

The Optimal Penalty for Sexually Transmitting HIV

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We develop an endogenous signaling model of sexual behavior and testing under risk of HIV infection to determine whether current criminal laws against exposure to HIV are efficient and to identify the socially optimal law. We consider a law to be socially optimal if it induces information revelation, so that non-fully-informed HIV transmission does not occur. We find that current HIV-specific criminal laws in the U.S., which stipulate a single penalty for knowingly exposing another individual to risk of HIV infection, are not generally socially optimal. The socially optimal law stipulates a single penalty for knowingly or unknowingly transmitting HIV, and no penalty for exposing another individual to risk of infection without transmitting the virus. The optimal expected penalty is estimated to be approximately 1-2 years of prison.

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I. Introduction

Recent evidence suggests that the HIV incidence rate in the U.S. is on the rise again (CDC, 1982-2005). There are about 40,000 new infections every year in the 33 states with confidential name-based reporting and 1.2 million people living with HIV/AIDS in the U.S. today (CDC, 2005; Glynn and Rhodes, 2005). Most cases of HIV transmission involve either unknowingly infected individuals engaging in risky behaviors or knowingly infected individuals engaging in risky behaviors with or without disclosure of status. According to estimates, at least one-third of people who have HIV (not AIDS) are not aware that they are infected (Glynn and Rhodes, 2005). In a recent sample of young men who engage in risky sexual behavior, 77% of those who tested positive were unaware that they were infected (MacKellar et al., 2005). Indeed, an individual's prior choices regarding sexual behavior and HIV testing, which may be unobservable to actual and potential partners, are associated with significant externalities that arise, in part, because sexual behavior occurs in the context of intricate sexual networks. In light of these externalities, it is crucial to craft effective public policies that involve both public health programs and statutory law. This paper considers, in particular, the role of laws on reckless criminal transmission of HIV in preventing the spread of the disease.¹

Today, 28 states have laws on criminal exposure to HIV through sexual contact. In most of these states, it is a felony to knowingly expose another person to HIV through any potentially risky sexual activity without prior disclosure of HIV status. While some studies extol the virtues of the laws, notably Grishkin (1997), several other studies criticize them. Collecting and analyzing data on prosecutions, Lazzarini, Bray, and Burris (2002) conclude that the laws have not been effective. Galletly and Pinkerton (2006) argue that the laws undermine public health

¹ See Ayres and Baker (2005) for an in-depth analysis of reckless sexual behavior.

efforts and imply that repealing them may be justified. Wolf and Vezina (2003) recommend substantial modifications to current laws, including requiring that the infected person have a specific intent to kill or injure his or her partner.

In this paper, we develop an endogenous signaling model of sexual behavior and HIV testing to determine whether current laws on criminal exposure to HIV are efficient and to identify the socially optimal law. The model we develop is characterized by several unique features. First, we assume that there is private information about HIV status. That is, a confidential or anonymous HIV test is available. Currently, all states have confidential testing, and nearly all have anonymous testing (Kaiser Family Foundation, 2005). Second, we examine the case of both unverifiable and verifiable HIV tests. When tests are unverifiable, only the person who takes the HIV test can directly observe the result. Prior to sex, it is either not possible or prohibitively costly to provide his or her partner with undisputable evidence of the test result. Third, we assume that “safe sex” is not perfectly safe, which corresponds with research on the effectiveness of condom usage (Pinkerton and Abramson, 1997; Saracco et al., 1993). Partners may choose to engage in risky sex, safe (i.e. less risky) sex, or no sex.

To simplify the model, we assume that there is only one-sided private information. Specifically, an individual who may or may not be infected with HIV, and who knows privately whether he is infected if he chooses to take an HIV test, is matched with another individual who is known by both to be uninfected. The assumption of one-sided informational asymmetry is not unrealistic for many situations. For instance, men are considerably more likely to have HIV than women. It is at least five times more likely that a man transmits HIV to a woman than a woman to a man assuming that partners are randomly selected, since many more men than women have the virus, and male-to-female transmission is more likely than female-to-male transmission

(CDC, 1982-2005; Downs and De Vincenzi, 1996; Mastro et al., 1994; Padian et al., 1997). Moreover, among gay men, one of the partners may be significantly more likely to have HIV than the other. In an extension to the basic model, we analyze the implications of two-sided informational asymmetry for our results.

In the basic model, after the potentially infected individual chooses whether to take a test to know his HIV status and is matched with his sexual partner, the two bargain over whether and how to have sex. The potentially infected individual has the option to choose no sex, in which case the game ends immediately. If the game continues, he chooses whether to propose safe or risky sex, and the other individual chooses whether to accept or reject the proposal. If the potentially infected individual knows his HIV status, his choice of whether to propose safe or risky sex may be a signal about his status. If the proposal is accepted, the partners have sex in the agreed upon way. Otherwise, the uninfected individual counter-offers safe or risky sex or chooses no sex. If the counter-proposal is accepted, the partners have sex as agreed. If the counter-proposal is rejected, the game ends with no sex.

We maintain that the socially optimal outcome involves potentially infected individuals choosing to test. Individuals who learn that they are not infected propose risky sex, which their partner accepts. Individuals who learn that they are infected either propose safe sex, which their partner accepts, or do not have sex at all. This depends on the preferences of the uninfected partner; we consider both cases. In both cases, the outcome entails testing and separation by HIV status. In this equilibrium, individuals make decisions with full information, and therefore non-fully-informed HIV transmission never occurs. Moreover, individuals who learn that they are HIV positive can receive treatment, and individuals who learn that they are HIV negative can have sex without taking precautions against HIV.

Using the signaling model, we evaluate whether or not current laws on criminal exposure to HIV can sustain the socially optimal outcome. We find that current state laws, in general, do not sustain the optimal outcome and are not efficient. The model identifies two underlying sources of inefficiency in current laws. First, the laws penalize knowing transmission and exposure equally. Therefore, when individuals choose to test, there may be insufficient incentive for the infected to choose safe sex, which may, in turn, result in an inefficient pooling equilibrium. Second, the laws penalize only knowing exposure/transmission. This may induce individuals not to test in order to have sex without punishment, which results, again, in an inefficient pooling equilibrium.

We find that the mechanism that sustains the optimal outcome involves a single penalty for knowingly or unknowingly transmitting HIV and no penalty for exposing another individual to risk of infection without transmitting the virus. Substituting known values for the model's parameters, we estimate that the optimal expected penalty roughly corresponds to 1-2 years of prison. Under the optimal expected penalty, both testing and separation occur. The penalty raises private incentives to test to the socially optimal level, since individuals are now liable for transmission whether or not they knew they were infected. Moreover, since individuals are only held accountable if HIV transmission actually occurs, the penalty raises the incentives to choose safe sex, which induces separation.

We also argue that the proposed law would be more efficient than current laws with respect to the costs of the criminal justice system, because the proposed law would be easier to enforce, and the cases that would arise would be easier to prove. In addition, the proposed law would enhance incentives to practice safer sex along many potential margins and would obviate the need to specify different penalties for different sexual practices.

We also consider two extensions of the model. First, we examine the case in which testing is verifiable and information is symmetric. That is, if the potentially infected individual takes an HIV test, both he and his partner observe the result. No private test is available. We show that either efficiency is achieved without any law, or efficiency is not achieved and current laws have no power to implement the efficient outcome. As before, the proposed law can implement the optimal outcome generally. This case helps to illustrate why, under certain circumstances, having a penalty for unknowing transmission is necessary. Second, we examine the case of two-sided informational asymmetry in which both players may be HIV positive. Here, testing is a type of Prisoner's Dilemma game. Given that one player tests, the other has less incentive to do so. This leads both players to be less likely to test, which reinforces the need for a penalty for unknowing transmission.²

A number of studies explore the economics of the HIV/AIDS epidemic in the U.S. and elsewhere (Ahituv, Hotz, and Philipson, 1996; Canning, 2006; Francis, 2008; Francis and Mialon, 2008; Mialon and Mialon, 2005; Johnson and Raphael, 2006; Kremer, 1996; Oster, 2005, 2007; Posner, 1992). Delavande, Goldman, and Sood (2007) investigate whether criminal penalties for exposure to HIV encourage individuals who know that they are infected to practice safe sex or risky sex with highly promiscuous partners. Using a nationally representative sample of infected individuals, they find that the intensity of prosecution is positively related to both the likelihood of safe sex and the likelihood of having sex with a prostitute without disclosure of infection status.

² We do not consider the repeated version of the model, and thus do not explicitly model the dynamics of disease propagation. However, under the optimal law, these dynamics are minimal, since non-fully-informed transmission does not occur. The only remaining dynamics involve fully-informed transmission, which lies outside the scope of criminal law. Thus, dynamic considerations do not bear much on the determination of the socially optimal law.

