POLICY RESEARCH WORKING PAPER 2321

Algorithms for Purchasing AIDS Vaccines

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"Demand" for AIDS vaccines varies by level of risk and by national wealth. At-risk individuals in poor countries suffer on both counts. Providing funds to develop and distribute AIDS vaccines should be a global concern.

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Summary findings

Bishai, Lin, and Kiyonga delineate two different algorithms for the purchase of AIDS vaccines, to show how differences in policy objectives can greatly affect projections of the number of courses of vaccine that will be needed.

They consider a hypothetical vaccine costing $10 to produce, and offering 60 percent, 75 percent, and 90 percent reductions in the risk of HIV for 10 years. For each of the world's 10 major geographic divisions, they use published estimates of the risk of AIDS, the value of medical costs averted, and the value of potential productivity losses.

Under the "health sector" algorithm — in which purchases are made to minimize the impact of AIDS/HIV on government health spending — 766 million courses of vaccine would be purchased. Under the "societal" algorithm — in which purchases are made to minimize the impact of AIDS/HIV on health spending and GDP — more than 3.7 billion courses of vaccine would be purchased.

Under an "equity" model — allocating vaccines to everyone in the world at high risk as if they had the financial resources of Western Europeans — vaccine would be offered to 4.7 billion people. For a Western European man, reducing the risk of HIV/AIDS would be a $789 concern; in Africa, the comparable risk would be a $48,577 crisis.

The authors conclude that financing AIDS vaccines solely on the fixed budget of a ministry of health means large vulnerable populations wouldn't receive the vaccine. Allocating the vaccine based on society's ability to pay would still exclude many poor infants who would probably be immunized if they were born in more developed regions.

Policymakers concerned about equity in health care must redouble efforts to making the financing of development and distribution of AIDS vaccines a global, not a regional, concern.

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Algorithms for Purchasing AIDS Vaccines

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Introduction

In this paper we attempt to answer the question, "If an AIDS vaccine arrived in the world on 1 January 2000, what are the ramifications of two different decision algorithms, in terms of *who* would get the vaccine and *how many* would be needed?" Anticipating the answer to this question will aid policy makers as they prepare for the efficient and equitable use of an AIDS vaccine.

An effective AIDS vaccine does not yet exist. Forecasting what will happen when a vaccine is developed is difficult. Unforeseen changes in the fundamental determinants of demand for a vaccine will occur between now and the time when a vaccine is released. These determinants not only include the epidemiology of AIDS/HIV, the world's demographic makeup, and the economic resources available for health, but also the properties of the vaccines themselves. Developments in vaccine production capacity and technology could change the determinants of supply. Because all of these unknown factors are interrelated, an attempt to simultaneously offer 10-year forecasts would lack credibility. Thus, rather than project what demand will be in the year 2010, we profile who the most likely vaccine recipients would be in the year 2000 according to 2 different algorithms. We enumerate likely vaccine recipients under each algorithm as a function of possible vaccine price regimes.

METHODS

Health Sector versus Societal Perspective

To select algorithms for AIDS vaccine allocation that are relevant to what might actually occur, we employ what is known from empirical studies of national decisions to purchase other vaccines. It has been shown from studies of the uptake of Hepatitis B and Hemophilus Influenza B vaccines that a country's adoption of a vaccine depends on the cost of the vaccine, the incidence of the disease, the GDP/capita, and the cost of the consequences of the disease (Brooks et al. 1999; Miller and Flanders 1999). There are two possible perspectives on the costs of an illness: 1) The *health sector perspective* in which the cost of an illness is the net present value of the sum of the costs of

the medical care required by the victims; and 2) *The societal perspective* in which the cost of an illness is not only the medical costs but the lost productivity of workers and families affected by the disease (Gold et al. 1996). Neither of these perspectives ordinarily includes the immense intangible costs of pain, suffering, and bereavement that are borne by individuals. The decision that countries will eventually have to make regarding the purchase of the AIDS vaccine could be motivated by either of these two perspectives on the cost of disease. The model that currently appears to be most prevalent for vaccine purchase decisions by health ministries is the health sector perspective. The government health ministry is allocated a fixed budget and asked to allocate purchases for all items (including vaccines) to maximize a population's health under that budget.

Health ministries may consider other objectives besides maximizing population health. Phoolcharoen et al (1999) consider a case where the health ministry saw its primary role as allocating vaccine to minimize the contagion externality regardless of the impact of AIDS on its own operating budget. Although such policies may be adopted in the future and may prove to be valid disease control strategies, there are few historical occurrences of vaccine policies selectively targeting those most likely to be contagious among a vast pool of susceptibles. Our algorithms whose principal objective is limiting the budgetary impact of AIDS will account for the budgetary ramifications of special populations with a high propensity to spread disease. This does lead to different priorities from policies which make the minimization of secondary spread the principal objective.

AIDS Vaccine Characteristics

We base our assumptions about the characteristics of an AIDS vaccine on known properties of current vaccines. Vaccination efficacy will be sequentially modeled at 60%, 75%, and 90% efficacy with a duration of exactly 10 years. For example a recipient of a vaccine with 75% efficacy experiences an immediate 75% reduction in the risk of contracting AIDS over the next decade. Lacking any basis to predict how risk behavior may change as a result of vaccination we assume it will be constant. With vaccines of low efficacy, vaccine induced increases in risky behavior could

have serious repercussions for policy (Anderson and Garnett 1996). Were we to apply our algorithms to vaccines of lower efficacy they would certainly require adaptation to account for behavioral effects of vaccine. There is an urgent need for empirical data on the behavioral responses of participants in vaccine trials.

Eventual responders cannot be distinguished from non-responders ex ante. We assume adverse effects of the vaccine are temporary and self-limited. We assume transportation and administration costs are no different for the AIDS vaccine than for current vaccines. We assume that the vaccine's protection will last at least 10 years. We do not consider here any applications of the vaccine to reduce viral shedding or viral load in those already infected. We assume that administering the vaccine to a susceptible pregnant woman protects the woman and is safe for the fetus. Infants born to pregnant vaccine recipients are susceptible until they themselves are vaccinated.

We profile potential vaccine recipients by first dividing the world's population geographically into the major geographical regions established by the UN. We arbitrarily classify as "less developed countries" (LDCs): North Africa/Middle East, sub-Saharan Africa, South/South-East Asia, Eastern Europe/Central Asia, East Asia/Pacific, Caribbean, and Latin America. We arbitrarily classify as "more developed countries" (MDCs): Western Europe, North America, and Australia/New Zealand. There are obvious grounds for many specific exceptions. The one exception we did allow was to consider Japan, Korea, and China separately from the East Asian Region to narrow the otherwise wide variation in HIV economics and risk in this region.

Within each region we disaggregate the general population into 4 groups on the basis of age and sex. In Table 1 we propose a possible further breakdown of the groups most likely to be considered individually for vaccine receipt due to their high risk. Table 1 indicates there is little comprehensive data upon which to base population estimates for high risk groups such as commercial sex workers (CSWs), injection drug users (IDUs), and men who have sex with men (MSM) in each region of the world. The likelihood that these populations would be targeted by

public health campaigns could influence the allocation of an AIDS vaccine. Here we analyze models that incorporate estimates of the numbers of commercial sex workers, IDUs, and MSM, but we note that the small size of these groups relative to the general population make estimates of the total need for vaccine relatively robust to their inclusion or exclusion in the model. In this paper we present the details relevant to the general populations and selected high-risk populations.

