The Asian Epidemic Model: a process model for exploring HIV policy and program alternatives in Asia

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Abstract

Background Process models offer opportunities to explore the effectiveness of different program and policy alternatives by varying input behaviors and model parameters to reflect programmatic/policy effects.

Methods Traditional theoretical HIV models set modeling parameters a priori and a small change in model parameters often gives widely varying results for the same behavioral inputs. The Asian Epidemic Model (AEM) has been designed to reflect the primary groups and transmission modes driving HIV transmission in Asia. The user adjusts AEM modeling parameters until HIV prevalence outputs from the model agree with observed epidemiological trends.

Results The AEM projections resulting are closely tied to the epidemiological and behavioral data in the country. In Thailand and Cambodia, they have shown good agreement with observed epidemiological trends in surveillance populations and with changes in HIV transmission modes, AIDS cases, male/female ratios over time and other external validation checks. By varying the input behaviors and STI trends, one can examine the impact of different prevention efforts on the future course of the epidemic.

Conclusions The AEM is a semi-empirical model, which has worked well in Asian settings. It provides a useful tool for policy and program analysis in Asian countries.

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Origins and approach of the Asian Epidemic Model

In contrast to the curve fitting approaches used in the UNAIDS Workbooks and the Estimation and Projection Package,[1, 2] the Asian Epidemic Model (AEM) is a full process model, which mathematically replicates the key processes driving HIV transmission in Asia. As a result it has more extensive epidemiological and behavioral input requirements but offers the ability, which these other packages cannot, to examine future scenarios in which prevention and care efforts induce behavior change. This paper will describe the AEM, explain its use, and discuss actual applications. For those working in Asian countries, AEM can provide a valuable tool for improving understanding of trends in national epidemics and exploring policy and program alternatives.

In 1998, Chin et al proposed that three major factors determined the spread of HIV in Asia: the general pattern of heterosexual risk behaviors, the percentage of men visiting sex workers, and the partner exchange rates of female sex workers.[3] With support from the United States Agency for International Development, the Asian Epidemic Model was developed to test this hypothesis by implementing a process model focused primarily on the most important transmission routes for HIV in Asia: sex work, marital sex, and injecting drug use, and then testing it against actual epidemiological trends in Asian countries.[4] The goal was to develop a model of sufficient complexity to capture the essential dynamics of Asian epidemics, while keeping it simple enough that behavioral and epidemiological inputs could be obtained from existing data sources.

Two key design decisions were made. First, the model would be semi-empirical, not theoretical in nature. It would be patterned after the dominant transmission modes in Asia with appropriate behavioral inputs. However, values for parameters such as HIV transmission probabilities and cofactors would be set on a country specific basis by comparing HIV trends generated by the model directly against observed epidemiological trends, rather than by assuming the parameters to have specific values a priori. Furthermore, important cofactors for HIV, e.g., trends in other sexually transmitted infections (STIs) would be entered empirically as data, rather than calculated from behavioral and transmission parameters. Second, it was decided that all behavioral inputs could be specified on an annual basis, rather than specifying constants or starting and ending values. This was essential because the two initial countries in which the model was applied, Thailand and Cambodia, have both seen substantial changes in behavior over short time frames in response to national programs.[5, 6]

The result is a semi-empirical model that is closely tied to real-world epidemiological and behavioral data that should normally be collected during national response planning, monitoring, and evaluation. As will be seen below, this approach has proven quite successful in replicating the epidemiological trends in HIV in both Thailand and Cambodia using behavioral inputs gathered from national surveys and surveillance systems.

The AEM internal model

The AEM considers HIV transmission within a population aged 15 years and older. People enter the population at age 15 and depart by either AIDS-related or non-AIDS related (background mortality) deaths. Pediatric impacts are then calculated after the fact based on fertility data and female infection levels. The population is divided into eight compartments, chosen specifically for their relevance to Asian epidemics:

- Males who are clients of sex workers
- Males who are not clients of sex workers
- Lower-risk general population females
- Direct female sex workers (those with a higher frequency of partnering)
- Indirect female sex workers (those with a lower frequency of partnering)
- Injecting drugs users in higher risk sharing networks
- Injecting drug users who are in lower risk networks or don't share
- Male sex workers
- Men who have sex with men (MSM), who are not sex workers[1]

Each compartment is divided into those infected with HIV and those not infected. Movement is allowed between compartments because in the real world, people do not remain in one category until death. For example, female sex workers normally work for a period anywhere from 2 to 10 years on average and then return to the lower-risk female population. This movement cannot be ignored because infections acquired during past sex work may have a substantial effect on prevalence in the lower-risk female population. The rate at which movements occur is determined from the average duration of sex work, which is one of the behavioral inputs. The basic structure of the heterosexual transmission component of the model is shown in Figure 1.