Schroeder and Rojas (2002) develop a signaling model of HIV transmission that predicts that uninfected individuals will engage in high-risk sex with potentially infected partners if the perceived rate of infection is sufficiently low, and engage in low-risk sex otherwise. The authors do not analyze laws against HIV transmission. Moreover, their model assumes that all individuals know their HIV status, and therefore does not address the issue of HIV testing. Several economists have examined HIV testing, which is a key policy issue related to laws about criminal exposure to HIV. Philipson and Posner (1995) develop a model that shows that the introduction or subsidization of testing may actually increase the HIV rate. Based on theoretical simulations, Mechoulan (2004) argues that, while the Philipson-Posner result is possible, testing becomes socially beneficial with the incorporation of altruism. The Philipson-Posner and Mechoulan models assume that testing is completely verifiable, and therefore there is no private information. Our paper departs from existing literature in that we develop a model in which individuals choose whether to learn their HIV status, and their status is not necessarily verifiable but may be signaled through sexual behavior. We also appear to be the first to employ a formal model to analyze the efficiency of laws regarding criminal exposure to HIV.

The remainder of the paper is organized as follows. Section II summarizes current state laws on criminal exposure to HIV through sexual contact. Section III describes the strategic signaling model. Section IV presents the main results. Section V extends the model to the case of verifiable testing. Section VI discusses the implications of two-sided informational asymmetry. Section VII discusses efficiency with respect to enforcement, trial, and privacy costs and issues of fairness. Section VIII concludes.

II. Current Laws

We examined state statutes and session law to compile a list of state laws on criminal exposure to HIV through sexual contact. Today, 28 states have such laws. Please see Table 1. Most of the laws are HIV-specific statutes, but some are general STD statutes. 6 states (California, Kansas, Maryland, Oklahoma, South Dakota, and Washington) have laws that criminalize exposure to HIV only when the infected person acted with the intent to infect his or her partner. Presumably, the purpose of these statutes is not to penalize reckless transmission of HIV but a specific type of murder or attempted murder. Most cases entail either unknowingly infected individuals engaging in risky behaviors or knowingly infected individuals engaging in risky behaviors with or without disclosure of status. Requiring the intent to infect, therefore, drastically limits the scope of the law. 22 states have laws that do not require intent to infect.

The penalty for criminal exposure to HIV differs markedly across state statutes. Of the 22 laws that do not require intent to infect, 7 are misdemeanors, while 15 are felonies. The penalties range from a fine of \$100 to imprisonment of up to 30 years. Furthermore, all of the statutes criminalize knowing, not unknowing, exposure or transmission. That is, the laws only apply to people who know that they are HIV positive. Nearly every law criminalizes exposure to HIV, regardless of whether transmission actually occurred. This is interesting given that even the most risky sexual activity, unprotected anal receptive sex, is associated with a per-contact transmission probability of less than one percent (Vittinghoff et al., 1999). Utah, the only state that penalizes transmission, has a general law that criminalizes the knowing introduction of an STD into “any county, municipality, or community.”

Most of the laws do not distinguish between risky and less risky sexual behaviors. Hence, most penalties are invariant to the type of sexual activity and the extent to which preventive measures are taken. While numerous sexual activities have some risk of transmission, the transmission probability varies considerably. California's statute specifies the prohibited behavior as "unprotected sex," while others designate behavior that is "probably" or "likely" to transmit HIV. Of the 22 laws, 4 (Alabama, Minnesota, Nevada, and Tennessee) exclude safer sex behaviors. Nevertheless, the statutory language in these laws remains problematic. For example, it is unclear whether even unprotected vaginal intercourse, with a 0.09% per-contact transmission probability, would qualify as behavior "probably" or "likely" to transmit HIV (Downs and De Vincenzi, 1996; Padian et al., 1997).

Many of the statutes explicitly state that disclosure of HIV status is an affirmative defense. No offense occurs if, prior to intercourse, an infected person informs his or her partner that he or she is HIV positive. This permits fully informed consensual sex. Disclosure is an affirmative defense in 17 of the 22 statutes. Disclosure or condom usage is an affirmative defense in Minnesota, while disclosure and condom usage are an affirmative defense in North Dakota. However, 5 states (Alabama, Montana, Rhode Island, Utah, and West Virginia) have laws that do not mention disclosure. These are all general STD laws in which the offense is a misdemeanor.³

Recently, a number of prosecutions and convictions for criminal exposure to HIV have occurred under state laws.^{4,5} The cases have involved exposure to HIV both with and without transmission.

³ In our view, any law relating to the reckless criminal transmission of HIV should include a provision delineating disclosure of status as an affirmative defense. Decriminalizing fully informed consensual sex is efficient and just.

⁴ See, for example, "Missouri Man Gets Life in Prison for Exposing Woman to HIV," *Associated Press News Report*, June 13, 2007; "Spreading HIV Nets Man Guilty Verdict," Aaron Bailey, *Knight Ridder Tribune Business*

In summary, most state laws make it a felony offense to knowingly expose another person to HIV through any potentially risky sexual activity without prior disclosure of HIV status, and they appear to be enforced to some degree.

III. Model

An individual, A, who may or may not be infected with HIV is matched with another individual, B, who is known by both individuals to be uninfected. At time 1, Nature begins by choosing whether A is infected with HIV. Define

p = probability that A is *not* infected with HIV,

where $p \in (0,1)$. At time 2, not knowing whether he is infected, A chooses whether to take a test to privately learn his HIV status.

News, Washington, May 3, 2007, p. 1; "Man with HIV Gets Prison: He Didn't Tell Sex Partners; Victims not HIV Positive," Taryn Brodwater, *Knight Ridder Tribune Business News*, Washington, June 2, 2006, p. 1; "Atlanta: Arrest Puts Gay Community on Edge," *Associated Press News Report*, July 16, 2005; "The Nation: Man Gets 3 Years in HIV Exposures," *Los Angeles Times*, California, November 18, 2004, p. A.30; "HIV/AIDS Exposure; Man Charged with Exposing Women to HIV," *Women's Health Weekly*, Atlanta, November 18, 2004, p. 87; "Man Convicted of Transmitting HIV Asks for Reduced Sentence," *Virus Weekly*, Atlanta, Jul 27, 2004, p. 60.; "Jury Finds Iowa City Man Guilty of Criminal Transmission of HIV," *Virus Weekly*, Atlanta, Feb 10, 2004, p. 31; "HIV Infection on Trial," *The Advocate*, Los Angeles, Oct 28, 2003, p. 16; "Woman Charged for Infecting Ex-boyfriend with HIV," *Miami Times*, Miami, Florida, Jul 16-Jul 22, 2003, Vol. 80, No. 45, p. 2.D; "The Nation: Teen Guilty of Exposing Sex Partner to HIV," *Los Angeles Times*, California, Jul 12, 2002, p. A.22; "Big HIV Problem Hits Small S.D. College Town," Megan Garvey, *Los Angeles Times*, California, Apr 27, 2002, p. A.14; "After Arrest, Campus Queues for HIV Tests," John Fountain, *New York Times*, New York, NY, May 1, 2002., p. A.16.

⁵ In the *CDC HIV/Hepatitis/STD/TB Prevention News Update*, 2002-2003, from the U.S. Centers for Disease Control and Prevention (see website <http://www.cdcnpi.org/scripts/index.asp>), the following cases are reported: "Iowa: Dahlberg Sentenced to Probation for Criminal Transmission of HIV," March 31, 2003; "South Dakota: Man Sentenced for Violating Probation on Exposure Sentence," October 2, 2002; "California: Prosecutor Seeks Lengthy Prison Term for HIV-Infected Woman," July 23, 2002; "New York: Man Sentenced to Probation for Infecting Wife With HIV," July 19, 2002; "Louisiana: Man Booked With Exposing Woman to AIDS Virus," May 24, 2002; "Florida: HIV Patient Could Get Prison Time," May 20, 2002; "Missouri Lawmakers Pass Bill Toughening HIV Laws," May 20, 2002; "Michigan: HIV-Positive Man Sentenced for Having Sex With Uninformed Partner," June 14, 2002; "Long Island Man Pleads Guilty to Passing On HIV," May 28, 2002.

We assume that the HIV test is perfect. In reality, there is a window of time between transmission and the point at which testing becomes effective. However, with modern nucleic amplification testing, this window is only 8 to 13 days (Stramer, Caglioti, and Strong, 2000). Moreover, estimated false-negative and false-positive rates in the general population are 0.0016% and 0.0004%, respectively (Kleinman *et al.*, 1998, and Busch, 1991).

Regardless of whether or not he is infected, A may incur a cost to take the HIV test. Besides any monetary expenses, he may have a high value of time or a fear of needles. Define

$c = A$'s cost of taking the HIV test in terms of money, time, and discomfort,

where $c > 0$. Note that c is likely to be low since modern HIV tests are affordable, accessible, and minimally invasive.⁶

In addition, if A is infected, it may be emotionally costly to find out his status and live with the fear of falling ill and dying. On the other hand, A may derive a benefit from knowing his HIV status if he is HIV positive, since he can then seek treatment, which may delay the onset of AIDS and increase his life expectancy. Define

$b = A$'s net benefit from knowing his HIV status when he is HIV positive,

where b could be positive or negative. Define $k \equiv b - c / (1 - p)$. Then, $(1 - p)k$ is the expected net benefit of testing in terms of treatment and direct costs.