Decision Rule Algorithm

We developed the following simple algorithm to profile the regional subgroups as vaccine recipients or non-recipients based on the "marginal benefit" **(MB)** of allocating AIDS vaccines to that group. **Group j is a "vaccine recipient" if $MB_j > P$; otherwise it is a non-vaccine recipient. [Rule 1]**

Where P is total price of a complete course of vaccine (including administration costs) and MB_j is marginal benefit of extending vaccination to include group j. MB_j is given as follows:

$$\mathbf{MB_j\ (Health\ Sector\ Perspective) = E \times I_{j10} \times (1+N_j) \times [PV(HC_j)] - VC_j} \qquad \textbf{[Equation 1]}$$

Where:
E = vaccine efficacy from 0-100%, assumed=75% for exactly 10 years in baseline analysis.
I_{j10} = decadal incidence of HIV expressed as the discounted likelihood that the average person in group j will seroconvert in the next 10 years.
N_j = the number of secondary cases that infected individuals in this group cause over 10 years
PV = denotes present value computed at a 3% discount rate
HC_j = health care costs between the onset of HIV/AIDS and death
VC_j = vaccine administration cost

We call Equation 1 the "health sector perspective" because it might reflect the perspective of a minister of health searching for investments which minimize the drain that a given disease poses to an arbitrarily fixed health sector budget. We also compute MB_j from a societal perspective alternative that includes lost productivity.

$$\mathbf{MB_j\ (Societal\ Perspective) = E \times I_{j10} \times (1+N_j) \times [PV(HC_j + W_j))] - VC_j} \qquad \textbf{[Equation 2]}$$

Where: W_j = lost lifetime wage after the onset of total disability from AIDS.

Computing MB_j according to equation 2 for each subgroup in each region produces what we call the "societal perspective", because the presence of lost productivity in the estimates makes MB_j reflect the perspective of a typical minister of finance searching for investments that would maximize the country's GDP. Equations 1 and 2 conform loosely to perspectives that might be taken by hypothetical social planners deciding to allocate AIDS vaccine to subgroups of a region. Since a planner pursuing either of these simplified objectives would end up explicitly rationing vaccine to individuals based on their economic status, neither algorithm is ethically appropriate if an equitable distribution is of value. To indicate the degree of inequity in vaccine distribution inherent in these two simple algorithms we recalculate MB_j throughout the world based on each group's AIDS/HIV incidence, but with Western European values for medical spending and lost productivity. We call this exercise the "*equity perspective*".

To implement the algorithm we gathered secondary data for each regional subgroup on HIV incidence(Bernard et al. 1998; UNAIDS and WHO 1998a), medical care costs (Mann, Tarantola and Netter 1992), and GDP/Capita (World Bank 1998). Sensitivity analysis of models incorporating high-risk groups demonstrated that estimates of the number of secondary cases spread by CSWs and IDUs was unnecessary—according to the algorithm their own high risk rendered them vaccine recipients whether or not they infected any secondary cases. We assume that for the general population that the number of secondary cases caused is negligible and make the approximation that $N_j \approx 0$

After using the algorithms to profile each subgroup as a "recipient" or "non-recipient", as a function of the vaccine price, we tabulated the cumulative population of recipients across all subgroups, based on demographic data for cohorts defined by age and sex. (United Nations 1997)

Medical Care Costs

We assume that in the developed world, a patient would begin to incur medical costs on average about 2 years after seroconverting and incur them for 10 years before succumbing to

disease(Curran et al. 1988). In the developed countries significant medical costs are incurred through the use of highly active antiretroviral therapy (HAART) for asymptomatic seropositive patients. The two-year duration reflects delays in seroconversion and delays in diagnosis of seroconverions. Prior to the development of HAART and improvements in opportunistic disease prophylaxis, the time between seroconversion and death was thought to be 10 years (Bartlett 1998). Responders to HAART may have dramatically prolonged survival, but it is too soon to tell. Indeed the very best answer to the question, "How long between seroconversion and death in the developed world in 1999?" is "Nobody knows." It is likely that HAART will increase the total medical costs per case of AIDS, so we treat this possibility in our sensitivity analysis.

We assume that in developing countries, an adult patient would begin to incur medical costs 5 years after seroconverting and incur them for an average of 2 years (Morgan et al. 1997). The natural history of HIV/AIDS in children regarding mean time to AIDS and mean time to death does not appear to deviate markedly from adults(Barnhart et al. 1996). Our model neglects possible regional differences in care seeking behavior and opportunistic infections that might lead adult groups to spend more on treatments than children. Little is known about these differentials. Thus medical costs are assumed to be the same for all ages and sexes. We discount the medical costs and lost wage costs by 3%. Estimates of the actual medical care costs of AIDS in each region are derived as shown in the appendix.

Productivity Costs

We assume that adults who seroconvert would withdraw from the labor force after six years in developed countries, and after four years in developing countries. In withdrawing from the labor force these patients would cease to add valuable goods and services to the economy. We assume that in every country for adults age 15-49 that the average age for the onset of AIDS is 30 and that retirement age is 65. AIDS thus yields 35 years of productivity loss. We compute the present value of this loss using a discount rate of 3%. As a measure of the value of these lost goods and services,

we use the regional GDP/Capita and apply it to both men and women. GDP/capita is a coarse measure of economic well being; however, there are few alternative measures. The global perspective of this paper makes it infeasible to account for the complex adaptation any individual economy may make to the loss of many productive workers (Over et al. 192). Furthermore, the morbidity and mortality of AIDS impose an intangible burden of pain and suffering that the GDP cannot possibly reflect.

Vaccine Administration Costs

A full consideration of the delivery costs would include the costs of marketing the vaccine to individual target groups (Cutts, Orenstein and Bernier 1992; Kim-Farley and EPI Team 1992). However, we suspect that in many parts of the world, the word about the vaccine will spread quickly--along with misinformation about its safety and efficacy. Much of the marketing costs will depend on what sorts of local rumors are spread about the vaccine and how deeply they are entrenched (Nichter 1995). Lacking a basis to estimate marketing costs we focus on administration costs. In developed countries, we take as an estimate the physician fee ($4.21) for therapeutic injection in the U.S. (CPT 90782) (Health Care Financing Administration 1998). In less developed countries, the administration cost of adding an additional vaccine to the EPI program has been estimated at $0.50 (Hall et al. 1993).

Results

Table 2 presents present value estimates of the lifetime cost of a single case of AIDS in each region of the world for children, teens, adult men, and adult women. The costs are presented for both the societal and the health sector perspective. These estimated medical costs range from a low of $38 per case of HIV/AIDS in sub-Saharan Africa to a high of nearly $300,000 per case in North America. The large variation in costs is due to both variation in the availability of costly treatments and variation in survival.

The societal costs are lower for infants than for children because the eventual lost lifetime productivity is discounted by more years. The societal costs are higher for children than adults because more years of productivity are lost on average for a child or teenager who is infected.

The Benefit of AIDS Vaccines

Given our estimates of HIV seroconversion risk, vaccine efficacy, and the economic loss, we can compute MB for each target group using Equation 1 for the health sector perspective, and Equation 2 for the societal perspective. These results are displayed in Tables 3 and 4.

Reviewing the health sector perspective, the groups with negative benefits (Table 3) are generally at a very low immediate risk of HIV, and primarily are infants of low risk mothers or those people residing in countries where the lack of treatments for HIV/AIDS makes the medical cost of the disease artificially low. Comparing the actual estimates of vaccination benefits to the benefits developing countries would gain if their medical spending were that of Western Europe indicates that as more medical treatments begin to be provided to HIV/AIDS patients the value of an AIDS vaccine in developing countries will only increase.

