, but it could be that 1 out of 4 PrEP users, will contract gonorrhea twice in a year, so the effect could be concentrated among those high-risk PrEP users.

5.3 Counterfactual Distribution of STIs

We conduct a simple counterfactual analysis to examine how STIs would evolve in a counterfactual world without PrEP. We subtract the additional STI cases caused by PrEP, as estimated from our specifications, from the actual aggregate yearly male STI cases. 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 assumption. However, we believe that this analysis can still be instructive. We use both the estimates from specification (2), and the scaled estimates from specification (4). We plot the counterfactual male STI rates distributions using these two estimates, as well as the actual male STI rates distributions of each of the STIs in Figure 10. In Table 7 we detail the actual, and the counterfactual number of cases for 2018.

Using the scaled estimates from our main specification (4), our counterfactual estimates suggest that PrEP was responsible for 204,019 male STI cases in 2018 and that male chlamydia, gonorrhea and syphilis rates would have been 17.9%, 25.6% and 25.6% lower in 2018, in the absence of PrEP. These estimates suggest that a large share of the increase in STIs in recent years is attributable to the rollout of PrEP.

6 Mechanisms

In the previous section we have shown that PrEP use differentially increased male STI rates. This suggests an increase in risky sexual behavior among gay men specifically. In this section we provide suggestive evidence of that, using 2 government surveys as well as a self-administered survey. Each survey enables us to examine a different aspect of gay mens' sexual behavior trends. Information on the three surveys was presented in Section 4.1.

NHANES: as mentioned in Section 4.1, we compare the responses of men who identified as gay and men who identified as straight. Due to the small sample size of men who identify as gay, we do not condition our sample on any characteristic. The results should therefore be seen as conveying general trends among the two group of men, rather than accurately representing the accurate share who of those engaged in a specific sexual behavior. We present results from 2 questions. First, participants were asked: "In the past 12 months, about how often have you had vaginal or anal sex without using a condom?" Figure 11 plots the share of men who responded "never", by sexual orientation. As seen in the figure, the share of gay men who never used a condom in the preceding 12 months was steady until the 2011/2012 survey round, and then increased considerably in the 2013/14 survey round, and increased further in the 2015/2016 survey round. The share of straight men who never used a condom in the preceding 12 months was rather steady throughout the 5 survey rounds.

In order to estimate the change in the condom use of gay men compared to straight men, in the period after PrEP compared to the period before PrEP, we estimate the following equation, separately for each one of the responses: "never", "less than half", "about half", "more than half", or "always used":

$$Y_{it} = \beta_1 \cdot Gay_i + \beta_2 \cdot Post_t + \beta_3 \cdot Gay_i \cdot Post_t + \gamma X_{it} + \epsilon_{it} \quad (5)$$

Where, Y_{it} is a binary variable that takes the value 1 in case the response of a participant was one of the aforementioned responses and 0 otherwise; Gay_i takes the value 1 in case the respondent identified as gay, and 0 in case he identified as straight; $Post_t$ takes the value 1 for survey rounds 2013/14 and 2015/16 and 0 for survey rounds 2007/8 and 2009/10[24]. We control for respondents' education, marital status, age and income. We only include participants who gave one of the aforementioned answers to this question. The coefficient of interest is the coefficient on the interaction term, β_3; its interpretation is the differential change in the share of gay men (compared to straight men) who answered a specific response after PrEP (compared to before PrEP).

Results are presented in Table 4. The share of gay men (compared to straight men) who responded that they "never used a condom" in the preceding 12 months increased by 24 percentage points in the period after PrEP (compared to the period before PrEP), a 100% increase from the pre-period ($p < 0.05$). With respect to the other responses, the coefficients of interest are negative although they are only statistically significant for "more than half", which suggests that after PrEP, the whole distribution of condom use shifted towards less condom use.

Second, gay participants were asked: "In the past 12 months, with how many men have you had anal or oral sex?", while straight men were asked "In the past 12 months, with how many women have you had any kind of sex? Figure 12 (left panel) plots the share of men whose response was 1 or higher, by sexual orientation; i.e. it plots that share of men who had sex in the preceding 12 months. Figure 12 (right panel) plots the median number of sexual partners in the preceding 12 months, by sexual orientation, conditional on having at least 1 sexual partner.

As the figures reveal, it does not seem that the decision to have sex altogether had changed throughout the period for either gay or straight men, nor was there a differential change in the median number of sexual partners among gay men (compared to straight men).

[24] We do not include responses from the 2011/12 survey round since 2012 is partially treated

NHBS: as mentioned in Section 4.1, we present results for the sample of HIV-negative gay men. Unfortunately, the individual level data is not publicly available, as it is with the NHANES, therefore we can only present measures that we could calculate from the different tabulations that that the CDC reports (CDC, 2019c). It is important to note that by the 2017 survey round, ≈25% of HIV-negative gay men in the survey reported using PrEP, which puts the large increases in sex without condoms exhibited in the results in perspective.

First, a slightly different variation on the condom use question from the NHANES. The survey reports the share of gay men who had anal sex without condoms with at least 1 partner in the preceding 12 months, by type of partner (main or casual). Therefore, comparing it to the previous survey question, it should include gay men who answered any of the responses except "always used". Results are plotted in Figure 13. As seen in the figure, the share who had anal sex without condoms with a casual partner has not changed between 2008 and 2011, but increased in 2014 and increased further in 2017. From 2011, right before the introduction of PrEP to 2017, the share increased from 45.6% to 66.5%, a 20.9 percentage point increase (45.8% increase). Gay men who have sex with casual partners are the most likely to take-up PrEP. Nonetheless, gay men who have sex with a main partner might also use PrEP. First, some gay men have open relationships, so are uncertain about their main partner's HIV status since he is engaged in other sexual encounters; even if relationships are exclusive, it could take time until a partner's trust is gained so that one can be certain of the partner's HIV status. Others might use PrEP as an added layer of protection in general, or specifically if one thinks his partner might cheat on him. Therefore, the increase in the share of gay men who have sex without condoms with a main partner could also be partially the result of PrEP use. For main partner, we see an increase in sex without condoms, but a relatively smaller increase compared to casual partner, and one that starts earlier.

Another form of risky sexual behavior is sex without condoms with an HIV-discordant partner. HIV-discordant partner means a partner whose HIV status is different than ones own status. In the case of HIV-negative individuals, HIV-discordant partner means either an HIV-positive partner or a partner of unknown HIV status. Although PrEP users are protected from contracting HIV, having sex with an HIV-discordant partner is risky since individuals of unknown HIV status, or HIV-positive status are more likely to have STIs [25]. Figure 14 (left panel) plots the share who had anal sex without condoms with an HIV-discordant partner in their last sexual encounter. As seen in figure, the share hasn't changed between 2008 and 2011, and then increased in 2014, and further increased in 2017, consistent with increase in risky sexual behavior after the introduction of PrEP. From 2011 to 2017, the share increased by 4.2 percentage points, a 35% increase. Another outcome of interest from the survey is the share of who were diagnosed with at least 1 STI in the preceding 12 months, as plotted in Figure 14 (left panel). As seen in the figure, the share was declining from 2008 to 2011, and increased in 2014, and further increased in 2017, consistent with our main results. From 2011 to 2017, the share increased by 8.9 percentage points, a 50.5% increase.

Self-Administered Survey Our main specification exploits cross-state variation in the gay population. If the gay community as a whole experienced changing sexual behavior norms, specifically risky sex practices becoming more acceptable, our main specification could pick up on that; this would bias our coefficient upwards. This is unlikely, since our main results show that the differential change in gay men's risky sexual behavior occurred only after 2012, in a pattern that is consistent with the rollout of PrEP. Nonetheless, we would like to show that the change in risky sexual behavior among gay men after the introduction of PrEP that our main specification, as well as the 2 previous surveys reveal, occurred mainly among PrEP users. To do so, we conducted an online survey with a high impact sample of gay men, as detailed in Section 4.1.

Table 5 details the survey participants' characteristics. First, we compare the characteristics of PrEP users in our survey to those of the general population of PrEP users as detailed

[25] For example, in the NHBS, 18% of HIV-negative men were diagnosed with a STI in the preceding 12 months, compared with 26% of HIS-positive men (CDC,2018).

in Ya-lin et al. (2018). PrEP users in our survey are younger than the general population of PrEP users, but are similar in race and residence. comparing PrEP and non-PrEP users in our survey, reveals that they are similar in age, and differ slightly on race, education and residence.

We asked participants questions pertaining to their sexual behavior in 2 periods. For PrEP users - the “before” period refers to the 12 months before they started taking PrEP; the “after” period refers to the 12 months of the year 2019[26]. For non-PrEP users - the “before” period refers to the 12 months of the year 2016; the “after” period refers to the 12 months of the year 2019. For non-PrEP users, the year 2016 was chosen as the “before” period since it it is halfway between 2020, and the year that PrEP was introduced, 2012. Since the “before” period for PrEP users changes according to the year in which they started taking PrEP, while it is fixed at 2016 for non-PrEP users, the “before” period for PrEP and non-PrEP users doesn’t necessarily match. Nonetheless, the median year in which the PrEP users in our survey started taking PrEP was 2017, thus, the median “before” period for PrEP users in our survey was 2016. Since exact recall could be an issue, one should consider the “before” and “after” being “in the past” and “recently”, which we also noted in our questions to participants.

In this section, we present results pertaining to condom use and number of sexual partners. Starting with the former, we asked participants “How frequently did you use condoms during anal sex” in the “before” and the “after” periods. Among PrEP users, 47.9% reported a decrease in condom use and 2% reported increase in condom use, whereas among non-PrEP users only 15.4% reported a decrease in condom use, while 10.9% reported an increase in condom use. We then coded the responses from 1 (never) to 5 (always). In Figure 15, we plot the average numeric response for each period, by PrEP status; higher number means greater condom use. In the “before” period, PrEP users had higher average condom use; in

[26]Due to the Corona pandemic which probably considerably altered the behavior of sexually active gay men, especially those who have sex with casual partners, we asked about the period just before the Corona pandemic, i.e. 2019.

the "after "period, the average declined slightly for for non-PrEP users, whereas it declined considerably (by $\approx$16.2%) for PrEP users suggesting a decrease in condom use among PrEP users.

We then plot the share of respondents who replied that they "never" or "rarely" used a condom in each period, by PrEP status (Figure 16). In the "before" period, that share for Non-PrEP users was higher than that share for PrEP users. In the "after" period, the share increased for both, but considerably more for PrEP users (from $\approx$18.75% to $\approx$37.5%, a 100% increase), such that in the "after" period, PrEP users they are more likely than non-PrEP users to never or rarely use condoms.

As with the NHANES, we estimate the following equation:

$$Y_{it} = \beta_1 \cdot Post_t + \beta_2 \cdot Post_t \cdot PrEP_i + \gamma_i + \epsilon_{it} \tag{6}$$

Where, Y_{it} is a binary variable that takes the value 1 in case the response of a participant was one of the aforementioned responses and 0 otherwise; $PrEP_i$ takes the value 1 in case the respondent is a PrEP user, and 0 otherwise; $Post_t$ takes the value 1 for the "after" period and 0 otherwise. We include person fixed effect, γ_i. The coefficient of interest is the coefficient on the interaction term, β_2; its interpretation is the differential change in the share of PrEP users (compared non-PrEP users) who answered a specific response in the "after" period (compared to "before" PrEP). We group "never" and "rarely", and "most of the time" and "always" for power given the small sample.

Results are presented in Table 6. The share of PrEP users (compared to non-PrEP users) who responded that they "never" or "rarely" used a condom increased by 13.3 percentage points in the "after" period (compared to the "before" period), a 70.1% increase from the pre-period ($p < 0.05$). The share of PrEP users who responded "most of the time" or "always" decreased by 17.8 percentage points in the "after" period ($p < 0.01$).

Other questions in the survey are also indicative of PrEP users' attitudes towards condom use. We asked PrEP users: “Because of PrEP, are you more or less likely to engage in anal sex without condoms?”. 69% responded that they are “more likely to engage in sex sex without condoms, because of PrEP”; the rest responded that they are “as likely...”. Of the latter, 63% actually reported decrease in condom use.

We also asked participants to rank different reasons as to “why did you decide to start taking PrEP”, 31% of PrEP users ranked ”To have sex without condoms without worrying about contracting HIV” as the most important reason.