⁶ Indeed, the FDA recently approved OraSure, a 20-minute HIV test that is administered orally and costs \$15 ("F.D.A. Approves OraSure Test," *New York Times*, March 27, 2004).

A knows whether he is infected if and only if he tests. We also assume that tests are unverifiable; only the person who takes the HIV test can directly observe the result. Prior to sex, it is either not possible or prohibitively costly to provide his or her partner with undisputable evidence of the test result.⁷

At time 3, A and B are matched and start bargaining over whether and how to have sex. A has the option to choose no sex from the start, in which case the game ends immediately. If A chooses to have sex, then A either proposes safe sex or risky sex. Not knowing whether A is infected, and not knowing whether A knows whether he is infected, B then accepts or rejects A's proposal. If B accepts A's proposal, the partners have sex in the agreed upon way, and the game ends. If B rejects A's initial proposal of risky (safe) sex, then B counter-offers safe (risky) sex or chooses no sex. If B chooses no sex, the game ends immediately with no sex. If B counter-offers, then at time 4, A chooses whether to accept or reject B's counter-offer. If A accepts B's counter-offer, A and B have sex in the agreed upon way, and the game ends. If A rejects B's counter-offer, then the game ends with no sex. We normalize the benefit from no sex to 0. Define

r = A and B's benefit from risky sex, and

s = A and B's benefit from safe sex,

where $r > s > 0$. Rejecting a proposal or having a proposal rejected, which results in an extra round of bargaining, may entail an embarrassment or time cost. Define

h = A and B's cost of an extra round of bargaining over whether and how to have sex,

⁷ In this case, verbal disclosure of HIV status is "cheap talk." However, actual behavior can still signal infection status in equilibrium. We analyze the case where testing is verifiable in Section V.

where $h > 0$. If A is infected with HIV, and A and B decide to have sex, then A may transmit HIV to B. The likelihood of transmission is lower if A and B decide to have safe sex than if they decide to have risky sex. Define

z = probability of getting HIV through risky sex, and

q = probability of getting HIV through “safe” sex,

where $z, q \in (0,1)$ and $z > q$. If B gets HIV, then B suffers a large cost in terms of loss of life.

Define

d = B’s cost of getting HIV,

where $d > 0$. If A exposes B to risk of getting HIV or actually transmits HIV to B, then A might face a criminal penalty. Define

α = A’s probability of apprehension if A exposes B to risk of infection and infects B,

β = A’s probability of apprehension if A exposes B to risk of infection but does not infect B,

where $\alpha, \beta \in (0,1)$ and $\alpha \geq \beta$. Define

f_1 = A’s penalty if A knowingly exposes B to risk of infection and infects B,

f_2 = A’s penalty if A knowingly exposes B to risk of infection but does not infect B,

f_3 = A's penalty if A unknowingly exposes B to risk of infection and infects B,

f_4 = A's penalty if A unknowingly exposes B to risk of infection but does not infect B.

Under current laws, $f_1 = f_2$ and $f_3 = f_4 = 0$.

IV. Optimal Law

We maintain that the socially optimal outcome involves (1) A testing, A proposing risky sex if he tests negative, and either proposing safe sex or choosing no sex if he tests positive, and (2) B accepting if A proposes risky sex, and either accepting or rejecting and having no sex if A proposes safe sex. This outcome entails testing and separation by HIV status, so non-fully-informed HIV transmission never occurs.

If B knows that A is infected, B is better off having safe sex than rejecting safe sex and having no sex with A if and only if $qd < s + h$, i.e., the expected cost of getting HIV from safe sex is small relative to the benefit from safe sex plus the cost of rejecting. We assume that if $qd < s + h$, then the socially optimal outcome involves A proposing safe sex if he tests positive and B accepting, and if $qd > s + h$, the optimal outcome involves A choosing no sex if he tests positive. In each case, we derive conditions for the optimal outcome to be implemented by a perfect Bayesian equilibrium (PBE) of the game.

Proposition 1. If $qd < s + h$, the socially optimal outcome is implemented by a PBE iff one of the following three sets of conditions holds:

- (1) $r - s > (1 - p)(z - q)(\alpha f_3 - \beta f_4)$, $r > (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$, $r - s < (z - q)(\alpha f_1 - \beta f_2)$,
 $s > q\alpha f_1 + (1 - q)\beta f_2$, and $r - s < z\alpha f_3 + (1 - z)\beta f_4 - q\alpha f_1 - (1 - q)\beta f_2 + k$.
- (2) $r - s < (1 - p)(z - q)(\alpha f_3 - \beta f_4)$, $s > (1 - p)(q\alpha f_3 + (1 - q)\beta f_4)$, $r - s < (z - q)(\alpha f_1 - \beta f_2)$,
 $s > q\alpha f_1 + (1 - q)\beta f_2$, and $p(r - s) > (1 - p)(q\alpha(f_1 - f_3) + (1 - q)\beta(f_2 - f_4) - k)$.
- (3) $r < (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$, $s < (1 - p)(q\alpha f_3 + (1 - q)\beta f_4)$, $r - s < (z - q)(\alpha f_1 - \beta f_2)$,
 $s > q\alpha f_1 + (1 - q)\beta f_2$, and $p(r) + (1 - p)(s + k - q\alpha f_1 - (1 - q)\beta f_2) > 0$.

Proof. See Mathematical Appendix.

The three sets of conditions are distinguished by what choice A makes off the equilibrium path. If A does not test, he offers risky sex in (1), safe sex in (2), and no sex in (3). The first two conditions in each set determine what A does off the equilibrium path. For example, in (1), the first condition specifies that if A does not test, he prefers risky to safe sex. The second condition specifies that if A does not test, he prefers risky to no sex. The third and fourth conditions are common across (1), (2), and (3). They induce A to make the socially optimal choice if he learns that he is infected. Specifically, the third condition guarantees that A prefers to offer safe sex to risky sex if he tests positive, while the fourth guarantees that he prefers to offer safe sex to no sex if he tests positive. The fifth condition in each set encapsulates the testing decision. In (1), the condition specifies that if A chooses risky sex if he does not test, then he prefers to test than not test. If all of the conditions associated with any one of the three sets hold, the socially optimal outcome is achieved.

Under current laws, $f_1 = f_2$ and $f_3 = f_4 = 0$.

Corollary 1. Suppose $qd < s + h$, $f_1 = f_2$, and $f_3 = f_4 = 0$. Then the socially optimal outcome cannot be achieved if $k < r - s$. If $k > r - s$, the socially optimal outcome can be achieved iff

$$\frac{r - s}{(z - q)(\alpha - \beta)} < f_1 < \min\left\{\frac{k - (r - s)}{q\alpha + (1 - q)\beta}, \frac{s}{q\alpha + (1 - q)\beta}\right\}.$$

Proof. See Mathematical Appendix.

According to this result, current laws may or may not be able to implement the socially optimal outcome in the case in which B is willing to have safe sex with A if B knows that A is infected. In (1), if $k < r - s$, there is no way to make A test without penalties for unknowing exposure/transmission. If $k > r - s$, current laws may sustain the optimal outcome, but this requires that the difference between α and β be sufficiently large. In this case, A wants to test, because the marginal benefit of testing is larger than the benefit from risky sex, which is what A would receive if he were not to test. If he tests positive, knowing penalties induce him to choose safe over risky sex only if the probability of apprehension for transmission is large relative to the probability of apprehension for exposure without transmission. If the difference between α and β is not large enough, the range within which the penalty is optimal does not exist, since, as the difference tends to zero, the lower bound on the range tends to infinity, and the upper bound remains finite. In this case, it is not possible to induce A to offer safe over risky sex if he tests positive.

To illustrate how the spread between α and β relates to the existence of the range bounding the optimal penalty assuming that $k > r - s$, we estimate the size of the bounds for various parameter values. Assume that $r = \$100$, $s = \$50$, $p = 0.99$, $z = 0.0009$, and $q =$

0.05*0.0009 (the condom failure rate is 0.05).⁸ If, for example, $\alpha = 0.25$ and $\beta = 0.01$, $\alpha = 1.00$ and $\beta = 0.01$, or $\alpha = 0.10$ and $\beta = 0.0001$, then the range does not exist. If $\alpha = 0.10$ and $\beta = 0.00001$, the range exists. Thus, the spread between the two probabilities of apprehension must be high in order to implement the optimal outcome under current laws.

In (2), if A does not test (which is off the equilibrium path), it is not possible to get him to choose safe over risky sex, since there is no penalty for unknowing transmission. In (3), if A does not test (which is off the equilibrium path), it is not possible to get him to choose no sex over safe or risky sex, since there are no penalties for unknowing exposure/transmission.

Essentially, current laws have two basic sources of inefficiency. First, penalties for knowing transmission and exposure are the same, which becomes problematic when the probabilities of apprehension, α and β , are sufficiently close. Second, there are no penalties for unknowing exposure/transmission.

Under our proposed law, $f_1 = f_3$ and $f_2 = f_4 = 0$.

