CHAPTER 8

WEAK LINKAGE BETWEEN HIV EPIDEMICS IN HOMOSEXUAL MEN AND INTRAVENOUS DRUG USERS IN NEW YORK CITY

The largest number of AIDS cases in the United States have occurred in homosexual men and intravenous drug users (IVDUs). The transmission mechanisms for HIV in these groups are needle–sharing between IVDUs and homosexual intercourse. Since homosexual men who are also IVDUs have both possible transmission mechanisms and interact with both homosexual men and IVDUs, they could be an important transmission link between these two groups. It is conceivable that a primary HIV epidemic in one of these groups could sustain a secondary HIV epidemic in the other group through the linkage provided by the homosexual IVDUs. The goal of this chapter is to evaluate the relative importance of HIV transmissions by homosexual IVDUs and to decide if they form an essential linkage between the HIV epidemics in homosexual men and IVDUs.

A geographic analysis of where HIV epidemics in homosexual men and IVDUs are occurring together and separately suggests that these epidemics are not strongly connected. Major HIV epidemics in homosexual men are occurring throughout the United States, but major epidemics in IVDUs are focused in the Northeast region of the U.S. (NE region). If epidemics in homosexual men generally sustained epidemics in IVDUs, then there would be major epidemics in IVDUs throughout the U.S., and this has not occurred. If HIV epidemics in IVDUs generally sustained HIV epidemics in homosexual men, then the minor epidemics in IVDUs outside the NE region would probably cause only minor HIV epidemics in homosexual men in these areas, and this has not occurred since there are major HIV epidemics in homosexual men in many places outside the NE region. Thus it does not appear likely that HIV epidemics in either homosexual men or IVDUs are supporting HIV epidemics in the other. It is possible that the reason why major HIV epidemics in IVDUs are occurring in the NE region but not elsewhere is that the needle–sharing and other IVDU behaviors are different in the NE region. Thus it seems desirable to investigate possible connections between epidemics in homosexual men and IVDUs more thoroughly in the NE region. The most AIDS cases in the NE region occur in New York City (NYC), so it seems appropriate to use NYC to test the theory that the epidemics are essentially independent and separate.

During the early phase of the HIV epidemic in homosexual men and IVDUs, the HIV transmission process was probably like a random or stochastic process. In this early phase the homosexual IVDUs may have been involved in the seeding of HIV in the populations of homosexual men and IVDUs (Battjes, Dickens and Amsel, 1989). The stochastic nature of the beginning of the HIV epidemic is not of interest here. The main concern is the role of homosexual IVDUs when the epidemics are established and growing. Although many simplifying assumptions are necessary in order to use a deterministic model for an HIV epidemic, this type of model is well–suited as a quantitative descriptor of an epidemiological process. A deterministic HIV epidemiological model has been developed for one population in Chapter 3 and applied to homosexual men in San Francisco in Chapters 5 and 6. This model has been generalized in

Chapter 7 to five risk groups including homosexual men, homosexual IVDUs, and IVDUs. This model is available to explore the importance of homosexual–IVDUs in connecting the HIV epidemics in homosexual men and IVDUs.

How can one test the hypothesis that the HIV epidemics in homosexual men and IVDUs are not crucially linked by homosexual IVDUs and are essentially separate epidemics? The approach used here is to first fit one risk group models to the AIDS incidence data in NYC for homosexual men and IVDUs separately; then the three risk group model for homosexual men, homosexual IVDUs, and IVDUs is fit to the AIDS incidence data. If the parameter values obtained in the simultaneous fitting of the three risk groups are quite similar to those obtained in the separate fits, then the homosexual IVDUs are not a crucial link between the other two groups, and their HIV epidemics can be treated separately.

Information on HIV and AIDS in NYC is given in Section 8.1, and parameter values are estimated in Section 8.2. A modified fit criterion which accounts for HIV–related deaths is presented in Section 8.3. Fits of the one group model to the NYC populations of homosexual men and IVDUs are found in Sections 8.4 and 8.5. Section 8.6 presents the simultaneous fitting to the AIDS incidence data for the three risk groups. A key conclusion in Section 8.7 is that the HIV epidemics in homosexual men and IVDUs are not strongly connected by the homosexual IVDUs. Thus the HIV epidemics in homosexual men and IVDUs can be modeled separately. This separation of the HIV epidemics in homosexual men and IVDUs is assumed to also hold in other subregions and in racial/ethnic groups.

8.1. Data on HIV and AIDS in New York City

The incidences of AIDS in NYC and SF given in Table 8.1 have been adjusted for reporting delays and for the 1987 change in definition in the AIDS surveillance definition. The delay–adjusted incidence data, as reported by October 1, 1991, were supplied by John Karon and Debra Hansen in the Division of HIV/AIDS, Center for Infectious Diseases, Centers for Disease Control (CDC). Patients are said to satisfy the consistent case definition of AIDS if they have a diagnosis (definitive or presumptive) of a disease in the pre–1987 case definition. Based on a study of homosexual men in SF, a procedure in Section 5.4.2 was developed for estimating when the nonconsistent cases would later meet the consistent case definition. This procedure has been used to obtain the total adjusted consistent cases in Table 8.1 as the sums of the consistent and the modified nonconsistent cases. The data have not been adjusted for underreporting.

Note that the pattern of yearly AIDS incidence for homosexual men in NYC is similar to the patterns in homosexual men in SF for the first five years in the sense that the ratios of incidences in succeeding years are similar. After the first five years, the AIDS incidence in homosexual men in NYC seems to grow faster than in SF. The AIDS incidence in homosexual men in SF is approximately equal to that in NYC about one year earlier so the NYC epidemic undoubtedly started earlier. The data in Table 8.1 are consistent with the observations of Karon and Berkelman (1991) that AIDS incidences in homosexual men in NYC was roughly constant from mid–1986 to 1990. The simulation modeling in Chapter 6 suggests that the AIDS incidence

Table 8.1. The AIDS incidence by categories in New York City is adjusted for reporting–delays and the 1987 AIDS definition change. The adjusted AIDS incidence in homosexual men in San Francisco is included for comparison.

Year	homosexual men	homosexual IVDUs	IVDUs	homosexual men – SF
1979	5	1	0	0
1980	23	3	5	2
1981	95	9	21	22
1982	272	45	115	86
1983	577	73	276	228
1984	1017	82	503	442
1985	1463	142	871	678
1986	2068	167	1314	1010
1987	2321	206	1754	1275
1988	2489	174	2326	1285
1989	2451	180	2542	1338
1990	2378	158	2895	1551

in homosexual men in SF reached a plateau in about 1989 and may decline in the future.

The pattern for about the first five years for AIDS incidence in IVDUs in NYC is similar to that for homosexual men in NYC one year earlier, but after five years the incidence in IVDUs continues to grow instead of leveling off or reaching a peak. Indeed, the AIDS incidence in IVDUs jumps significantly in 1988 and then increases slowly. The AIDS incidence in homosexual–IVDUs in NYC is roughly 7 to 9% of that in homosexual men with larger differences in a few years. Thus the AIDS incidence pattern in homosexual men in NYC who are also IVDUs is similar to that for homosexual men in NYC.