Next, we plot the median number of sexual partners in each period, by PrEP status (Figure 17). We construct the median for each period from participants’ answer to the question: “With how many man have you had anal sex with?”. The figure shows that PrEP and non-PrEP users had the same median number of sexual partners in the “before” period, and that remained the same in the “after period”. Similarly to the results from the NHANES, PrEP did not seem to alter sexual behavior along this margin[27].

To sum up, results from the first 2 surveys illustrate that risky sexual behavior among gay men increased considerably after the introduction of PrEP; it manifested itself in an increase in sex without condoms, and sex with HIV-discordant partners. There does seem to be a change in the number of sexual partners. The third survey suggest that the increase in risky sexual behavior among gay men was driven primarily by PrEP users. Overall, the results of these surveys draw a pattern that is consistent with our main results on the effect of PrEP on STIs.

[27]The median number of sexual partners in this survey is higher than in NHANES since we condition participants to have had at least 2 sexual partners in 2019

7 Additional Analyses

7.1 Results by Age

The PrEP use data reveals differential take-up by age group. This could be due to differences across age groups in health coverage, PrEP awareness, risk aversion, or other factors. We are interested in leveraging these differences by age, to show that the age group that took-up PrEP the most is the one for which we find the largest treatment effects. Considerable increases in STIs in age groups that did not take-up PrEP would suggest that our identification is picking up other factors that effect STIs. To do so, we estimate our main specification (4) separately for 3 different age groups - 15-24, 25-44 and 45+ using PrEP and STI data by age group. The male same-sex partnerships variable is as previously defined.

First, we estimate our "first stage", in which the dependent variable is the PrEP rate, separately for each age group. The results are plotted in Figure 18. As seen in the figure, in the years after the introduction of PrEP, the coefficients for the 25-44 age group are considerably higher than the coefficients for the 45+ age group, which are higher than those for the 15-24 age group, meaning that take-up was highest for the 25-44 age group; 15-25 age group had very low PrEP take-up.

Then, we estimate our main triple-difference specification (4) separately for each age group. The results are plotted in Figure 19. The coefficients in the years before the introduction of PREP are mostly statistically insignificant, suggesting no differential pre-trends. In the years after the introduction of PrEP, for the 25-55 age group, the coefficients follow a similar pattern as our main results, in which they become positive and increase over time. For the 15-25 age group, which had the lowest PrEP take-up, in the years after the introduction of PrEP, the coefficients are indeed statistically insignificant, and remain rather flat, although due to large confidence intervals, we cannot rule out that they are similar to the coefficients for the 25-44 age group. For the 45+ age group, which had intermediate PrEP take-up, in the years after the introduction of PrEP, the coefficients are statistically significant and slightly increasing, although they are small in magnitudes.

The baseline levels (in 2011) of STIs differ across these age groups. The male chlamydia, gonorrhea and syphilis rates for the 13-24 age group were 825, 259 and 9.3 respectively. For the 25-44 age group they were 208, 125, 12.1, respectively, and for the 45+ age group they were 16.9, 16.3 and 3.7, respectively. When taking into account the fact that the chlamydia and gonorrhea male STI rates were 2-4 times higher in the 15-24 age group than in the 25-44 age group, the treatment effects estimated for the 25-44 age group are even more impressive, given that the baseline STI rate for that group is much lower

Overall, these results suggest that indeed the largest increases in STIs, occurred for the age groups that took-up PrEP the most.

7.2 County Level Analysis

Our main specification exploits across-state variation in the population of gay men, while ignoring within-state variation that is often large. For example, although California as a whole is ranked in the top quartile of states in terms of its gay population (see Figure 4), some of its counties, such as Kings county, are ranked in the bottom quartile of counties (see Figure 20). Similarly, although Alabama as a whole, are ranked in the bottom quartile of states, some counties in Alabama, such as Mobile county, are ranked in the top quartile. In order to exploit this large within-state variation, we conduct our analysis at the county level as well. Since separate male and female STI data are not available at the county level, we cannot run our main triple-difference specification. Therefore, we run the following difference-in-difference specification, that is equivalent to the specification detailed in equation (3), where state S has been replaced with county C:

$$STI_{ct} = \sum_{\substack{t=2008 \\ t \neq 2011}}^{2018} \beta_t * MaleSSP_c + \gamma X_{ct} + \mu_c + \tau_t + \epsilon_{ct} \tag{7}$$

where $MaleSSP_c$, is the share of partnerships that are male same-sex in county c and

STI_{ct} is the total (i.e. male and female) STI rate per 100K in county c in year t. We include year and county fixed effects, τ_t and μ_c, as well as the same controls, X_{ct}, that were mentioned previously, at the county level. We run the regression separately for each STI. The regressions are population weighted and the errors are clustered at the state level.

Using county-level data carries a few disadvantages; first, as mentioned, having to use total STI rates doesn't allow to control for time-variant state-specific shocks that affect both male and female STI rates. Second, total STI is a noisier measure of male STI in general, and gay men STI specifically, as the estimation could pick up factors that are correlated with the share of the population that is gay and female STIs. Lastly, PrEP rates, STI rates, and male same-sex partnerships cannot be calculated for counties with small populations due to data suppression. Therefore, we use a balanced panel of counties for which all data was available for all years. Although we are left with only 286 counties, these are large counties that encompass most of the gay population. PrEP users in these counties account for $\approx$85% of PrEP users in the United States in 2018.

The advantages of using county-level data, beside the higher number of observations, is a larger variation in treatment, since the male same-sex partnerships are not averaged out within a state and used at the state level. In addition, using smaller geographic units, assigns "treatment" to counties more accurately. For example, Florida a a whole isn't assigned the same treatment, as it is allowed to vary between counties within Florida, to more accurately assign large and small gay populations the relevant counties.

The identifying variation - the share of partnerships that are male same-sex across counties, is detailed in Figure 20. The results are detailed in Figure 21. The top left panel is the "first stage", in which the dependent variable is the PrEP rate. Similarly to the state-level analysis, PrEP take-up is higher in counties with larger gay populations. The other 3 panels are the results for the 3 STI. The patterns exhibited at the county-level are generally similar to those exhibited at the state-level. The coefficients in the years before the introduction of PrEP are slightly negative and statistically significant for some of the years for chlamydia and gonorrhea; for syphilis, those are not statistically significant. Nonetheless, for gonorrhea at least, they are small in magnitude compared to the magnitude in the years after the introduction of PrEP. It is important to note that only a third of male chlamydia cases are attributable to MSM, and in this case, we are identifying of the distribution of the total (male and female) chlamydia rates, making the treated group even smaller. This makes finding an effect harder. In the years after the introduction of PrEP, the coefficients become positive and increase over time, consistent with the rollout patterns of PrEP. Overall, the estimated effects are smaller than the estimated effects using our main specification at the state-level, which is consistent with the estimation using total STI rates, instead of male STI rates. The estimates for chlamydia are much noisier than the estimates for the other STIs, due to the reasons mentioned above.

7.3 HIV Prevalence as a Treatment Intensity Measure

We repeat our main specification (4) but instead of proxying for PrEP with the share of the population that is gay in each state, we proxy for PrEP with the HIV prevalence rate in each state in 2008, 4 years before the introduction of PrEP. The HIV prevalence rate is defined as the number of people living with HIV infection per 100K population. This measure is likely to be predictive of PrEP take-up as men living in areas with high HIV prevalence are those that benefit from PrEP use the most. The event studies for this specification are plotted in Figure 22.

First, the "first stage", in which PrEP is the dependent variable, shows that this measure is highly predictive of PrEP take-up. After the introduction of PrEP, the coefficient is positive and increasing over time, suggesting that states with higher HIV prevalence are those in which PrEP take-up was higher. The increase over time is consistent with the rollout of PrEP. Next, the "reduced form", in which each STI is the dependent variable, reveal patterns similar to the ones exhibited in our main specifications. The coefficients for the years before the introduction of PrEP are statistically insignificant, while the coefficients for the years after the introduction of PrEP are positive, and increasing over time.

8 Discussion

8.1 Recommended STI Testing

As detailed in Subsection 2.1, The CDC recommends that PrEP users undergo HIV testing every 3 months and testing for other STIs every 3-6 months, compared to testing for all STIs every 3-12 months for gay men who are not on PrEP. Therefore, some PrEP users might undergo more frequent testing after initiating PrEP. However, it is unclear whether medical practitioners indeed administer more frequent STI testing for PrEP users, since it is at their discretion. Furthermore, it could be the case that some PrEP users already screen for STIs more often than non-PrEP users (for example, if some PrEP users are at high risk of contracting STIs).

In any case, if more frequent STI testing is practised by PrEP users, it could have an ambiguous effect on reported STIs. On one hand, since chlamydia, gonorrhea and syphilis are sometimes asymptomatic, increased STI testing could pick up STI cases that would have not been picked up without regularly scheduled testing. Thus, the differential increases in STIs that we are picking up in states where the PrEP rate grew more, could have partially been increases in reported STIs, not increases in the underlying distribution of STIs. On the other hand, increased testing that result in increased diagnoses of asymptomatic STIs could decrease STIs 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 STI testing that will enable us to test whether STI testing increases more, the higher the PrEP rate, we are able to provide suggestive evidence that this is likely not the case using data on HIV testing, as testing for other STIs is usually coupled with HIV testing. As explained in Subsection 4.1, using data from the BRFSS, we construct the HIV testing rate per 100k in the 6 months preceding the interview for males aged 18-45 for the years 2008-2018 for all states for male and female. We then estimate our main triple-difference specification (4), where the dependent variable is the HIV testing rate we constructed, to examine whether states with larger gay populations, experienced higher increases in HIV testing. The event study results appear in Figure 23. As seen in the figure, the coefficients for each of the years are insignificant, and they do not form an upward trend, as the event studies for the STIs do. Therefore, there is no evidence that HIV testing did increase differentially for states with larger gay populations,and consequently higher male PrEP rate.

8.2 Other potential Confounders

A potential omitted variable in our analysis is the rise of 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 increased STI incidences in states with larger gay populations. Given that we identify the effect of PrEP using variation in the share of the population that is gay, our estimates could potentially be picking up some of the effect of Grinder on STIs.

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 Grindr. Grindr was introduced in 2009 and by 2011, the year before the introduction of PrEP, it already had an estimated 1.4 million active users in the Unites Stated (Cison PR Newswire, 2012). If indeed the use of Grinder increases STIs, it should show up as positive coefficients in our event study specification (illustrated in Figure 9), for the years 2009, 2010, 2011 and 2012, which is not the case. Moreover, Tinder, which is the equivalent of Grindr, but caters for straight men and women, was introduced in 2012. Similarly to Grindr, it could have increased the availability of sex, potentially resulting in more STI among straight men and women. As we control for yearly shocks in our specifications that affect men and women across states, the effects of Grindr and Tindr should be controlled for.

An additional confounder is the decrease in HIV risk in recent years. HIV infections have been declining since 2000. More recently, in 2008, the male HIV infection rate per 100K was 29.2; it decreased monotonically over the years, reaching 21.3 in 2018, a 27% drop (CDC, 2019a). The reduced HIV risk makes risky sexual behaviors less costly. As HIV mostly affects gay men, the reduced risk could disproportionately affect gay men, which could be picked up in our identification. Nonetheless, if reduced HIV risk increases risky sexual behavior, and therefore STIs, it should show up as positive coefficients in our main event study much before 2012, which is not the case, as mentioned previously.

8.3 Cost-Benefit Analysis

We conduct back of the envelope calculations that estimate the costs associated with the additional STI cases that occurred due to the introduction of PrEP. We then conduct a break-even analysis, calculating how many HIV cases should have been prevented by PrEP to make PrEP neutral on net. The analysis is presented in Table 8.

The first column reports the lifetime cost of treating each of the STIs based on Owusu-Edusei Jr et al. (2013), in 2010 dollars. The estimates include the direct medical costs of treating the STI, plus the cost of common complications weighted by their likelihood. We then take the estimated effect of 1 additional PrEP user on each STI, as estimated from our main specification (4), and multiply it by the cost of each STI to get an average cost of STI per PrEP user (column 2). These estimates suggest that each PrEP user generates additional STIs that cost \$88.4 annually. We then multiply the average cost by the number of male PrEP users in 2018 to get the total cost associated with the additional STIs caused by PrEP in 2018 (column 3), for each STI. Finally, we sum up theses costs for the 3 STIs and find that the total costs associated with the additional STIs caused by PrEP are \$15,723,314.