Figure 1 about here

Movement between or out of compartments may also occur due to deaths or infection with HIV. For example Figure 2 shows the possible movements of uninfected male clients between compartments in the model. They may move into one of the other uninfected male compartments, may die of non-AIDS related causes, or may become infected either from sex workers or from other lower-risk female partners. In the latter case they move into the infected male client compartment.

Figure 2 about here

Infection occurs either through sexual behavior or needle sharing with an infected partner, which has some probability of transmission per contact, a value set on a country-specific basis as described below. The number of new infections, i.e.,

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[1] To date little work has been done with the MSM components because of the paucity of data on these men in Asia; however, it has been added to focus attention on the need for data collection systems to gather information on these men in light of recent surveys showing high HIV prevalence around Asia.[7,8] The earliest application in Thailand used only the first 6 compartments and the Cambodia work used only the first 4, as there is no evidence of any influence of injecting drug use on the epidemic in Cambodia.[9,10]

movement from the uninfected to the infected compartment, is calculated based on the prevalence in the partner population, the frequency of sex or injecting acts, and the probability of transmission of HIV. Corrections are made for increased HIV transmission in the presence of other STIs or due to lack of male circumcision by adding cofactors that increase the effective transmission probability by a fixed amount. These cofactors are also chosen on a country specific basis. Finally a correction is made for protective behaviors such as using condoms. For example, the number of male clients infected by direct sex workers in a year would be calculated as:

> Number of new infections in male clients from direct sex workers =
>   Probability of female to male transmission per contact ×
>   Number of client contacts per year with direct sex workers ×
>   Fraction which are not protected by condoms ×
>   Percent of sex workers infected ×
>   Corrections for other STDs and for circumcision

Similar terms are included for each key transmission mode in the model and are described in detail in the web annex.

AEM has much more stringent input requirements than either the UNAIDS workbooks or EPP. The inputs fall into a number of general categories and are primarily behavioral in nature:

- *The sizes of key populations* (total male and female population, male clients, direct and indirect female sex workers, IDUs, MSM, etc.).
- *Sexual risk behaviors* (frequency of sexual contact between different partner types, levels of condom use with different partners).
- *Injecting risk behaviors* (frequency of injection, levels of sharing).
- *Average duration in different key populations* (average time in sex work, average time as a client, etc.).

To calculate the number of new infections one additional set of trends is needed:

- *Levels of STIs* (by type of partner, e.g., among sex workers, general population couples, etc.)

This is used in conjunction with STI cofactors to calculate increases in HIV transmission due to other STIs. The user must also enter HIV surveillance data for the key populations, but these are used to adjust the transmission parameters in the model *not* for the calculation of new infections. All inputs, both behavioral and epidemiological, can be entered for each year to reflect changing behavior. For example, in Thailand the proportion of male clients dropped from 22% of adult males in 1990 to 10% in 1993 and stabilized at this level.[7-9]

Summary description of the software
The software has been structured to assist the user in the three key steps of preparing an AEM projection:

- collating the various forms of input data together,
- adjusting the transmission probabilities and cofactors to obtain a fit, and
- generating useful outputs for policy and programming.

Figure 3 about here

On the inputs screen, (see Figure 3a), the user enters the values for the various population sizes, behavioral inputs, and epidemiological inputs. By selecting a particular input item in the tree on the left, the user can enter the corresponding values in the spreadsheet and view the results in graphical form. The figure shows the inputting of the total adult male population size with a graph of the input values over time displayed on the right. The user can also export all inputs and outputs directly to a Microsoft Excel spreadsheet, edit them there, and then re-import them into AEM.