In modeling the HIV prevalence in IVDUs it is significant that some HIV positive IVDUs are dying from HIV–related causes that do not meet the AIDS definition. These causes include pneumonia, endocarditis and tuberculosis. Stoneburner et al. (1988) estimated these HIV–related deaths by comparing observed narcotics–related deaths in 1982 to 1986 with those that would be expected without the AIDS epidemic and those reported as AIDS–related deaths. The number of IVDUs was assumed to be constant from 1979 to 1986 and AIDS–related cases were subtracted so that the average annual narcotics–related deaths for 1979 to 1981 was 488 deaths per year. Thus 2440 narcotics–related deaths would be expected for 1982 to 1986. Hence of the actual 6157 narcotics–related deaths in 1982 to 1986, 2440 were expected and 1197 were AIDS–related deaths, so that the excess deaths were 2520. Stoneburner at al. (1988) provide evidence that these 2520 excess deaths are HIV–related, but they occur in people who do not have AIDS.

In February 1989, the NYC Department of Health (NYCDOH, 1989) gave revised estimates of the number of NYC residents in various risk groups who were HIV–positive. Their estimated ranges were 33,015 to 75,998 for men who have sex with men (MSM), 60,000 to 90,000 male IVDUs, 20,000 to 30,000 female IVDUs, 10,000 to 15,000 other men, 1,000 to 20,000 other women and 1600 to 4400 children. Their estimated range for MSM were obtained in three ways. Assuming 15% underreporting, they compared white and other categories of MSM in NYC with MSM in San Francisco. Using back–calculation, they obtained the estimate of 33,015. By direct calculation with 30% to 50% positivity and a risk population estimate of about 150,000, they obtained a range of 42,406 to 75,998 for HIV prevalence in MSM. The IVDU estimates are based on 40% to 60% prevalence in a population of 200,000 IVDUs where one quarter of them are women. They note that there is some evidence for a leveling off of HIV prevalence in IVDUs beginning in 1985 (Des Jarlais et al., 1988).

8.2. Parameter Estimates for New York City

The linkage between the HIV epidemics in homosexual men and IVDUs in NYC is analyzed in later sections. The simulation modeling needs *a priori* estimates and initial estimates for parameter values for the three group model consisting of homosexual men, homosexual IVDUs, and IVDUs. These estimates are used in fitting the model or as initial estimates of parameters that are adjusted in the fitting process.

8.2.1 Estimates of Population Sizes and Turnover

Estimates of the population size of the homosexual men in NYC have ranged up to 500,000, but the estimate in 1988 was reduced to about 100,000 (Lambert, 1988). A recent estimate of the NYC Department of Health of this population size is about 150,000 (NYC DOH, 1989). In the NYC model the size of the population of homosexual men is taken to be 100,000. The migration rate with equal immigration and emigration is taken to be 5% per year as it was in the SF model in Section 5.2.

Friedland and Klein (1987) note that ninety percent of the IVDUs are heterosexual, implying that 10% are homosexual. If there are about 200,000 IVDUs in NYC, then there would be about 20,000 homosexual–IVDUs in NYC, but this estimate is very crude. In a study of homosexual men (Darrow et al., 1987), 20% said that they had injected drugs and 60% of the drug users said that they had shared hypodermic needles. Since 12% of these homosexuals were needle–sharing IVDUs, roughly 12,000 of the 100,000 would be homosexual–IVDUs who share needles. Due to the uncertainty of the size of the homosexual–IVDU population, this size is taken as a variable in the NYC model which is to be determined to fit the homosexual–IVDU AIDS data.

Many papers (e.g., Friedland and Klein, 1987; Selwyn et al., 1987; Drucker, 1986) have given 200,000 as the approximate size of the IVDU population in NYC; however, it is not clear if these are independent estimates or are all based on one original source. Dolan et al. (1987) found that 59% of 193 in a drug abuse treatment program (1983–1985) reported that they had shared needles. Other studies of IVDUs in treatment programs found that 66% (Mulleady and Green, 1985) and 68% (Black et al., 1986) reported needle-sharing. Of course, these percentages may be unrealistically low since they are based on self–reporting of people in treatment programs. Darrow (personal communication, 1988) states that nearly all IVDUs share needles. Schuster (1988) reports that 70% to 90% of IVDUs are needle–sharers. If 20,000 (10% of 200,000 IVDUs) are homosexuals, and 30,000 (17% of the remaining 180,000 IVDUs) do not share needles, then the size of the non-homosexual needle–sharing IVDU population in NYC would be 150,000. In the rest of this chapter IVDU will mean non–homosexual needle–sharing IVDUs, and the size of this population in the NYC model is taken to be 150,000.

It is not clear whether the size of the needle–sharing population has changed with time. Kozel and Adams (1986) reported that the number of heroin users seems to have remained reasonably stable, but the number of people injecting forms of cocaine has increased. Others found that needle–sharing among drug users has decreased. Des Jarlais et al. (1987, 1988) found that 54% of 59 IVDUs in a treatment program in 1985 reported some risk reduction in needle–sharing; 75% in 1986 and 85% in 1987 reported some AIDS reduction behavior. Of course, self–reported changes of these IVDUs may be biased. In the model the number of needle–sharing IVDUs is fixed at 150,000, but it would be possible to change this size with time if more information becomes available.

Since three–fourths of all IVDUs in the United States are male (Des Jarlais et al., 1988) it is assumed that this fraction is also true for needle–sharers in NYC. This means that there are about 37,500 female IVDUs and 112,500 male IVDUs in NYC. Friedland and Klein (1987) state that 30% to 50% of the IVDU women have engaged in prostitution.

The migration or turnover rates in homosexual men and in IVDUs in NYC are difficult to estimate. One study found an annual inactivation rate of 13–25% for IVDUs who died, relocated outside of NYC, or ceased all intravenous use (Drucker and Vermund, 1989). Another study (Des Jarlais et al., 1989) of a 1987 subject group found that 11% had begun injecting illicit drugs after 1980 and 4% had begun after 1984; thus the entry rate was about 2% per year. The high exit rate is not consistent with the low entry rate. As a compromise, the migration rate is chosen as 5% per year, which is the same as for homosexual men.

The transfer rates between the very active and active classes is estimated to be 5% per year as in the SF model in Section 5.2. The natural mortality rate in all four risk groups is taken to be $\mu = 0.000532$, which is the value used in the SF model for homosexual men. This corresponds to the death rate of men aged 45–54. Although not all people in the risk groups are men or are in this age bracket, this slightly higher death rate is suitable for people in these groups with a somewhat risky lifestyle.

8.2.2 Estimates of Parameters Related to the Stages

Very little information seems to be available for the progression of IVDUs from HIV infection to AIDS. Thus it is assumed that all adults who become infected progress through the T4–cell count stages to AIDS in the same way as that found for homosexual men in Section 2.2. The probabilities ω_k of transmission by a person in stage k and relative sexual or needle–sharing activity ρ_k of a stage k individual are assumed to be the same as those estimated in Section 5.1 for the baseline parameter set in Section 6.1. The fixed parameters in Table 6.1 are based on many data sources and sexual behavior surveys; the optimization parameters are those values which give the best fit to the HIV and AIDS incidence estimates for SF.

8.2.3. Sexual Behavior Parameter Estimates

The AIDS incidence pattern for homosexual men in NYC in Table 8.1 is similar to that of homosexual men in SF about 1 year later. Thus the *a priori* estimates for homosexual men are the baseline parameter values in Table 6.1 except that the NYC population size is 100,000 and the epidemic starting date is one year earlier.

8.2.4. Needle–Sharing Behavior Parameter Estimates

Needle–sharing seems to occur primarily within a particular group. In a study of IVDUs in NYC, Selwyn et al. (1987) found that about half of those sharing needles gave as reasons the need to inject drugs with no clean needle being available and needle–sharing was done only with a close friend or relative. Thus a needle that is shared is most likely to have been used by someone in the same group. Since the pattern of development of the AIDS epidemic in IVDUs is similar initially to the pattern for homosexual men in NYC and SF, it is assumed that the distribution of the number of needle–sharing partners is similar to that for homosexual men. Thus, it is assumed that 5% or 10% are in the very active class and that they have ten times as many needle–sharing partners as those in the active class. The sensitivity of the results to these parameter choices is checked.

