Modeling the Impact of Prevention in the Spread of HIV for the Purposes of Economic Evaluation

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It is not possible to *know* how many cases of HIV would have occurred in the absence of concerted prevention efforts, or of work by any given AIDS Service Organization, for how do you count what doesn't happen? This problematic has provided the impetus for the current project. The aim is to develop a methodology that can adequately evaluate prevention efforts. This evaluation is achieved through mathematical modeling of both the epidemiology and the process of prevention of HIV. The following article provides a detailed description of only the prevention model, as it is this model which is unique in the literature. This will be first contextualized by the rationale and the history of evaluation of prevention in the spread of HIV. Examples and data used are from the Canadian context.

1. MOTIVATION

The importance of evaluation of HIV prevention efforts

Evaluation of prevention investment is an important step for informing the policy process. As evidence based decision making is gaining acceptance in the policy process, evidence about the impact of prevention is becoming increasingly necessary. In addition, spending in health care or health services is coming under increasing scrutiny. As resources are becoming increasingly scarce, there needs to be an allocation of resources among what may be competing or parallel interests. As a result, decisions to spend in one area over another are being made.

Evaluation, based on past experience, will contribute information to future decision processes for policy and program options. In Canada, prevention investment is largely allocated to community based organizations (CBOs) and AIDS service organization (ASOs) who do ground level advocacy, support and education. In this decision making context, it is important to specifically value the prevention efforts of AIDS Service Organizations: to inform the decision process not only about prevention but also about the role of ASOs.

The challenge of HIV prevention evaluation

The outcome of interest for policy, broadly speaking, is infections averted. Whether an intervention is aimed at behavioural change, client support, or attitude change, it can be argued that the end goal for prevention is avoiding an infection.

Evaluating prevention in accordance with the outcome of interest is inherently challenging, given ethical limitations on available research methods. We cannot intentionally deny or protect some populations information that may be critical to their health.

There are a number of evaluative methods that have been developed to examine individual interventions in isolated populations and locales. Many of these are process oriented (i.e. number of clients seen, number of condoms / needles distributed), with no definitive link to changing the outcome of interest. We may know how many condoms are in distribution, and the effectiveness of them if used, but we lack the information on actual use. Other evaluations focus on measurable outcomes such as knowledge, or self-reported behaviour, as reported through pre / post questionnaires to the participants in an intervention. These, as well, have the problem that they are not linked to the outcome of interest.

Efforts at evaluation of prevention on a larger scale are not common in the literature, and they tend to take the form of reviews or meta-analyses. Prevention evaluation has historically been done in conjunction with a specific intervention in a specific location or population, and not necessarily with a mind to generalization. Examples include examination of street outreach for HIV prevention at various US sites[1], targeted condom promotion for Ghanian prostitutes[2], education evaluation in Rhode Island[3], and prevention among female sex partners of injection drug users in Ciudad Juarez, Mexico[4]. Meddings (1997)[5] gives an in-depth, critical overview of the literature on prevention evaluation.

As well, our tools of evaluation do not necessarily capture the full accounting of the intervention in the context of an infectious disease. Infections averted have a multiplier effect in the future: with a reproduction rate of more than 0, one less infection today translates into more than one cases averted, considering potential future infections. Not considering this effect leads to a potentially large underestimation of the impact of a given intervention. This is often lacking in evaluations.

Beyond the technical challenges of evaluation, significant is the social challenge: a fairly common lack of community support for evaluation. Agencies know that evaluation is important, but there is often an unwillingness to participate due to the inability of evaluative methods to fully value their work. A large part of this deficiency is due to our inability to measure what doesn't happen; the agency runs the danger of not being able to provide the required information to justify continued funding of their programs.