The heart of the AEM is the parameter-fitting screen, shown in Figure 4. The graphs show four key populations: IDUs, female sex workers, general population males and general population females. The jagged lines in the graphs are the observed HIV prevalence entered by the user from actual surveillance data during the process of defining inputs. The smooth curves show the results of AEM calculations of HIV prevalence based on the parameters on the right hand side of the screen and the behavioral inputs provided earlier by the user. These user-adjustable parameters include: start years of sexual and IDU epidemics, probability of transmission per injection with an infected needle, probabilities of transmission per sexual contact from male to female and from female to male, and cofactors for STIs among males and females and for circumcision.

When the user changes a parameter, AEM recalculates the epidemic and adjusts the smooth lines shown in Figure 4. For example, Figure 4a shows the effect of setting the female to male transmission probability to 0.00086. This produces far too many infections (a much more severe epidemic: the smooth curves produced by the model are much higher than the surveillance data). When this value is reduced to 0.00056, the value used in the best fit for Thailand shown in Figure 4b, the model curves and the surveillance lines are in good agreement for all populations. Similar effects can be seen if the start years or the cofactors are altered. The user can keep adjusting these parameters until he/she obtains a satisfactory fit or an automatic fitting routine can be used to fit the parameters within user supplied upper and lower bounds.

Some might expect that the same transmission probabilities and cofactors would be used for all countries. However, this is not necessarily the case.[10, 11] The mix of types of STIs may vary substantially from country to country, requiring different STI cofactors. The HIV subtypes, the structure of sexual networks, the levels of vaginal trauma in sex work, and other factors may influence per contact probabilities of HIV transmission. As a result, these parameters are set on a country-specific basis based upon fitting local epidemiological data.

On the outputs screen (see Figure 3b) the user can explore any of the model's outputs, including HIV prevalence, new and cumulative HIV infections, AIDS cases, and deaths. Any of these variables may be extracted for the population as a whole, by age, or by at-risk population. An output window (not shown) allows the user to view age distributions of HIV, AIDS and deaths as well as new infections by mode of

transmission over time. This gives the user the ability to explore how HIV transmission has shifted from one group to another over time – a critical element in using it to evaluate past, present and future program directions.

The updated version software and documentation will be made available on the East-West Center (www.EastWestCenter.org) and UNAIDS (www.unaids.org) websites in the second quarter of 2004.

Examples of the application of the AEM – Thai National Projections and the effects of IDU epidemics

To date the AEM has been applied to the modeling of national epidemics in Thailand and Cambodia. Full reports on these applications of the AEM can be obtained from the Thai Ministry of Public Health or Family Health International Cambodia or from the corresponding author.[8, 12] As can be seen in Figure 4b, the Thai AEM fit is quite close to the actual HIV surveillance values measured in the country (Note: male and female general population surveillance values are based upon adjustments to HIV surveillance data in military conscripts and antenatal clinic women). Using behavioral inputs gathered from Thai national behavioral surveys over the period from 1990 to 2000, the AEM projection reasonably reproduces 10 years of seroprevalence trends in all the populations measured using parameter values in agreement with those in the modeling literature. The agreement between modeled and observed HIV prevalence values in Cambodia is comparable to that seen in Thailand.[12]

Another advantage of AEM (and other process models) is that it allows the user to examine changes in the dominant modes of transmission over time. Figure 5 shows how the source of new infections in the Thai epidemic has changed, going from a predominance of new infections among IDUs in the mid-1980s, to sex workers and clients in the early 1990s, and to married couples and IDUs once again in the early 2000s. This clearly shows the need to adapt the national prevention response over time. Another major advantage of process models with behavioral inputs is that they allow one to examine "what if" or alternative future scenarios. Figure 6 shows how the Thai epidemic might resurge should condom use between sex workers and clients fall from 85% to 60% in 1998. This drives home the importance of sustaining the hard won successes in condom promotion among clients and sex workers.

Figures 5 and 6 about here

Strengths

Because AEM is patterned after the dominant modes of HIV transmission in Asian settings and uses semi-empirical fits to actual country data, the resulting projections are likely to reflect the actual HIV transmission patterns in the country. The large variety of outputs available, including transmission routes, male/female ratios, AIDS cases, and HIV trends allow numerous opportunities for external validation of the projections produced against other sources of data. If the projections stand up well against such validity checks, as they have in Thailand and Cambodia, it gives some confidence that the model itself reflects local reality. Program and policy analyses done with a well-validated model are more likely to be both accurate and relevant to the local conditions.

