HIV and STI epidemiology in high-risk populations in the Netherlands
van Veen, M.G.

Citation for published version (APA):
van Veen, M. G. (2010). HIV and STI epidemiology in high-risk populations in the Netherlands

General rights
It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations
If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: http://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.
Can migrants from high-endemic countries cause new HIV outbreaks among heterosexuals in low-endemic countries?

M. Xioudou, M.G. van Veen, R.A. Coutinho, M. Prins

Centre for Infectious Diseases Control, National Institute of Public Health and the Environment, Bilthoven, the Netherlands; Academic Medical Center, University of Amsterdam, Amsterdam, the Netherlands; Amsterdam Municipal Health Service, Amsterdam, the Netherlands

Objectives: To investigate how the sexual behaviour of migrants originating from HIV-endemic countries affects the spread of HIV among heterosexuals in low-endemic countries.

Methods: A mathematical model is developed describing the transmission of HIV in heterosexual partnerships between African migrants, Caribbean migrants, and local natives. The model accounts for infection of migrants before migration and during trips to their home country. The model is parameterised using data from the Netherlands.

Results: Among new and newly imported, heterosexually acquired, infections in 2010 in the Netherlands, the individual acquiring HIV is an African in 53% of cases, a Caribbean in 26% of cases, and a Dutch native in 21% of cases. The percentage of new infections acquired outside the Netherlands is 40% among African migrants and 32% among Caribbean migrants; these are mostly acquired before migration to the Netherlands. The prevalence of HIV in the Netherlands is hardly affected by changes in risk behaviour of migrants during trips to their home country after migration. If migrants mix more with the Dutch in forming partnerships, then HIV prevalence among migrants will decrease. The more initiating antiviral therapy is delayed among migrants, the higher the resulting prevalence in their own ethnic group and among the Dutch.

Conclusions: The serostatus of individuals migrating to low-prevalence countries as well as their sexual behaviour in the country of residence affect considerably the spread of HIV. Preventive measures should focus on targeted interventions, promoting safe sex practices, HIV testing, and entry to specialized HIV care among migrants.

Keywords: HIV, heterosexuals, migrants, mathematical model, sexual risk behaviour, antiretroviral therapy

Introduction

Individuals originating from HIV-endemic countries comprise a relatively large proportion of heterosexually acquired HIV infections in Europe. Migrants may engage in unsafe sexual practices in their country of residence, but also in their country of origin, while visiting their family and friends. Most partners of migrants are individuals from their own country, but sometimes also natives of their country of residence. If migrants originate from a country with a higher HIV prevalence than that in their country of residence, they may form a bridge population that imports new infections from the high-endemic to the low-endemic country. Furthermore, via their sexual partners in the country of residence, they may spread the infection to the general indigenous population. Molecular studies have shown that indeed import of heterosexual HIV infections from high-endemic countries has occurred. It is imperative, therefore, to understand the contribution of migrants originating from high-endemic countries to the spread of HIV in lower-endemic countries, such that prevention efforts can be targeted at the populations most at risk for infection.

To investigate that, a mathematical model is developed, that describes the formation of heterosexual partnerships between local natives and migrants. The model is parameterised using data from the Netherlands. The heterosexual epidemic in the Netherlands serves as an example of a European country with low HIV prevalence, concentrated mainly in specific risk groups (such as men having sex with men, injecting drug users, and migrants from HIV-endemic countries). In the Netherlands, there are two large groups of migrants from countries with medium to high HIV prevalence: migrants from sub-Saharan Africa and migrants from Suriname, the Netherlands Antilles, and Aruba (former Dutch colonies), comprising 1% and 3% of the adult population, respectively.
CHAPTER 3.4

The prevalence of HIV was estimated at 0.2% in 2005 in the whole Dutch population\textsuperscript{15}, which is lower than that in the Caribbean (1.1%) and in sub-Saharan Africa (5%).\textsuperscript{16,17} We examine to what extent migrants “drive” the epidemic, what fraction of new and prevalent heterosexual infections can be attributed to migrants, and how behavioural and treatment changes among migrants could affect the heterosexual transmission of HIV. The model includes migration of infected individuals and travel-related infection during visits of migrants to their country of origin. We show that public health measures focussing on the sexual risk behaviour of migrants, facilitating HIV testing and access of migrants to antiretroviral therapy can considerably contribute to reducing HIV transmission and the burden of disease in migrant communities.