In summary, the practical challenge to evaluating prevention is enormous, whether it is linking outcomes to evaluation, or generalization of interventions necessary for abstraction and comparison, or the inability of evaluation to fully account for the benefits of interventions. Nonetheless, evaluation needs to be done for the aforementioned reasons. Investment has taken place, and in order to ensure prevention is appropriately considered for future resources, it must be evaluated. Our current tools for prevention evaluation are not sharp enough to allow us to answer pertinent questions, such as:

- How does one estimate what would happen under different investment scenarios?
- How does one account for "multiplier effects" that occur in the context of an

infectious disease?
- How does one consider changes in transmission of an infectious disease that result from prevention programs?

Consequently, it is necessary to develop methods to estimate the impact of primary prevention from a broad perspective. This is the broad mandate of the current paper.

operations research or system dynamics modeling

Given the complexity of HIV prevention as well as its epidemiology, system dynamic modeling is considered to be a valuable method for pursuit of evaluation. Through the use of simulation models, one can hypothetically recreate the epidemic and its interventions as a means of considering the impact any or all of the interventions had on the course of the infection.

As Hethcote and VanArk[6] described, the assets a modeling approach holds are many. Among them are:
- Modeling requires the researcher to be explicit about their assumptions of biological and social processes. In research and evaluation, assumptions are always made, but not always acknowledged.
- A model provides the flexibility to test and modify assumptions.
- It also allows the researcher to perform sensitivity analyses of parameters - to see how essential it is to get a precise estimate for that parameter.
- It enables one to test theories or conjectures. This is conducive to the research and learning process.
- Finally, the process of modeling may suggest data that need to be collected in order to broach difficult policy decisions.

In short, modeling provides a good, clear, rigorous structure.

It is important to also address the serious limitation of a modeling approach to decision making - that it is a simplification of reality, rife with concomitant assumptions and hypotheses. This limitation should not affect the decision to use modeling for research, but it should affect the manner in which outcomes are interpreted.

literature review: prevention evaluation and modeling

The literature on modeling of infectious disease, and specifically modeling the epidemiology of HIV/AIDS, is very rich. Since the late 80s there has been extensive exploration and development in this field. Published modeling efforts that incorporate prevention, however, are at a relatively early stage of development. Existing work in prevention modeling often takes prevention as given exogenously. Prevention is characterised by a change in the transmission, or through an addition of a “prevention” parameter. Interventions include education, barrier implements and testing, and preliminary work has been done regarding drug therapies. Interventions are usually modeled in a specific population.

Education has been modeled assuming that it works - and changes behaviour[7, 8]. Brandeau[8] examines what the effect is of non-permanent risk reductions, incorporating the knowledge that education has an immediate impact following counselling, and then the impact lessens with time. People revert to risky behaviour. Becker et. al.[9]incorporate "behaviour change" - not attributing it to any specific intervention. More recently, Pinkerton et al.[10]incorporate retrospective estimates into a model to examine the efficiency of two different educational interventions - pushing the envelope of prevention modeling away from assumed changes toward calculated changes.

Use of implements - condoms and needle exchange products - are poorly modeled. We are able to determine the effectiveness when used properly[11], however little is known as to what extent they are in fact used. Condom use is not generally modeled directly - it is lumped under the rubric of "intervention,"[12-14] represented by reduced transmission probability. It is difficult to distinguish between educational interventions and use of implements, as interventions' positive outcomes are usually what is modeled.

Needles have been studied by three groups - Kaplan and coauthors[15-18], Siegel et al.[19] and Homer[20]. In Kaplan's "Needles that Kill"[21] he considers the impact of bleach or cleaning on the equipment of IDUs, using a set number of randomly distributed needles to share in a shooting gallery. He later moves on to model needle exchange programs, using a circulation theory of needle exchange[17]. Siegel et al. use a staged Markov model to examine needle sharing, and demonstrate the benefit of introducing a program that decreases needle sharing early in the epidemic. Homer adds a bit more complexity to the basic principles of Kaplan. He includes mixing patterns in the sharing of injection equipment.

Testing is considered on its own, but should also be seen as affected by behavioral response. McCarthy et. al.[22] do a cost effectiveness analysis of screening, as does Hsieh[23]. Hsieh uses both constant and variable infectivity. The results under the two cases differ, bringing attention to the need for the substructure of intervention modeling to be as accurate as possible.