Table 4 shows the net present benefits of vaccination from the societal perspective. The table shows that if the goal is to maximize the GDP, there are few population groups anywhere in the world with an HIV risk so low that vaccine *administration* costs exceed the benefits. A person in a high-risk region like sub-Saharan Africa faces a greater than 10% chance of annihilation from HIV/AIDS. Thus, it is not surprising that the benefit of removing this threat is a large fraction of the remaining lifetime incomes shown in Table 2. The values in Tables 3 and 4 should be interpreted as the returns per individual from an investment in AIDS vaccine, not as a prediction of what individuals would actually spend to obtain these returns. Poor populations have difficulty financing such large investments despite their manifest importance.

The parenthesized values in Tables 3 and 4 indicate the benefit that a Western European would derive from the AIDS vaccine if they faced the same risk as corresponding groups in other

areas of the world. This exercise offers a lens with which to view the economics of the AIDS epidemic from a standardized perspective. The relatively low risk of a Western European man makes reducing that HIV/AIDS risk a $789 nuisance, but if that same man were to confront the HIV/AIDS risk of an African then this threat would be a $48,577 crisis.

Vaccine Demand Curves

Each different algorithms is designed to label the various subpopulations of the world as "vaccine recipients" or "non-recipients" as the price of vaccine varies from $200 to $1.00 per course.

The graphs enumerate the number of vaccine recipients as a function of the price of vaccine. Figure 1 does this according to the health sector decision algorithm. Figure 2 shows the "demand curve" that would be generated from the societal perspective algorithm. We use the term "demand curve" to suggest isomorphism to the typical price vs. quantity graphs from economics. We do not mean to suggest that the quantity demanded on the horizontal axis will result from the aggregate decisions of individual households in a private market. However, country level decision-makers are very likely to make purchase decisions as a function of price. Country level heterogeneity in HIV risk and national resources will lead countries of low financial resources and/or low risk to defer vaccine adoption until the price becomes quite low. These curves ignore the constraints that poor populations will face in obtaining sufficient financing to purchase a quantity of vaccine that achieves an optimal allocation according to the algorithm. Estimates of these financing shortfalls are discussed below.

The callout boxes in Figures 1 and 2 identify some of the main sub-populations that make the transition from non-recipients to recipients as the price goes down. The callout boxes are far from comprehensive as there are over 91 separate subpopulations being tracked (13 regions x 7 risk groups). The general pattern depicted by the callout boxes is that at high prices the vaccine recipients have very high risk or very high medical and productivity costs of AIDS. As the price drops below $25 (Health Sector Algorithm) and below $50 (Societal Algorithm) very large

populations from less developed countries convert to vaccine recipients and account for highly elastic price response at the lower price ranges.

Sensitivity Tests

To test the robustness of our model to our estimates of incidence we re-estimated the demand curves with the assumption that incidence was 25% lower and 25% higher for each population. These alternative demand curves are displayed as dotted lines in the figures. Testing sensitivity to the cost assumptions by altering assumed medical and productivity costs by ± 25% generates identical results to those plotted as dotted lines in Figures 1 and 2, due to the structure of the equations.

Assumptions about vaccine efficacy also affect the number of vaccines distributed by the algorithm. The dotted lines in Figures 3 and 4 plot out how much more or less vaccine is distributed if the vaccine lowers risk by 90% or 60%.

Discussion

Limitations

On a population basis, it is reasonable to conduct policy analysis using the notion of population risk. Caution is warranted however, however, because the risk of HIV/AIDS is not the same for every individual in a group. The possibility of safer lifestyles makes a vaccine an optional but not unique way to prevent HIV/AIDS. If one were to survey individuals on how much they would pay for an AIDS vaccine, responses would likely diverge from our values based on differences between an individual's own perceived HIV risk and the population risk measures our model would impute to him. Some individuals who are able to choose an absolutely risk free lifestyle may choose to never obtain an AIDS vaccine. For now, our model makes the arbitrary assumption that all individuals above age 49 are categorically able to eliminate their HIV risk through safe lifestyles. This achieves simplicity at the expense of disregarding the evidence that risk free lifestyles exist for

individuals in younger cohorts and that HIV continues to be transmitted between individuals well beyond age 49.

Policy Analysis for a $10 Vaccine

Until an AIDS vaccine is discovered, the marginal cost of producing it is unknown. The claim by industry (Dupuy and Freidel 1990) that there are increasing returns to scale in the production of vaccine suggests that in the first few years of vaccine production, the cost could be significantly higher than for subsequent generations of vaccine users. Unless firms are given incentives to rapidly extend capacity, it could be an additional decade *after the first vaccine* before one could expect an AIDS vaccine whose marginal production cost for a course is less than $1.00. Perhaps after this decade, additional factories will have been built throughout the world to reap returns to scale.

Suppose the marginal cost just to produce and deliver a single course of the first generation of vaccine is $10.00. The health sector allocation strategy suggests that 766 million people would obtain benefits in excess of $10.00 and hence would wish to buy the vaccine. The model predicts that of these roughly 235 million are estimated to be in LDCs. In contrast, the societal allocation strategy suggests that 3.7 billion persons (3.3 billion in LDCs) would obtain benefits in excess of $10.00. The equity model predicts that if everybody in the world had the resources of Western Europe, virtually everybody in the world under the age of 49 (4.7 billion out of 4.8 billion) would bear sufficient HIV risk to justify a $10.00 investment in AIDS vaccine.

Which Vaccine Allocation Curve?

Health ministries in regions like Africa would still be reluctant to purchase vaccine at a $10 price because $10.00 per person would exhaust all of the average annual health ministry budget. Our model predicts that it would require a $9.00 purchase subsidy to make the most optimal vaccine purchase affordable for health ministries in sub-Saharan Africa. With a $9.00 subsidy, a typical sub-

Saharan health ministry could expect to recoup its own $1.00 outlay in the form of reduced medical expenditure for HIV/AIDS.

In contrast to health ministries, our model predicts that treasury departments in every region of the world ought to be willing to spend $10.00 per citizen on AIDS vaccination for large portions of the teenage and adult populations. Such investment decisions would pay their way through enhanced survival of working populations. Indeed, there is a growing recognition that confronting AIDS is not just a health issue, but a development issue (World Bank 1997).

An important caveat is that both the health sector perspective and the societal perspective would allocate vaccine based on ability to pay just like any other commodity. Rationing by ability to pay, based on the societal perspective model would still deny AIDS vaccine to roughly 700 million LDC infants who would have obtained earlier protection had they been born in wealthier countries. Unless world leaders agree to policies supporting public and private cooperation to correct inequity, the AIDS vaccine is likely to be allocated as unequally as any other scarce commodity.

Is There Enough AIDS Vaccine Research & Development?

The AIDS vaccine allocation that we project is compatible with substantial profitability depending on the marginal cost of the vaccine. Profits in the pharmaceutical industry are difficult to predict because regulators retain tight control over firms' abilities to use the monopoly privileges they have earned through research. Although potential demand is important in projecting profit, potential regulations are equally important. It is unlikely that any pharmaceutical company could afford to behave like an unfettered monopolist in setting profit margins for the AIDS vaccine, but unless the vaccine production costs are exorbitant, a markup of $1.00 per course of vaccine would generate between $1-4 billion in profit. One route to higher profits is the ability to charge wealthier countries more than poorer countries for pharmaceuticals. Regulatory changes discussed by the EEC (Danzon 1997), and statements by US Congressmen (Russell 1997) threaten to erode this option. The recent experience of South Africa indicates that when poorer countries can obtain life-saving AIDS drugs at

lower prices, the temptation to re-import them proves irresistible to politicians. Credible signals that international regulatory institutions were prepared to tolerate and enforce higher profit margins for a pharmaceutical firm with a patent on the AIDS vaccine would substantially inflate the estimates of future profitability and stimulate private investment in AIDS vaccine research.