Methods

The model

In the model, three ethnic groups are distinguished: African migrants, Caribbean migrants, and the remaining “general” Dutch population. The last group will be referred to as Dutch natives to contrast with the group of migrants and includes (i) indigenous Dutch: those who themselves and their parents were born in the Netherlands, (ii) migrants from countries with HIV prevalence lower than that in the Netherlands, and (iii) other small migrant groups (not from Africa or the Caribbean). The group of migrants comprises of first and second generation migrants, meaning those who were themselves or one of their parents born in the specific country. The heterosexual population of the Netherlands is, therefore, stratified into six subgroups, according to gender (male, female) and ethnicity (Dutch, Africans, and Caribbeans). Each of the six subgroups is further divided into five classes, according to HIV status: uninfected, acute HIV infection, chronic HIV infection untreated, pre-AIDS untreated, and HIV treated (see Fig. S1 in Supplemental Digital Content, for a schematic diagram of the model). Among those with chronic HIV, a proportion initiates combination antiretroviral therapy (cART) and progresses to the treated class, while the rest remains in the chronic class and progresses to the pre-AIDS class. From the pre-AIDS and treated classes, individuals may progress to AIDS.

Individuals get infected via unprotected sexual intercourse in the Netherlands. Migrants can also get infected via sexual contacts in their country of origin, while visiting these countries. Some migrants report having concurrent steady partners or casual partners along with a steady partner.\textsuperscript{18} To account for that, we model two kinds of sexual partnerships: main and secondary partnerships. Main partnerships are of long duration with many sexual contacts per partner; secondary partnerships are of shorter duration, with less sexual contacts per partner than main partnerships, and include a second (concurrent) steady partner or casual partners.

The population includes all sexually active adult heterosexuals, 15–69 years old. Dutch heterosexuals enter the population uninfected. Among migrants, a large fraction is born in their country of origin and enter the Netherlands as adults.\textsuperscript{7} Therefore, a fraction of those migrating to the Netherlands is already infected (for simplicity assumed to be with chronic HIV) and the remaining individuals are uninfected.

Data sources and parameter estimates

Parameters relating to sexual behaviour of migrants living in the Netherlands were estimated from data from the “HIV survey among migrants in Amsterdam”\textsuperscript{19}. Parameters relating to sexual behaviour of Dutch natives were estimated using data from two national surveys, the second PIENTER study\textsuperscript{20} and the surveys of the Rutgers Nisso Group.\textsuperscript{21} In the Supplemental Digital Content more information about the data sources and about the parameter estimation is provided. The values of the parameters are summarised in Table 1 and in Tables S1-S3 in the Supplemental Digital Content. These values will be referred to as the basic scenario.

Initial conditions for numerical results

From data from the HIV Monitoring Foundation\textsuperscript{22} the numbers of individuals living with HIV/AIDS and of those receiving cART were estimated for the whole country for each year since the beginning of the epidemic in the Netherlands, in 1980. From these numbers we calculated the percentage of those living with HIV/AIDS receiving cART. This percentage starts increasing from 1996 steadily every year; since 2002, it is around 75–80%.\textsuperscript{23} Because data on sexual behaviour are also for the same time period (2003–2006), we initiated the numerical results at the year 2002. It was assumed that since that year, cART administration has been constant.\textsuperscript{24} The prevalence of HIV among migrants from Suriname and the Netherlands Antilles in the ‘HIV survey among migrants in Amsterdam’ was 0.4% in 2003–04.\textsuperscript{19} The prevalence of HIV among women undergoing standard screening during pregnancy was 0.025% in 2006.\textsuperscript{25} For 2008, the prevalence of HIV in the Netherlands was estimated at 0.2% in the whole population; excluding men having sex with men and splitting the analysis according to ethnic origin of those living in the Netherlands, the
prevalence was estimated at 3.44% among African migrants, 0.35% among Caribbean migrants, and 0.04% in the remaining (mostly) indigenous heterosexual population.\textsuperscript{6} Therefore, for the numerical results the initial prevalence used was 3.5% for Africans, 0.5% for Caribbeans, and 0.05% for Dutch natives.

Results
HIV prevalence among adult heterosexuals
From the model, we calculated the prevalence and incidence during the first 20 years after CART administration reached the current levels (years 2002-2022). The prevalence among Dutch natives (calculated as the number of Dutch infected divided by the total number of Dutch) slightly decreases from 0.050% in 2002 to 0.043% in 2022 (Fig. 1b). Among African migrants the prevalence increases from 3.5% to 4.4%, among Caribbean migrants from 0.5% to 0.7% (Fig. 1a), and in the total heterosexual population from 0.098% to 0.106% (Fig. 1b) in the same period. Among all the infected individuals being alive in 2010, 39% originate from Africa, 17% from the Caribbean, and 44% from the Netherlands.