Since our research design isn't suitable for the identification of the causal effect of PrEP on HIV, and the medical literature does not provide one either, we conduct a break-even analysis. We divide the total cost for each STI by the lifetime cost of contracting HIV –

\$304,500, resulting in the number of HIV cases that would need to be prevented by PrEP to offset the cost of the additional STIs (column 4). For PrEP to break-even on the cost of the additional STIs, PrEP would need to prevent only 51.6 yearly cases based on our estimate. This implies that each additional PrEP user would need to prevent 0.0002 HIV cases. Given the number of PrEP users, it is likely that PrEP prevents more than 51.6 HIV cases a year, making PrEP a net-benefit in the context of this cost analysis.

The costs taken into account in this analysis do not encompass all private and social costs associated with the additional STIs that are caused by PrEP. One such cost is antibiotic resistance that is increasing with each additional STI case. This entails that the future medical costs, as well as other costs, associated with STIs would be much higher once some of the STIs become antibiotic resistance to conventional treatment. These costs also do not take into account the implicit costs of the additional STIs (shame, stigma, etc.). Nonetheless, given the high direct costs of HIV compared to other STIs, it is unlikely that the additional costs that are not taken into account in the above analysis, will be so large, as to make PrEP a net loss in this context.

Suggestive evidence that the number of HIV infections that were prevented by PrEP are sufficient to outweigh the costs of the additional STIs can be found from analyzing the The frequency of condom use question in the "before" period from our self-administered survey (as discussed in Section 6). In the "before" period, 18.7% of PrEP users stated that they "never" or "rarely" used condoms. Given the risk of sex without condoms, it is likely that PrEP has prevented new HIV infections in some of these PrEP users. The number of prevented cases is likely greater the number suggested above, due to the large number of PrEP users, even if taking into account the additional costs not included in the analysis.

Moreover, the above analysis does not take into account implicit benefits of PrEP that arise from the increase in sex without condoms among PrEP users; this is outside the scope of this paper.

Overall, we do not argue that PrEP is bad per se. Nonetheless, we assert that the unintended consequences of PrEP could be mitigated through several channels that are discussed in the next subsection.

8.4 Public Policy Implications

PrEP has been embraced by governments and public health organizations as an effective tool in reducing new HIV infections. Although PrEP was proven effective in clinical trials it is not clear that a national rollout would confer similar HIV reductions, as it depends on the HIV risk profile of individuals who take-up PrEP. One can think of 2 opposite types of PrEP users. The first are those who were low HIV risk before going on PrEP; i.e. those who did not engage in risky sex. These PrEP users are not likely to enjoy reductions in HIV risk, since they would have not contracted HIV even in the absence of PrEP. However, they might be induced to engage in risky sexual behaviors after going on PrEP; these would increase their risk of contracting other STIs. For these users, PrEP essentially subsidizes risky sex without the benefit of a reduction in HIV risk. On the other extreme are PrEP users who were at high HIV risk before going on PrEP; i.e. those who did engage in risky sex. These PrEP users are likely to enjoy reductions in HIV risk, since they could have contracted HIV in the absence of PrEP. Since they already engaged in risky sex before going on PrEP, the margins for their risky sexual behavior to increase are smaller than for the previous type.

The frequency of condom use question in the "before" period from our self-administered survey (as discussed in Section 6), provides a snapshot of PrEP users' HIV risk-profile before going on PrEP. In the "before" period, 56.2% of PrEP users stated that they used condoms "always" or "most of the time". In other words, the majority of PrEP users were of low HIV risk before going on PrEP. Indeed, the medical literature reports low take-up of PrEP among some high HIV risk individuals, such as gay Black and Hispanic men[28] (Ya-lin et al., 2018). For these, reductions in HIV infections due to PrEP, will be minimal. But, 55.55% of these

[28] Black gay and bisexual men are more affected by HIV than any other group in the United States. In 2018, they accounted for 26% (9,712) of the 37,968 new HIV diagnoses and 37% of new diagnoses among all gay and bisexual men. Much higher than their share in the population. (CDC, 2020e)

PrEP users reported reductions in condom use in the "after" period, suggesting increases in other STIs. Although their new steady state (i.e. more sex without condoms, more STIs) is likely utility-improving, it belies public efforts in containing the STI epidemic and confers social costs such as increasing antibiotic resistance.

Various reasons have been raised as to the low take-up of PrEP among populations of high HIV risk, among them - stigma (Golub, 2018; Philbin et al., 2016), reduced willingness of providers to prescribe PrEP to patients that are perceived as more likely to engage in sex without condoms (Calabrese et al., 2014), lower awareness of PrEP (Kanny et al., 2019) and high cost (Luthra and Gorman, n.d.). Public health efforts should address these.

Additional efforts should be put into controlling the STI spread. As noted in Section 2.1, 1.2 million Americans are indicated for PrEP use by the CDC, due to their high HIV risk (Siegler et al., 2018). However, In 2018, there were only 188,903 PrEP users, some of which, as discussed in the last paragraph, were probably not even indicated for PrEP use. As efforts to scale-up PrEP use increase (see Section 2.1), the number of users is likely to grow considerably. Given the findings of this paper, unless action is taken to mitigate the unintended consequences of PrEP, large increases in male STIs are inevitable, generating large private and social costs. Public health efforts should therefore be concentrated in containing the continued spread of STIs. Chow, Grulich and Fairley (2019) discuss possible interventions to control STIs that have been suggested in the literature; among others these included more frequent STI testing and accessible health care for the treatment of STIs. The literature suggests that the former could be achieved through increased home testing (Cook et al., 2007), providing monetary incentives for testing (Lee et al., 2014), providing the option for rapid testing (Whitlock et al., 2018) and active recall (Desai et al., 2015).

9 Conclusion

We explore moral hazard in the context of a medical innovation that is inexpensive, accessible, and confers a substantial and salient reduction in risk to users.

Record STI rates present a major public health crisis. In this paper, we suggest that the introduction of a drug that prevents HIV infections, PrEP, is responsible for a considerable share of the increase in male STIs in recent years. PrEP decreased the expected costs of risky sex, pushing some users to alter their sexual behavior towards risky practices; leading to increased STI diagnoses.

To test this, we exploit the cross-state variation in the gay population, the group that took-up PrEP the most. We show that STIs trended almost identically across states before the introduction of PrEP, but diverged significantly after, with STIs rising in states that had larger gay populations, i.e. higher PrEP take-up. We estimate that one additional male PrEP user increases male chlamydia, gonorrhea and syphilis cases by 0.66, 0.51 and 0.04, respectively; a sizeable effect given that in 2018 there were almost 180,000 male PrEP users. We also estimate that male STIs would have been 17.9% - 25.6% lower in the absence of PrEP and show that increase in sex without condoms is likely responsible for the rise in STIs.

This paper is the first to analyze the effect of PrEP on aggregate STIs, informing an open question regarding the recent rise in STIs. It also adds to the literature on moral hazard in health interventions. Our results emphasize the need to take into account the behavioral response of users to health interventions that entail moral hazard. This is especially important in the case of PrEP, as the number of users is likely to grow rapidly in the near future.

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Tables

Table 1: **Summary Statistics**

height	**2008-2011**		**2012-2018**	
	Low	*High*	*Low*	*High*
Male PrEP Rate	0	0	19.2	65.6
Female PrEP Rate	0	0	2.3	6.9
Male chlamydia Rate	276	287	348	392
Male gonorrhea Rate	115	112	161	194
Male syphilis Rate	5.1	11.8	9.1	20.7
Male HIV Rate (Male to Male Contact)	13.4	26.6	13.3	23.3
Female chlamydia Rate	752	689	793	734
Female gonorrhea Rate	159	109	169	120
Female syphilis Rate	1.5	1.0	1.9	2.1
Female HIV Rate	4.4	9.2	3.6	6.2
	2008-2018			
	Low	*High*		
Share White	78.9	59.4		
Share Hispanic	3.7	8.4		
Share Black	8.6	14.4		
Unemployment Rate	5.5	7.0		
Gross State Product Per Capita	47,414	68,874		
Poverty Rate	14.0	12.6		
	2000			
	Low	*High*		
Share of Male Same-Sex Par.	0.41	0.67		

Notes: The table provides summary statistics for states according to their PrEP take-up for the years before the introduction of PrEP (2008-2011) and the years after the introduction of PrEP (2012-2018). States were ranked according to their male PrEP rate in 2018; "Low" are states that are in the lowest quartile of PrEP take-up, whereas "High" are states that are in the highest quartile of PrEP take-up. All summary statistics are population weighted. "Rate" refers to the rate per 100K.

Table 2: **PrEP Specification Results**

	Chlamydia				**Gonorrhea**				**Syphilis**			
	(1)	(2a)	(2b)	(2c)	(1)	(2a)	(2b)	(2c)	(1)	(2a)	(2b)	(2c)
PrEP	0.371***	-0.041	-0.119	0.160	0.280***	-0.135**	-0.300***	-0.162	0.014**	0.001	-0.012**	-0.010
	(0.095)	(0.135)	(0.127)	(0.164)	(0.089)	(0.052)	(0.072)	(0.138)	(0.007)	(0.004)	(0.005)	(0.011)
Male		-575.426***	-575.492***	575.336***		-43.371***	-43.283***	-43.038***		4.713***	4.719***	4.730***
		(6.696)	(6.726)	(6.899)		(3.415)	(3.354)	(3.438)		(0.411)	(0.410)	(0.419)
Male*PrEP		0.516***	0.512***	0.513***		0.599***	0.597***	0.599***		0.032***	0.032***	0.032***
		(0.116)	(0.117)	(0.121)		(0.053)	(0.052)	(0.054)		(0.006)	(0.006)	(0.006)
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	561	1,122	1,122	1,122	561	1,122	1,122	1,122	561	1,122	1,122	1,122
R-Squared	0.952	0.981	0.982	0.988	0.939	0.908	0.926	0.960	0.919	0.935	0.952	0.965

Note: The table provides the results from estimating equation (1) and (2) where the dependent variable is either chlamydia rate, gonorrhea rate or syphilis rate. For each STI, 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×gender and state×gender 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) and is population weighted.

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

Table 3: **Event Studies - DDD - STI Rate per 100K & PrEP Rate Rate per 100K**

	(1) Chlamydia	(2) Gonorrhea	(3) Syphilis	(4) PrEP
β_{2008}	-30.79	-11.00	-1.09	0.08
	(32.06)	(11.61)	(1.26)	(.22)
β_{2009}	0.08	-6.05	-2.19	0.06
	(28.50)	(4.84)	(1.97)	(0.26)
β_{2010}	0.01	-14.29**	-2.40***	0.04
	(18.64)	(6.21)	(.79)	(0.08)
β_{2011} (Omitted)	-	-	-	-
	-	-	-	-
β_{2012}	10.96	14.12***	0.73	4.22***
	(14.31)	(4.79)	(1.15)	(0.69)
β_{2013}	31.50	20.91**	0.13	6.81***
	(22.53)	(9.44)	(2.67)	(1.41)
β_{2014}	4.01	3.03	-1.03	30.95***
	(28.05)	(14.94)	(4.26)	(4.30)
β_{2015}	59.01**	55.27***	-2.04	79.19***
	(26.20)	(11.43)	(5.88)	(10.34)
β_{2016}	99.99***	98.97***	3.34	123.73***
	(31.44)	(16.00)	(5.24)	(17.98)
β_{2017}	132.55***	139.12***	9.29***	150.03***
	(37.84)	(25.44)	(2.97)	(22.39)
β_{2018}	118.77***	126.19***	10.41***	221.82***
	(38.82)	(23.74)	(3.84)	(30.42)
Observations	1,122	1,122	1,122	1,122
R-squared	0.958	0.919	0.982	0.879

Note: This table provides the estimates for β_ts from estimating triple-difference equation (4). The dependent variables are the STI rates per 100K. The year prior to the introduction of PrEP (2011) is omitted. β_t are the additional cases per 100K of an STI (i.e. the change in the STI rate) that occur in year t, compared to 2011, with a 1 percentage point increase in the share of male same-sex partnerships. For context, the difference in the share of male same-sex partnerships between New York and North Dakota is about 0.5 percentage points, so halving the coefficient values reported is the predicted difference in STIs between New York and North Dakota in a given year due to PrEP. We also report the β_ts from estimating equation (4) where PrEP rate is the dependent variable (i.e. our "first stage"). All specifications include year×gender and state×gender 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.
* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 4: **NHANES Condom Use Regression Results**