The ability to extract a more complete picture of what is driving the epidemic, coupled with the ability to explore alternative scenarios based upon achievable levels of behavior change are two other major strengths of the AEM. The ability to change behaviors on a yearly basis allows the user to explore both what might have been, allowing retrospective evaluation of earlier program impacts, and what might be, permitting relative efficacy of different program alternatives to be explored.

The use of both behavioral and epidemiological inputs encourages users to undertake an integrated analysis of epidemiological and behavioral data, as recommended in the UNAIDS/WHO 2nd generation guidelines.[13] It also helps in identifying gaps in national and local data collection systems. Almost all data inputs for AEM have other uses in program planning and evaluation, and if they are currently unavailable it will be difficult to evaluate coverage, effectiveness, or impact of programs. Thus, as monitoring and evaluation systems are strengthened over the next several years, it can be expected that more and more countries, provinces, and major cities will be able to apply AEM.

Limitations
While AEM provides a dynamic and realistic picture of an epidemic, the more complex set of inputs compared to the UNAIDS workbooks or EPP also limits the number of places in which AEM can currently be applied. Most countries at present lack sufficient data to apply the model, although as data collection systems strengthen in the near future, this will change. In low prevalence countries, AEM cannot be applied at all, as there is no basis on which to set the parameters.

Caution must also be exercised because the AEM internal model may not be fully appropriate in all settings. For example, if a major mode of transmission is not included, such as sex workers who inject as observed in some cities in Vietnam, the resulting projections may be wrong. Thus, users must understand what is driving their local epidemic and make certain that the key local modes of transmission are already included in AEM. If not, modifications to AEM may be required before use.

Finally, models are only as good as their inputs. This is especially true for process models, which are more complex than the other tools described in this volume. Thus, unless the user takes great caution in evaluating the quality and validity of epidemiological and behavioral inputs to the AEM, a "garbage in – garbage out" situation will ensue.

Future directions for the AEM
Several future directions are anticipated for the AEM. With the support of WHO work is currently underway to incorporate the impacts of antiretrovirals on HIV prevalence, including the impacts of behavioral backlash. In the future more attention will be paid to expanding automatic input and output validity checks along with review of the user selected parameters for fitting. A sensitivity analysis module is planned which will allow users to better assess the impact of specific changes and to determine what changes will have the greatest impact on downstream infections. And further work will be undertaken to improve the fitting algorithms in the AEM package.

Conclusions
AEM provides a policy and planning tool for Asian countries, provinces or cities that have sufficient epidemiological and behavioral data to apply it. The process of developing an AEM projection encourages close, integrated analysis of epidemiological and behavioral data and will also help in identifying and filling gaps in the data required for planning and evaluating HIV programs. Once a baseline fit has been developed, it can be easily modified to explore alternative future behavioral patterns and provide important feedback on the relative impact of alternative prevention and care scenarios. As such, AEM is a valuable complement to the UNAIDS workbooks and EPP for the countries of Asia.