Corollary 2. If $qd < s + h$, $f_1 = f_3$, and $f_2 = f_4 = 0$, then the socially optimal outcome can be

achieved iff $\max\left\{\frac{r-s}{(z-q)}, \frac{r-s-k}{(z-q)}\right\} < \alpha f_1 < \min\left\{\frac{r-s}{(1-p)(z-q)}, \frac{s}{q}\right\}$, or $\frac{r-s}{(1-p)(z-q)} < \alpha f_1 < \frac{s}{q}$

when $k > \frac{-p(r-s)}{(1-p)}$.

Proof. See Mathematical Appendix.

⁸ Less than one percent of sexually active men in the U.S. have HIV/AIDS (CDC 2005). The per-contact probability of male-to-female HIV transmission through unprotected vaginal sex is about 0.09% (Downs and De Vincenzi, 1996; Padian et al., 1997). Condoms are about 90-95% effective against heterosexual transmission of HIV (Pinkerton and Abramson 1997; Saracco et al. 1993).

Generally, the proposed law can implement the socially optimal outcome in the case that B is willing to have safe sex with A if B knows that A is infected. Relative to current laws, the proposed law has two key features. First, it penalizes transmission of HIV, not exposure. Second, it penalizes both knowing and unknowing transmission.

To achieve optimality, the expected penalty for knowing and unknowing transmission must lie within one of the two ranges in Corollary 2. If $k > 0$, the lower bound of the first range stipulates that the expected penalty must be greater than $(r - s)/(z - q)$ so that A proposes safe sex if he knows that he is infected. Because the penalty for unknowing transmission is the same as the penalty for knowing transmission, this also guarantees that A chooses to test. If $k < 0$, the lower bound of the first range stipulates that the expected penalty must be greater than $(r - s - k)/(z - q)$ so that A chooses to test. Because the penalty for unknowing transmission is the same as the penalty for knowing transmission, this also guarantees that A proposes safe sex if he knows that he is infected. The upper bound of the first range stipulates that the expected penalty must be smaller than s/q . If the penalty is too high, then if A tests and learns that he is infected, he would not want to propose safe sex and instead would want to choose no sex.

Optimality can be achieved by placing the expected penalty within the second range in Corollary 2 only if $k > -p(r - s)/(1 - p)$. If k is too negative, it is not possible to induce A to test by placing the penalty within this range. If k is not too negative, it is possible to do so. The lower bound on the second range stipulates that the expected penalty must be greater than $(r - s)/(1 - p)(z - q)$. This ensures that if A tests and learns that he is infected, then he chooses safe over risky sex. The upper bound on the second range stipulates that the expected penalty must be smaller than s/q . Once again, if the penalty is too high, then if A tests and learns that he is infected, he would not want to propose safe sex and instead would want to choose no sex.

The first range that bounds the socially optimal penalty exists as long as k is not very negative, and $qr < sz$, which is reasonable. The latter condition stipulates that the condom failure rate be less than the ratio of s to r . Assuming that the condom failure rate is 0.05, the condition is satisfied as long as the benefit of risky sex is less than 20 times the benefit of safe sex. Substituting estimated values for the theoretical parameters, we can place numerical bounds on the optimal expected penalty. Assume, as before, that $r = \$100$, $s = \$50$, $p = 0.99$, $z = 0.0009$, and $q = 0.05 \cdot 0.0009$. Using the first range to calculate the lower bound and assuming that $k > 0$, the lower bound is \$58,480.

We now turn to the case where $s + h < qd$, i.e., B is not willing to have safe or risky sex with A if B knows that A is infected. In this case, we assume that the socially optimal outcome involves A testing and choosing no sex if he is infected and proposing risky sex if he is uninfected, and B accepting if A proposes risky sex. In any PBE implementing this optimal outcome, proposing safe sex is off the equilibrium path. To ensure that B's off-equilibrium-path beliefs are reasonable, we derive conditions for the optimal outcome to be implemented by a PBE surviving iterative elimination of equilibrium dominated strategies, i.e., satisfying the Intuitive Criterion (Cho and Kreps, 1987).

Proposition 2. Assume $s + h < qd < \frac{s+h}{1-p}$.

If $s > q\alpha f_1 + (1-q)\beta f_2$, the socially optimal outcome is implemented by a PBE satisfying the Intuitive Criterion iff one of the following two sets of conditions holds:

- (i) $r > (1-p)(z\alpha f_3 + (1-z)\beta f_4)$, $r < z\alpha f_1 + (1-z)\beta f_2$, and $r < z\alpha f_3 + (1-z)\beta f_4 + k$.
- (ii) $r < (1-p)(z\alpha f_3 + (1-z)\beta f_4)$, $r < z\alpha f_1 + (1-z)\beta f_2$, and $pr + (1-p)k > 0$.

If $s < q\alpha f_1 + (1-q)\beta f_2$, the socially optimal outcome is implemented by a PBE satisfying the Intuitive Criterion iff one of the following three sets of conditions holds:

(iii) $r - s > (1-p)(z-q)(\alpha f_3 - \beta f_4)$, $r > (1-p)(z\alpha f_3 + (1-z)\beta f_4)$, $r < z\alpha f_1 + (1-z)\beta f_2$, and
 $r < z\alpha f_3 + (1-z)\beta f_4 + k$.

(iv) $r - s < (1-p)(z-q)(\alpha f_3 - \beta f_4)$, $s > (1-p)(q\alpha f_3 + (1-q)\beta f_4)$, $r < z\alpha f_1 + (1-z)\beta f_2$, and
 $p(r-s) > (1-p)(s - q\alpha f_3 - (1-q)\beta f_4 - k)$.

(v) $r < (1-p)(z\alpha f_3 + (1-z)\beta f_4)$, $s < (1-p)(q\alpha f_3 + (1-q)\beta f_4)$, $r < z\alpha f_1 + (1-z)\beta f_2$ and,
and $pr + (1-p)k > 0$.

Proof. See Mathematical Appendix.

In an equilibrium implementing the social optimum in this case, if A is uninfected, he proposes risky sex, and B accepts. If A were to deviate to proposing safe sex, his payoff would be strictly lower whether or not B would accept safe sex. Thus, if A is uninfected, proposing safe sex is equilibrium dominated. In contrast, if A is infected, he may or may not do better if he were to propose safe sex. If $s > q\alpha f_1 + (1-q)\beta f_2$, A would be better off deviating from choosing no sex to proposing safe sex if B were to accept safe sex, so proposing safe sex is not equilibrium dominated. Thus, in an equilibrium implementing the social optimum and satisfying the Intuitive Criterion, B would believe that A is infected if he were to propose safe sex, and therefore would reject safe sex since $s + h < qd$. Sets of conditions (i) and (ii) sustain the social optimum when A would prefer safe sex to no sex if he learned that he is infected and B were to accept safe sex.

If instead $s < q\alpha f_1 + (1-q)\beta f_2$, A would not find it profitable to deviate to proposing safe sex if he learned that he is infected and B were to accept safe sex. In this case, proposing

safe sex is not equilibrium dominated, whether A learns that he is infected or uninfected. B then understands that, in this situation, if A were to propose safe sex, it does not necessarily signify that A is infected. In an equilibrium satisfying the Intuitive Criterion, B believes that A is not infected with probability p and is infected with probability $1-p$ if A proposes safe sex. Given these beliefs, B accepts safe sex off the equilibrium path, since $qd < (s+h)/(1-p)$. Sets (iii), (iv), and (v) sustain the social optimum when A would prefer no sex to safe sex if he learned that he is infected and B were to accept safe sex.

The first condition in (i) and (ii) specifies what A does off the equilibrium path. If he does not test, A prefers risky to no sex in (i), whereas he prefers no sex to risky sex in (ii). If A does not test, he always prefers no sex to safe sex, because safe sex would be rejected by B if it were proposed. The two sets have the second condition in common. It guarantees that A chooses to offer no sex over risky sex if he finds out that he is infected. If A tests, he always prefers no sex to safe sex, because, again, safe sex would be rejected by B if it were proposed. The third condition induces A to test. In (i), if A proposes risky sex if he does not test, then he prefers to test than not test.

Likewise, the first two conditions in (iii), (iv), and (v) relate to what A does off the equilibrium path. For example, in (iii), the first specifies the conditions under which A prefers risky to safe sex if he does not test, while the second specifies the conditions under which A prefers risky to no sex if he does not test. The third condition is common across (iii), (iv), and (v). It guarantees that A chooses no sex over risky sex if he finds out that he is positive. As we have already mentioned, he prefers to choose no sex over proposing safe sex. The fourth condition induces A to test. In (iii), the condition specifies that if A chooses risky sex if he does not test, then he prefers to test than not test.

Corollary 3. If $s + h < qd < \frac{s+h}{1-p}$, $f_1 = f_2$, and $f_3 = f_4 = 0$, then the socially optimal outcome

cannot be achieved if $r > k$. If $r < k$, then the socially optimal outcome can be achieved iff

$$\frac{r}{z\alpha + (1-z)\beta} < f_1.$$

Proof. See Mathematical Appendix.