	Never Used	Less than Half	About Half	More than Half	Always Used
Gay	-0.22***	0.08	0.02	0.05	0.08
	(0.08)	(0.05)	(0.04)	(0.04)	(0.07)
Gay $\cdot Post$	0.24**	-0.03	-0.05	-0.11**	-0.05
	(0.11)	(0.07)	(0.05)	(0.06)	(0.09)
Observations	4,889	4,889	4,889	4,889	4,889
R-squared	0.057	0.056	0.037	0.049	0.030

Note: The table provides the results from estimating equation (6) where the dependent variable is a binary variable that equals 1 if the respondent gave one of the responses detailed in the top row to the following question from the NHANES: "In the past 12 months, about how often have you had vaginal or anal/vaginal/anal sex without using a condom". The regression is run separately for each response. Controls include education, marital status, age and income.
* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 5: **Survey Participants Characteristics**

	Survey		**CDC**
	PrEP	*Non-PrEP*	*PrEP*
Age	33.2	34.7	37.2
Black	0.11	0.09	0.11
Hispanic	0.11	0.16	0.13
White	0.74	0.62	0.69
Other	0.04	0.03	0.07
California	0.13	0.12	0.14
New York	0.09	0.21	0.14
Florida	0.11	0.02	0.08
High School	0.13	0.09	-
Some College/Associate	0.13	0.42	-
Bachelor's	0.45	0.37	-
Graduate	0.30	0.12	-
Observations	47	52	

Note: The table provides the demographic characteristics of survey participants who use PrEP versus those who do not use PrEP. It also provides the demographic characteristics of the general PrEP users population, as detailed in Ya-lin et al. (2018)

Table 6: **Survey Condom Use Regression Results**

	Never / Rarely	Sometimes	Most of the Time / Always
Post	0.055	-0.045	-0.009
	(0.033)	(0.042)	(0.036)
PrEP $\cdot Post$	0.133**	0.045	-0.178***
	(0.060)	(0.077)	(0.065)
Observations	316	316	316
R-squared	0.855	0.688	0.859

Note: The table provides the results from estimating equation (7) where the dependent variable is a binary variable that equals 1 if the respondent gave one of the responses detailed in the top row to the following question from the self-administered survey: "How frequently did you use condoms during anal sex". The regression is run separately for each response. Controls include education, marital status, age and income.
* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 7: **Counterfactual Analysis**

	Observed	Counterfactual	% Difference
Chlamydia	609,430	500,275	-17.9%
Gonorrhea	341,120	253,934	-25.6%
Syphilis	30,021	22,333	-25.6%

Note: This table reports the estimated STI cases that would have existed in the absence of PrEP in 2018; these are based on our estimates of the effect of an additional PrEP user from our triple-difference main specification (equation (4). We report the observed (actual) cases in 2018 in the first column, the counterfactual cases in the second column, and the percent difference in the third column. This analysis implicitly assumes that effects are constant across time and states.

Table 8: **Estimated Costs**

	Cost to Treat	Avg Cost Per PrEP User	Total Cost	Prevented HIV Cases to Offset
Chlamydia	$30	$19.81	$3,519,747	11.6
Gonorrhea	$79	$40.29	$7,162,152	23.5
Syphilis	$709	$28.36	$5,041,415	16.6
HIV	$304,500	-	-	-
Total (Non-HIV STIs)	$818	$88.45	**$15,723,314**	**51.6**

Note: This table puts the costs of PrEP into context. It reports a naive cost-benefit analysis comparing the costs of PrEP – the additional STIs – to the benefit of PrEP – the reduction in HIV. We present the lifetime costs of treating different STIs in 2010 dollars using Owusu-Edusei Jr et al. (2013). These take into account just the direct medical costs associated with STIs. We give the average estimated costs by taking our estimated effect of an additional male PrEP user on male STIs and multiplying it by cost of treatment. To get total cost, we take the average cost per PrEP user and multiplying it by the number of male PrEP users in 2018. Benefits are given as negative costs. Since our identification cannot causally estimate the effect of PrEP on HIV diagnoses, we conduct a break-even analysis; we estimate how many cases of HIV would need to be prevented to make the policy neutral on net, which we do by dividing the total cost of treating an STI by lifetime cost of treating one HIV case.

Figures

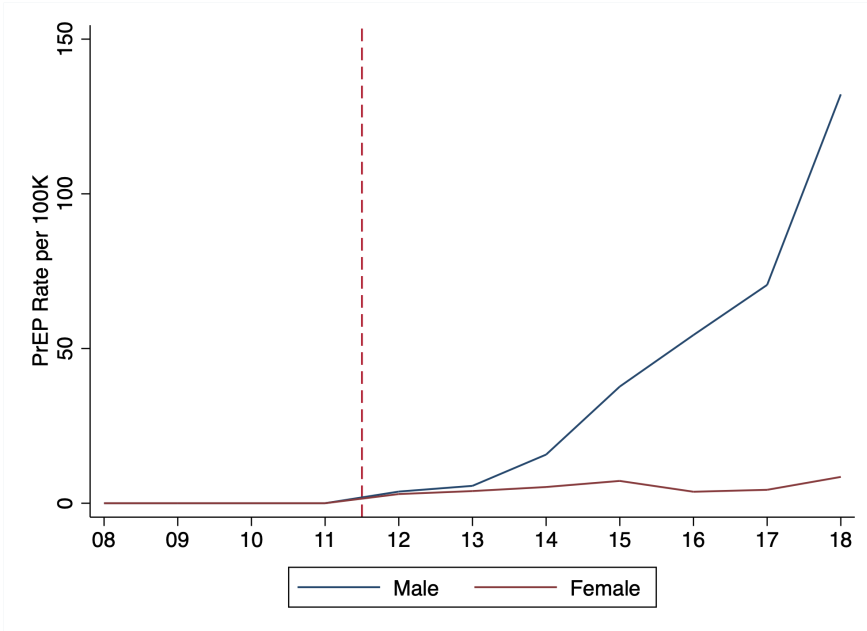

Figure 1: **PrEP Rate Over Time, by Sex**

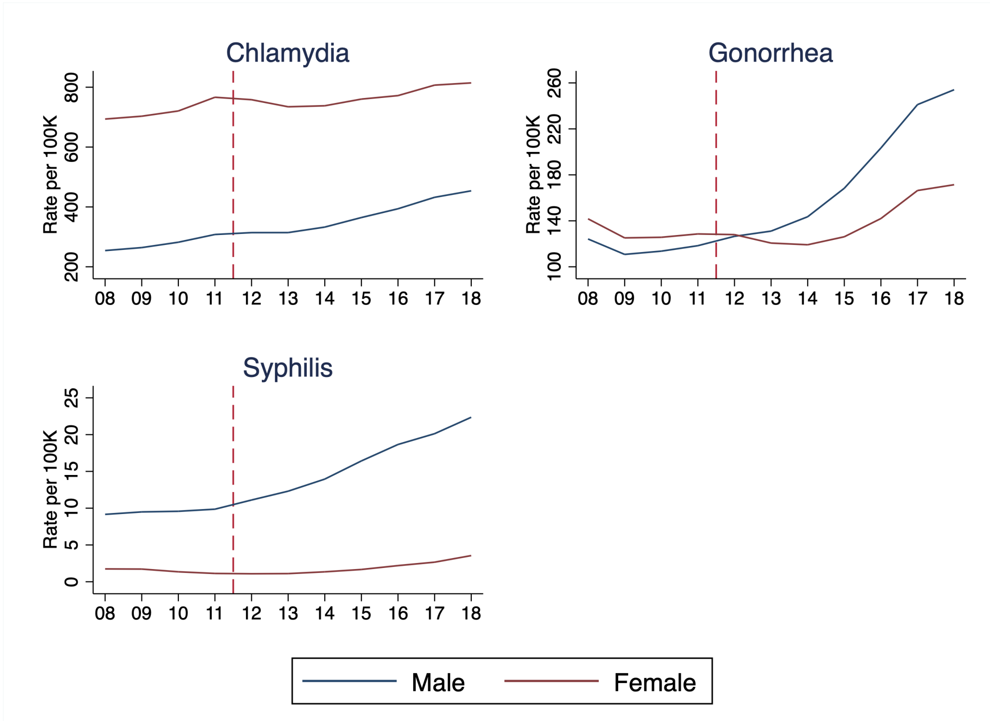

Figure 2: **STI Rates, by Sex**

Notes: The figure plot the STI rates per 100K of the 3 most common STIs that are annually tracked by the CDC.