Acknowledgements

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Figure 1 The basic structure of the heterosexual component of the AEM
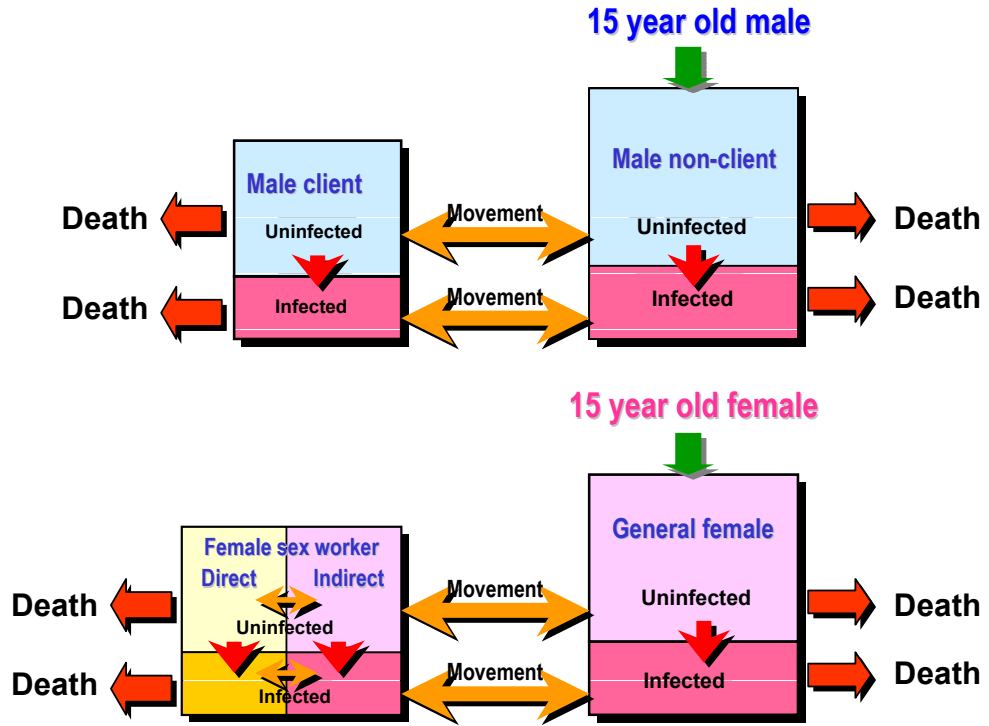
Figure 2 Movement of those in the uninfected male client compartment to other
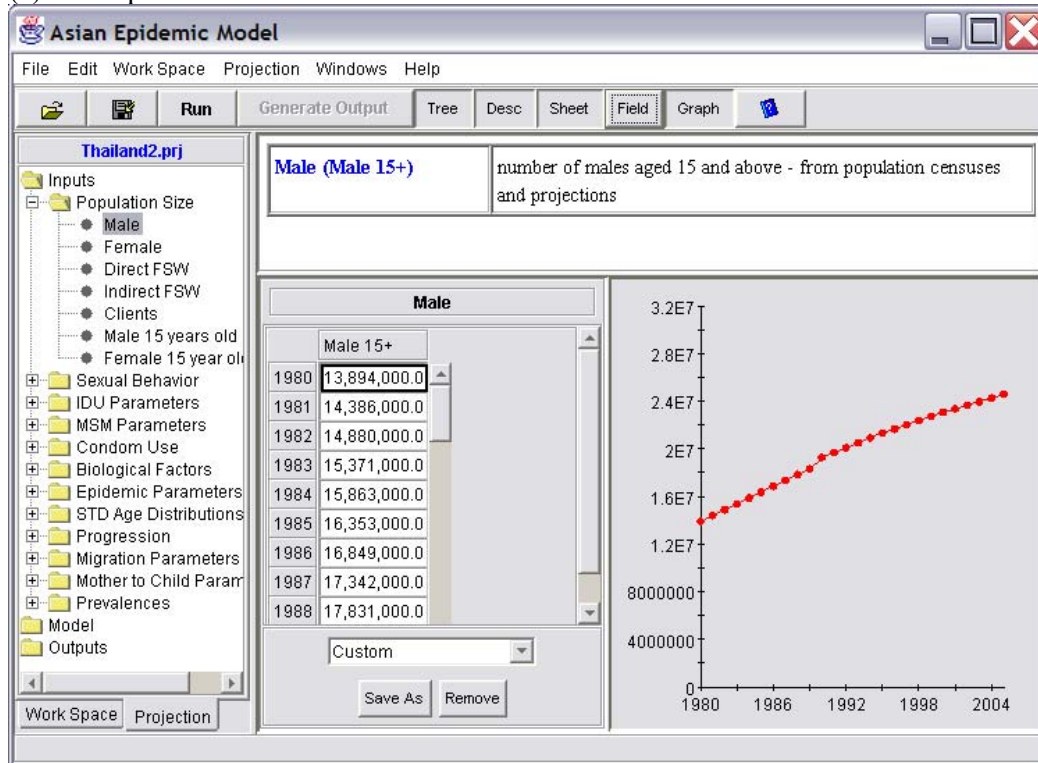compartments