IVDUs may inject several times a day, but usually share needles less often. Although some needle–sharing occurs in shooting galleries with many people, it usually occurs with a few acquaintances. Although partnerships formed with unknown individuals in shooting galleries are of short duration and involve one needle–sharing, the partnerships with acquaintances can be of long duration and involve many needle sharings. No estimates have been found for the probability of transmission per needle–sharing partnership; however, the probability of transmission from one needle–sharing partner is likely to be higher than the probability of transmission from one homosexual partner. In the NYC model it is assumed that the probability of transmission QHD per new needle–sharing partner is 0.05.

It is not clear whether the needle–sharing partnership rate has changed with time. Selwyn et al. (1987) found that some IVDUs reported that they had either stopped needle-sharing or ceased being an IVDU. Des Jarlais et al. (1987, 1988, 1989) found in a drug treatment center that 54% of IVDUs in 1985, 75% in 1986 and 85% in 1987 reported some reduction in behavior that could lead to AIDS, but this reporting could be biased. Thus in the NYC model, the reduction factor per year in the average number of needle-sharing partners is expected to be near 1 in contrast to the expected range of 0.4 to 0.7 for homosexual men. Since the AIDS incidence of homosexual men in NYC is about a year ahead of the incidence in SF, the starting date of the epidemic in homosexual men should be at least a year earlier than the starting date of July 1976 in SF. It is likely that the epidemic started in the IVDUs and in homosexual men at about the same time.

8.3 Modified Fit Criteria for the New York City Model.

Because of the significant number of HIV–related deaths described in Section 8.1, the fitting criteria for the NYC model are changed slightly from that described in Section 7.2. The parameter ALP is the rate constant for HIV–related deaths in stages 4, 5, and 6 for IVDUs and is adjusted so that these deaths in 1982 to 1986 are close to the observed value of 2520 given in Section 8.1. The initial guesses for the IVDU parameters are that PASD is about half of PASH and RDND is one. If the 42 HIV–related deaths per month (2520 in 5 years) occurred in a population of 10,000 pre–AIDS IVDUs, then the death rate would be 0.0042 so that this is taken as an initial estimate for ALP. The fit to the AIDS incidence data in the homosexual–IVDU population is obtained by adjusting the population size NSIZEB which is initially assumed to be 10,000. The HIV–related death rate constant ALP now joins the list of optimization parameters. The expression to be minimized in the fitting procedure is now changed to

$$\text{CHISQH} + \text{CHISQB} + \text{CHISQD} + 0.01(\text{DTH26}-2520)^2$$

which is the sum of the chi–square values for the homosexual men, homosexual–IVDUs and IVDUs plus a measure of how close the HIV–related deaths in IVDUs in later HIV stages are to the observed value of 2520. The coefficient 0.01 has been found by trial and error to give a reasonable balance between the last term and the chi–square terms.

8.4. Fitting in the New York City Population of Homosexual Men

The model for homosexual men in Chapter 3 is also used for NYC. Indeed, since the AIDS epidemic in NYC homosexual men is about the same, but one year earlier in NYC than in San Francisco, one would expect the pattern in NYC to be similar to that in SF.

The best fit for the NYC homosexual men is shown in Table 8.2. The parameter values are quite similar to those for the best fit in SF except that the population size in Table 8.2 is 100,000 instead of 56,000 in SF and the starting date in the NYC epidemic is May 1974 instead of October 1975 in SF. In Table 8.2 the average number of partners per month is 0.49 before July 1982 and the yearly reduction factor is 0.41 until December 1984. In the best fitting parameter set for the SF homosexual men, the average number of sexual partners per month was 0.75 before August 1981 and the yearly reductions factor was 0.61. The external mixing fraction η in the simulation of the epidemic in NYC homosexual men is 0.58, while η was 0.82 for the baseline simulation in SF. Some other parameter sets also give reasonable fits, so it is not possible to conclude much about the partners per month and changes in sexual behavior other than the general conclusion that the average number of partners per month was approximately constant until around mid–1982 and then it decreased rapidly. Note that it was not possible to get an adequate fit using a parameter set without any change in sexual behavior. For all parameter sets which satisfy the fit criteria, the pattern is similar to the pattern in Table 8.2. Namely, the yearly HIV incidence peaks in about 1980, the HIV prevalence peaks at in about 1983, the AIDS incidence peaks in 1988 or 1989 and the AIDS deaths peak in about 1989 or 1990. Note that the

Table 8.2 Simulation results for the best fit to the AIDS incidence data for NYC homosexual men.

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THE POPULATION SIZE IS       100000, THE VERY ACTIVE FRACTION IS
  1.000000E-01 AND THE ACTIVITY RATIO IS          10.000000
THE NATURAL MORTALITY RATE XMU IS   5.320000E-04
THE INTERCHANGE RATE  FROM THE VERY ACTIVE CLASS TO THE ACTIVE CLASS IS
   4.166667E-03  AND THE TURNOVER RATE IS DLT =    4.166667E-03
THE NUMBER OF INFECTIOUS STAGES IS  M =           7
THE G PARAMETERS FOR THE TRANSFER BETWEEN STAGES ARE    7.355444E-02
   6.433708E-02    4.867545E-02    4.199281E-02    3.997889E-02
   5.152515E-02    5.398798E-02
THE WEIGHTS OF TRANSMISSION PER INFECTIOUS PARTNER TIMES THE FRACTION STILL
SEXUALLY ACTIVE FOR THE STAGES ARE WRH(I) =        2.000000        1.000000
       1.000000         1.500000         1.500000         1.500000
       7.500000
THE PROBABILITY OF TRANSMISSION IS QH =     5.000000E-02
THE EXTERNAL MIXING FRACTION IS ETA =     5.750000E-01
THE AVERAGE NUMBER OF PARTNERS PER MONTH IS     4.923000E-01 BEFORE         1982
          7, THEN IT IS REDUCED EACH YEAR BY A FACTOR OF    4.088000E-01UNTIL
DEC,        1984
THE STARTING YEAR AND MONTH ARE           1974            5
THE STARTING NUMBER OF VERY ACTIVE INFECTIVES IS        1.000000

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YEAR	HIV INC SIM	HIV PREV	FRACTNAL_PREV ALL	V_A	ACT	YR AIDS DATA	INC SIM	AIDS(SIMULATION) PREV	DTHS	OUTSF
1974	4.	4.	.00	.00	.00	*****	0.	0.	0.	0.
1975	24.	28.	.00	.00	.00	*****	0.	0.	0.	0.
1976	132.	156.	.00	.01	.00	*****	0.	0.	0.	0.
1977	709.	843.	.01	.06	.00	*****	0.	0.	0.	0.
1978	3148.	3883.	.04	.26	.01	*****	1.	1.	0.	0.
1979	7699.	11189.	.11	.65	.05	5.	5.	4.	1.	1.
1980	8612.	18956.	.19	.87	.11	23.	24.	22.	7.	3.
1981	7745.	25432.	.25	.93	.18	95.	93.	85.	29.	14.
1982	6788.	30544.	.31	.93	.24	272.	265.	252.	98.	49.
1983	3277.	31809.	.32	.88	.26	572.	578.	577.	253.	126.
1984	1489.	31023.	.31	.82	.25	1017.	1018.	1076.	518.	263.
1985	1100.	29564.	.30	.75	.25	1463.	1520.	1708.	888.	459.
1986	1232.	27921.	.28	.68	.23	2068.	1987.	2376.	1319.	693.
1987	1336.	26091.	.26	.62	.22	2321.	2328.	2965.	1738.	930.
1988	1399.	24123.	.24	.57	.20	2489.	2494.	3383.	2076.	1133.
1989	1417.	22102.	.22	.52	.19	2451.	2490.	3587.	2286.	1273.
1990	1398.	20121.	.20	.49	.17	2378.	2355.	3586.	2356.	1340.