According to this result, current laws may or may not be able to implement the socially optimal outcome in the case in which B is not willing to have safe or risky sex with A if B knows that A is infected. First, suppose that, under current laws, A would prefer safe to no sex if he tested positive, and B would accept safe sex. In (i), if $r > k$, there is no way to make A test without penalties for unknowing exposure/transmission. However, if $r < k$, current laws may be sufficient to sustain the optimal outcome, but this requires that the difference between α and β be sufficiently large. Otherwise, if A tests positive, it is not possible to induce him to choose no sex over risky sex, because he prefers safe to no sex (if safe sex were accepted), and penalties for knowing transmission and exposure are identical under current laws. In (ii), if A does not test (which is off the equilibrium path), it is not possible to induce him to choose no sex over risky sex, since there are no penalties for unknowing exposure/transmission.

Now, suppose that, under current laws, A would prefer no sex to safe sex if he tested positive, and B would accept safe sex. In (iii), if $r > k$, there is no way to make A test without penalties for unknowing exposure/transmission. However, if $r < k$, then current laws may be sufficient to sustain the optimal outcome. A wants to test, because the marginal benefit of treatment is larger than the benefit from risky sex. If he tests positive, knowing penalties can be

sufficient to induce him to choose no sex over both safe and risky sex. In (iv), if A does not test (which is off the equilibrium path), it is not possible to induce him to prefer safe over risky sex, since there is no penalty for unknowing transmission. Also, if k is sufficiently small, A will not want to test, since there are no penalties for unknowing exposure/transmission. In (v), if A does not test (which is off the equilibrium path), A will not choose no sex over risky sex without penalties for unknowing exposure/transmission.

In short, it is easier to achieve separation when B is not willing to have any type of sex with A when B knows A is infected. In this situation, current laws may support the optimal outcome, but only if k is sufficiently high.

Corollary 4. If $s + h < qd < \frac{s+h}{1-p}$, $f_1 = f_3$, and $f_2 = f_4 = 0$, then the socially optimal outcome

can be achieved iff $\max\{\frac{r}{z}, \frac{r-k}{z}\} < \alpha f_1 < \min\{\frac{r}{(1-p)z}, \frac{s}{q}\}$.

Proof. See Mathematical Appendix.

The proposed law can generally achieve optimality. It does so if the expected penalty for knowing and unknowing transmission lies within the range specified in Corollary 4. If $k > 0$, the lower bound of this range stipulates that the expected penalty must be greater than r/z so that A proposes no sex instead of risky sex if he knows that he is infected. This also guarantees that A chooses to test. If $k < 0$, the lower bound in the first range stipulates that the expected penalty must be greater than $(r-k)/z$ so that A chooses to test. This also guarantees that A proposes no sex if he knows that he is infected. The range in Corollary 4 exists as long as k is not very negative, and $qr < sz$, which is reasonable (see the discussion following Corollary 2). Assuming

that $r = \$100$, $s = \$50$, $p = 0.99$, $z = 0.0009$, and $q = 0.05 \cdot 0.0009$, the lower bound of the range is \$111,111.

According to Corollaries 2 and 4, optimality can be achieved under the proposed law by setting the expected penalty for knowing and unknowing transmission greater or equal to $(r-s)/(z-q)$ if $qd < s+h$, and greater or equal to r/z if $qd > s+h$. Since r/z is the higher of the two lower bounds, optimality can be achieved across both these parameter ranges by setting the expected penalty for knowing and unknowing transmission equal to r/z , which we computed above to be \$111,111. This roughly corresponds to an expected penalty of 1-2 years in prison assuming that each year incarcerated is equivalent to a monetary fine of about \$50,000-100,000. Thus, the model suggests that the overall optimal law should stipulate an expected penalty of 1-2 years of prison for knowing and unknowing transmission of HIV and no expected penalty for exposure without transmission.

V. Verifiable Testing and Symmetric Information

In this subsection, we examine the case in which testing is verifiable and information is symmetric. No private test is available to A. However, A can take a test, and both A and B observe the result. Here we assume that the optimal outcome involves A testing, proposing risky sex if uninfected, which B accepts, and choosing no sex if infected.

Proposition 3. If $qd < \frac{s+h}{1-p}$ and $zd < \frac{r+h}{1-p}$, the socially optimal outcome is implemented by a

PBE iff one of the following three sets of conditions holds:

(a) $r - s > (1 - p)(z - q)(\alpha f_3 - \beta f_4)$, $r > (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$, and

$$r < z\alpha f_3 + (1 - z)\beta f_4 + k,$$

(b) $r - s < (1 - p)(z - q)(\alpha f_3 - \beta f_4)$, $s > (1 - p)(q\alpha f_3 + (1 - q)\beta f_4)$, and

$$p(r - s) > (1 - p)(s - q\alpha f_3 - (1 - q)\beta f_4 - k),$$

(c) $r < (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$, $s < (1 - p)(q\alpha f_3 + (1 - q)\beta f_4)$, and $pr + (1 - p)k > 0$.

If $qd < \frac{s+h}{1-p}$ and $zd > \frac{r+h}{1-p}$, the socially optimal outcome is implemented by a PBE iff one of

the following two sets of conditions holds:

(d) $s > (1 - p)(q\alpha f_3 + (1 - q)\beta f_4)$ and $p(r - s) > (1 - p)(s - q\alpha f_3 - (1 - q)\beta f_4 - k)$,

(e) $s < (1 - p)(q\alpha f_3 + (1 - q)\beta f_4)$ and $pr + (1 - p)k > 0$.

If $qd > \frac{s+h}{1-p}$ and $zd < \frac{r+h}{1-p}$, the socially optimal outcome is implemented by a PBE iff one of

the following two sets of conditions holds:

(f) $r > (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$ and $r < z\alpha f_3 + (1 - z)\beta f_4 + k$,

(g) $r < (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$ and $pr + (1 - p)k > 0$.

If $qd > \frac{s+h}{1-p}$ and $zd > \frac{r+h}{1-p}$, the socially optimal outcome is always implemented by a PBE.

When testing is verifiable, and there is no private information, there is no need to induce A to choose no sex if he tests positive, since B directly observes the result of the HIV test. Furthermore, penalties for knowing exposure/transmission are unnecessary, because it will never occur. In (a), (b), and (c), B prefers to accept safe or risky sex than reject and have no sex when A does not test. The first two conditions determine what A does off the equilibrium path. If A

does not test, he offers risky sex in (a), safe sex in (b), and no sex in (c). The third condition induces A to test given his decision off the equilibrium path.

In (d) and (e), B prefers to accept safe sex than reject and have no sex but prefers to reject and have no sex than accept risky sex when A does not test. Thus, B rejects risky sex off the equilibrium path. The first condition specifies whether A chooses to offer safe sex (d) or have no sex (e) when he does not test. The second condition guarantees that A prefers to test than not test. In (f) and (g), B prefers to accept risky sex than reject and have no sex but prefers to reject and have no sex than accept safe sex when A does not test. Thus, B rejects safe sex off the equilibrium path. The first condition specifies whether A chooses to offer risky sex (f) or have no sex (g) when he does not test. The second condition guarantees that A prefers to test than not test. Lastly, B may prefer to reject both safe and risky sex and have no sex when A does not test. In this situation, laws are never needed to implement the optimal outcome. It is always optimal for A to test, and since B directly observes the test result, the optimal outcome is easily achieved.

Corollary 5. None of the conditions implementing the socially optimal outcome include f_1 or f_2 . Thus, if $f_3 = f_4 = 0$, then none of the conditions include any legal parameters. Hence, either efficiency is achieved without any law or efficiency is not achieved and the current laws have no power to implement the efficient outcome.

Corollary 6. Suppose $f_1 = f_3$, and $f_2 = f_4 = 0$. If $zd < \frac{r+h}{1-p}$, the socially optimal outcome can

be achieved with $\frac{r-k}{z} < \alpha f_1 < \min\left\{\frac{r}{(1-p)z}, \frac{r-s}{(1-p)(z-q)}\right\}$. If $zd > \frac{r+h}{1-p}$, the socially optimal

outcome can be achieved with $\frac{-p(r-s) + (1-p)(s-k)}{q(1-p)} < \alpha f_1 < \frac{s}{(1-p)q}$ or $\alpha f_1 > \frac{s}{(1-p)q}$.

When testing is verifiable and information is symmetric, the lower bound on the penalty is similar in size to the lower bound associated with previous cases if B is willing to have risky sex if A does not test, but it is much higher if B is only willing to have safe sex if A does not test. Because A is only punished for transmission, and has safe sex if he does not test, the penalty for transmission must be high to induce him to test since the probability that A both is infected and transmits the infection through safe sex is low. In general, this case helps to illustrate why, under certain circumstances, having a penalty for unknowing transmission is necessary to implement the optimal outcome.