13
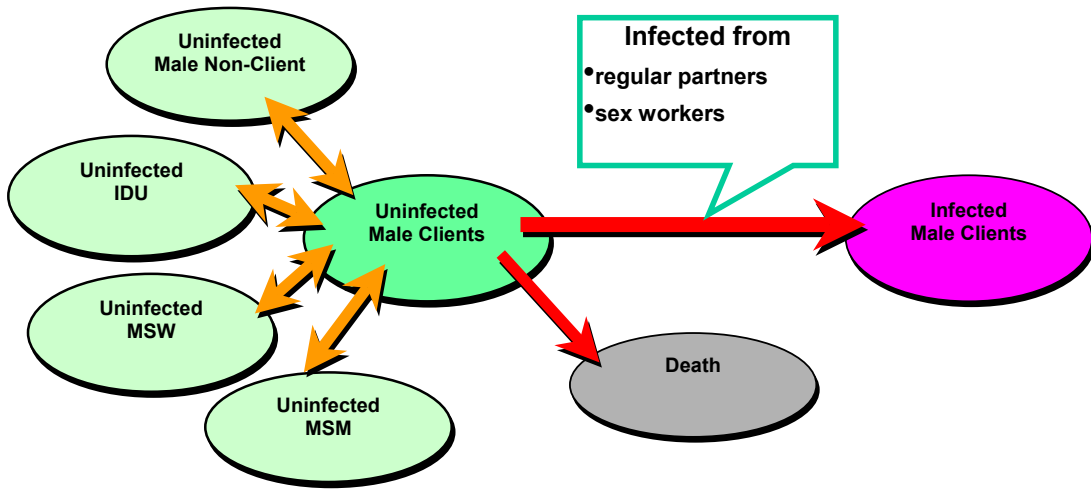
Figure 3
(a) The inputs screen of the AEM