Conclusion

This paper has offered depictions of two models of AIDS vaccine allocation based on ability to pay and one alternative model of allocation based on equity. The *ability to pay model* was based on predictors of vaccine uptake such as incidence, medical spending, and GDP/capita that were proven empirically to have been associated with regional uptake of Hepatitis B vaccine and Hemophilus Influenza B vaccine (Miller and Flanders 1999). The *equity model* was based on what demand would be if populations with higher the HIV/AIDS risk had the financial resources of Western Europeans. The model reveals that large disparities in the attention given to HIV/AIDS could be based on global resource inequalities. The relatively low risk of a Western European man makes reducing this HIV/AIDS risk a $789 concern, but if that same man were transplanted to sub-Saharan Africa HIV/AIDS would be a $48,577 crisis.

Our finding that financing the AIDS vaccine solely within the fixed budget of a ministry of health could exclude large and vulnerable populations from vaccine receipt offers a strong reminder that HIV/AIDS must be considered a development issue affecting an entire economy. Nevertheless we find that allocation of AIDS vaccine based on societal ability to pay would still exclude large numbers of poor infants who would be immunized if they were born in more developed regions. Policymakers concerned with equity in health need to redouble efforts to make financing the human confrontation with AIDS a global, rather than a regional, issue.

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Table 1. Target Groups and Rationale. See Appendix for Population Size Estimates.

Groups Analyzed	Rationale	Data Sources for Estimating Population
1. Infants/Toddlers Aged 0-4	Can add AIDS vaccine to standard battery of Expanded Program on Immunization (EPI) vaccines. Can enforce receipt with school entry requirements	(United Nations 1997)
2. Children/Teens Aged 5-14	Transition period from low risk to high risk Many Accessible through schools	(United Nations 1997)
3. Women, aged 15-49	High risk group Often accessible through antenatal care	(United Nations 1997)
4. Men, aged 15-49	High risk group	(United Nations 1997)
5. Older Adults	Not targeted Generally lower risk Generally lower contagion to others	
Other Target Groups		
Medical Personnel	Highly accessible through medical system Highly motivated to obtain vaccine	(Reddy 1994)
Men Who Have Sex With Men	High risk group High rate of contagion Accessible via NGOs in developed countries	(Biggar and Rosenberg 1993; China Ministry of Health and China 1997; Isomura and Mizogami 1992; MacKellar et al. 1996; Sy et al. 1998)
Military Staff	Highly accessible through military medical facilities Military & strategic interest in their immunity	(Reddy 1994)
IV Drug Users	High risk group High rate of contagion	(China Ministry of Health and China 1997; Crofts, Reid and Deany 1998; Guerena-Burgueno, Benenson and Sepulveda-Amor 1991; MacDonald et al. 1997; Mastro et al. 1994; McCarthy et al. 1996)
Commercial Sex Workers	Highest risk group in many areas High rate of contagion	(Brown and Sittitrai 1995; China Ministry of Health and China 1997; Hanenberg and Rojanapithayakorn 1998; O'Connor et al. 1996)

Table 2: Present value lost per new case of AIDS by age and by region. [1]

Region	Infants/Toddlers (age 0-4)	School Children (age 5-14)	Average for Adults (age 15-49)
Western Europe, Medical	$255,014	$255,014	$255,014
Western Europe, Societal [1]	$573,552	$683,102	$583,263
North Africa & Middle East, Medical	$1,335	$1,335	$1,335
North Africa & Middle East, Societal	$103,300	$138,368	$117,525
Sub-Saharan Africa, Medical	$38	$38	$38
Sub-Saharan Africa, Societal	$16,140	$21,678	$18,386
South & South-East Asia, Medical	$441	$441	$441
South & South-East Asia, Societal	$53,829	$72,190	$61,277
Eastern Europe & Central Asia, Medical	$5,035	$5,035	$5,035
Eastern Europe & Central Asia, Societal	$31,274	$40,298	$34,934
China, Medical	$1,896	$1,896	$1,896
China, Societal	$10,972	$14,093	$12,238
Japan, Medical	$150,591	$150,591	$150,591
Japan, Societal	$801,166	$1,024,909	$821,001
Korea, Medical	$67,031	$67,031	$67,031
Korea, Societal	$218,860	$271,077	$223,489
East Asia & Pacific, Medical	$2,820	$2,820	$2,820
East Asia & Pacific, Societal	$25,151	$32,831	$28,266
Australia & New Zealand, Medical	$122,163	$122,163	$122,163
Australia & New Zealand, Societal	$409,977	$508,961	$418,752
North America, Medical	$299,894	$299,894	$299,894
North America, Societal	$650,616	$771,235	$661,309
Caribbean, Medical	$3,322	$3,322	$3,322
Caribbean, Societal	$68,946	$91,515	$78,101
Latin America, Medical	$1,942	$1,942	$1,942
Latin America, Societal	$42,683	$56,694	$48,366

[1] Discounting at 3% . Note that this places less weight on the productivity losses of children who acquire AIDS.
[2] "Societal" refers to the sum of medical and productivity losses

Table 3: Health Sector Perspective Estimates. Net Expected Benefit of Vaccination by Group and By Region. Numbers in parentheses are the values that would be obtained if the ability to pay in that region were equal to that of Western Europe Negative values indicate that the savings to the medical sector from vaccination do not exceed vaccine delivery costs.

More Developed Countries	Infants/Toddlers (age 0-4)	Children/Teens (age 5-14)	Women (age 15-49)	Men (age 15-49)	Female CSW	MSM	IDUs
Western Europe (WE)	$31.61	$105.39	$87.13	$342.87	$4,945.84	$14,784.09	$12,625.79
	($31.61)	($105.39)	($87.13)	($342.87)	($4945.84)	($14784.09)	($12635.79)
Australia & NZ (A & NZ)	-$2.10	$16.02	$0.51	$72.00	$176.21	$8,682.82	$652.14
	($0.19)	($38.02)	($5.64)	($154.87)	($372.40)	($18129.78)	($1365.91)
North America (N. Am)	$87.94	$262.94	$209.51	$850.66	$61.61	$10,899.69	$12,471.42
	($74.15)	($222.96)	($177.52)	($722.73)	($51.76)	($9267.86)	($10604.38)
Japan	-$3.74	$95.23	$0.83	$77.66	$1,071.98	NA	NA
	-($3.77)	($163.82)	($3.97)	($133.07)	($1817.88)	NA	NA
S. Korea	-$3.72	$44.46	$1.19	$31.05	$474.94	NA	$15,898.62
	-($3.14)	($179.16)	($15.54)	($129.13)	($1817.88)	NA	($60495.45)
Less Developed Countries							
North Africa & Middle East (NA & MC)	-$0.41	-$0.06	-$0.15	$0.89	$0.85	NA	$12.44
	($17.04)	($82.63)	($66.01)	($265.53)	($257.17)	NA	($4380.80)
Sub-Saharan Africa (SSA)	-$0.10	$1.07	$2.61	$2.67	$15.83	NA	-$10.50
	($2,656.19)	($10,513.90)	($20,818.01)	($21238.58)	($109414.76)	NA	NA
South & South East Asia (SSEA)	-$0.30	$1.23	$1.32	$4.59	$98.17	NA	$240.50
	($112.70)	($999.10)	($1,051.71)	($2945.69)	($57110.57)	NA	($145285.01)
East Europe & Central Asia (EE & CA)	-$0.22	$9.74	$8.14	$31.80	$1,187.34	NA	$524.60
	$13.66	$518.01	$437.36	($1635.70)	($60163.24)	NA	($26595.52)
East Asia & Pacific (EA & Pac)	-$0.45	$0.11	$0.46	$6.12	$19.65	$382.46	$668.40
(excluding China, Japan, S. Korea)	($4.19)	($54.46)	($86.02)	($598.58)	($51919.56)	NA	($52952.65)
China	-$0.46	$0.78	$0.17	$4.44	$13.04	NA	$449.20
	($4.40)	($171.90)	($90.04)	($663.44)	($5638.66)	($1352.82)	($4194.79)
Caribbean	$5.12	$27.91	$36.63	$76.03	$675.81	NA	$689.27
	($430.80)	($2,180.90)	($2,849.86)	($5874.73)	($51919.56)	NA	($52952.65)
Latin America (L Am)	$0.05	$4.05	$2.86	$14.35	$61.92	$317.41	$375.68
	($71.09)	($597.18)	($440.87)	($1948.86)	($8196.25)	($41744.06)	($49395.82)