In summation, a few generalizations are made here about weaknesses in the existing literature that deals with prevention modeling:
1) populations are considered in isolation, i.e. IDUs in Connecticut, or gay men in San Francisco. In fact, populations interact, and risk groups may be exposed to multiple routes of transmission.
2) the treatment of prevention is underdeveloped - often included as simply an exogenous parameter change. Outcomes are modeled rather than the intervention itself.
3) prevention information is often not grounded in experience. There is an assumption

that prevention works, and also an assumption of its impact. The models have been admittedly hypothetical in order to first understand the dynamics.
4) lack of economic treatment. There are limited considerations of the economic aspects of prevention, despite the fact that decisions surrounding prevention are largely economic.

As more precise modeling of the epidemiology of HIV was useful for insights on the importance of viral load and transmission rates, more precise modeling of prevention holds promise for our understanding of interventions in the spread of infectious disease. Now that the context in which this work takes place has been discussed, we can turn to the theory and methods specific to the current project. The objective of this study, to reiterate, is to explicitly model the process of prevention in the spread of HIV with particular attention to economics.

2. Theory

Prevention

Evidence, or lack thereof, of the impact of prevention on populations is likely a major contributing factor to the generalized treatment of prevention in modeling. The Meddings paper referenced above gives a solid overview of what we do and do not know in prevention. The results were pessimistic, in that prevention evaluations are by and large poorly done and not generalizable. The outcome measures are often unlinked to behaviour change and sometimes unlinked to the intervention itself. This calls for forging of new directions in evaluation, but until that time, it should be recognized that there is a general lack of *concrete* knowledge regarding the impact of prevention.

One concept that seems to be at the core of any work in prevention or prevention modeling is that prevention efforts cause behaviour change (i.e. education or implement distribution causes changes the transmissibility of HIV).

This premise should be questioned. Many, if not most, prevention evaluations use changes in *knowledge and attitudes* as outcomes. The impact of prevention in this case is often positive. Where evaluations of education have been done with *behaviour change* as an outcome measure, the impact of prevention is not always convincing. Magura et al.[24] and Des Jarlais et al.[25], provide reviews of the literature that clearly indicate this.

Does this mean that prevention doesn't work? A different approach to evaluating the impact of prevention is needed to account for non-behaviour changing outcomes. Given how little we know about prevention, in order to develop an evaluation for prevention, there was the need to base it on some theoretical hypothesis.

There is a significant literature on theories of behaviour change. Many of the evaluations that appear in the literature seem to be based on individualistic cognitive / decision making theories such as the Theory of Reasoned Action[26-28], or Planned Behaviour, or the Health Belief Model[27, 29, 30], where "risk-taking" is the result of rational decision making[31]. Thus, if people are given the information, they ought to change.

These families of theories do not help us make sense of what we witness in fact: our observations do not seem to be relevant to these theories. People are not changing behaviour as soon as they gain a *knowledge* of HIV transmission or of its impact.

There are more societal-based theoretical approaches to behaviour change, such as social learning theory[32] that incorporates the concept of environment in individual behaviour change. One particular model that seems to generalize theories that use a social process of risk is the Stages of Change approach[31, 33-35]. The stages include: 1) no contemplation of behaviour change, 2) precontemplation of behaviour change, 3) contemplation of behaviour change, 4) preparation for behaviour change, 5) behaviour change, and 6) maintenance of behaviour change. The number of stages may vary, but essentially this introduces the concept that the isolated intervention does not necessarily cause risky behaviour to be reduced. Many of the interventions that have taken place to date may have had impact with regards to stages 1, 2, 3 or 4 - necessary before interventions could be directed at stages 5 and 6.

If this model is accepted, prevention strategies should pinpoint one of these aspects, and evaluate accordingly: knowledge or attitude change may be valid outcome measures. Our witnessed outcomes seem to be more relevant to this theoretical direction. Although more challenging to model because of the associated uncertainties, it is this theoretical model that underlies the current project of prevention modeling.