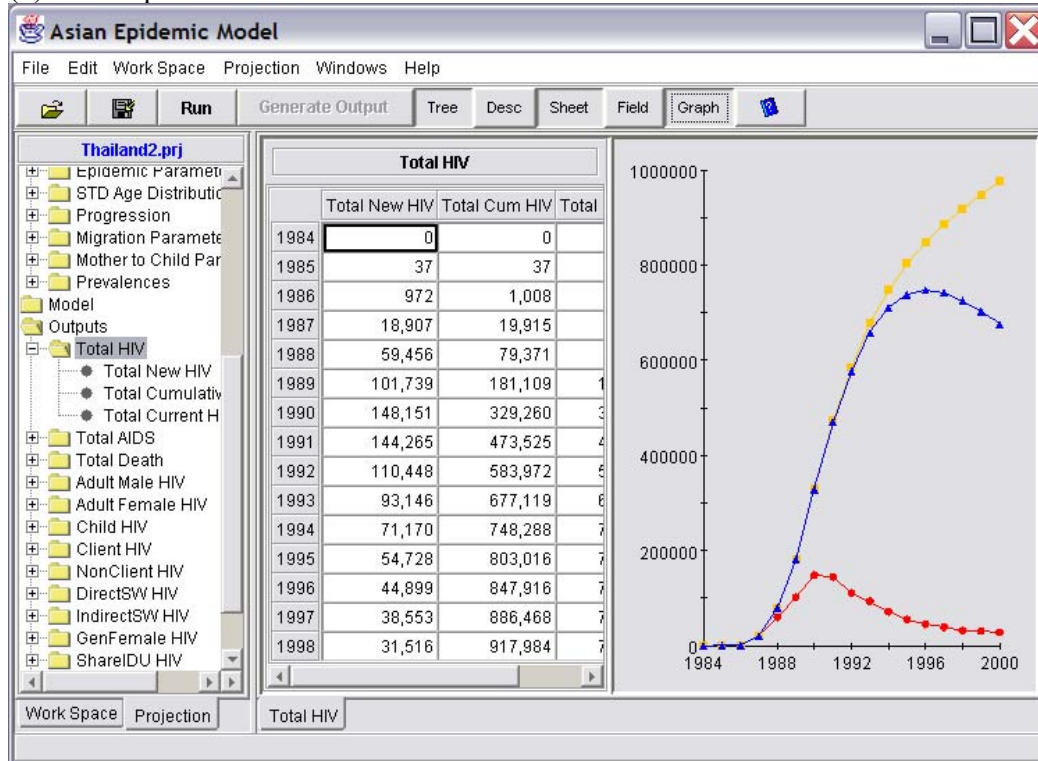
(b) The outputs screen of the AEM

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Figure 4 Example of the AEM parameter fitting screen in use. The jagged lines represent the actual measured HIV prevalence in each population, the smooth lines are the prevalence calculated by AEM from behavioral inputs. Figure (a) shows effects of setting too high a male to female transmission probability – all of the curves, except for injecting drug users are too high. Figure (b) shows the final best fit obtained for the Thai epidemic, correctly reproducing trends in all key populations.
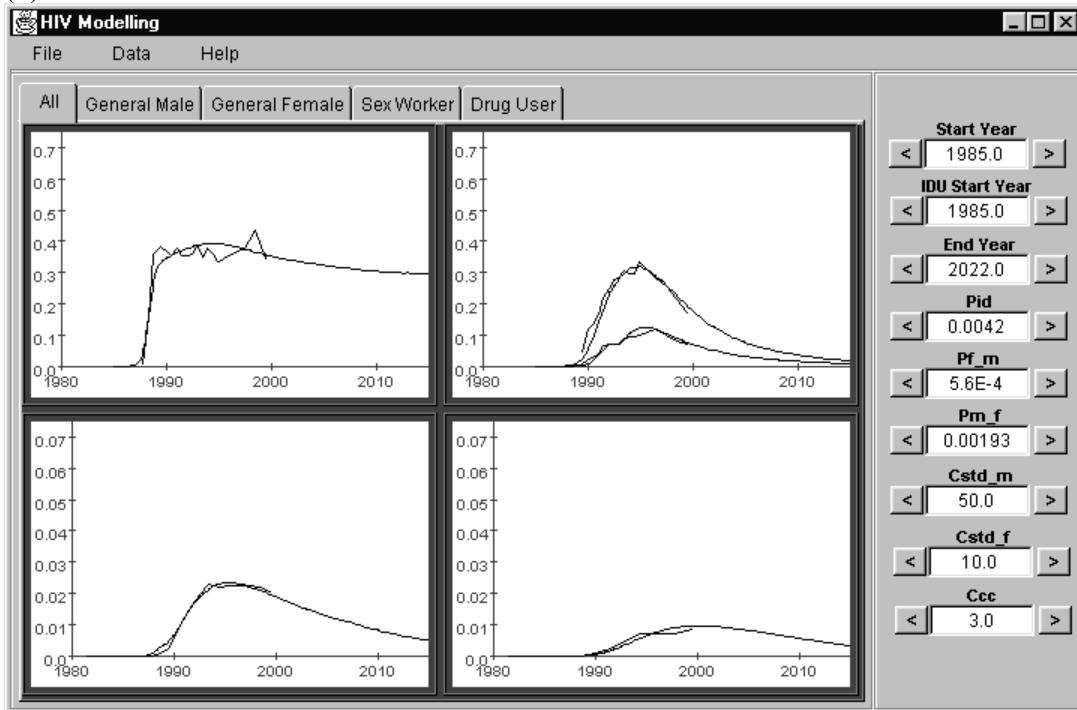
(a)

(b)