New (incident) HIV infections
Incidence among adult heterosexuals in 2010 was calculated as 1.50 new infections (occurring via sexual contacts in the Netherlands or during trips of migrants to their home country) per 100,000 individuals per year. Including also those migrating to the Netherlands (in 2010) being already infected, results in a total of 2.11 "new" infections per 100,000 individuals per year (here "new" refers to infections ‘new to the country’, because they are acquired abroad, but they are not necessarily recent infections). Among these "new" infections, 70.3% occurred via sexual contacts in the Netherlands, 0.7% during visits of migrants to their home country, and 29% were individuals who migrated in 2010 to the Netherlands being already infected (Fig. 1c). The individual acquiring HIV was an African migrant in 53% of "new" infections (32% via sex in the Netherlands, 0.5% during trips to home country, and 21% infected before migration); or a Caribbean migrant in 26% of "new" infections (18% via sex in the Netherlands, 0.2% during trips to home country, and 8% infected before migration); or a Dutch native in 21% of "new" infections (Fig. 1c). Among infections via sexual contacts in the Netherlands, in 53% the infectious partner was an African migrant, in 22% a Caribbean migrant, and in 25% a Dutch native (Fig. 1d). One in five newly infected Dutch natives acquired their infection from a migrant and 80% from another Dutch native (Fig. 1e). Finally we investigated whether migrants were mostly infected in the Netherlands or abroad. In 2010, 40% of new infections among African migrants and 32% among Caribbean migrants were acquired outside the Netherlands (see Fig. 52 in Supplemental Digital Content).

Sexual behaviour in country of origin
Since only a few infections occur during trips of migrants to their home country, moderate variations in the factors determining infections abroad have only a minor impact on HIV prevalence in the Netherlands. We calculated HIV prevalence in the different ethnic subpopulations in the Netherlands, under different scenarios for the level of sexual behaviour during trips of migrants to their home country. By increasing, for instance, the number of partners, or decreasing condom use, only minor changes were observed in the prevalence in the Netherlands.

Ethnic mixing in sexual relationships in the Netherlands
We investigated the impact of changing the number of partners of migrants on the prevalence of HIV (see Fig. 53 in Supplemental Digital Content). If Caribbean or African migrants have more partners, the prevalence of HIV increases considerably in their own community, but only slightly in the other ethnic groups. Specifically among Dutch natives and in the total heterosexual population, the prevalence is hardly affected. Decreasing condom use or increasing the frequency of sexual intercourse of migrants have the same effect (results not shown).

Sexual behaviour of migrants while in the Netherlands
We investigated the impact of changing the number of partners of migrants on the prevalence of HIV (see Fig. S3 in Supplemental Digital Content). If Caribbean or African migrants have more partners, the prevalence of HIV increases considerably in their own community, but only slightly in the other ethnic groups. Specifically among Dutch natives and in the total heterosexual population, the prevalence is hardly affected. Decreasing condom use or increasing the frequency of sexual intercourse of migrants have the same effect (results not shown).

Ethnic mixing in sexual relationships in the Netherlands
Figure 2 shows the effect of increasing mixing, such that migrants form more partnerships with Dutch natives and less with individuals of their own ethnic background (the mixing between Africans and Caribbeans was kept as estimated from the data – see Table 1). Looking at the first twenty years of such a change, the prevalence among migrants decreases, while that among the natives slightly increases. This happens because the prevalence among natives is much lower than that among migrants and since more ‘mixed’ partnerships are being formed, it becomes more likely (a) for an infected migrant to have a Dutch partner and spread the infection to the Dutch population rather than to the migrant population and (b) for an uninfected migrant to have a Dutch partner and hence avoid getting infected.
Effect of cART uptake
Migrants frequently appear late to health services for testing or for treatment\textsuperscript{12,25} due to fear of their partners or their community. In addition, several migrant communities suffer from underreporting and/or large number of illegal migrants who do not consult the local health authorities. It is possible, therefore, that the levels of cART administration that we obtained from the HIV registries are rather overoptimistic. In order to investigate the effect of this, we calculated the prevalence of HIV, with lower levels of cART administration and longer interval until initiation of cART among migrants (Fig. 3). For Dutch natives, cART administration was as in the basic scenario (see Table S3 in Supplemental Digital Content). We see here that the higher the fraction of infected migrants not receiving cART and the longer they remain untreated, the higher the resulting prevalence in all ethnic groups. As for the previous results, this change is more profound among migrants. For instance, if 50% of migrants initiate cART one year after infection, then HIV prevalence among African and Caribbean migrants is 3.80% and 0.57%, respectively, but the prevalence is 4.76% and 0.74%, if cART is initiated five years after infection. Among Dutch, there is only a minor change in prevalence (0.043% or 0.044% if cART is initiated one or five years after infection).