3. Methods

Two semi-autonomous deterministic simulation models were developed: prevention and the epidemiology of HIV/AIDS. The epidemiological model was based on best information available within a fairly well developed body of knowledge. The prevention model relied on a number of new assumptions and conventions that were developed for the purposes of modeling. For the current project, reference to the epidemiological model will be made only where needed. It will be the prevention model that will be discussed. Both models were developed using the simulation software Stella.

Both method and data are explored here, for they are intertwined in such a modeling exercise. The methodology, therefore, will focus on both characteristics of the model and well as methods used to derive the necessary data to implement it.

The population aged 15-55 is divided into twelve groupings, based on gender (male, female), sexual orientation (gay, bisexual, heterosexual), and injection drug behaviour (ever inject / never inject) assumptions. Each of these twelve groups have a further division into risk groups - high, medium and low. Transmission can occur through injection activity or through sexual activity.

As has been mentioned, prevention in the current model is developed on a simplified version of the social theory of stages of behaviour change. Only two major stages are used, translating into contemplation and action. Crudely, this allows us to divide prevention interventions into three types: education for knowledge or attitude change (E1), testing (T) and education for behaviour change (E2). E1 represents the first stage, and E2 / T one reflective of the second stage. One needs to have experienced E1 before T or E2 will have a possibility of impact.

As we are modeling the impact of investment in prevention of HIV, we start with investment itself. The data used for this come from the CPRN Economic Burden of HIV paper's section on prevention[36] that documents Canadian government investment in HIV prevention. There are three levels of government - federal, provincial and municipal. Specific funding to HIV prevention started in 1985/86 in Canada. The figures in that paper were actual dollars (not adjusted for inflation). For the current project, adjusted dollars were calculated. A yearly average of the general CPI was used for this adjustment. The base year is 1996.

For most of the investment funds, a line item was given. From there, general allocation of funds to E1, E2, or T was done (see Figure 1). Funds were then broken out into targeted and general - given that initially investment funds were more or less spent on the general population, and over time we have moved more and more toward targeted investment - to a current estimate of 82%. Targeted populations are gay/bisexual men at high risk, and IDUs at high risk. We mapped this into a nonlinear positive relationship between targeting fraction and time. See Figure 2. Prevention investment was extrapolated very conservatively to 1999. Targeted funds are divided proportionally according to targeted population, and general funds are divided proportionally among all populations, including the targeted population. The role of investment is crucial to prevention: it determines how many can be exposed to prevention.

Figure 1: Total(national, provincial and municipal) investment in prevention, divided into categories E1, E2 and T.