15
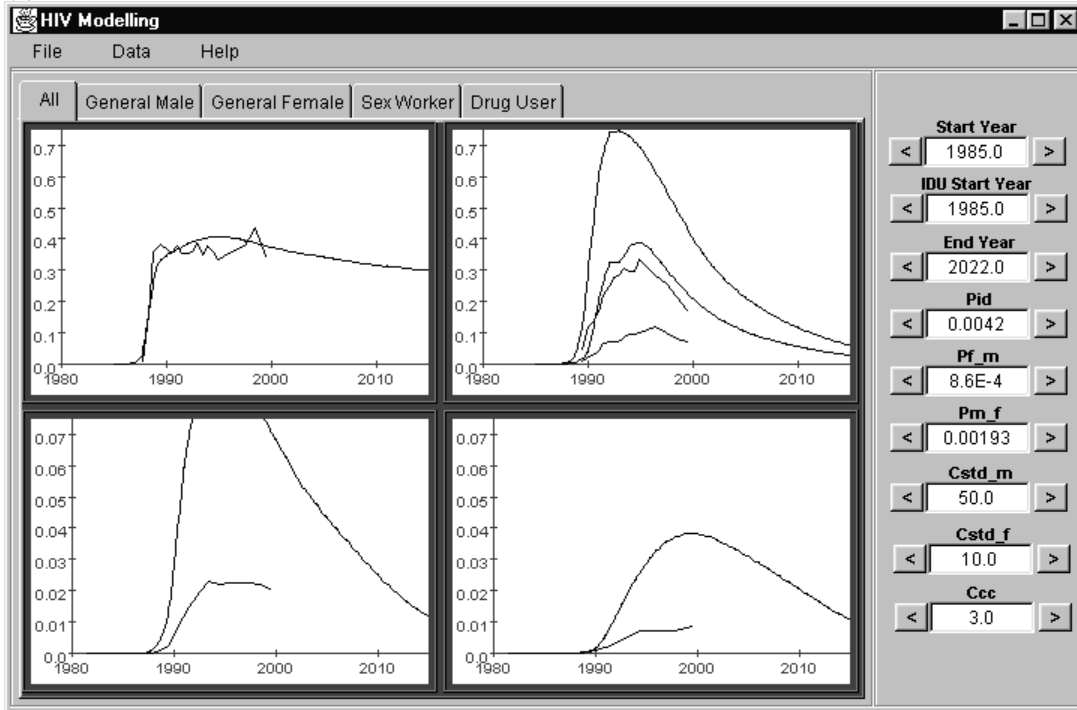
Figure 5 The changes in routes of transmission of new HIV infections in Thailand over time as calculated by the AEM. Source: Thai Working Group on HIV/AIDS Projection.[8]
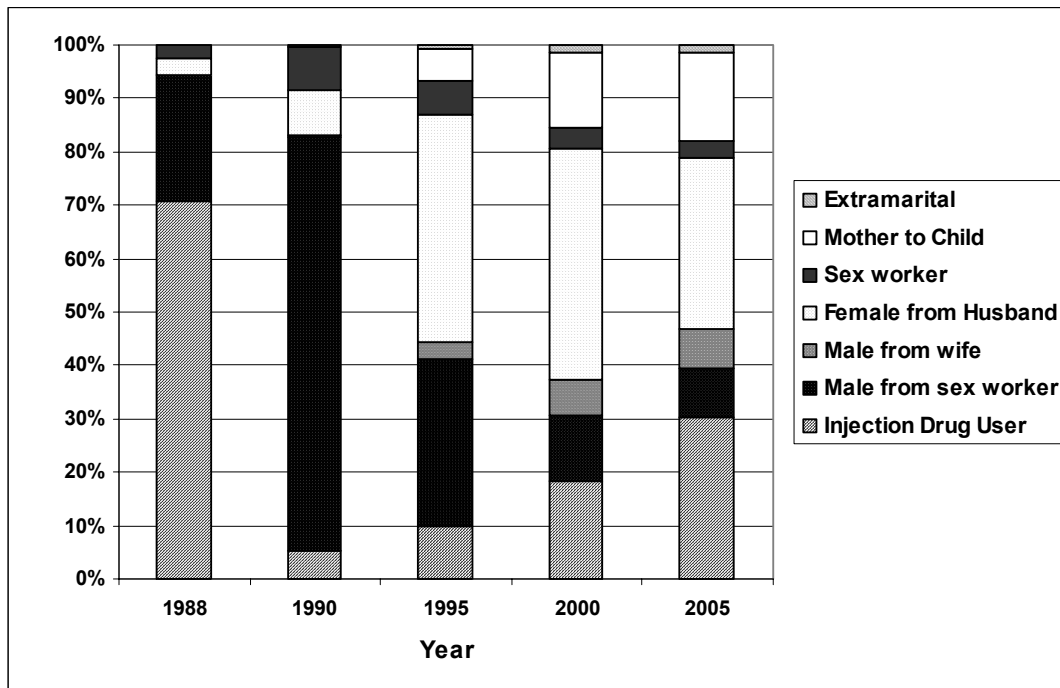
Figure 6 A hypothetical scenario for Thailand in which condom use between clients
and sex workers drops from 85% to 60% starting in 1998, leading to a resurgent
epidemic. A major strength of process models such as the AEM is the ability to
explore alternative projections in this way. Source: Thai Working Group on
HIV/AIDS Projection.[8]