CHISQ =   7.490914

peak AIDS incidence occurs about 8 or 9 years after the peak HIV incidence and about 5 years after the peak HIV prevalence.

Note in Table 8.2 that in the very active class the HIV prevalence rises rapidly until 93% are infected in 1981–82, and then the HIV prevalence decreases as infected very–active people either die from AIDS, migrate out of NYC, or move into the active class. The prevalence in the active class rises more slowly and reaches a peak of 26% infected in 1983 and then declines slowly. Note that the HIV prevalence peaks in the very active class in 1981–82 and peaks in the total population and in the active class in 1983. Since very sexually active men have more partnerships and hence are more likely to be infected, it is reasonable that the HIV fractional

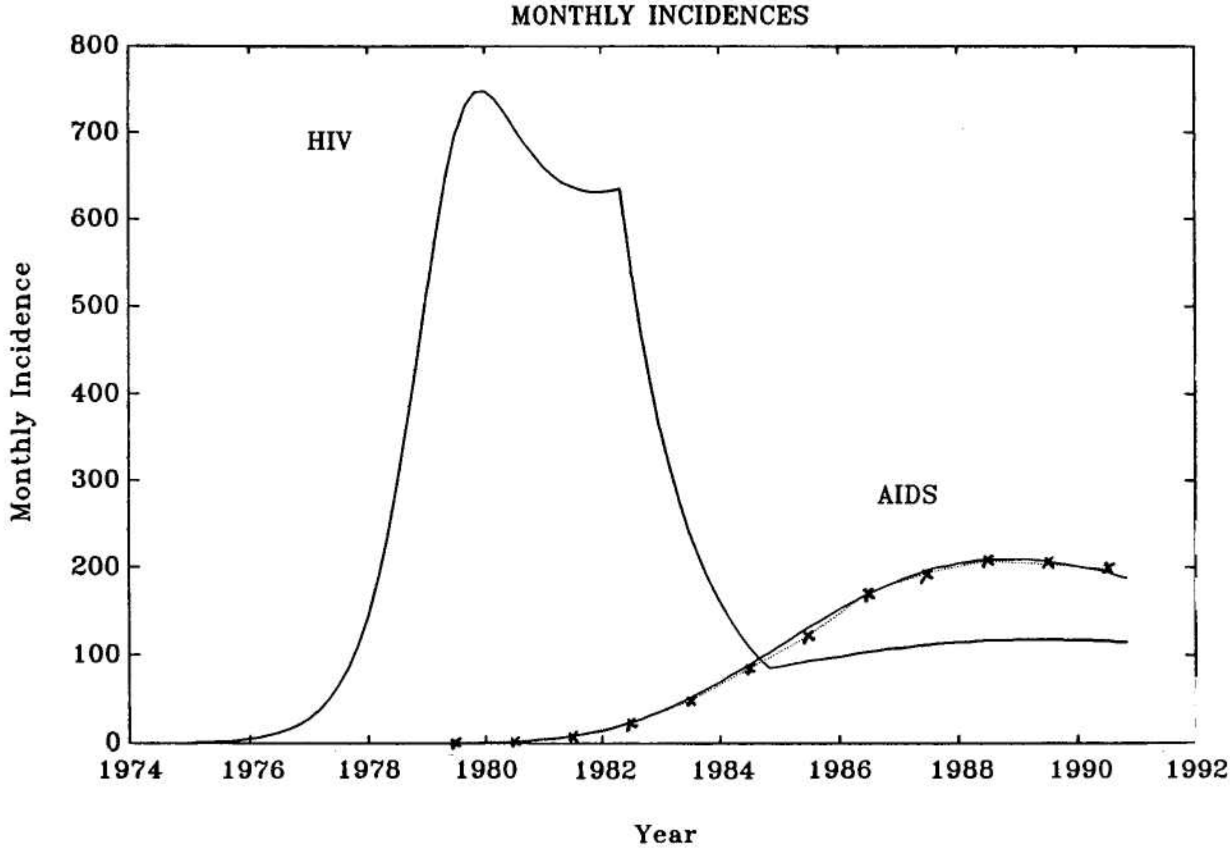

Figure 8.1. The best–fitting simulations for HIV and AIDS incidences for NYC homosexual men corresponding to Table 8.2. The AIDS incidence data (x symbols) correspond to the data in Table 8.1.

prevalence should have a peak in the very active class before the peak in the active class. As expected, nearly everyone with AIDS in the early years is in the very active class, but only 25% are in the very active class when the AIDS incidence peaks in 1988–89. Graphs of the HIV prevalence and yearly AIDS incidences are given in Figure 8.1.

A sensitivity analysis for the simulation for homosexual men in SF has been presented in Section 6.4. The relative sensitivities to the parameters found there would also apply here to the simulations for homosexual men in NYC. The peak HIV prevalence of about 32,000 in homosexual men in NYC is not too surprising since the AIDS incidence in homosexual men in NYC is similar to that in SF and the peak HIV prevalence there was about 20,000. If the AIDS incidence is uniformly underreported by 10% or 20%, then the HIV prevalence would increase by approximately these percentages. If all AIDS incidences in homosexual men were scaled up by 15% as done in the NYC Department of Health calculations, then the peak HIV prevalence in our model would be approximately 37,000. The HIV prevalence in this model is at the bottom of the range of 33,015 to 75,998 estimated for homosexual men in NYC in the NYC Department of Health report (NYCDOH, 1989). Note that the estimate in the dynamic model here is closest to their back–calculation procedure which yielded the estimate of 33,015 (see Section 8.1). Unless people develop AIDS more slowly than the current data indicates, the HIV prevalence cannot be higher and still lead to the given AIDS incidence data.

Table 8.3 Simulation results for the best fit to the AIDS incidence data for NYC IVDUs