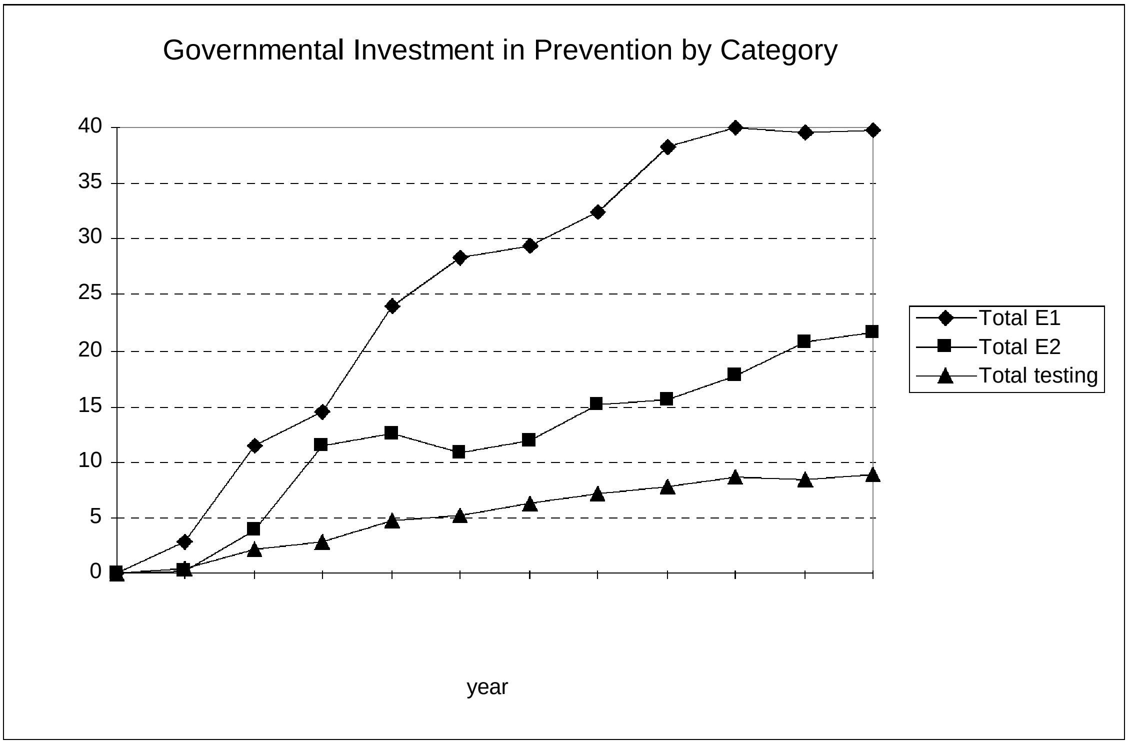
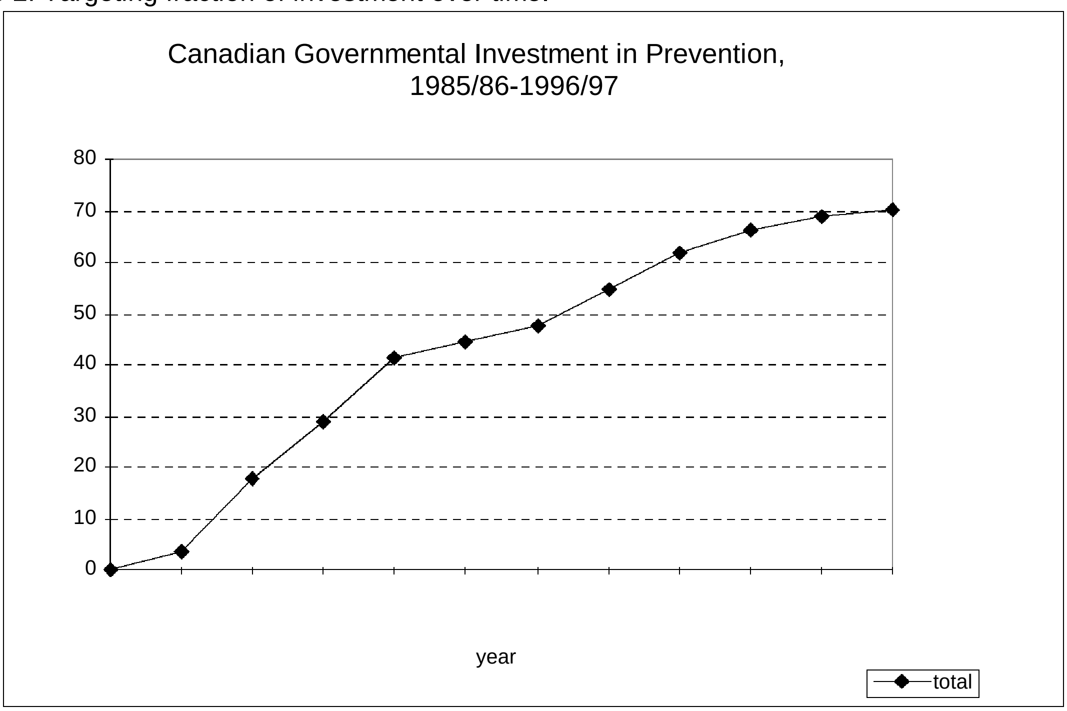


Figure 2: Targeting fraction of investment over time.