Discussion
The present study shows that the heterosexual epidemic in the Netherlands is relatively low and stable, despite the presence of migrant groups from HIV-endemic countries. The epidemic is kept at this level and does not further diminish, partly due to the immigration of individuals being already infected and the relatively high prevalence among migrants living in the Netherlands. Nevertheless, due to the small number of migrants, their relatively moderate sexual risk behaviour and low mixing with the Dutch, migrants cannot easily trigger major rises in HIV among heterosexuals. This can be observed from the fact that behavioural and treatment changes among migrants have a major impact in the migrant communities, but hardly affect the prevalence among Dutch natives. The sexual contacts that migrants have during trips to their home country result in only a very small number of new infections. On the other hand, immigration of infected individuals accounts for a considerable fraction of the current HIV prevalence. Consequently, the sexual behaviour of migrants during trips to their home country hardly affect the heterosexual epidemic in the Netherlands, while their sexual behaviour in the Netherlands has a major impact on HIV prevalence.

Earlier HIV-diagnosis and initiation of cART among migrants can also result in considerable reductions in HIV transmission.

These findings are applicable not only to the Netherlands but other European and high income countries as well. In England, for instance, there are also large migrant communities from sub-Saharan Africa and the Caribbean. In 2007, the prevalence of diagnosed HIV in Black African and Black Caribbean communities in England was estimated at 3.7% and 0.4%, respectively, while among the indigenous population at 0.09%\textsuperscript{21}. In addition, the proportion of late diagnoses was 42% and 27% among African and Caribbean migrants, respectively\textsuperscript{21}. A recent study in the United Kingdom indicated that for 25-33% of infected black-African migrants, the infection was acquired in the United Kingdom\textsuperscript{22}. In Ireland\textsuperscript{23}, high rates of heterosexual HIV transmission among migrants have also been reported. We expect that in other European countries, as for the Netherlands, the travel behaviour of migrants is not important for the heterosexual HIV epidemic, but their sexual risk behaviour in the country of residence is important. In addition, as shown in our study, other European countries also report a large fraction of migrants acquiring their infection before migration to Europe\textsuperscript{24}. Furthermore, our model can be easily used to investigate the spread of HIV among heterosexuals in other countries, by adjusting appropriately the parameters relating to sexual risk behaviour.

The present study can be extended to investigate the impact of other factors relating to migration, such as the changing size of migrant populations (if a country becomes more or less ‘popular’ to migrate to or if stringent policies limit the influx of migrants) and the fact that migrants may stay in a new country only for short periods of time. The model can also be extended to account for the presence of coinfections with other STI and investigate their impact on the spread of HIV. The presence of other STI may increase susceptibility to HIV infection and infectiousness of those with the coinfection\textsuperscript{25}. Migrants from the Caribbean and sub-Saharan Africa living in the Netherlands have been shown to have higher prevalence of STI than the general Dutch population\textsuperscript{26}. Furthermore, it would be interesting to include in the model other risk groups, such as sex workers or injecting drug users, which also ‘mix’ with the general heterosexual Dutch population, and hence could account for a fraction of HIV transmission; the contribution of these risk groups to the heterosexual epidemic in the Netherlands could then be investigated.
Our findings indicate that the heterosexual transmission of HIV in the Netherlands is mainly occurring within migrant communities. Therefore, limiting migration or imposing travel restrictions would hardly affect the prevalence of HIV in the country. Prevention should focus on the sexual behaviour of migrants while in the Netherlands, and less on their behaviour during trips to their home country. Moreover, it is essential to detect those entering the country being infected as soon as possible. Timely initiation of cART is extremely important not only for the infected individual\textsuperscript{5,12}, but also for limiting the spread of HIV to the community.\textsuperscript{6,12} Socioeconomic status, HIV stigma, along with cultural and language barriers might impair the uptake of HIV testing and treatment, and compliance with cART. Policy making should focus on targeted interventions avoiding stigmatization and on facilitating testing and referral of infected migrants to specialized HIV care, in order to reduce the burden of disease in migrant communities.

Acknowledgement
The authors would like to thank the WHO Regional Office for Europe for partially funding this project and in particular Martijn Donoghoe, Annemarie Rinder Stengaard, and Stine Nielsen (currently at the Koch Institute, Berlin) for their assistance and suggestions. The authors are grateful to Liesbeth Mollena and Fiona van der Kils for providing the PIENTER data and to Martijn van Rooyen and Han Fennema (Municipal Health Service Amsterdam) for providing the data from the Anonymous Unlinked HIV Testing Survey in Amsterdam. The authors thank Eline Op de Coul, Merlijn Kramer, and Ingrid van de Broek for information and assistance with the data; Marianne van der Sande, Jacco Wallinga, and Mirjam Kretzschmar for useful comments and suggestions. The anonymous referees are also thanked for several constructive comments that improved the manuscript. The participants of all the studies from which data were used are gratefully acknowledged.