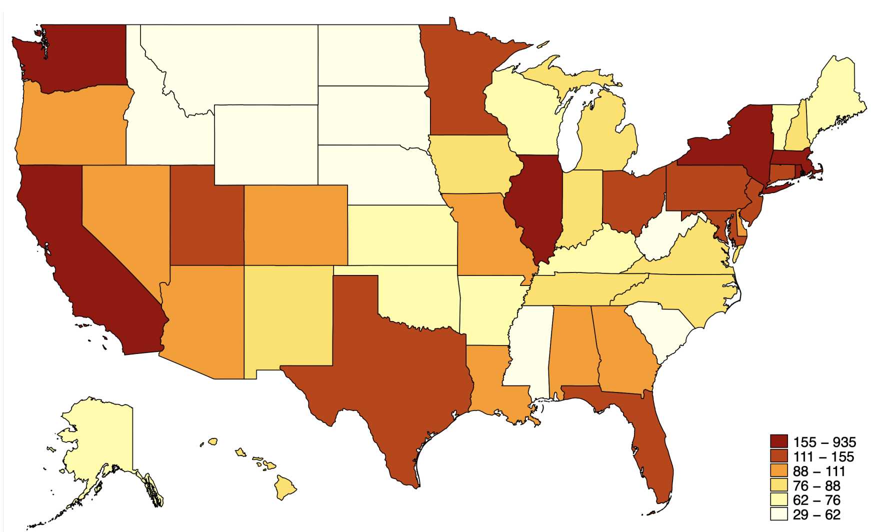

Figure 3: **Male PrEP Rate Per Across States - 2018**

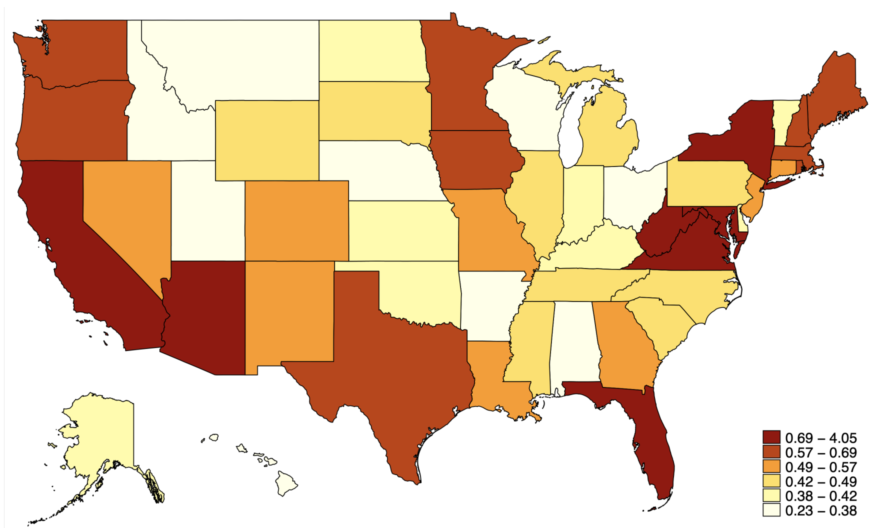

Figure 4: **Share of Partnerships That Are Male Same Sex Across States - 2000**

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

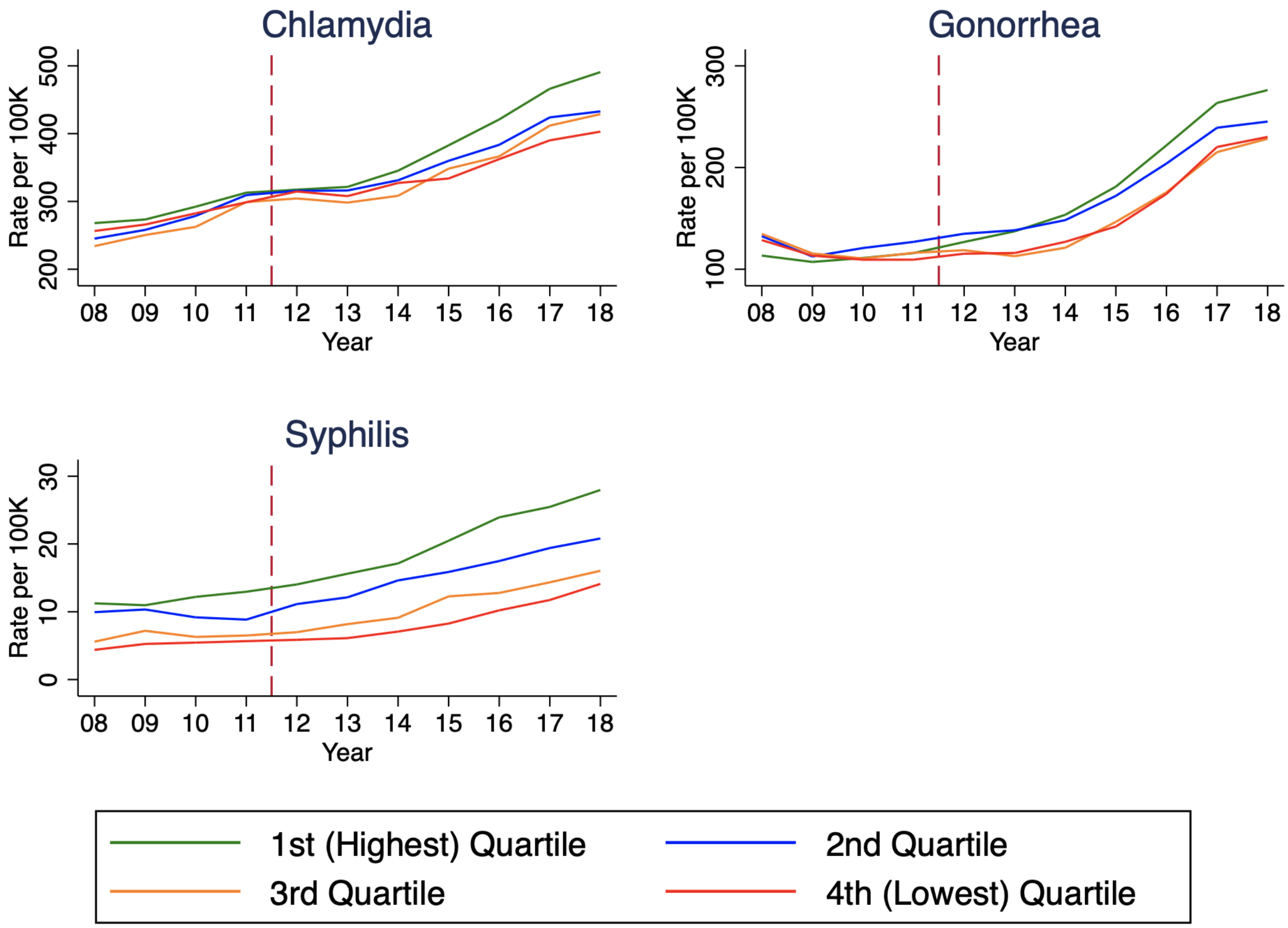

Figure 5: **Male STI Trends, by Quartile of PrEP take-up**

Note: The figure plots the male STI rates per 100K over time for states with different PrEP take-up. States were ranked according to their male PrEP rate in 2018 and put into quartiles, where quartile 1 includes states with the highest PrEP rate, and quartile 4 includes states with the lowest PrEP rate. The variables are population weighted.

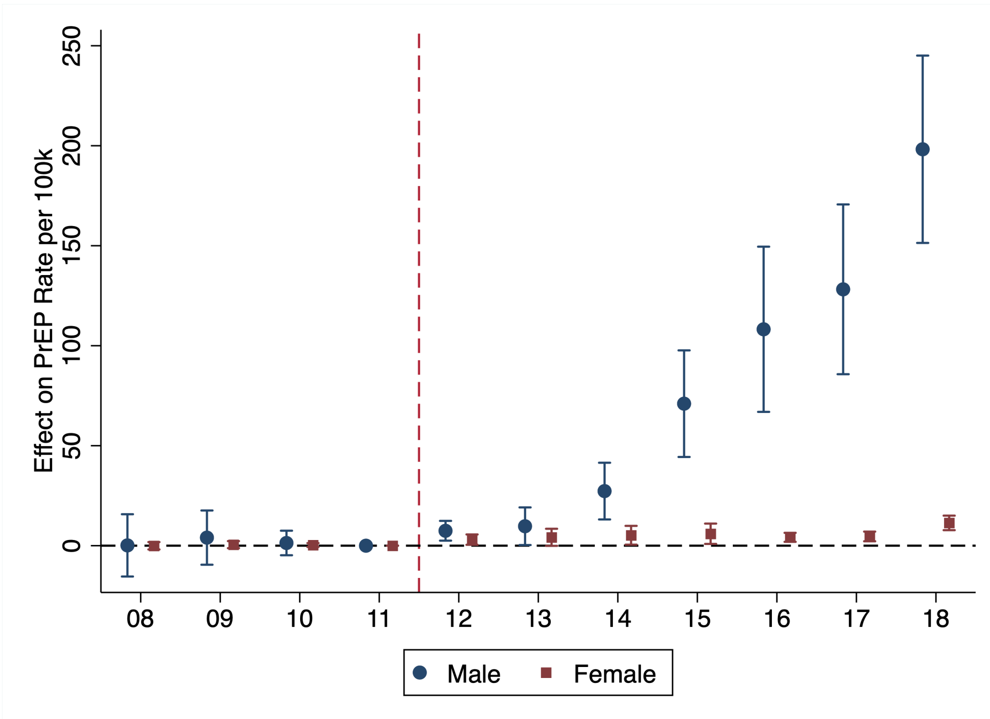

Figure 6: **Event Studies - DD - PrEP Rate per 100K, by Sex**

Note: 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.

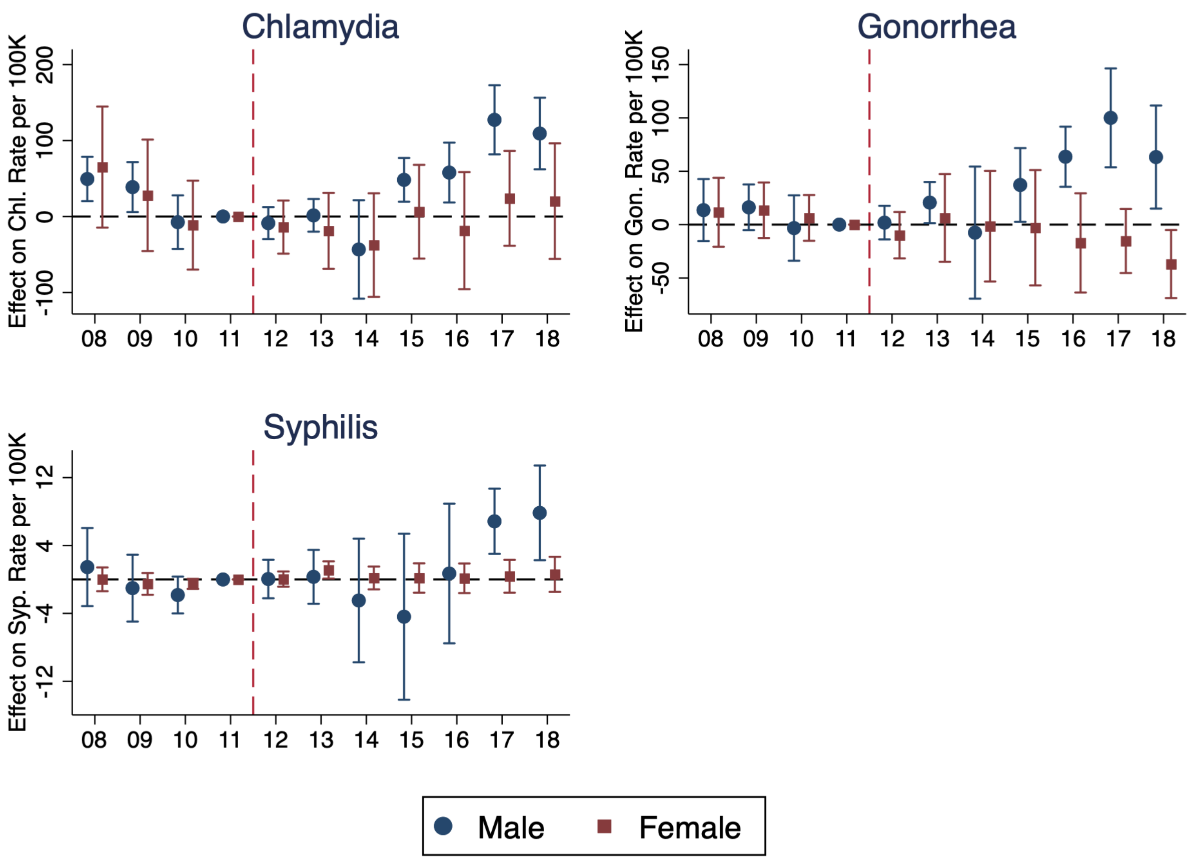

Figure 7: **Event Studies - DD - STI Rates per 100K, by Sex**

Note: The figure plots the event-study estimates from estimating difference-in-difference Equation (3) separately for male and female for the different STIs. The dependent variables are the STI 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.

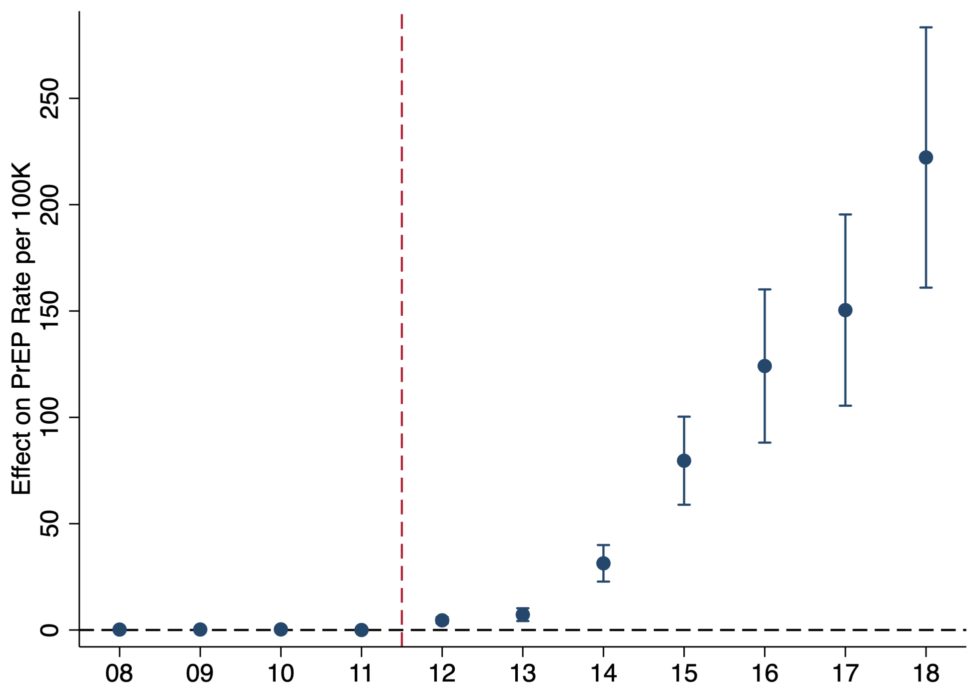

Figure 8: **Event Study - DDD - PrEP Rate per 100K**

Note: 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×gender and state×gender 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.