Table 4: Societal Perspective Estimates. Net Expected Benefit of Vaccination by Group and By Region.Numbers in parentheses are the values that would be obtained if the ability to pay in that region were equal to that of Western Europe. Negative values indicate that the savings to the GDP from vaccination do not exceed vaccine delivery costs.

More Developed Countries	Infants/Toddlers (age 0-4)	Children/Teens (age 5-14)	Women (age 15-49)	Men (age 15-49)	Female CSW	MSM	IDUs
Western Europe (WE)	$76.34	$289.38	$204.69	$789.62	$11,330.35	$33,819.38	$28,895.81
	($76.34)	($289.38)	($204.69)	($789.62)	($11330.35)	($33819.38)	($28905.81)
Australia & New Zealand (A & NZ)	$2.87	$80.08	$11.97	$257.01	-$3.21	$29,773.20	$2,245.64
	($5.69)	($108.92)	($18.33)	($359.63)	($857.18)	($41471.60)	($3129.52)
North America (N Am)	$195.71	$682.81	$467.07	$1,880.91	$140.92	$24,040.42	$27,506.31
	($172.03)	($604.30)	($411.45)	($1658.43)	($123.80)	($21202.75)	($24259.60)
Japan	-$2.61	$671.32	$22.35	$441.18	$5,862.10	NA	NA
	-($3.21)	($445.89)	($14.51)	($311.06)	($4163.25)	NA	NA
S. Korea	-$3.08	$0.00	$13.31	$112.85	$1,592.85	NA	$53,016.81
	-($1.80)	($488.67)	($40.97)	($300.76)	($4163.25)	NA	($138369.76)
Less Developed Countries							
North Africa & Middle East (NA & MC)	$6.61	$44.61	$30.15	$122.10	$118.25	NA	$2,008.66
	($38.95)	($222.19)	($151.61)	($607.96)	($588.84)	NA	($10020.35)
Sub-Saharan Africa (SSA)	$167.64	$893.29	$1,500.50	$1,530.82	$7,888.27	NA	-$10.50
	($5,974.66)	($28,164.31)	($47,615.30)	($48577.24)	($250252.55)	NA	NA
South & South East Asia (SSEA)	$23.40	$282.47	$252.33	$707.43	$13,722.58	NA	$34,899.80
	($254.11)	($2,677.11)	($2406.10)	($6737.97)	($130623.14)	NA	($332294.47)
East Europe & Central Asia (EE & CA)	$1.24	$81.44	$59.48	$223.64	$8,241.34	NA	$3,642.89
	($31.34)	($1,388.44)	($1,000.96)	($3741.80)	($137605.15)	NA	($60829.55)
East Asia & Pacific (EA & Pac) (excluding China, Japan, S. Korea)	-$0.04	$6.58	$9.09	$65.90	$201.46	$3,838.83	$6,705.43
	($10.04)	($146.73)	($197.38)	($1369.71)	($118750.33)	NA	($121113.20)
China	-$0.29	$9.03	$3.84	$31.36	$86.94	NA	$2,902.80
	($10.53)	($461.32)	($206.57)	($1518.05)	($12897.31)	($3094.79)	($9594.91)
Caribbean	$116.11	$782.33	$872.46	$1,798.86	$15,900.65	NA	$16,217.05
	($969.54)	($5842.79)	($6,518.80)	($13437.25)	($118750.33)	NA	($121113.20)
Latin America (L Am)	$11.48	$132.38	$83.21	$369.22	$1,554.12	$7,916.88	$9,368.13
	($160.52)	($1,600.51)	($1,008.99)	($4458.06)	($18746.99)	($95477.07)	($112978.07)

Figure 1. Health Sector Perspective Algorithm for AIDS Vaccine Distribution . Callout boxes are not comprehensive but suggest the principle populations receiving vaccine as a function of price. Details and region abbreviations listed in Table 3 Dotted lines show sensitivity of demand estimates to variation in HIV incidence rates.