The model accounts for the fact that prevention doesn't begin as soon as prevention funds are available. There are time lags introduced: lags between the time the money is announced and the money is available, and lags between the availability of money and the introduction of prevention programs. (This is called “building capacity”. Capacity, such as the establishment or expansion of an ASO, is needed before the program can be offered. This takes both time and money.) For now, the *total* lag is 12 weeks (a conservative figure), and capacity captures 15% of all prevention funds. The 15% seemed feasible since research and provincial staff salaries alone comprised about 10% of total government investment in HIV prevention. A bit more was added to account for overhead of ASOs, etc.

It is known that more intense interventions have greater impact - and this is reflected in the model. As has been mentioned in the literature review, the information we have on prevention evaluations is not precise and not easily generalizable. As a means for overcoming this for the purposes of the current project, a system of reviewing papers was developed. Information was collected on both the intensity of the intervention and its subsequent impact. Intensity was rated using scores from one to 3 of “resource weight intensity”. Table 7 demonstrates our inclusion and exclusion criteria. A score of three represents an intensive intervention resource-wise, likely one-on-one, or for a longer period of time. A score of 1 represents a passive, less expensive intervention. See Appendix 1 for a few examples of this review.

Table 1: Resource Intensity Weight (RIW)

	1	2	3
general	minimal contact	some contact	intensive contact
E1 (knowledge, attitude change interventions)	i.e. videotape, poster campaign	i.e. group counselling	i.e. individual, small group counselling
E2 (behaviour change interventions)	i.e. condom distribution, needle exchange	i.e.group education; one session	i.e.individual or small group skills training; multiple sessions
testing	via doctor	drop in site (i.e. STD clinic)	street outreach recruiting

Outcomes for each of the studies considered were also rated, so as to form a relationship between RIW and outcomes. The chance that exposure has resulted in an impact on knowledge, attitudes or behaviour (the first two being E1 and the last E2), or that given a test / knowledge of HIV status that someone will change behaviour was approximated in the same fashion as resource intensity weights. Table 8 gives details of the rating breakdown.

Table 2: Knowledge / Attitude / Behaviour Rating Scale / Outcome rating

0	1	2	3
No effect measured	Small effect found, but is either 1) statistically insignificant, or 2) there is no data to support it	Some effect, 20-50% change	Significant effect, >50% change

The two ratings allowed outcomes to be mapped onto RIWs, giving an expected nonlinear positive relationship of likelihood of change of outcome with RIW.

From here, a rough approximation of the "cost" of each type of intervention according to RIW was estimated. For E1 this varied from $5 for a RIW of 1 to $50 for RIW 3. For T it was $10 to $30, and for E2, $50 to $100. This cost per intervention based on RIW in conjunction with funding levels for each population allows a rough estimate of exposure to the intervention in the group. As we do not have a clear sense of what the distribution of the programs has been nationally, RIWs (and thus programs) have simply been drawn at random. This indicates an assumption of an even distribution of passive to intensive interventions within each of E1, E2 and T.

To summarize, interventions are assumed to be distributed uniformly according to intensity. Each intervention is characterised by a RIW, which has an associated cost per person of intervention. The level of prevention funds and this cost per person determine how much prevention in what areas is available to what populations, on average. The relationship of the outcome rating with the RIW allows us to estimate the likely impact of the program, given that someone has completed it. Those that have a positive impact from E1 are then susceptible to programs offered in other areas of prevention - E2 and testing.

If someone is found to have experienced a positive effect from E2 or testing, and the level of effect is calculated, they are considered to be in a "reduced risk" category for approximately a year (a normal distribution with 52 week mean, s.d.=26). As the model currently is defined, people resume risky behaviour. This is not unrealistic as in many evaluations it has been shown that the impact lessens with time. In fact, maintenance is considered to be a stage of prevention in the Stages of Change theory.