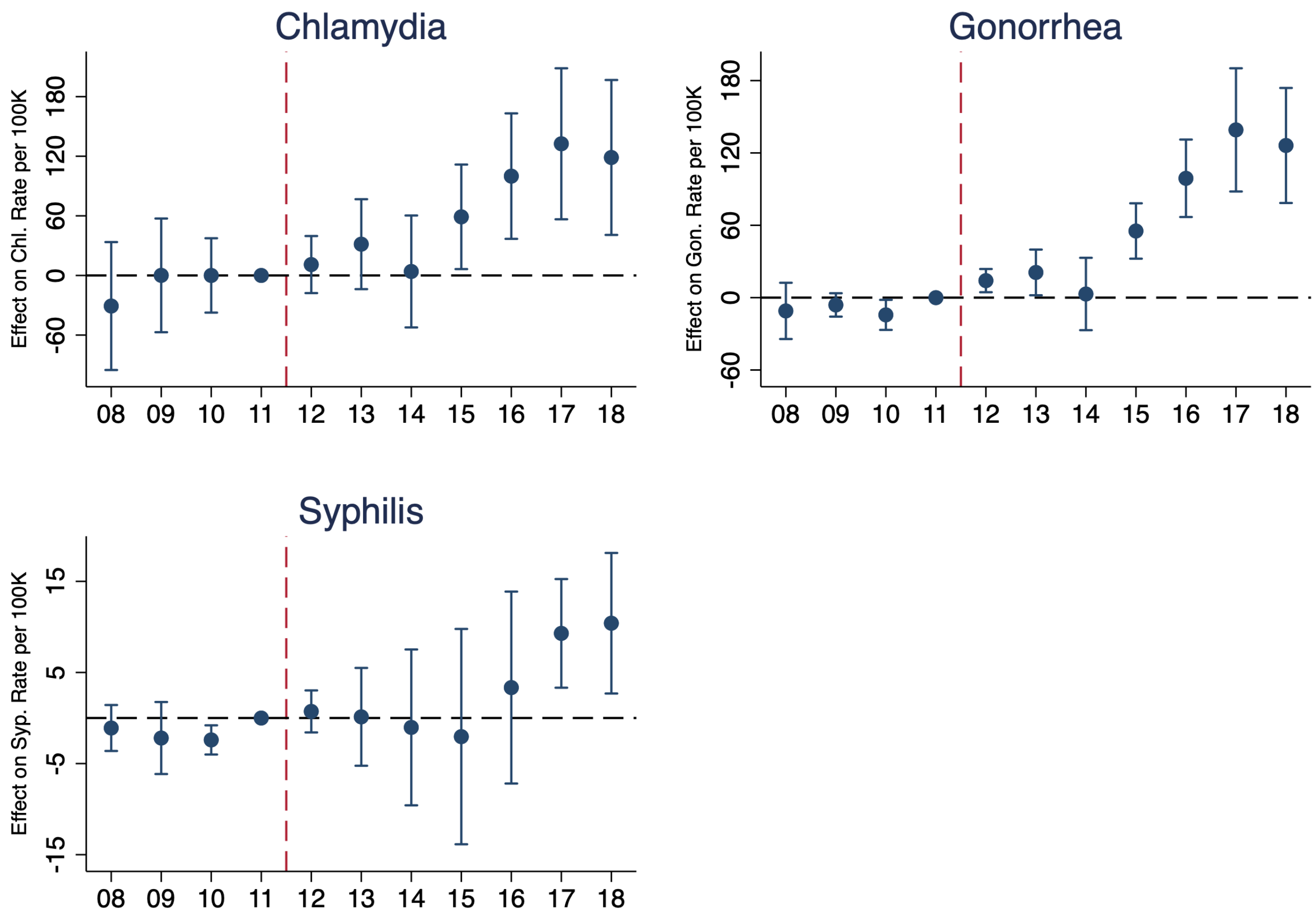

Figure 9: **Event Studies - DDD - STI Rates per 100K**

Note: The figure plots the event-study estimates from estimating triple-difference Equation (4) for different STIs. The dependent variables are the STI rates per 100K. The year prior to the introduction of PrEP (2011) is omitted. Estimation includes year×gender and state×gender 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.

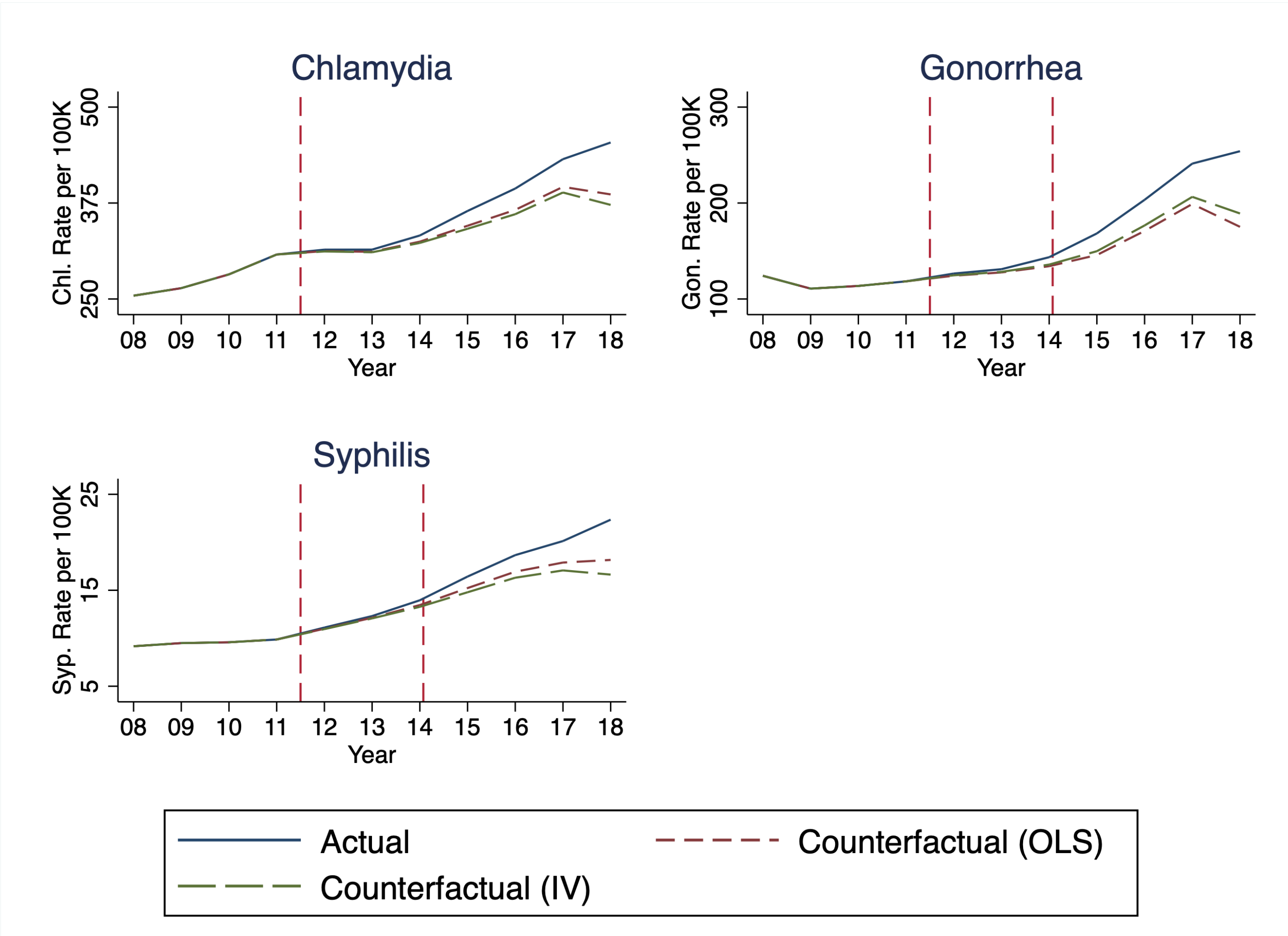

Figure 10: **Counterfactual STI Distributions in the Absence of PrEP**

Note: These figures plot the aggregate STI rates in the absence of PrEP using two different estimates; the OLS triple-difference specification, and the IV specification.

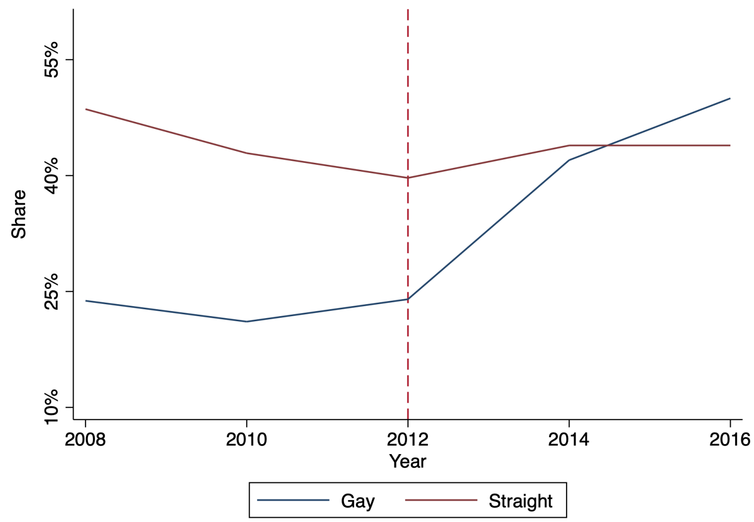

Figure 11: **Share Who Never Used a Condom - Past 12 Months, by Sexual Orientation (Male)**

Note: The figure plots the share of men, by sexual orientation, who responded "never" to the question: "In the past 12 months, about how often have you had vaginal or anal/vaginal/anal sex without using a condom?" from the NHANES

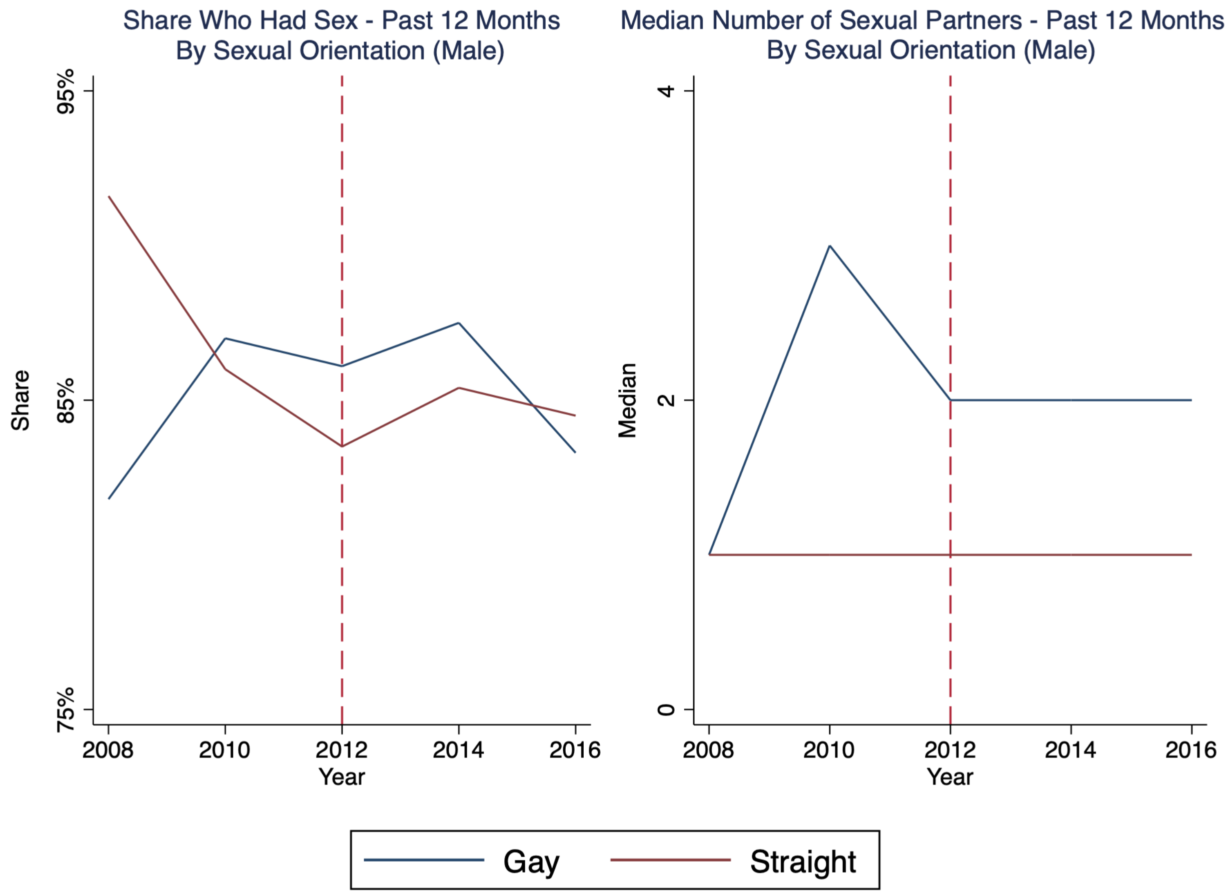

Figure 12: **Additional Outcomes from the NHANES, by Sexual Orientation (Male)**

Note: The left figure plots the share of men, by sexual orientation, who had at least 1 sexual partner in the preceding 12 month. The right figure plots the median number of sexual partners in the preceding 12 months. Both are deduced from following NHANES questions: The question posed to gay men - ”In the past 12 months, with how many men have you had anal or oral sex?” The question question posed to straight men - ”In the past 12 months, with how many women have you had any kind of sex?”