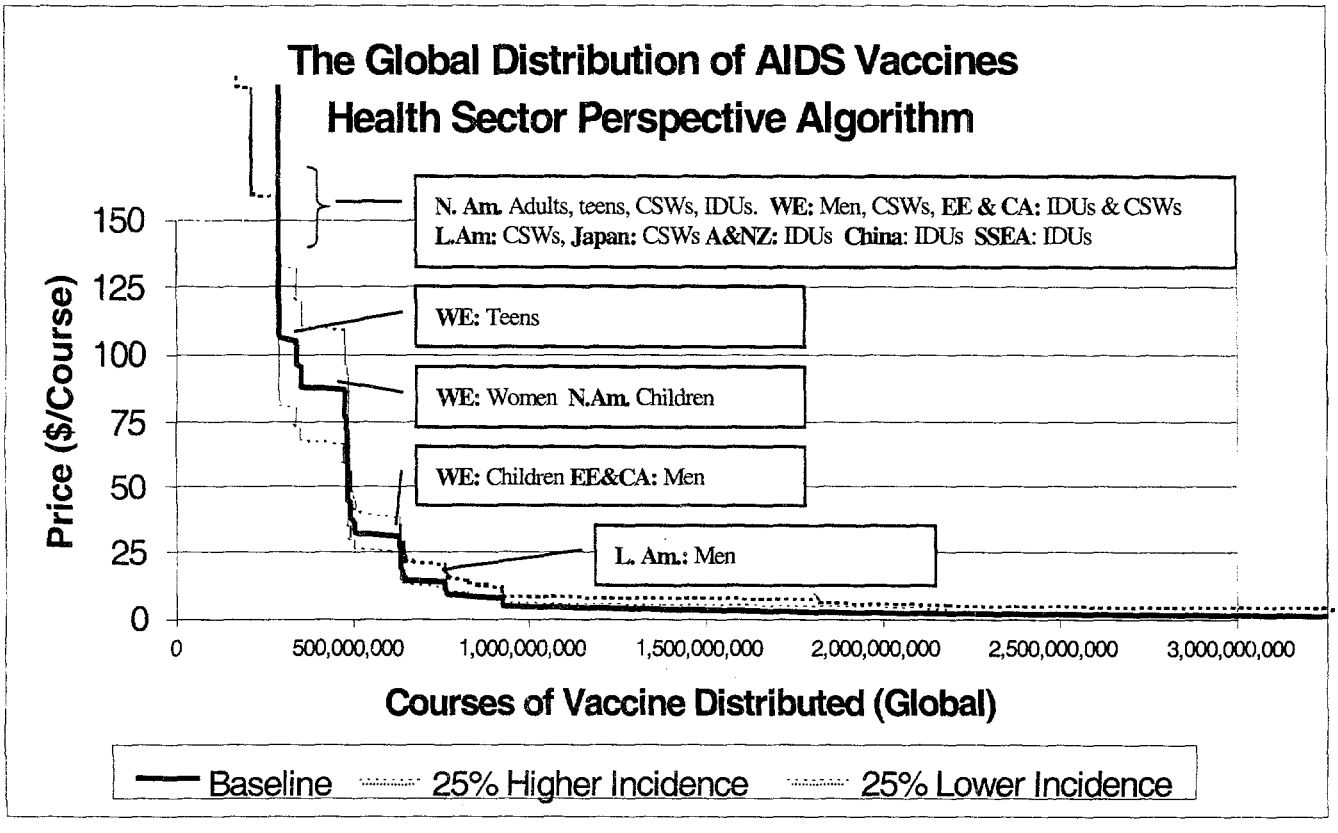


Figure 2. Societal Perspective Allocation Algorithm for AIDS Vaccine Distribution Callout boxes are not comprehensive but suggest the principle populations receiving vaccine as a function of price. Details and abbreviations listed in Table 4. Dotted lines show sensitivity of demand estimates to variation in HIV incidence rates.

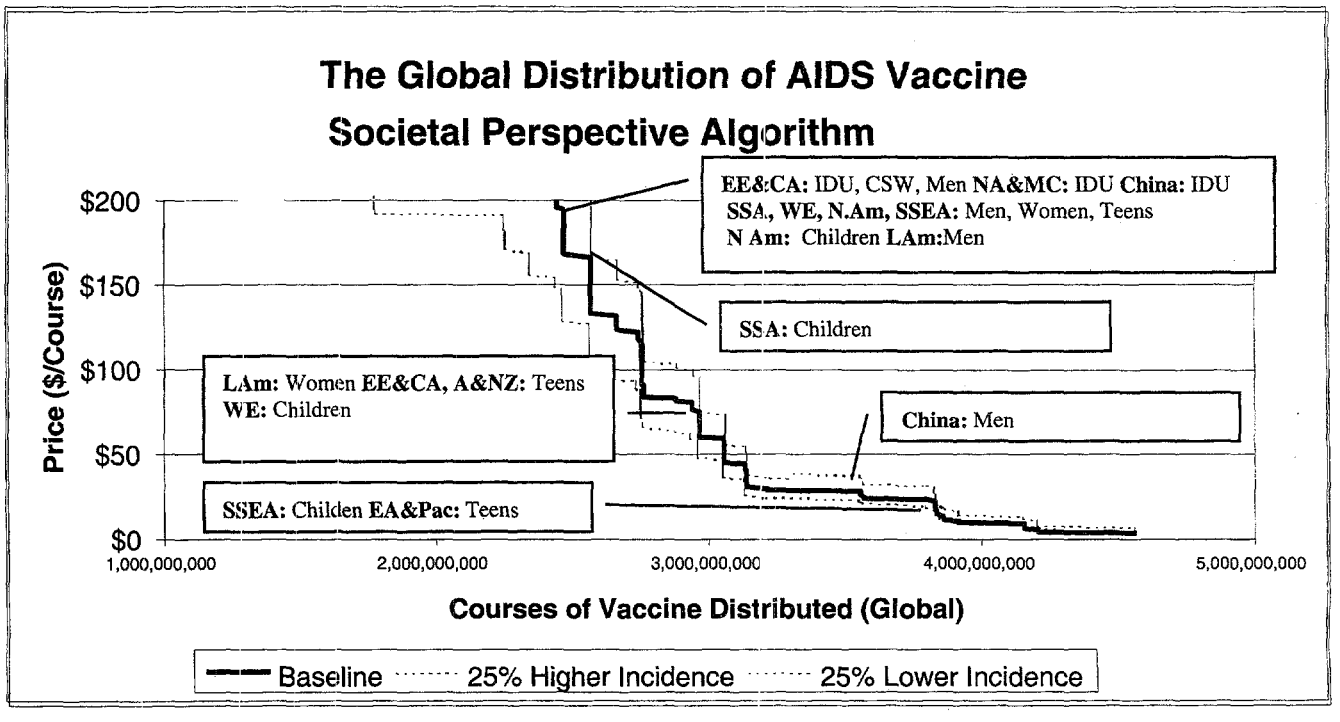


Figure 3. Sensitivity Tests for Vaccine Efficacy based on Health Sector Algorithm. Dotted lines show sensitivity of demand estimates to variation in AIDS Vaccine Efficacy