References


For individuals of gender k and ethnicity i, $\pi_{kij}$ is the percentage of their main partners who are of ethnicity j and $\rho_{kij}$ is the percentage of their secondary partners of ethnicity j. In each row of $\pi_{kij}$ and $\rho_{kij}$ values, the first three elements (for males) add to 100% and the last three elements (females) add to 100%. The parameters for Dutch were estimated from the second PINTER study [12] and those for migrants from data from the HIV survey among migrants in Amsterdam [10].

Table 1. Ethnic mixing in sexual partnerships in the Netherlands

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dutch</td>
<td>Africans</td>
</tr>
<tr>
<td>Mixing$^a$ in main partnerships, $\pi_{kij}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dutch</td>
<td>99.7%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Africans</td>
<td>10%</td>
<td>80%</td>
</tr>
<tr>
<td>Caribbeans</td>
<td>21%</td>
<td>2%</td>
</tr>
<tr>
<td>Mixing$^a$ in secondary partnerships, $\rho_{kij}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dutch</td>
<td>99.7%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Africans</td>
<td>22%</td>
<td>50%</td>
</tr>
<tr>
<td>Caribbeans</td>
<td>31%</td>
<td>7%</td>
</tr>
</tbody>
</table>

$^a$For individuals of gender k and ethnicity i, $\pi_{kij}$ is the percentage of their main partners who are of ethnicity j and $\rho_{kij}$ is the percentage of their secondary partners of ethnicity j. In each row of $\pi_{kij}$ and $\rho_{kij}$ values, the first three elements (for males) add to 100% and the last three elements (females) add to 100%. The parameters for Dutch were estimated from the second PINTER study [12] and those for migrants from data from the HIV survey among migrants in Amsterdam [10].
(a) Percentage of African migrants (solid line) and percentage of Caribbean migrants (dashed line) who are infected. (b) Percentage of Dutch natives (solid line) and percentage of the whole adult heterosexual population (dashed line) who are infected. (c) Distribution of all new infections (including those acquired before migration to the Netherlands) in 2010 according to type of infection and ethnicity of the individual acquiring HIV. White: infections via sexual contacts of migrants during trips to their home country; light grey: infections via sexual contacts in the Netherlands; dark grey: infections acquired before migration to the Netherlands. (d) Among all new infections acquired via heterosexual contacts in the Netherlands, the percentage where the infectious partner is an African (solid line), a Caribbean (dashed line), or a Dutch native (dotted line). (e) Percentage of newly infected Dutch who acquired their infection from an African migrant (solid line), a Caribbean migrant (dashed line), or a Dutch native (dotted line). In all plots, the parameters are as shown in Table 1 and Tables S1-S3 in Supplemental Digital Content (basic scenario).
HIV prevalence (%) in 2022: (a) among Dutch natives, (b) among African migrants, (c) among Caribbean migrants, and (d) among all adult heterosexuals. The horizontal axes show the percentage of (main and secondary) partners of migrants with Dutch natives: only mixing of Africans changes (dotted lines), or only mixing of Caribbeans changes (dashed lines), or mixing of all migrants changes (solid lines).

Figure 2. Effect of increasing sexual mixing between Dutch natives and migrants living in the Netherlands.
Figure 3. The impact of combination antiretroviral therapy (cART)

(a) prevalence among Dutch natives, (b) prevalence among African migrants, (c) prevalence among Caribbean migrants, and (d) total prevalence in the Netherlands (NL) in 2022. The horizontal axes show the percentage of migrants initiating cART before progressing to late-stage infection. The three curves are calculated with an interval between infection and cART initiation of 1 year (dotted lines), 3 years (dashed lines), or 5 years (solid lines). The other parameters are as in the basic scenario.
Can migrants originating from high-endemic countries cause new HIV outbreaks among heterosexuals in low-endemic countries?

Maria Xiridou, Maaike van Veen, Roel Coutinho, Maria Prins

Supplemental digital content

Note: Reference numbers in this document are different from those in the main text