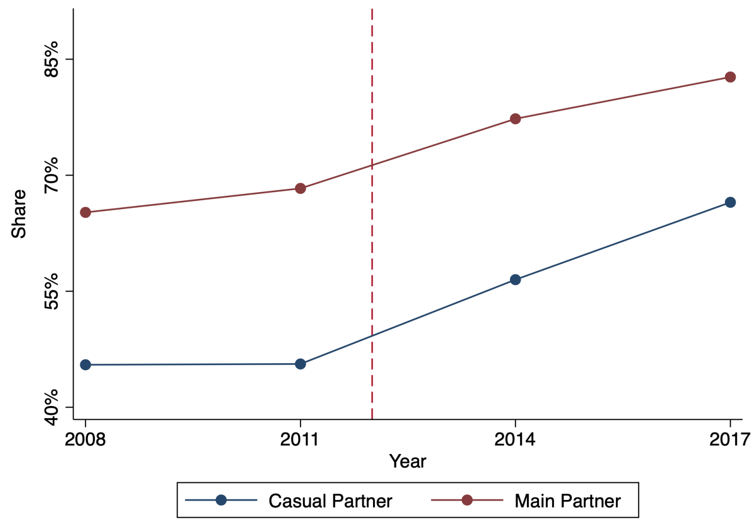

Figure 13: **Share Who Had Anal Sex Without Condoms - Past 12 Months, by Type of Partner**

Note: The figure plots the share of HIV-negative gay men who had at least one anal sex encounter without condoms in the preceding 12 months from the NHBS, by type of partner.

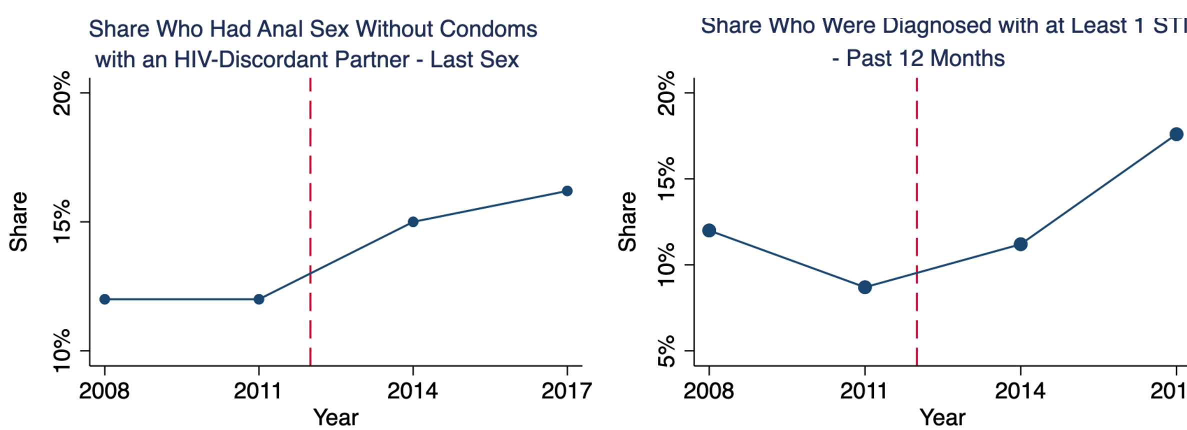

Figure 14: **Additional Outcomes from the NHBS**

Note: The left figure plots the share of HIV-negative gay men whose last sexual encounter involved anal sex without a condom with an HIV-discordant partner (i.e. a partner whose status is either unknown, or positive). The right figure plots the share of HIV-negative gay men who were diagnosed with at least 1 STI in the preceding 12 months. Both are deduced from the NHBS.

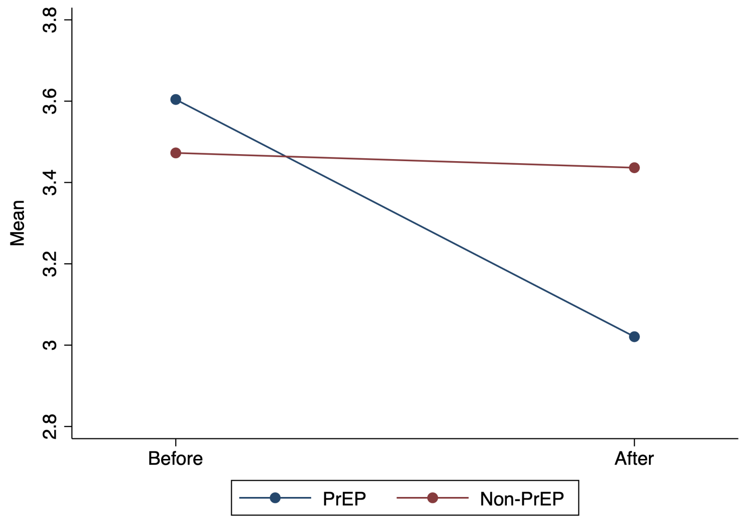

Figure 15: **Respondents' Mean Condom Use Category, by PrEP Status**

Note: The figure plots respondents' mean condom use category, by their PrEP status. Respondents' answer to the question: "How frequently did you use condoms during anal sex" were coded from 1 (Never) to 5 (Always). For PrEP users, "before" refers to the period before starting PrEP, and the "after" refers to 2019. For non-PrEP users, "before" refers to 2016, and the "after" refers to 2019.

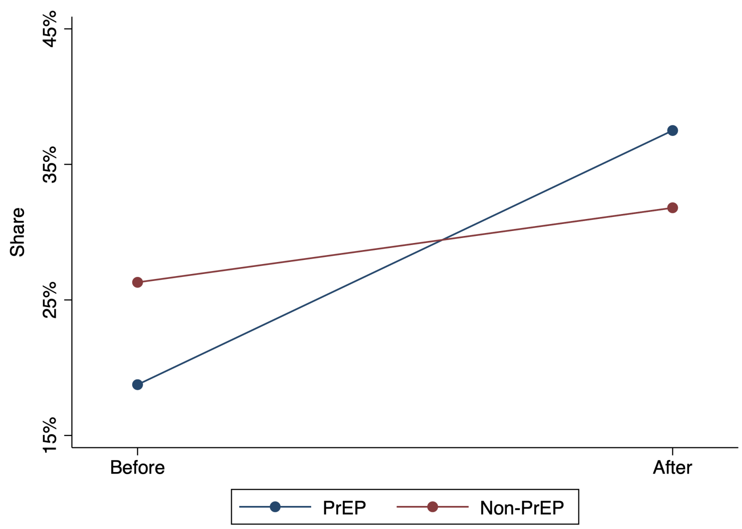

Figure 16: **Share of Respondents Who Rarely or Never Used a Condom, by PrEP Status**

Note: The figure plots the share of respondents' who responded "never" or "rarely" to the question: "How frequently did you use condoms during anal sex". For PrEP users, "before" refers to the period before starting PrEP, and the "after" refers to 2019. For non-PrEP users, "before" refers to 2016, and the "after" refers to 2019.

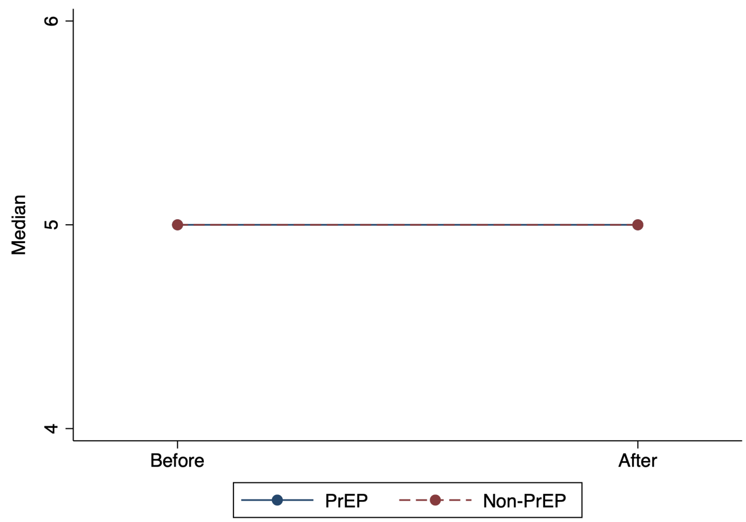

Figure 17: **Median Number of Sexual Partners, by PrEP Status**

Note: The figure plots the median number of sexual partners, by PrEP status. It is constructed from respondent's answer to the question: "With how many men have you had anal sex with?". For PrEP users, "before" refers to the period before starting PrEP, and the "after" refers to 2019. For non-PrEP users, "before" refers to 2016, and the "after" refers to 2019.

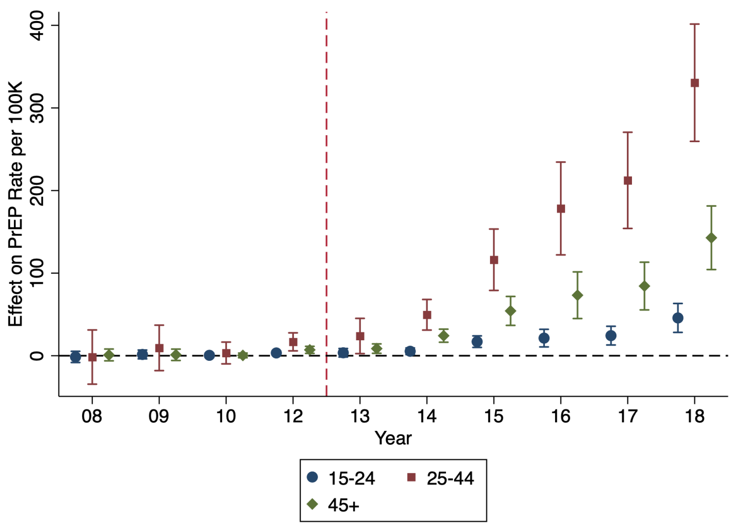

Figure 18: **Event Study - DD - PrEP Rate per 100K, by Age Group**

Note: The figure plots the event-study estimates from estimating difference-in-difference Equation (3) for men, separately for different age groups. 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.

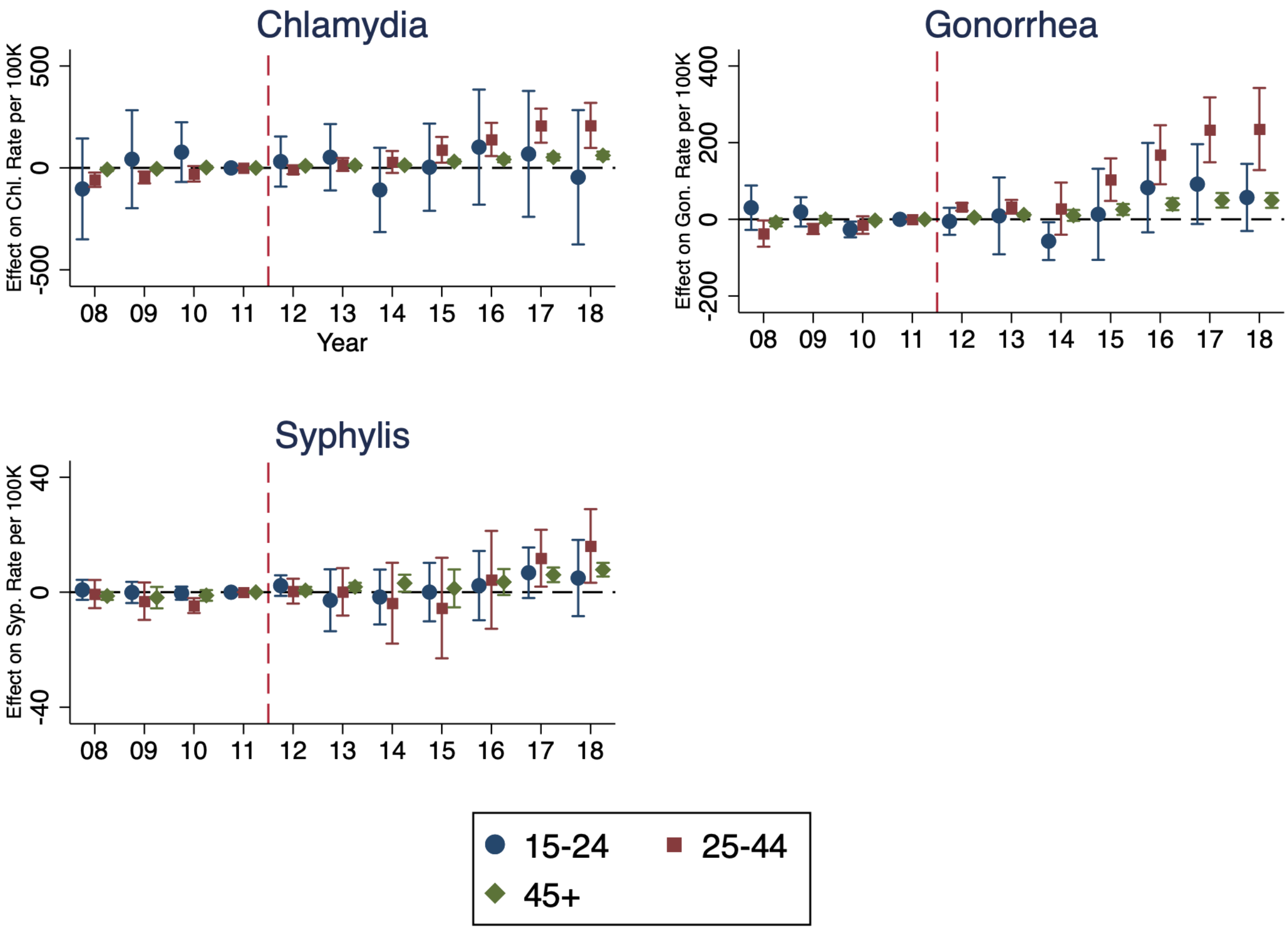

Figure 19: **Event Studies - DDD - STI Rates per 100K, by Age Group**

Note: The figure plots the event-study estimates from estimating triple-difference Equation (4) separately for different age groups. The dependent variables are the STI 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.