VI. Two-Sided Informational Asymmetry

In the basic model, we assumed that the potential informational asymmetry is one-sided. In particular, we assumed that player A is always certain that player B is uninfected, while player B is at least initially uncertain about whether A is infected. We now discuss informally what happens when this assumption is relaxed. Now both players are at least initially uncertain about whether the other is infected. They simultaneously choose whether to test and then bargain over whether and how to have sex. During the bargaining, they choose whether to propose or counter-

propose safe or risky sex, and their choices are a signal about whether they are infected only if they chose to test. If the players reach agreement, they have sex in the agreed-upon way, and otherwise, they do not have sex.

The outcome that society may be interested in sustaining is the one in which both players test; each player proposes or counter-proposes safe sex if he or she tests positive; each player proposes or counter-proposes risky sex if he or she tests negative; the players either have no sex or agree to have safe sex if one of them proposed or counter-proposed safe sex; and the players agree to have risky sex if both of them proposed or counter-proposed safe sex or both of them proposed or counter-proposed risky sex.

This outcome is sustained only if it is unprofitable for either player to unilaterally deviate to not testing. If player i deviates to not testing while player j continues to test and separate by type, where $i, j \in \{A, B\}$ and $i \neq j$, then i can choose to agree to safe or risky sex with full information about whether j is infected. If j is infected, i can choose no sex or safe sex to minimize the risk of acquiring the infection if he is not already infected. If j is uninfected, i can choose risky sex knowing for certain that he will not acquire a new infection from j . This makes not testing an attractive unilateral deviation for i . Moreover, such a deviation by i can be harmful to j , since it can result in j being unknowingly infected by i . Thus, in this case, a penalty for unknowing transmission is still required to sustain the socially optimal outcome just as in the case in which the potential informational asymmetry is one-sided.

Indeed, in the case where the potential informational asymmetry is two-sided, it may be even more important to impose a penalty for unknowing transmission, because the players may face a Prisoners' Dilemma in testing. If player j tests and separates by type, player $i \neq j$ may have incentive to deviate unilaterally to not testing since i might then be able to have risky sex

without worrying about being infected by j . Thus, both players may end up not testing even though they might both be better off if they both tested and separated by type, in which case both could make a full information decision. While player i may derive a private benefit from testing if he turns out to be infected, player j also benefits from i 's testing, as well as all the future partners of both players, their future partners, and so on. That is, testing is a public good, which is likely to be underprovided. Current laws, which only punish for knowing transmission, discourage testing and only make matters worse. A law that includes a punishment for unknowing as well as knowing transmission reduces the disincentives to test and, therefore, makes the problem of underprovision of testing less severe.

VII. Discussion

A. Enforcement and Trial Costs

In addition to implementing the optimal outcome in the game theoretic model, the proposed law would have further advantages. The proposed law would likely be more efficient than current laws with respect to the costs of the criminal justice system. It would be much more costly to enforce current laws as written than to enforce the proposed law, since, presumably, uncovering cases of exposure without transmission is much more difficult than uncovering cases of actual transmission. Moreover, cases that would arise under the proposed law would be easier to prove, since the court would no longer have to establish whether the defendant knew that he was infected, whether the defendant had the intent to infect, or whether he took precautions, such as wearing a condom, at the time he transmitted the virus. The court would only have to establish

whether the defendant was the individual who transmitted the virus to the victim, as well as whether the defendant informed the victim of his or her infection status. There may even be fewer court cases, since exposure to risk alone (without transmission) would no longer constitute grounds for a lawsuit. While unknowing transmission would now be grounds for a lawsuit, knowing exposure is significantly more likely to occur than unknowing transmission. Having fewer cases may also help to minimize the loss of privacy associated with the revelation of HIV status that occurs during the court proceedings.⁹ In addition, the proposed law, by penalizing for transmission alone, would obviate the need to specify different penalties for different sexual practices.

B. Implementability and Fairness

The proposed law against “reckless criminal transmission of HIV” would be part of a large body of existing law known as criminal negligence law, under which an individual can be punished for unknowingly or recklessly injuring or killing another person.

Implementing the proposed law is also likely to be politically feasible. That is, policy-makers would not likely face too much resistance from the public in implementing the law. People who are generally not at risk of becoming infected would likely not be against the proposed law. Even individuals who are especially at risk of becoming infected might benefit from the proposed law *ex ante*, because it reduces the chances that they would ever be infected in the future. Every potential offender under the proposed law is also a potential victim.

⁹ In each court case, a warrant to search medical records is likely to be requested. For economic analyses of privacy and search warrants in criminal cases, see Posner (1983) and Mialon and Mialon (2008).

One might still question the fairness of a law that would punish people for unknowingly transmitting HIV. But what are the chances that an individual is just “unlucky,” i.e., is infected with HIV from one act of risky sex and unknowingly passes it on to another individual?¹⁰

Consider three possible cases for men:

(1) Take a man A who had risky unprotected anal receptive sex once with a man B. Later, he has unprotected anal insertive sex 100 times with another man C, who is known to be HIV free. The probability that A gives HIV to C is 0.054% or 54 of 100,000.

(2) Take a man A who had risky unprotected vaginal sex once with a woman B. Later, he has unprotected vaginal sex 100 times with a woman C, who is known to be HIV free. The probability that A gives HIV to C is 0.000002% or 0.002 of 100,000.

(3) Take a man A who had risky unprotected anal receptive sex once with a man B. Later, he has unprotected vaginal sex 100 times with a woman C, who is known to be HIV free. The probability that A gives HIV to C is 0.008% or 8 of 100,000.

Assuming that there are 100 million sexually active adult men in the U.S., case (1) applies to 25% of gay men, who make up 2% of the male population, case (2) applies to 25% of the male population, and case (3) applies to 2% of the male population, then there would be about 436 infections per year due to the three categories of “unlucky” men (269.8, 0.6, and 165.6, respectively). This would represent only 1.1% of the approximately 40,000 new infections that occur each year. In any matter, if courts are able to identify “unlucky” cases, then they are likely to be more lenient and appropriately moderate the punishment.

¹⁰ The overall probability that A transmits HIV to C is the probability that A got HIV from B multiplied by the probability that A gave HIV to C if he were infected. The calculations are based on estimates of the per-contact probability of HIV transmission by sexual activity (Downs and De Vincenzi, 1996; Mastro et al., 1994; Padian et al., 1997; Vittinghoff et al., 1999), the number of HIV infected (Brookmeyer, 1991; CDC, 2002), and the percentage of male homosexual and female AIDS cases (CDC, 1993). We assume that sexual partners (person B) are randomly selected, and that the percentages of HIV infected people who are male homosexual and female are the same as those for AIDS cases in 1992. See Francis (2007) for related calculations.

VIII. Conclusion

We developed a signaling model of sexual behavior and testing under risk of HIV infection to examine the efficiency of current HIV-specific criminal laws and to determine the socially optimal law. The socially optimal law is defined as the law that induces separation and full information revelation, so that non-fully-informed HIV transmission does not occur. Our main results may be summarized as follows. First, the optimal law involves a penalty for both knowing and unknowing transmission of HIV. This creates incentives to test. The optimal law involves no penalty for exposure without transmission. This creates incentives to use safer sex practices. Second, the optimal expected penalty is estimated to be about 1-2 years of prison. Third, current laws are not generally efficient, because they penalize only knowing transmission, which discourages testing, and because they penalize exposure as well as transmission, which does not promote safer sex practices. Fourth, the above qualitative results continue to hold if testing is verifiable and information is symmetric, or if the informational asymmetry is two-sided. Fifth, the optimal law is also efficient with respect to enforcement and trial costs. Sixth, the optimal law is not unfair and is likely to be implementable.

Mathematical Appendix

Proof of Proposition 1. In the socially optimal outcome, A tests and offers safe sex if he is infected and risky sex if he is uninfected, so B knows whether A is infected. Thus, B accepts when A proposes risky sex, and since $qd < s + h$, B also accepts when A proposes safe sex.

Now, given these strategies for B, we find the conditions for A's strategies to be optimal. If A does not test, then in any PBE implementing the optimal outcome, his belief that he is infected is $1 - p$, so his expected payoff from proposing risky sex is $r - (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$, his expected payoff from proposing safe sex is $s - (1 - p)(q\alpha f_3 + (1 - q)\beta f_4)$, and his expected payoff from choosing no sex is 0. Thus, A prefers proposing risky sex to proposing safe sex iff $r - s > (1 - p)(z - q)(\alpha f_3 - \beta f_4)$, prefers proposing risky sex to choosing no sex iff $r > (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$, and prefers proposing safe sex to choosing no sex iff $s > (1 - p)(q\alpha f_3 + (1 - q)\beta f_4)$.

If A tests and learns that he is infected, his expected payoff from proposing safe sex is $s + b - c - q\alpha f_1 - (1 - q)\beta f_2$, from proposing risky sex is $r + b - c - z\alpha f_1 - (1 - z)\beta f_2$, and from choosing no sex is $b - c$. Thus, A prefers proposing safe sex to proposing risky sex iff $r - s < (z - q)(\alpha f_1 - \beta f_2)$, prefers proposing safe sex to choosing no sex iff $s > q\alpha f_1 + (1 - q)\beta f_2$, and prefers proposing risky sex to choosing no sex iff $r > z\alpha f_1 + (1 - z)\beta f_2$.