S1. Model equations

A schematic diagram of the model is shown in Fig. S1. The population includes all sexually active heterosexuals, 15–69 years old, and is stratified according to gender, ethnicity, and state of HIV infection. Let $Y_{i,k}$ be the number of individuals of gender $k = m,f$ (male, female), ethnicity $i = 1, 2, 3$ (Dutch natives, Africans, and Caribbeans), and HIV state $s = 0, 1, 2, 3, 4$ (uninfected, acute, chronic, pre-AIDS, treated). Let $Y_i = \sum_k Y_{i,k}$ be the total size of the ethnic group $i$. The model is described by the following differential equations, for $i = 1, 2, 3$ and $k = m,f$:

$$\frac{dY_{0i}}{dt} = \frac{1}{4}(1-b_{e,i})Y_i - \mu Y_{0i} - (\lambda_{i,1} + \delta_{i,1})Y_{01i},$$

$$\frac{dY_{1i}}{dt} = (\lambda_{i,1} + \delta_{i,1})Y_{0i} - (\gamma + \mu)Y_{1i},$$

$$\frac{dY_{2i}}{dt} = \frac{1}{4}b_{e,i}\gamma_{i,2}Y_{1i} - [(1 - \tau_{i,2})\delta + \tau_{i,2}\theta_{i,2} + \mu]Y_{2i} + e_{i}Y_{4i},$$

$$\frac{dY_{3i}}{dt} = (1 - \tau_{i,3})\delta Y_{2i} - (\gamma + \mu + \mu_3)Y_{3i},$$

$$\frac{dY_{4i}}{dt} = \mu_4 Y_{3i} + \zeta Y_{5i} - (e + \mu + \mu_4)Y_{4i}.$$

The definitions of the parameters are summarised in Tables S1–S3 and in Table 1 in the main text. The removal rate out of the population for causes not related to HIV/AIDS is $\mu$; this is also the rate at which individuals enter the population, such that the total population remains constant in the absence of the infection. A fraction $b_i$ of migrants is born in their own country (first generation migrants), while a fraction $1 - b_i$ is born in the Netherlands (second generation migrants). Among first generation migrants, a fraction $e_i$ is infected when entering the country. Therefore, in total, a fraction $b_i e_i$ of migrants entering the population is infected at the time of entry (for simplicity assumed all with chronic infection), while a fraction $1 - b_i e_i$ is uninfected. Dutch natives enter the population uninfected. The ratio of men to women among those entering the population (uninfected or infected) is 1.1. The rates at which uninfected individuals get infected from sexual contacts in the Netherlands and abroad are $\lambda_{i,1}$ and $\lambda_{i,2}$, respectively (see following paragraphs). The rate of progression from acute to chronic HIV is $\gamma$, from chronic to pre-AIDS $\delta$, and from pre-AIDS to AIDS and death $\mu_3$. Those progressing to AIDS flow out of the population, to account for the fact that those with AIDS are not sexually active or refrain from unsafe sexual practices. Individuals with chronic HIV infection initiate treatment before progressing to pre-AIDS (after $1/b$ years with chronic infection) with probability $\tau_{i,2}$ or progress to pre-AIDS (without being treated) with probability $1 - \tau_{i,2}$. Also, a fraction of pre-AIDS cases is treated, at a rate $\zeta$. The treatment failure rate is $e_i$; cART usually achieves a reduction in viral load, hence, those failing cART ‘move’ to the chronic phase (and not to pre-AIDS).
S2. Infection from sexual contacts in the Netherlands

The per capita rate of acquiring infection via sexual contacts in the Netherlands, $\lambda_{ki}$, with $k = m, f$ and $i = 1, 2, 3$, is defined apart for contacts with main partners ($\lambda_{k1}^{\text{main}}$) and for contacts with secondary partners ($\lambda_{k2}^{\text{sec}}$) from the formulas

$$\lambda_{ki} = \lambda_{ki}^{\text{main}} + \lambda_{ki}^{\text{sec}},$$

$$\lambda_{k1}^{\text{main}} = \alpha_{k1} \sum_{j=1}^{4} \sum_{i=1}^{4} \left[ 1 - \beta_{k1} Y_{k1}^{(j,i)} \right] Y_{k1}^{(j,i)},$$

$$\lambda_{k2}^{\text{sec}} = \phi_{k2} \sum_{j=1}^{4} \sum_{i=1}^{4} \left[ 1 - \beta_{k2} Y_{k2}^{(j,i)} \right] Y_{k2}^{(j,i)}.$$

Here, $k'$ denotes the gender opposite to $k$ and $\beta_{ki}$ is the per contact transmission probability from an individual at the $s > 0$ state of infection. For main partnerships, we define the following parameters for individuals of gender $k$ and ethnicity $i$: $\alpha_{ki}$ is the average number of main partners per year; $\tau_{ki}$ is the fraction of these partners with individuals of ethnicity $j$; $\alpha_{ki}$ is the frequency of sexual contacts between main partners (of ethnicity $i$ and $j$) in the Netherlands; and $\eta_{ki}$ is the proportion of these contacts that are unprotected. For secondary partnerships, the following parameters are used, for individuals of gender $k$ and ethnicity $i$: $\phi_{ki}$ is the average number of secondary partners per year; $\rho_{ki}$ is the fraction of these partners with individuals of ethnicity $j$; $\alpha_{ki}$ is the frequency of sexual contacts between secondary partners (of ethnicity $i$ and $j$) in the Netherlands; and $\xi_{ki}$ is the proportion of these contacts that are unprotected.