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THE IVDU POPULATION SIZE IS       150000
THE VERY ACTIVE FRACTION IS    1.000000E-01
THE ACTIVITY RATIO IS        10.000000
THE NATURAL MORTALITY RATE XMU IS   5.320000E-04
THE INTERCHANGE RATE  FROM THE VERY ACTIVE CLASS TO THE ACTIVE CLASS IS
   4.166667E-03  AND THE TURNOVER RATE IS DLT =    4.166667E-03
THE HIV-RELATED DEATH RATE CONSTANT IS    4.865000E-03
THE NUMBER OF INFECTIOUS STAGES IS  M =           7
THE G PARAMETERS FOR THE TRANSFER BETWEEN ADULT STAGES ARE    7.355444E-02
   6.433708E-02    4.867545E-02    4.199281E-02    3.997889E-02
   5.152515E-02    5.398798E-02
THE WEIGHTS OF TRANSMISSION PER INFECTIOUS PARTNER TIMES THE FRACTION STILL
SEXUALLY ACTIVE FOR THE STAGES ARE WRH(I) =       2.000000         1.000000
       1.000000        1.500000        1.500000        1.500000
       7.500000
THE PROBABILITY OF TRANSMISSION IS QH =    5.000000E-02
THE EXTERNAL MIXING FRACTION IS ETA =    4.734000E-01
THE AVERAGE NUMBER OF NEEDLE-SHARING PARTNERS PER MONTH IS    3.753000E-01
BEFORE         2000            1, THEN IT IS REDUCED EACH YEAR BY A FACTOR OF
     1.000000 UNTIL DEC,        2000
THE STARTING YEAR AND MONTH ARE        1974          1
THE STARTING NUMBER OF VERY ACTIVE INFECTIVES IS      1.000000
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YEAR	HIV INC	HIV PREV	HIV DTHS	FRACTNAL_PREV ALL	V_A	ACT	YR AIDS DATA	INC SIM	AIDS(SIMULATION) PREV	DTHS	OUTSF
1974	5.	5.	0.	.00	.00	.00	****	0.	0.	0.	0.
1975	18.	22.	0.	.00	.00	.00	****	0.	0.	0.	0.
1976	68.	87.	0.	.00	.00	.00	****	0.	0.	0.	0.
1977	258.	335.	0.	.00	.02	.00	****	0.	0.	0.	0.
1978	949.	1245.	1.	.01	.06	.00	0.	1.	1.	0.	0.
1979	3062.	4170.	5.	.03	.20	.01	0.	2.	2.	1.	0.
1980	6972.	10733.	18.	.07	.48	.03	5.	9.	8.	3.	1.
1981	9179.	19022.	59.	.13	.74	.06	21.	31.	29.	10.	5.
1982	8546.	26121.	151.	.17	.86	.10	115.	97.	92.	34.	17.
1983	7997.	32088.	304.	.21	.88	.14	276.	250.	243.	99.	48.
1984	8078.	37493.	495.	.25	.88	.18	503.	521.	527.	236.	116.
1985	8432.	42539.	694.	.28	.85	.22	871.	900.	960.	467.	232.
1986	8815.	47205.	877.	.31	.83	.26	1314.	1343.	1514.	789.	396.
1987	9104.	51389.	1035.	.34	.79	.29	1754.	1795.	2134.	1174.	597.
1988	9254.	54986.	1168.	.37	.75	.32	2326.	2216.	2765.	1586.	816.
1989	9263.	57922.	1279.	.39	.72	.35	2542.	2586.	3361.	1990.	1034.
1990	9155.	60168.	1370.	.40	.68	.37	2895.	2901.	3898.	2363.	1241.

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CHISQ =       22.860970
DTH26 =      2520.323000
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8.5. Fitting in the New York City Population of IVDUs

Here the AIDS incidence data for the IVDU population is fit using the submodel obtained by ignoring the homosexual and homosexual–IVDU populations. In Section 8.6, all three risk groups are fit simultaneously. The best fitting simulation is given in Table 8.3 and shown in Figure 8.2. Note that 10% of the population of 150,000 is ten times as active and the external mixing fraction is 0.47. In Table 8.3 the epidemic starts in January of 1974 and the average number of needle–sharing partners is 0.38. Note that this best–fitting parameter set does not

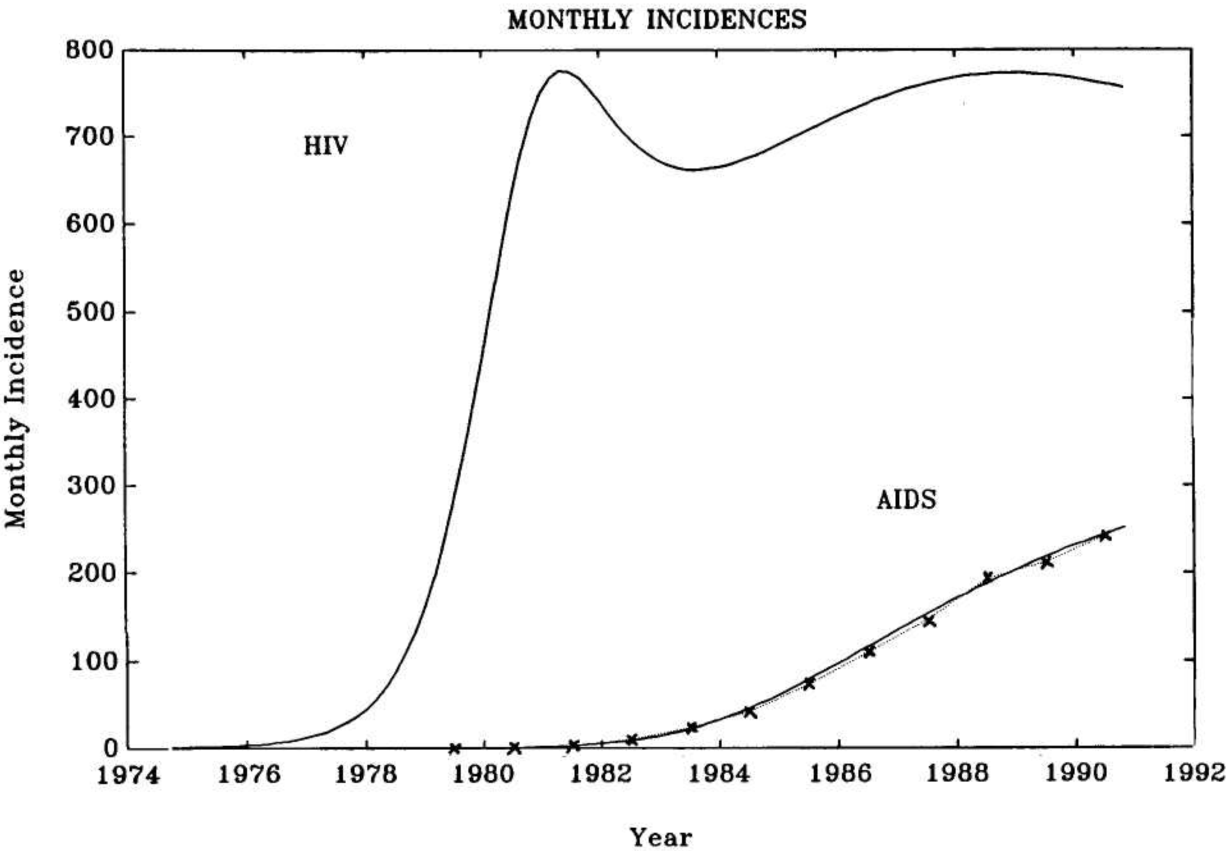

Figure 8.2 The best fitting simulations for HIV and AIDS incidences in NYC IVDUs corresponding to Table 8.3. The AIDS incidence data (x symbols) correspond to the data in Table 8.1.

have any reduction in the needle–sharing partnership rate. This is significantly different from the best fit in Section 8.4 for homosexual men.

The pattern in Table 8.3 is that the HIV incidence is approximately level after 1981, but both the HIV prevalence and AIDS incidence increase steadily. The HIV incidence of approximately 9000 per year is consistent with the HIV incidence of 10,000 cases per annum used in Pagano et al. (1991). The HIV–related deaths in the simulation match the estimated deaths of 2520 in the years 1982 to 1986. In the simulation, the HIV–related deaths are about 1000 to 1400 per year in 1987 to 1990. The simulation in Table 8.3 and Figure 8.2 is not intended to be used for forecasting; however, it does show that good fits to the AIDS data through 1990 are obtained without any reduction in needle–sharing partnership rates. There may have been changes in the needle–sharing behavior of IVDUs in NYC in recent years, since these changes would have almost no influence on the fit to the AIDS data through 1990.