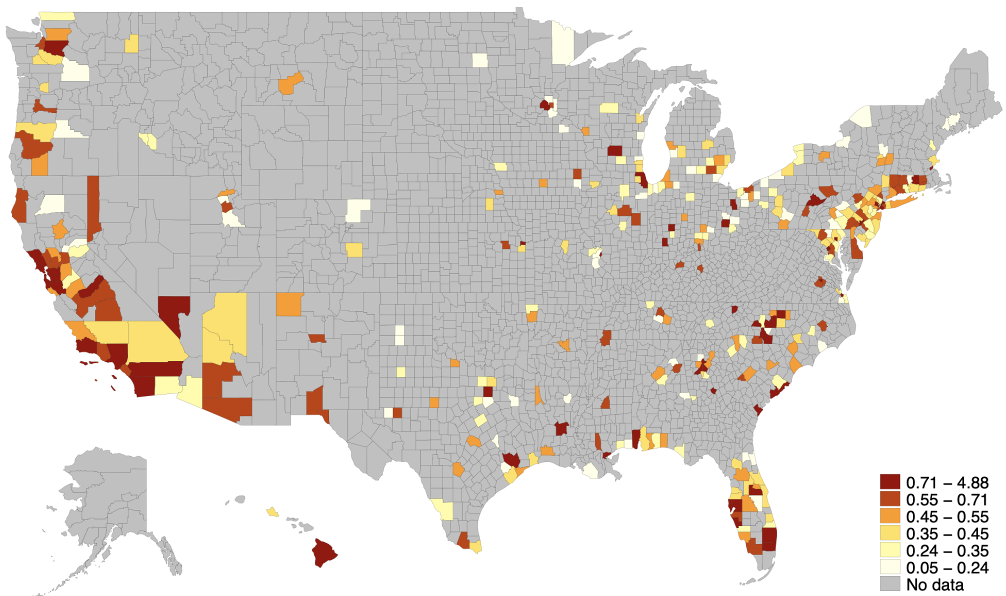

Figure 20: **Share of Partnerships That Are Male Same Sex Across Counties - 2000**

Note: The figure details the percentage share of partnerships that are male same-sex across counties, for counties included in our balanced panel; this is the measure we use to gauge each state's gay male population.

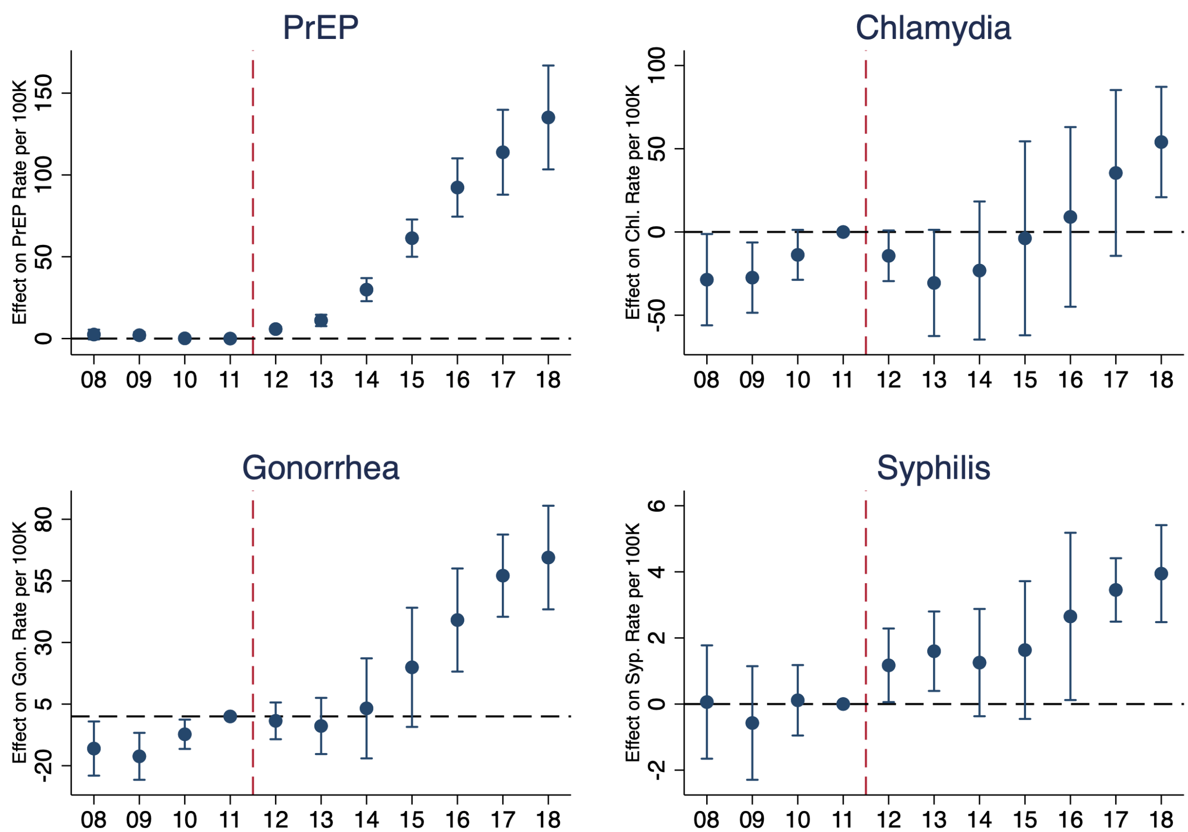

Figure 21: **County-Level Event Studies - DD - PrEP Rate per 100K and STI Rates per 100K**

Note: The figure plots the event-study estimates from estimating difference-in-difference Equation (5) separately for the different STIs. The dependent variables are the total (male and female) STI rates per 100K, since county level data is not available by gender. 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.

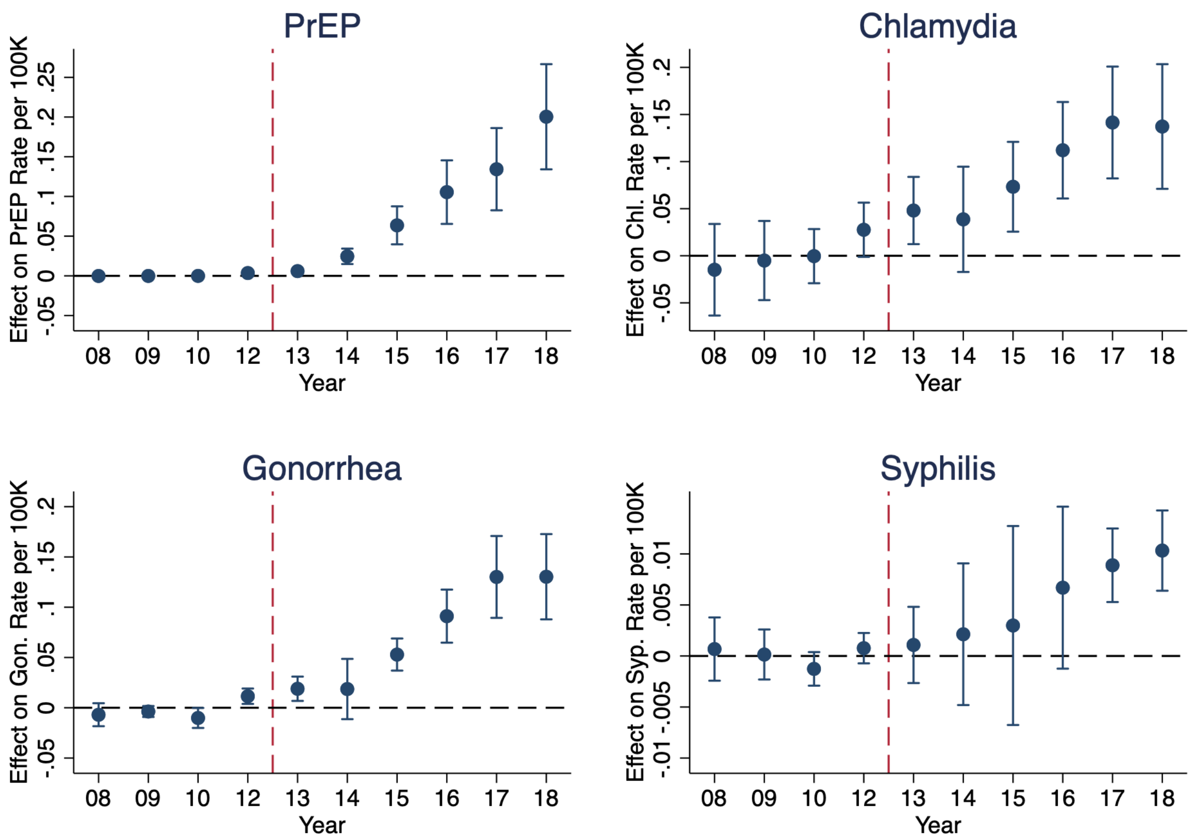

Figure 22: **HIV Prevalence Event Studies - DDD - PrEP Rate per 100K and STI Rates per 100K**

Note: The figure plots the event-study estimates from estimating triple-difference Equation (5) for PrEP and for different STIs. The dependent variables are the the PrEP rate per 10K and the STI 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.

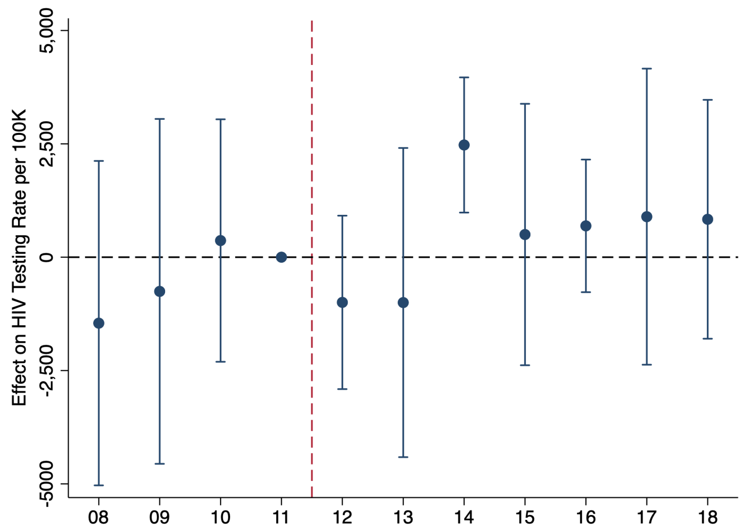

Figure 23: **Event Study - DDD - HIV Testing Rate per 100K - Last 6 Months**

Notes: The figure plots the event-study estimates from estimating Equation (4); the dependent variable is the HIV testing (in the last 6 months) rate per 100K.