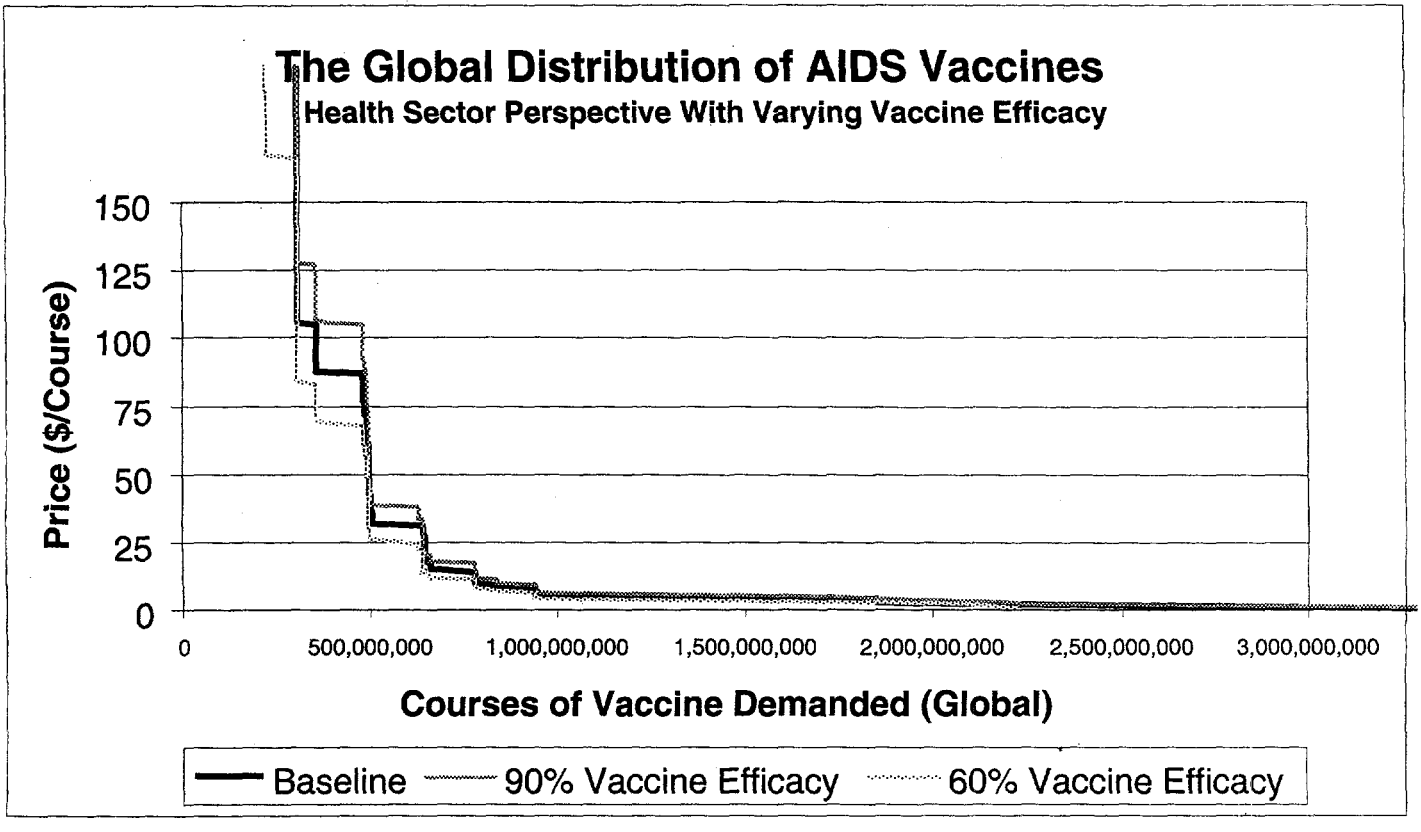
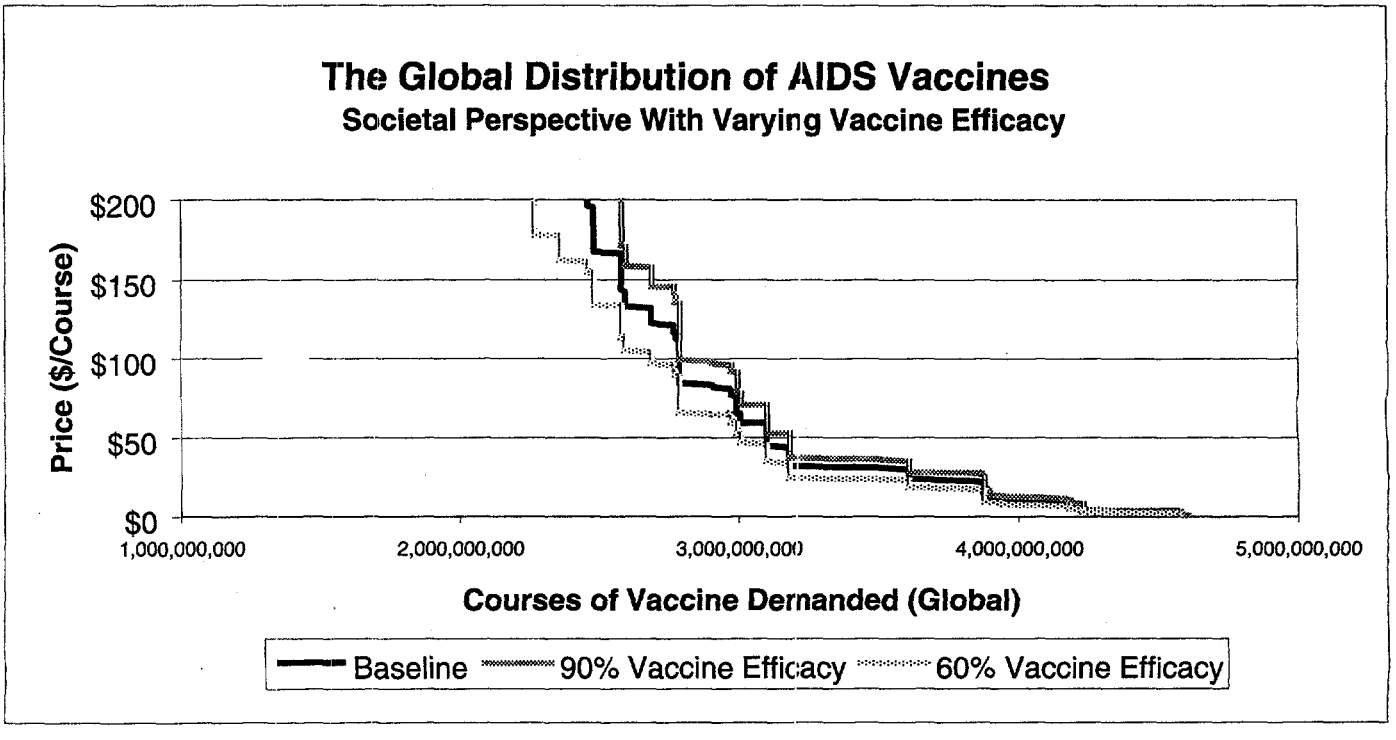


Figure 4. Sensitivity Tests for Vaccine Efficacy based on Societal Algorithm. Dotted lines show sensitivity of demand estimates to variation in AIDS Vaccine Efficacy



Appendix A: Estimating AIDS Incidence over 10 Years by Population Subgroup

We base our incidence rates on UNAIDS estimates for regional populations of the world (Bernard et al. 1998; UNAIDS and WHO 1998b). It is important to point out that the most common identifiable risk factor for HIV/AIDS in most parts of the world is being a heterosexual adult who has had sex with multiple partners or with a partner with multiple partners. In those few areas where the bulk of incident HIV cases have some other identifiable risk factor, attributing UNAIDS incidence estimates to the general population results in an overestimate of risk. Sensitivity analyses show that demand at higher vaccine prices is more sensitive than at prices under $10.00. As improved HIV incidence data are assembled our model will be updated.

Using UNAIDS estimates of incidence rates for adults in the major regions of the world, (Bernard et al. 1998; UNAIDS and WHO 1998b) we make the assumption that the gender ratio of prevalent cases is a good approximation of the gender ratio of incident cases. This assumption is an oversimplification of the complex dynamics of the AIDS epidemic, but it permits us to leverage what we know about prevalence among target groups at the regional level to offer a rough suggestion of annual attack rates in the adult target groups. Sensitivity analyses discussed in the text reveal how important these assumptions are in determining the results of the model.

We assume that annual attack rate in the cohort of age 5-14 is 50% of adult incidence because over the subsequent decade, half of the life years of this cohort will be spent in the age group 15-24.

We assume that incidence for a cohort age 0-4 is exclusively due to mother-child transmission. We use as the probability that the child of a seropositive mother will experience HIV seroconversion prior to age 10 the estimate of 42.8% and the probability that the infection occurred post-natally of 44% (Datta et al. 1994). When we estimate decadal incidence in this group as 42.8% × 44%× HIV Prevalence in Women Age 15-49, we are assuming that births are as frequent for HIV+ as HIV- women although this may not be the case (Gray et al. 1998). Our sensitivity tests cover incidence rates in this cohort that are as much as 25% lower to cover this possibility.

To convert annual attack rates, A_{jt}, to decadal incidence, I_{j10} we use the formula:

$$I_{j10} = \sum_{t=1}^{10} (1 - I_{jt-1}) A_t (1 + r)^t$$

where r is the discount rate. We adopt the approximation that $1-I_{jt-1} \cong 1$. Discounting is necessary because seroconversion t years into the ten year period postpones the costs by t additional years.

Appendix Table A1 shows the source data on attack rates and our estimates of the discounted decadal incidence rates for each group.

Appendix Table A1: Decacal Incidence Rates for General Population by Regional Group

Region[1]	Adult Incidence (Bernard et al. 1998; UNAIDS and WHO 1998b)	Infant/Toddlers (age 0-4)	Children/Teens (age 5-14)	Women (age 15-49)	Men (age 15-49)
	HIV Conversions per 100,000 Person-yrs	HIV Conversions per 100,000 Person-DECADES			
Western Europe	14.56	18.73	57.31	47.75	181.47
North Africa & Middle East	10.35	9.17	43.47	34.77	139.09
Sub-Saharan Africa	1277.76	1,389.04	5,497.43	10,884.91	11,104.81
South & South-East Asia	127.08	59.19	522.64	550.15	1,540.41
Eastern Europe & Central Asia	48.41	7.40	271.10	228.93	855.48
China		2.56	90.14	47.34	313.23
Japan		0.23	87.85	4.28	347.14
Korea		0.56	20.66	10.33	72.30
East Asia & Pacific	21.85	2.45	28.74	45.23	69.71
Australia & New Zealand	5.16	2.30	22.08	5.15	83.17
North America	27.87	40.97	118.77	95.02	380.08
Carribean	268.31	225.51	1,140.54	1,490.30	3,071.85
Latin America	72.90	37.43	312.50	230.77	1,019.22

Estimates of incidence in CSWs, IDUs and MSM are more problematic. Clearly the incidence rates in these populations have been higher than those of the general adult population as reflected in their higher prevalence rates. Assuming that incidence rates and case fatality rates in both the high risk groups and general

population have always both been subject to the exact same historic trends permits the following approximation: $PR=(Prevalence_i / Prevalence_j) \approx IR=(Incidence_i/Incidence_j)$.