At each moment, the total number of partnerships formed by all men of ethnicity $i$ with women of ethnicity $j$ must be equal to the number of partnerships formed by all women of ethnicity $j$ with men of ethnicity $i$:

$$\pi_{ki} \alpha_{ki} \sum_{j=1}^{4} Y_{k1}^{(j,i)} = \pi_{kj} \alpha_{kj} \sum_{k=1}^{4} Y_{kj}^{(j,i)} \quad \text{and} \quad \rho_{ki} \phi_{ki} \sum_{j=1}^{4} Y_{k1}^{(j,i)} = \rho_{kj} \phi_{kj} \sum_{k=1}^{4} Y_{kj}^{(j,i)},$$

for main and secondary partnerships, respectively. To ensure that this holds, we calculate the “imbalance”

$$D_{ki} = \pi_{ki} \alpha_{ki} \sum_{j=1}^{4} Y_{k1}^{(j,i)} - \pi_{kj} \alpha_{kj} \sum_{k=1}^{4} Y_{kj}^{(j,i)},$$

$$F_{ki} = \rho_{ki} \phi_{ki} \sum_{j=1}^{4} Y_{k1}^{(j,i)} - \rho_{kj} \phi_{kj} \sum_{k=1}^{4} Y_{kj}^{(j,i)},$$

and adjust the rates of partner change as follows

$$\alpha_{ki} \text{ becomes } \alpha_{ki} \beta_{ki}^{\alpha_{ki}^{-1}} \quad \text{and} \quad \alpha_{kj} \text{ becomes } \alpha_{kj} \beta_{kj}^{\alpha_{kj}^{-1}},$$

$$\phi_{ki} \text{ becomes } \phi_{ki} \beta_{ki}^{\phi_{ki}^{-1}} \quad \text{and} \quad \phi_{kj} \text{ becomes } \phi_{kj} \beta_{kj}^{\phi_{kj}^{-1}}.$$

The parameters $v_1$ and $v_2$ determine how much of the imbalance (in the reported partner change rates between men and women) is determined by men or by women: the first one is for main partnerships and the second one for secondary partnerships. In the numerical results we used the values $v_1 = v_2 = 0.5$; this assumes that the imbalance in the reported partner change rates can be equally attributed to ‘overreporting’ by men and ‘underreporting’ by women.
S3. Infection from sexual contacts while visiting country of origin

For migrants the per capita rate of acquiring infection via sexual contacts during visits to their country of origin is defined from the following formula:

\[ \tilde{\lambda}_k = h_k(M_k + S_k)p_i, \quad k = m, f; \quad i = 2, 3, \]

where \( h_k \) is the frequency of travelling to the country of origin of the migrants; \( p_i \) is the prevalence of HIV infection in the specific country; \( M_k = \theta_1 k [1 - (1 - \beta)\tilde{\psi}_k\tilde{\alpha}_k] \) is the transmission probability from main partners per trip; and \( S_k = \theta_2 k \tilde{\xi}_k \tilde{\phi}_k \beta \) is the transmission probability from secondary partners per trip. In the last formulas, \( \theta_1 k \) and \( \theta_2 k \) are the fractions of migrants who engage in sexual intercourse with main and secondary partners respectively during their trips to their home country; \( \tilde{\psi}_k \) is the fraction of sexual contacts with secondary partners that is unprotected and \( \tilde{\phi}_k \) the fraction of contacts with main partners that is unprotected; \( \tilde{\xi}_k \) is the average number of secondary partners per trip; \( \tilde{\alpha}_k \) is the number of sexual acts between main partners per trip. The transmission probability per sexual act, \( \beta \), is the average probability over the whole duration of HIV infection. Infection of Dutch heterosexuals while they are abroad has been shown to be limited [1,2]; therefore, we took \( \tilde{\lambda}_1 = 0. \)