A's expected payoff from testing is $p(r) + (1 - p)(s + k - q\alpha f_1 - (1 - q)\beta f_2)$. If he proposes risky sex if he does not test, then his expected payoff from not testing is $r - (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$. If he proposes safe sex if he does not test, then his expected payoff from not testing is $s - (1 - p)(q\alpha f_3 + (1 - q)\beta f_4)$. If he chooses no sex if he does not test, then his expected payoff is 0. Thus, if A proposes risky sex if he does not test, then A prefers to test iff $r - s < z\alpha f_3 + (1 - z)\beta f_4 - q\alpha f_1 - (1 - q)\beta f_2 + k$. If A proposes safe sex if he does not test, then A prefers to test iff $p(r - s) > (1 - p)(q\alpha(f_1 - f_3) + (1 - q)\beta(f_2 - f_4) - k)$. If A chooses no sex if he does not test, then he prefers to test iff $p(r) + (1 - p)(s + k - q\alpha f_1 - (1 - q)\beta f_2) > 0$.

Hence, a PBE arises in which A tests, A offers safe sex if he tests positive and risky sex if he tests negative, A would offer risky sex if he did not test, and B accepts any offer from A iff all the conditions in (1) are satisfied; a PBE arises in which A tests, A offers safe sex if he tests positive and risky sex if he tests negative, A would offer safe sex if he did not test, and B accepts any offer from A iff the conditions in (2) are satisfied; and a PBE arises in which A tests, A offers safe sex if he tests positive and risky sex if he tests negative, A would choose no sex if he did not test, and B accepts any offer from A iff the conditions in (3) are satisfied. **Q.E.D.**

Proof of Corollary 1. If $f_1 = f_2$ and $f_3 = f_4 = 0$, then the conditions in (1) reduce to $r - s > 0$, $r > 0$, $r - s < (z - q)f_1(\alpha - \beta)$, $s > f_1(q\alpha + (1 - q)\beta)$, and $r - s < k - f_1(q\alpha_1 - (1 - q)\beta)$. Thus, all the conditions in (1) are satisfied iff

$$\frac{r - s}{(z - q)(\alpha - \beta)} < f_1 < \min\left\{\frac{k - (r - s)}{q\alpha + (1 - q)\beta}, \frac{s}{q\alpha + (1 - q)\beta}\right\}.$$

A necessary condition for this range to exist is $k > r - s$. The first condition in (2) reduces to $r - s < 0$, which contradicts the assumption that $r > s$. The first condition in (3) reduces to $r < 0$, which contradicts the assumption that $r > 0$. Hence, if $k < r - s$, the socially optimal outcome cannot be implemented as a PBE, and if $k > r - s$, it can be implemented as a PBE iff

$$\frac{r-s}{(z-q)(\alpha-\beta)} < f_1 < \min\left\{\frac{k-(r-s)}{q\alpha+(1-q)\beta}, \frac{s}{q\alpha+(1-q)\beta}\right\}.$$

when $f_1 = f_2$ and $f_3 = f_4 = 0$. **Q.E.D.**

Proof of Corollary 2. If $f_1 = f_3$ and $f_2 = f_4 = 0$, then the conditions in (1) reduce to $r - s > (1-p)(z-q)\alpha f_1$, $r > (1-p)z\alpha f_1$, $r - s < (z-q)\alpha f_1$, $s > q\alpha f_1$, and $r - s < (z-q)\alpha f_1 + k$. Conditions $s > q\alpha f_1$ and $r - s > (1-p)(z-q)\alpha f_1$ imply condition $r > (1-p)z\alpha f_1$. Condition $r - s < (z-q)\alpha f_1$ implies condition $r - s < (z-q)\alpha f_1 + k$ if $k > 0$, and $r - s < (z-q)\alpha f_1 + k$ implies $r - s < (z-q)\alpha f_1$ if $k < 0$. Thus, all the conditions in (1) are satisfied iff

$$\max\left\{\frac{r-s}{(z-q)}, \frac{r-s-k}{(z-q)}\right\} < \alpha f_1 < \min\left\{\frac{r-s}{(1-p)(z-q)}, \frac{s}{q}\right\}.$$

The conditions in (2) reduce to $r - s < (1-p)(z-q)\alpha f_1$, $s > (1-p)q\alpha f_1$, $r - s < (z-q)\alpha f_1$, $s > q\alpha f_1$, and $p(r-s) > (1-p)(-k)$. Condition $r - s < (1-p)(z-q)\alpha f_1$ implies condition $r - s < (z-q)\alpha f_1$, and condition $s > q\alpha f_1$ implies condition $s > (1-p)q\alpha f_1$. Condition $p(r-s) > (1-p)(-k)$ is satisfied if

$$k > \frac{-p(r-s)}{(1-p)}.$$

All the other conditions are satisfied iff

$$\frac{r-s}{(1-p)(z-q)} < \alpha f_1 < \frac{s}{q}.$$

The conditions in (3) reduce to $r < (1-p)z\alpha f_1$, $s < (1-p)q\alpha f_1$, $r - s < (z-q)\alpha f_1$, $s > q\alpha f_1$, and $p(r) + (1-p)(s+k - q\alpha f_1) > 0$. Conditions $s < (1-p)q\alpha f_1$ and $s > q\alpha f_1$ contradict, so all the conditions in (3) cannot be jointly satisfied. Hence, if $f_1 = f_3$ and $f_2 = f_4 = 0$, the socially optimal outcome can be achieved iff

$$\max\left\{\frac{r-s}{(z-q)}, \frac{r-s-k}{(z-q)}\right\} < \alpha f_1 < \min\left\{\frac{r-s}{(1-p)(z-q)}, \frac{s}{q}\right\},$$

or

$$\frac{r-s}{(1-p)(z-q)} < \alpha f_1 < \frac{s}{q} \text{ if } k > \frac{-p(r-s)}{(1-p)}. \text{ **Q.E.D.**}$$

Proof of Proposition 2. In the optimal outcome, A tests and chooses no sex if he is infected and proposes risky sex if he is uninfected, and B accepts if A proposes risky sex. In any PBE implementing the optimal outcome, if A is uninfected, his equilibrium payoff is $r - c$ since he proposes risky sex and B accepts. If he were to deviate to proposing safe sex, his payoff would be strictly lower no matter how B would respond. Thus, proposing safe sex is equilibrium dominated for A if he is uninfected. If A is infected, his equilibrium payoff is $b - c$. If he were to deviate to proposing safe sex he might do better depending on how B would respond. In

particular, if B would respond by accepting, A's payoff would be $b - c + s - q\alpha f_1 - (1 - q)\beta f_2$. If $s > q\alpha f_1 + (1 - q)\beta f_2$, A's deviation would be profitable. In this case, proposing safe sex is not equilibrium dominated for B. Hence, if $s > q\alpha f_1 + (1 - q)\beta f_2$, in any PBE implementing the optimal outcome and satisfying the Intuitive Criterion, B believes that A is infected if he proposes safe sex, and since $s + h < qd$, B rejects and chooses no sex if A proposes safe sex.

Given the strategies for B in this case, we find conditions for A's strategies to be optimal. If A does not test, his expected payoff from proposing risky sex is $r - (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$, his expected payoff from proposing safe sex is $-h$, and his expected payoff from choosing no sex is 0. Thus, A prefers proposing risky sex to proposing safe sex iff $r + h > (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$, prefers proposing risky sex to choosing no sex iff $r > (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$, and always prefers choosing no sex to proposing safe sex.

If A tests and learns that he is infected, his expected utility from proposing safe sex is $b - c - h$, from proposing risky sex is $r + b - c - z\alpha f_1 - (1 - z)\beta f_2$, and from choosing no sex is $b - c$. Thus, A always prefers choosing no sex to proposing safe sex and prefers choosing no sex to proposing risky sex iff $r < z\alpha f_1 + (1 - z)\beta f_2$.

A's expected payoff from testing is $p(r) + (1 - p)(k)$. If he proposes risky sex if he does not test, then his expected payoff from not testing is $p(r) + (1 - p)(r - z\alpha f_3 - (1 - z)\beta f_4)$. If he proposes safe sex if he does not test, then his expected payoff from not testing is $-h$. If he chooses no sex if he does not test, then his expected payoff is 0. Thus, if A proposes risky sex if he does not test, then A prefers to test iff $r < k + z\alpha f_3 + (1 - z)\beta f_4$. If A chooses no sex if he does not test, then A prefers to test iff $pr + (1 - p)k > 0$.

Hence, a PBE satisfying the Intuitive Criterion arises in which A tests, A chooses no sex if he tests positive and offers risky sex if he tests negative, A would offer risky sex if he did not test, B accepts if A offers risky sex and would reject if A offered safe sex iff all the conditions in (i) are satisfied; and a PBE satisfying the Intuitive Criterion arises in which A tests, A chooses no sex if he tests positive and offers risky sex if he tests negative, A would choose no sex if he did not test, B accepts if A offers risky sex and would reject if A offered safe sex iff the conditions in (ii) are satisfied.