Where subscripts ii and j denote two different risk groups.

Although it is doubtful that this assumption holds it does offer us a means of estimating incidence in CSWs, IDUs, and MSM which we can then subject to rigorous sensitivity analysis. Our procedure is to multiply the adult population incidence estimates listed in the table above by the ratio of prevalence in the high risk : prevalence in adult population. These incidence figures are tabulated below. We did not compute incidence for the high risk groups for regions where there was no reason to believe that the regional governments would be able to effectively target the high risk group. In each of these cases the high risk groups are subsumed within the general population. Fortunately for our estimates the population sizes in these groups are small and do not contribute heavily to the overall number of doses of vaccine that are allocated by the algorithm.

Appendix Table A2: Decadal Incidence Rates for High Risk Population by Regional Group

Region	CSWs	MSM	IDUs
Western Europe	0.025933523	0.077320318	0.066087963
North Africa & Middle East	0.001347224	NA	0.022907548
sub-Saharan Africa	0.572075489	NA	NA
South & South-East Asia	0.298604078	NA	0.759622341
Eastern Europe & Central Asia	0.314564878	NA	0.139056759
China	0.009526755	NA	0.316321247
Japan	0.009526755	NA	NA
Korea	0.009526755	NA	0.316321247
East Asia & Pacific	0.009526755	0.181102604	0.316321247
Australia & New Zealand	0.001969122	0.094813205	0.007163664
North America	0.029262008	0.048478849	0.055466791
Carribean	0.271462984	NA	0.276864461
Latin America	0.042856538	0.218260594	0.258267671

Appendix B: Estimating The Medical Costs of AIDS by Region

Because existing estimates of worldwide health care costs for AIDS assume that each AIDS patient consumes the full complement of medical treatments that are standard in that region, they provide an admitted overestimate (Mann, Tarantola and Netter 1992). We adjust these estimates downward by replacing the assumption of full complement utilization by a health care access index. For each region of the world, we compute the access index as the ratio of physicians per capita in region j to the physician per capita ratio in Western Europe. Appendix Table B shows our revised AIDS health care costs for each person-year of AIDS. We inflate the Mann et al. (1992) cost estimates to 1997 dollars using the United States Consumer Price Index for medical care. We are aware that new treatments available, primarily in developed countries, have substantially increased the medical costs in these regions since 1992 and plan to update Table B as estimates of these new treatment costs are produced.

Appendix Table B: Adjusted Medical Costs per Person Year of AIDS by Region

Region	Health Access Index [1]	Cost/Person Year of AIDS, 1990	Cost/Person Year of AIDS $1997 $US [3]	Access Adjusted Medical Cost/Person Year of AIDS in $ 1997
Western Europe	1.00	$22,391	$31,716	$31,716
North Africa & Middle East	0.23	$2,446	$3,465	$809
Sub-Saharan Africa	0.04	$393	$557	$23
South & South-East Asia	0.11	$1,700	$2,408	$267
Eastern Europe, Ctrl. Asia[4]	1.42	$1,520	$2,153	$3,050
East Asia & Pacific excl China, Japan, &S. Korea [2]	0.71	$1,700	$2,408	$1,708
China [2]	0.48	$1,700	$2,408	$1,148
Japan	0.57	$23,160	$32,805	$18,729
Republic of Korea	0.25	$23,160	$32,805	$8,337
Australia & New Zealand	0.77	$14,015	$19,852	$15,193
North America	0.82	$31,995	$45,320	$37,298
Caribbean	0.66	$2,157	$3,055	$2,013
Latin America	0.42	$1,992	$2,822	$1,177

[1] Health Access Index for each region is Physicians per Capita relative to Physicians per Capita in Western Europe

[2] *Applying Mann et al (1992) figure for S. SE Asia*

[3] Adjusted using US Medical Care 1990-98 Inflator=1.42

[4] Central Asia has a surplus of physicians by Western European standards. Whether this translates into increased medical access is unclear.

Appendix C. Number of People in Each Regional Group

In Appendix Table C. Displayed are the numbers of people in each region of the world according to the major age and sex groups considered in the model. Data are from UNAIDS, 1998 (UNAIDS and WHO 1998a) and United Nations, 1997 (United Nations 1997). Data on the numbers of CSWs, IDUs, and MSM in the world are quite limited. Based on the sources listed in Table 1, we make the following assumptions: CSWs make up 0.7% of adult women (age 15-49) in every region of the world, IDUs make up 0.10% of adult men (age 15-49) in every region of the world, and MSM make up 3% of adult men (age 15-49) in every region of the world. Because it is doubtful that MSM and IDUs will be effectively targeted in many regions of the less developed world we simply set the effective population estimate for these groups to zero in the regions noted by "NA" in Appendix Table A2.

Sensitivity analyses indicate that because these high risk groups make up a relatively small proportion of the population facing a risk of HIV/AIDS that the amount of vaccine required is not changed significantly even if we set the size of these populations to zero. However regional policy makers will need to form better estimates of these population's sizes because their high risk makes allocating vaccine to them a priority even at high vaccine prices.

Appendix Table C: Numbers of People In Each Risk Category By Region

	Population Categories					
	Total Population	Children 0-4	Children 5-14	Women 15-49	Men 15-49	Sum of Included Categories
Western Europe	403,603,000	24,010,860	48,021,720	100,565,500	100,565,500	273,163,580
North Africa & Middle East	322,211,000	44,465,118	77,975,062	82,129,500	82,129,500	286,699,180
sub-Saharan Africa	593,027,000	100,221,563	160,710,317	134,219,500	134,219,500	529,370,880
South & South-East Asia	1,859,821,000	228,757,983	420,319,546	477,255,000	477,255,000	1,603,587,529
Eastern Europe & Central Asia	373,424,000	29,500,496	60,121,264	96,692,500	96,692,500	283,006,760
East Asia & Pacific excluding C, J, & K	36,614,000	3,331,874	6,114,538	10,475,000	10,475,000	30,396,412
China	1,243,738,000	104,473,992	222,629,102	352,474,500	352,474,500	1,032,052,094
Japan	125,638,000	7,161,366	13,443,266	30,866,500	30,866,500	82,337,632
Republic of Korea	45,717,000	3,428,775	6,583,248	13,462,500	13,462,500	36,937,023
Australia & New Zealand	21,891,000	1,641,825	3,130,413	5,725,000	5,725,000	16,222,238
North America	301,591,000	22,016,143	43,127,513	78,138,500	78,138,500	221,420,656
Carribean	30,932,000	3,185,996	6,124,536	8,184,000	8,184,000	25,678,532
Latin America	455,247,000	48,711,429	95,146,623	120,741,000	120,741,000	385,340,052
World	5,813,454,000	620,907,420	321,163,447,148	1,510,929,000	1,510,929,000	4,806,212,568

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