The report (NYCDOH, 1989) of the Department of Health in NYC estimated that the HIV prevalence in IVDUs is 60,000 to 90,000 men and 20,000 to 30,000 women for a total of 80,000 to 120,000 (40% to 60%) out of their estimated IVDU population of 200,000. Their estimates of 40% to 60% HIV positivity are based on IVDUs in treatment centers in Manhattan and may be too high for NYC since the percentages are probably lower in the other boroughs. In Table 8.3 the predicted value is about 43,000 HIV positive IVDUs (non–homosexual) in 1988. This is lower than their estimated range and is 29% of the 150,000 needle–sharing IVDUs in the

NYC model. In Table 8.3 the simulated HIV prevalence increases up to about 60,000 in 1990, which is 40% of the NYC needle–sharing IVDUs.

8.6. Fitting in the Three New York City Risk Groups

In the previous sections the best fits were found for the populations of homosexual men and IVDUs. Here three risk groups are fit simultaneously by using the modified fitting procedure outlined in Section 8.3, which is the sum of the chi–squares and the weighted square of the deviation from the 2520 HIV–related deaths in 1982–86. Table 8.4 gives the parameter set an the computer simulation output which satisfies the modified fit criteria. Graphs of the monthly HIV and AIDS incidences for the three risk groups are given in Figure 8.3.

Table 8.4 Simulation results for the best fit to the AIDS incidence data for NYC homosexual men, homosexual IVDUs and IVDUs.

```
THE SIZE OF THE HOMO POPULATION IS          100000
THE SIZE OF THE HOMO-IVDU POPULATION IS            6500
THE SIZE OF THE IVDU POPULATION IS          150000
THE VERY ACTIVE FRACTIONS ARE     1.000000E-01 FOR HOMOSEXUALS
, AND     1.000000E-01 FOR IVDUs, AND THE ACTIVITY RATIO IS          10.000000
THE HIV-RELATED DEATH RATE CONSTANT FOR IVDUs IS     4.887000E-03
THE STARTING YEARS AND MONTHS ARE            1974            5
FOR HOMOSEXUALS, AND           1974            1 FOR IVDUs.
THE NATURAL MORTALITY RATE XMU IS    5.320000E-04
THE INTERCHANGE RATE  FROM THE VERY ACTIVE CLASS TO THE ACTIVE CLASS IS
   4.166667E-03  AND THE TURNOVER RATE IS DLT =      4.166667E-03
THE WEIGHTS OF TRANSMISSION PER INFECTIOUS PARTNER TIMES THE FRACTION STILL
SEXUALLY ACTIVE FOR THE STAGES ARE WRH(I) =          2.000000         1.000000
        1.000000         1.500000         1.500000         1.500000
        7.500000
THE PROBABILITY OF TRANSMISSION IS QH =      5.000000E-02
THE EXTERNAL MIXING FRACTIONS ARE ETAH, ETAD =      5.419000E-01     5.171000E-01
THE AVERAGE NUMBER OF HOMOSEXUAL PARTNERSHIPS PER MONTH IS     4.865000E-01 BEFO
RE          1982            7 AND IS REDUCED EACH YEAR BY A FACTOR OF
  4.191000E-01 UNTIL DEC,          1984
THE AVERAGE NUMBER OF NEEDLE-SHARING PARTNERS PER MONTH IS     3.445000E-01
BEFORE          2000            1, THEN IT IS REDUCED EACH YEAR BY A FACTOR OF
      1.000000 UNTIL DEC,          2000
*****************************************************
```

CLASS	HIV INC	HIV PREV	HIV DTHS	FRACTNAL_PREV ALL	V_A	ACT	YR AIDS DATA	INC SIM	AIDS(SIMULATION) PREV	DTHS	OUTSF
--1970--											
HOMO	0.	0.	0.	.00	.00	.00	****	0.	0.	0.	0.
HMDU	0.	0.	0.	.00	.00	.00	****	0.	0.	0.	0.
IVDU	0.	0.	0.	.00	.00	.00	****	0.	0.	0.	0.
--1971--											
HOMO	0.	0.	0.	.00	.00	.00	****	0.	0.	0.	0.
HMDU	0.	0.	0.	.00	.00	.00	****	0.	0.	0.	0.
IVDU	0.	0.	0.	.00	.00	.00	****	0.	0.	0.	0.
--1972--											
HOMO	0.	0.	0.	.00	.00	.00	****	0.	0.	0.	0.
HMDU	0.	0.	0.	.00	.00	.00	****	0.	0.	0.	0.
IVDU	0.	0.	0.	.00	.00	.00	****	0.	0.	0.	0.
--1973--											
HOMO	0.	0.	0.	.00	.00	.00	****	0.	0.	0.	0.
HMDU	0.	0.	0.	.00	.00	.00	****	0.	0.	0.	0.
IVDU	0.	0.	0.	.00	.00	.00	****	0.	0.	0.	0.
--1974--											
HOMO	4.	4.	0.	.00	.00	.00	****	0.	0.	0.	0.
HMDU	0.	0.	0.	.00	.00	.00	****	0.	0.	0.	0.
IVDU	4.	5.	0.	.00	.00	.00	****	0.	0.	0.	0.

--1975--											
HOMO	25.	29.	0.	.00	.00	.00	****	0.	0.	0.	0.
HMDU	2.	3.	0.	.00	.00	.00	****	0.	0.	0.	0.
IVDU	14.	18.	0.	.00	.00	.00	****	0.	0.	0.	0.
--1976--											
HOMO	146.	171.	0.	.00	.01	.00	****	0.	0.	0.	0.
HMDU	12.	14.	0.	.00	.02	.00	****	0.	0.	0.	0.
IVDU	55.	71.	0.	.00	.00	.00	****	0.	0.	0.	0.
--1977--											
HOMO	807.	954.	0.	.01	.07	.00	****	0.	0.	0.	0.
HMDU	62.	74.	0.	.01	.08	.00	****	0.	0.	0.	0.
IVDU	231.	293.	0.	.00	.01	.00	****	0.	0.	0.	0.
--1978--											
HOMO	3545.	4377.	0.	.04	.29	.02	0.	1.	1.	0.	0.
HMDU	262.	327.	0.	.05	.34	.02	0.	0.	0.	0.	0.
IVDU	977.	1234.	1.	.01	.06	.00	0.	0.	0.	0.	0.
--1979--											
HOMO	7928.	11874.	0.	.12	.69	.06	5.	5.	5.	1.	1.
HMDU	571.	866.	0.	.13	.75	.06	1.	0.	0.	0.	0.
IVDU	3310.	4402.	5.	.03	.20	.01	0.	2.	2.	1.	0.
--1980--											
HOMO	8202.	19202.	0.	.19	.89	.11	23.	27.	24.	7.	4.
HMDU	615.	1417.	0.	.22	.93	.14	3.	2.	2.	1.	0.
IVDU	6957.	10935.	18.	.07	.47	.03	5.	8.	7.	2.	1.
--1981--											
HOMO	7398.	25324.	0.	.25	.93	.18	95.	102.	94.	33.	16.
HMDU	614.	1935.	0.	.30	.96	.22	9.	8.	7.	2.	1.
IVDU	8808.	18850.	61.	.13	.71	.06	21.	31.	28.	10.	5.
--1982--											
HOMO	6605.	30255.	0.	.30	.93	.23	272.	285.	272.	107.	53.
HMDU	588.	2393.	0.	.37	.95	.30	45.	21.	20.	8.	4.
IVDU	8433.	25846.	155.	.17	.83	.10	115.	99.	93.	34.	17.
--1983--											
HOMO	3291.	31535.	0.	.32	.88	.25	572.	605.	608.	269.	135.
HMDU	405.	2637.	0.	.41	.93	.35	73.	45.	45.	20.	10.
IVDU	7971.	31798.	307.	.21	.87	.14	276.	254.	247.	101.	49.
--1984--											
HOMO	1545.	30798.	0.	.31	.82	.25	1017.	1044.	1112.	540.	275.
HMDU	324.	2770.	0.	.43	.90	.37	82.	78.	83.	40.	20.
IVDU	7983.	37124.	495.	.25	.87	.18	503.	525.	532.	239.	118.
--1985--											
HOMO	1161.	29392.	0.	.29	.75	.24	1463.	1537.	1738.	911.	471.
HMDU	320.	2866.	0.	.44	.87	.39	142.	117.	132.	68.	35.
IVDU	8255.	42017.	691.	.28	.85	.22	871.	899.	962.	470.	233.
--1986--											
HOMO	1303.	27814.	0.	.28	.68	.23	2068.	1990.	2393.	1335.	702.
HMDU	337.	2943.	0.	.45	.84	.41	167.	156.	185.	102.	54.
IVDU	8574.	46483.	872.	.31	.82	.25	1314.	1335.	1509.	788.	396.
--1987--											
HOMO	1414.	26061.	0.	.26	.63	.22	2321.	2317.	2965.	1744.	935.
HMDU	348.	2995.	0.	.46	.80	.42	206.	188.	237.	137.	73.
IVDU	8817.	50439.	1028.	.34	.79	.29	1754.	1779.	2120.	1168.	594.
--1988--											
HOMO	1482.	24181.	0.	.24	.58	.20	2489.	2475.	3368.	2072.	1132.
HMDU	354.	3021.	0.	.46	.76	.43	174.	212.	280.	168.	91.
IVDU	8935.	53800.	1157.	.36	.75	.32	2326.	2192.	2739.	1573.	809.
--1989--											
HOMO	1505.	22254.	0.	.22	.53	.19	2451.	2468.	3562.	2273.	1268.
HMDU	354.	3023.	0.	.47	.73	.44	180.	225.	312.	193.	107.
IVDU	8925.	56506.	1263.	.38	.71	.34	2542.	2553.	3322.	1969.	1024.
--1990--											
HOMO	1491.	20371.	0.	.20	.50	.17	2378.	2336.	3559.	2339.	1332.
HMDU	350.	3007.	0.	.46	.69	.44	158.	231.	332.	211.	118.
IVDU	8810.	58541.	1350.	.39	.68	.36	2895.	2856.	3845.	2334.	1225.