4. Limitations and conclusions

Weaknesses in this project stem primarily from where the use of conventions has been necessary to achieve the objective. One major weakness continues to be unsettling: the lack of good data to inform the model. This issue is not new: it underlies this effort as well as those that came before and those that will follow . What it has caused is the development of an algorithm on an heuristic; the development of a very scientific, rigorous, calculated problem-solving methodology on top of a methodology (with respect to our knowledge of the infection or of prevention) that is essentially an educated guess. We must not lose sight of this in the interpretation of what seem to be rigorous results.

Another limitation of the work was the assumption that all changes from the base model were attributable to preventive interventions funded through government. In fact, this is not likely true. As people got infected in the gay community, for example, and people were falling to AIDS, it is likely that others started to change behaviour with or without proactive prevention. Also, ASOs existed before governments officially invested in prevention, and the impact they had in a grassroots sense is not acknowledged in the model, whether it be through accounting for funding from other sources, or for the value of the significant levels of volunteer work from which ASOs benefit.

A final limitation has to do with the manner in which we derived outcome data for the model. We have mapped RIWs onto outcomes to give a unique outcome for each RIW number (1,2 or 3), rather than a distribution of possible outcomes. As a result, a simple division of RIW by its outcome would allow us to derive elementary and unchanging cost-benefit ratios, and thus set the single preferred intervention intensity. Evidently, this is not a good reflection of reality where cost curves are more than likely nonlinear. Interventions likely reach decreasing returns to scale at a certain point. Currently we do not have information on this topic, however such an area could potentially be explored with the added concept of recruitment: enrolling people in a program may be easy at first, and as the population gets saturated, the cost of recruitment increases.

Despite these limitations, such an explicit treatment of prevention in the spread of HIV is useful for economic evaluation purposes. This project can be considered to be an exploratory step in modeling of a challenging social process. If used correctly, it can be a powerful tool of learning. Using this model one can pose policy questions that relate not only to the timing or intensity of intervention, but also to their type and implementation in diverse populations. We can experiment with sensitivities of parameters in order to identify critical areas for more detailed research on the costs and benefits of prevention interventions. Finally, both average and marginal costs can be examined, giving us a much more informative evaluation that those that currently exist.

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APPENDIX 1: excerpts from the review / classification of prevention evaluations

Article number:	16355 - Controlling HIV in Africa: effectiveness and cost of an intervention	16726	17101 - Evaluation of a targe AIDS prevention interventior increase condom use
When:	followed since Jan 1985	between 1987 and 1990	1987 to 1988 then again in 19
Where:	Nairobi	San Francisco, CA	Ghana
Target population:	Prostitutes in low income areas (note: 80& seropositive rates)	Drug users entering publicly supported drug use treatment.	Prostitutes (female)
Control:	N/A - before and after	N/A	N/A
# in intervention group:	cohort of over 1000 women	35460 (IDU specific admissions 24120)	Various
# in control group:	N/A	N/A	N/A
Infrastructure:	Health clinic		Project staff from Ghana, med school, pH nurse, community outreach workers, trained 6 women as peer counsellors
Program/ Intervention:	Health education program to encourage the use of condoms. Women asked to attend health clinic every 6 months.	Needle exchange (data is 2 years before and after needle exchange was implemented in 1988)	6 month pilot intervention, recruited women through outreach. Offered education, counselling, distribution of condoms, education sessions
Rate interv. (1-3):	2	1	3
Outcome measurement:	Questionnaire	Analysis based on 2 cohorts (before and after needle exchange) - before (459) and after (707).	Self reported condom use
Follow-up	Every 6 months		in 1991 (when program revived
Results:	Modelled how many cases of HIV infection should have been avoided based on this, the outcome is highly significant.	No good data but in general, admissions reporting ID use and increased frequency of injecting were greater in non exchange areas.	6 month intervention: always using condoms - prior (6%) an after (71%)
Rate of outc. (1-3):	3	1	3