On the other hand, if $s < q\alpha f_1 + (1 - q)\beta f_2$, then in any PBE implementing the optimal outcome, proposing safe sex is equilibrium dominated for A whether he is infected or not. Thus, in this case, in any PBE implementing the optimal outcome and satisfying the Intuitive Criterion, B believes that A is infected with probability $1 - p$ if he proposes safe sex, and B accepts if A proposes safe sex since $qd < (s + h)/(1 - p)$.

Given the strategies for B in this case, we find conditions for A's strategies to be optimal. If A does not test, then in any PBE implementing the optimal outcome, his belief that he is infected is $1 - p$, so his expected payoff from proposing risky sex is $r - (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$, his expected payoff from proposing safe sex is $s - (1 - p)(q\alpha f_3 - (1 - q)\beta f_4)$, and his expected payoff from choosing no sex is 0. Thus, A prefers proposing risky sex to proposing safe sex iff $r - s > (1 - p)(z - q)(\alpha f_3 - \beta f_4)$, prefers proposing risky sex to choosing no sex iff $r > (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$, and prefers proposing safe sex to choosing no sex iff $s > (1 - p)(q\alpha f_3 + (1 - q)\beta f_4)$.

If A tests and learns that he is infected, his expected utility from proposing safe sex is $s + b - c - q\alpha f_1 - (1 - q)\beta f_2$, from proposing risky sex is $r + b - c - z\alpha f_1 - (1 - z)\beta f_2$, and from choosing no sex is $b - c$. Thus, A prefers choosing no sex to proposing safe sex iff $s < q\alpha f_1 + (1 - q)\beta f_2$ and prefers choosing no sex to proposing risky sex iff $r < z\alpha f_1 + (1 - z)\beta f_2$.

A's expected payoff from testing is $p(r) + (1 - p)(k)$. If he proposes risky sex if he does not test, then his expected payoff from not testing is $r - (1 - p)(z\alpha f_3 + (1 - z)\beta f_4)$. If he proposes safe sex if he does not test, then his expected payoff from not testing is $s - (1 - p)(q\alpha f_3 + (1 - q)\beta f_4)$. If he chooses no sex if he does not test, then his expected payoff is 0. Thus, if A proposes risky sex if he does not test, he prefers to test iff $r < z\alpha f_3 + (1 - z)\beta f_4 + k$. If A proposes safe sex if he does not test, he prefers to test iff $p(r - s) > (1 - p)(s - q\alpha f_3 - (1 - q)\beta f_4 - k)$. If A chooses no sex if he does not test, then he prefers to test iff $pr + (1 - p)k > 0$.

Hence, a PBE satisfying the Intuitive Criterion arises in which A tests and offers no sex if he tests positive and risky sex if he tests negative, A would offer risky sex if he did not test, and B accepts any offer from A iff all the conditions in (iii) are satisfied; a PBE satisfying the Intuitive Criterion arises in which A tests, A offers no sex if he tests positive and risky sex if he tests negative, A would offer safe sex if he did not test, and B accepts any offer from A iff the conditions in (iv) are satisfied; and a PBE satisfying the Intuitive Criterion arises in which A tests, A offers no sex if he tests positive and risky sex if he tests negative, A would choose no sex if he did not test, and B accepts any offer from A iff the conditions in (v) are satisfied. **Q.E.D.**

Proof of Corollary 3. Condition $s > q\alpha f_1 + (1 - q)\beta f_2$ reduces to $s > f_1(q\alpha + (1 - q)\beta)$. Conditions in (i) reduce to $r > 0$, $r < f_1(z\alpha + (1 - z)\beta)$, and $r < k$. These conditions can only be jointly satisfied if $r < k$ and

$$\frac{r}{z\alpha + (1 - z)\beta} < f_1 < \frac{s}{q\alpha + (1 - q)\beta}.$$

The first condition in (ii) reduces to $r < 0$, which contradicts the assumption that $r > 0$.

Condition $s < q\alpha f_1 + (1 - q)\beta f_2$ reduces to $s < f_1(q\alpha + (1 - q)\beta)$. Conditions in (iii) reduce to $r - s > 0$, $r > 0$, $r < f_1(z\alpha + (1 - z)\beta)$, and $r < k$. These conditions can only be jointly satisfied if $r < k$ and

$$\max\left\{\frac{r}{z\alpha + (1 - z)\beta}, \frac{s}{q\alpha + (1 - q)\beta}\right\} < f_1.$$

The first condition in (iv) reduces to $r - s < 0$, which contradicts the assumption that $r > s$. The first condition in (v) reduces to $r < 0$, which contradicts the assumption that $r > 0$. Hence, the socially optimal outcome cannot be achieved if $r > k$, and if $r < k$, the socially optimal outcome can be achieved iff

$$\frac{r}{z\alpha + (1 - z)\beta} < f_1. \quad \mathbf{Q.E.D.}$$

Proof of Corollary 4. Condition $s > q\alpha f_1 + (1-q)\beta f_2$ reduces to $s > q\alpha f_1$. Conditions in (i) reduce to $r > (1-p)z\alpha f_1$, $r < z\alpha f_1$, and $r < z\alpha f_1 + k$. Condition $r < z\alpha f_1$ implies condition $r < z\alpha f_1 + k$ if $k > 0$, while $r < z\alpha f_1 + k$ implies $r < z\alpha f_1$ if $k < 0$. Hence, the socially optimal outcome can be achieved if

$$\max\left\{\frac{r}{z}, \frac{r-k}{z}\right\} < \alpha f_1 < \min\left\{\frac{r}{(1-p)z}, \frac{s}{q}\right\}. \text{ Q.E.D.}$$

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Table 1
State Laws on Criminal Exposure to HIV through Sexual Contact (2007)

State	Year Enacted	Penalty	Max Sentence	Intent to Infect	Knowing or Unknowing	Exposure or Transmission	Safer Sex Behaviors Excluded ^d	Disclosure Affirmative Defense
Alabama	1987	Misdemeanor	\$500		Knowing	Exposure	Yes	
Arkansas	1989	Felony	30 years		Knowing	Exposure		Yes
California	1998	Felony	8 years	Yes	Knowing	Exposure	Yes	Yes
Florida	1986	Felony	5 years		Knowing	Exposure		Yes
Georgia	1988	Felony	10 years		Knowing	Exposure		Yes
Idaho	1988	Felony	15 years		Knowing	Exposure		Yes
Illinois	1989	Felony	7 years		Knowing	Exposure		Yes
Iowa	1998	Felony	25 years		Knowing	Exposure		Yes
Kansas	1992	Felony	1 year	Yes	Knowing	Exposure		
Louisiana ^a	1987	Felony	10 years		Knowing	Exposure		Yes
Maryland	1989	Misdemeanor	\$2,500	Yes	Knowing	Exposure		
Michigan	1988	Felony	1.5 years		Knowing	Exposure		Yes
Minnesota	1995	Misdemeanor	\$1,000		Knowing	Exposure	Yes	Yes
Missouri	1988	Felony	15 years		Knowing	Exposure		Yes
Montana	1967	Misdemeanor	\$500		Knowing	Exposure		
Nevada	1993	Felony	10 years		Knowing	Exposure	Yes	Yes
New Jersey	1997	Felony	5 years		Knowing	Exposure		Yes
North Dakota ^b	1989	Felony	20 years		Knowing	Exposure		Yes
Ohio	2000	Felony	8 years		Knowing	Exposure		Yes
Oklahoma	1988	Felony	5 years	Yes	Knowing	Exposure	Yes	Yes
Rhode Island	1921	Misdemeanor	\$100		Knowing	Exposure		
South Carolina	1988	Felony	10 years		Knowing	Exposure		Yes
South Dakota	2000	Felony	15 years	Yes	Knowing	Exposure		Yes
Tennessee	1994	Felony	15 years		Knowing	Exposure	Yes	Yes
Utah ^c	1981	Misdemeanor	\$2,500		Knowing	Transmission		
Virginia	2004	Misdemeanor	\$2,500		Knowing	Exposure		Yes
Washington	1986	Felony	10 years	Yes	Knowing	Exposure		
West Virginia	1921	Misdemeanor	\$100		Knowing	Exposure		

NOTE. This table does not include sentence enhancement statutes. Missing states do not have statutes. CO and NY have general STD laws, but the state public health agency and case law, respectively, exclude HIV. Year enacted is the year in which an HIV-specific statute was first adopted or, if the state does not have one, the year in which a general STD statute was adopted. Some of the misdemeanor offenses may involve incarceration in addition to or instead of the fine. (a) LA’s statute uses the word “intentionally” in a way that means “knowingly.” (b) ND’s affirmative defense provision requires both informed consent and condom use. (c) UT criminalizes the knowing introduction of an STD into “any county, municipality, or community.” (d) These laws only apply to certain risky behaviors, but the statutory language referring to the behaviors varies considerably: “probably or likely transmit” (AL), “unprotected sex” (CA), “likely to transmit” (NV), “reasonably likely to result in the transfer” of body fluids into the bloodstream of another (OK), and “significant risk of HIV transmission” (TN). In MN, condom use is an affirmative defense.