CHISQH = 12.757770
CHISQB = 93.055450
CHISQD = 22.162120
DTH26 = 2520.463000

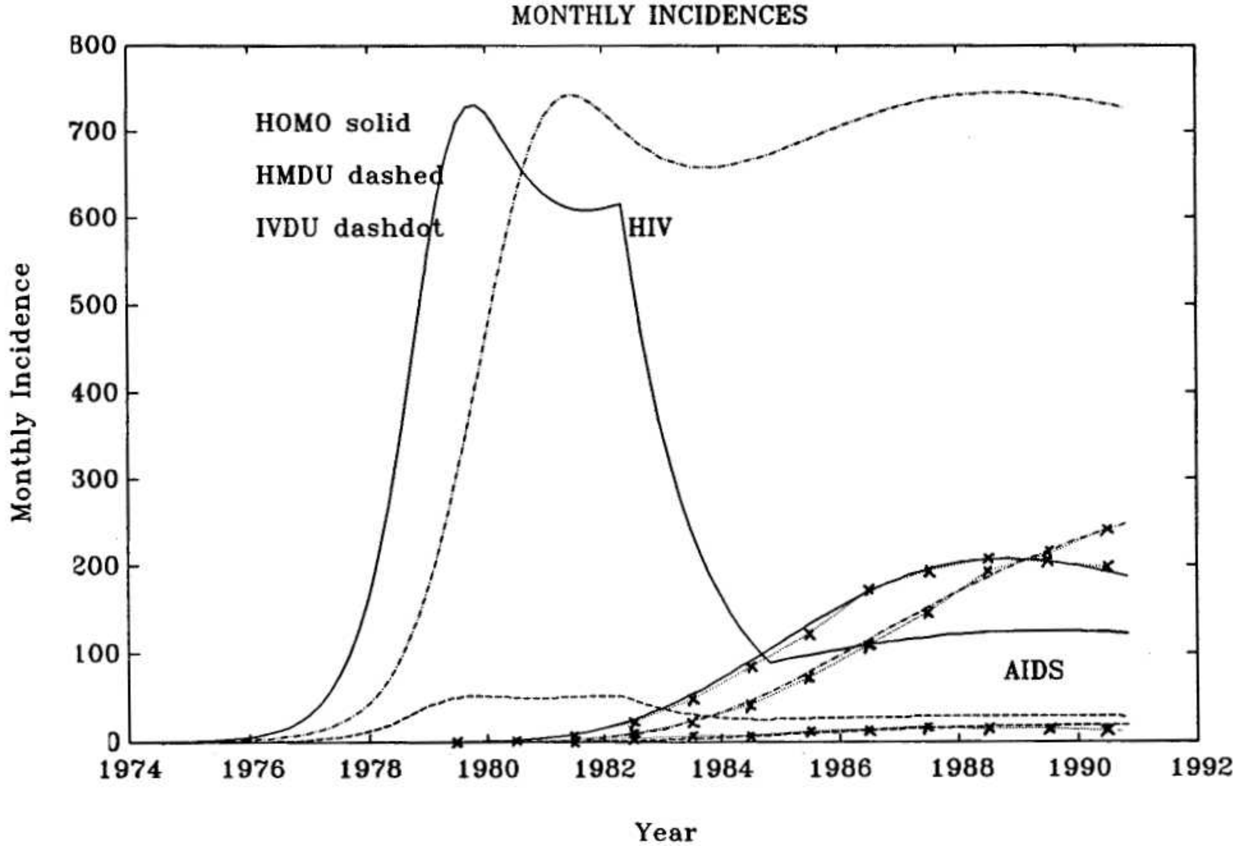

Figure 8.3 The best fitting simulations for HIV and AIDS incidences for homosexual men, homosexual IVDUs and IVDUs in NYC corresponding to Table 8.4. The AIDS incidences (x symbols) correspond to the data in Table 8.1.

The fits of the model simulations to the AIDS incidence data are quite good as shown in Figure 8.3 or as measured by the chi–square values at the bottom of Table 8.4. The largest chi–square value occurs for the homosexual–IVDUs and this is primarily because the 1988–90 AIDS incidence values are very low compared to a trend curve through the previous years. For the other risk groups the largest deviations also occur in 1988.

For the homosexual men the peak HIV incidence in Table 8.4 occurs in 1980, the peak HIV prevalence occurs in 1983, and the peak AIDS incidence occurs in 1988–89. This pattern is essentially the same as that in Table 8.2 where the population of homosexual men is fit separately. Essentially the same means that the peaks are within 5% of the previous peaks and they occur in the same year or within one year of the previous peaks. The starting date of the epidemic in Table 8.4 is May 1974 which is the same as in Table 8.2. The activity structure of 5% being ten times as active is like that in Table 8.2. The average number of homosexual partners per month before reduction and the external mixing fraction are slightly lower in Table 8.4, while the yearly reduction factor is slightly higher. The sexual activity reduction starting and stopping dates are the same in Tables 8.2 and 8.4. Thus the homosexual men part of the simultaneous fit in Table 8.4 is very similar to the separate fit for homosexual men.

For the IVDU population in Table 8.4 , the HIV incidence is approximately level after 1981, but both the HIV prevalence and the AIDS incidence increase steadily. This pattern for the IVDUs in the simultaneous fitting in Table 8.4 is very close to the pattern in Table 8.3 where the IVDUs were fit separately. In Table 8.4 compared to Table 8.3, the average number of new needle–sharing partnerships per month is slightly lower, the yearly reduction factor is still one (no reduction), and the external mixing factor is slightly higher. The decrease in the initial average number of needle–sharing partnerships per month is not surprising, since the IVDUs now also have some needle–sharing partnerships with homosexual–IVDUs. The dates for the start of the IVDU epidemic and the starting and stopping of reduction in partnerships per month are the same in Tables 8.3 and 8.4. Thus the IVDU part of the simultaneous fit in Table 8.4 is also very similar to the separate fit of the IVDUs in Table 8.3.

For the homosexual–IVDU population in Table 8.4 , the HIV incidence peaks in 1980–81, and then decreases before it levels off at about half the peak value. The HIV prevalence increases up to 1983 and then is approximately level. These behaviors are roughly between the corresponding behaviors for homosexual men and IVDUs. This is expected since the homosexual–IVDUs are linked to the HIV epidemics in both the other groups. The population size of 6500 homosexual–IVDUs is only 6.5% of the population size of 100,000 for homosexual men and only 4.3% of the population size of 150,000 for IVDUs. Thus the homosexual–IVDUs seem to be small in number compared to the other two groups. Although the homosexual–IVDUs do have some influence on the other two risk groups, this influence does not appear to be a crucial connection between the HIV epidemics in the two other risk groups.

From the simultaneous fitting of the three risk groups and the separate fittings of the homosexual men and IVDUs, one observes that the essential patterns are the same. Thus for these two groups the simultaneous fitting does not really change their patterns and the HIV epidemics in these two groups seem to be proceeding almost independently. This near independence is used in subsequent modeling.

8.7. Discussion of the Separate–Epidemic Theory

In both the separate fitting of the AIDS incidence in homosexual men in Section 8.4 and the simultaneous fitting in Section 8.6, the peak HIV incidence in homosexual men occurs in 1980, the peak HIV prevalence at about 32% occurs in 1983 and the peak AIDS incidence occurs in 1988–89. In Tables 8.2 and 8.4 the fractional HIV prevalence peaks at 93% in 1981–82 in the very active class and peaks at 25–26% in 1983 in the active class. Thus the general patterns of HIV and AIDS incidences and prevalences are the same for the separate fitting of homosexual men in Table 8.2 and the simultaneous fitting of the three risk groups in Table 8.4. In Table 8.4, the average number PASH of sexual encounters per month, the yearly reduction RDNH in sexual partners and the external mixing fraction ETAH are very close to those in Table 8.2. The dates for the start of the epidemic and the starting and stopping of partnership reduction are chosen to be the same in Table 8.4 as in Table 8.2. Thus the parameter values in the simultaneous fitting are close to the separate fitting of homosexual men. The patterns described above occur for a variety of parameter sets which satisfy the fit criteria. For example, they persist when the population size is doubled.

The pattern for the best–fitting parameter sets for IVDUs in Tables 8.3 and 8.4 is that the HIV incidence levels off around 1981, but both the HIV prevalence and the AIDS incidence are increasing. Thus the general patterns of HIV and AIDS incidences and prevalences are the same whether IVDUs are fit separately or simultaneously with homosexual men and homosexual–IVDUs. Moreover, the parameter values for the IVDU fit in Table 8.3 are the same as or similar to those in Table 8.4. Hence it seems that the simultaneous fitting of the three risk groups does not have much effect on the IVDU pattern and parameter values. This observation is consistent with the theory that the linkage provided by the homosexual–IVDUs is weak enough to be considered negligible.

In the fit of the data for the homosexual–IVDUs in Section 8.6, it is interesting to note that the best population size is 6500 which is 6.5% of the size of the non–IVDU homosexual men. It is plausible that a homosexual–IVDU population which is 6.5% of the population of homosexual men could have an AIDS incidence which is 7–9% of the AIDS incidence in homosexual men since homosexual–IVDUs can also be infected through needle–sharing. The pattern in the homosexual–IVDUs is that the HIV prevalence rises rapidly until it is about half of the population size and then remains approximately level. The fractional prevalence is high (near 50%) in homosexual–IVDUs since they are infected by both homosexual and needle–sharing partnerships. The early rise in HIV prevalence in homosexual–IVDUs seems to be due to infections from the homosexual men and then the HIV prevalence is maintained by infections from the IVDUs. Thus the pattern in homosexual–IVDUs is that their HIV epidemic follows and is sustained by the HIV epidemics in homosexual men and IVDUs. The HIV epidemic in homosexual–IVDUs does not seem to be a mechanism by which one of the HIV epidemics in homosexual men or in IVDUs supports or sustains the other.

Another argument supports the concept that the HIV epidemics in homosexual men and IVDUs are essentially independent. If one HIV epidemic were feeding another HIV epidemic, then there would be a delay of 4 to 6 years between the start (or peak) in the feeder epidemic and the start (or peak) in the sustained epidemic. In simulations of HIV epidemics in IVDUs and their heterosexual partners, delays of about 5 years are observed between the starts of the HIV epidemics, the peaks of the HIV epidemics, the starts of the AIDS incidences, and the peaks of the AIDS incidences (see Chapter 10). Similar delays are also observed for female IVDUs and perinatal cases in their children and for female heterosexual partners and perinatal cases in their children. A simplified explanation is that the delays of approximately 5 years occurs because the average time of infecting someone is in the middle of the 10 year infectious period. Since these delays do not occur between the HIV epidemics or between the AIDS incidence curves for homosexual men and IVDUs in NYC, this strongly suggests that neither of these epidemics is sustaining the other.

Forecasting future yearly AIDS incidence is difficult. The AIDS incidence data for homosexual men peaked in 1988–89 and declined slightly in 1990. This data and the best fitting simulations to this data suggest that a possible forecast is that the yearly AIDS incidence in NYC homosexual men has leveled off and may decline in the future. However, this forecast may be incorrect if the model is not realistic or if the data is incorrect for any reason. Possible data problems are recent increases in underreporting or recent changes in reporting delay patterns or a temporary leveling off of AIDS cases due to effects of the treatment of some pre–AIDS people with zidovudine (AZT) and aerosol pentamidine.

It is interesting to compare the HIV/AIDS epidemics in homosexual men in NYC and SF. In SF homosexual men the AIDS incidence in Table 8.1 appeared to be leveling off in 1987–89 and then it jumped up again in 1990. Thus the AIDS incidence in 1990 would probably not be consistent with a forecast based on data up through 1989. Simulations in Section 6.3.3 of the HIV/AIDS epidemic in SF homosexual men suggest that therapy may not have had much effect on the AIDS incidence in homosexual men there. Although saturation in the very active homosexual men did occur in the simulations of homosexual men in SF in Section 6.2.1, a reduction in sexual partners per month was essential in fitting the data there.

The simulations in Table 8.3 for NYC IVDUs suggest that there may not have been significant changes in needle–sharing behavior in IVDUs in NYC. Thus the HIV incidence remains high in Figure 8.2 and AIDS incidence continues to increase. This forecast without any change in behavior may be a "worst case" prediction, but it is consistent with the AIDS data so far. Blower et al. (1991) also modeled IVDUs in NYC and also found that their simulation scenario was able to fit the AIDS incidence data in NYC IVDUs without any change in needle–sharing behavior.