S4. Parameter estimates

Data sources: The "HIV survey among migrants in Amsterdam" is a cross-sectional community-based survey, carried out in 2003-2004 [3]. Participants were included in the survey if they or one of their parents were born in Surinam, the Netherlands Antilles, Aruba, or Ghana, if they were 18-55 years old and living in the Netherlands. Participants were interviewed face-to-face with a questionnaire covering demographic characteristics, sexual behaviour, ethnicity of their sexual partners, and travelling to the country of origin. Data from the participants originating from Surinam, Antilles, and Aruba were used for the parameters relating to the Caribbean subpopulation in the model; data from migrants from Ghana were used to inform the parameters for the African subpopulation. The study on "Sexual Health in the Netherlands" was carried out by the Rutgers-NISSO Group in 2006 [4]. This was a population study with two phases of recruitment via internet panel. For the first phase the respondents were randomly selected. For the second phase respondents were selected non-randomly to achieve a representative sample with regard to demographics: age, gender, education, and ethnicity. The 4170 respondents completed an internet-based questionnaire about demographic characteristics and sexual behaviour. Also behavioural data from the second PIENTER study were used [5]. This is a study aiming to evaluate the effectivity of the current National Immunization Program in the Netherlands. During 2006 and 2007, individuals living in the Netherlands aged up to 80 years old were randomly selected. Blood samples were tested for the presence of several antibodies for infectious diseases. Also a self-completed questionnaire was given; from this questionnaire, data on sexual behaviour were obtained and used in our study for the participants who were at least 15 years old.

Parameters relating to sexual behaviour of migrants in the Netherlands: These parameters were estimated from data from the "HIV survey among migrants in Amsterdam" [3]. The migrants participating in this survey were asked about their sexual partners in the Netherlands: whether they have 'steady' partners, how many 'other' partners they have (if any), frequency of condom use with these partners, and the ethnicity of these partners. The frequency of intercourse between main partners was estimated from data from the study 'Sexual health in the Netherlands' [4]. Among individuals with a main relation, 19% reported having sex at most once per month, 40% reported at most once per week, and 40% reported a few times per week up to daily [6]. These data result in an average of 8.9 sexual contacts per month (106.8 contacts per year).
Parameters relating to sexual behaviour of Dutch natives: The rate of change of main partners for Dutch natives was estimated from the study ‘Sexual Health in the Netherlands’ [4]. When asked about their main or steady relationship, 8% of Dutch heterosexuals reported a duration of less than one year, 22% reported a duration of 1-5 years, and 70% reported a duration of more than five years [4]. From these data we calculated an average rate of partner change of 0.32 per year. The other parameters relating to sexual behaviour of Dutch natives were estimated from data from the second PIENTER study [5]. The participants were asked how many sex partners they had in the previous six months; if they had a ‘steady’ partner; the country of origin of the partners; and frequency of condom use with these partners. Two hundred of the Dutch participants reported having casual partners in the preceding year. Among them, only one had a partner from sub-Saharan Africa or the Caribbean, resulting in 0% mixing of Dutch women with Africans and with Caribbeans, 0% mixing of Dutch men with Caribbeans, and 1.2% mixing of Dutch men with Africans. In addition, 31% of men and 34% of women reported not knowing the ethnicity of their casual partner. Hence, these data were insufficient to assess the ethnicity of the secondary partners of Dutch natives. Other data were not available, to inform these parameters, therefore the mixing of Dutch natives in secondary partnerships was taken equal to that in main partnerships. Other levels of mixing were examined in the sensitivity analysis and the results were robust.

Condom use and frequency of intercourse with secondary partners: For the parameters relating to condom use, we had data on condom use reported by Dutch natives, by Africans, and by Caribbeans ($\xi_1$, and $\psi_1$, for $i=1, 2, 3$, respectively). For mixed partnerships, we took the maximum of the two rates, giving a sort of upper bound for the parameter: $\xi_{ij} = \xi_i = \max(\xi_{1i}, \xi_{2i}, \xi_{3i})$ and $\psi_{ij} = \psi_i = \max(\psi_{1i}, \psi_{2i}, \psi_{3i})$, for $i,j = 1, 2, 3$. For the frequency of intercourse with secondary partners, we could not find any data. Therefore we used the arbitrary value of $\beta_{ij} = 10$ contacts per partner per year for all $i,j = 1, 2, 3$, assuming that these frequencies must be much lower than the respective frequencies for main partners (due to the sorter duration of the relations). Other values for this parameter were examined in sensitivity analysis.

Parameters relating to imported transmissions: The prevalence of HIV in the Netherlands Antilles in 2004 was estimated at 0.8% [7]. In 2007, the prevalence of HIV in Surinam was estimated at 2.4% and in the Caribbean in total at 1.1% [8]. In Ghana, the prevalence of HIV was 1.9% in 2007 and the whole sub-Saharan Africa 5.0% [8]. Based on these estimates, we assumed an aggregate prevalence of 5% in sub-Saharan Africa and 1% in the Caribbean region ($P = 5\%, P_0 = 1\%$). The prevalence of HIV among those migrating to the Netherlands was taken equal to the prevalence among migrants living in the Netherlands ($\alpha_2 = 3.5\%, \alpha_3 = 0.5\%$), in order to avoid creating an increasing or decreasing trend in prevalence due to the prevalence among entrants being higher or lower, respectively, than the prevalence among those already in the country. The other parameters were estimated from the “HIV survey among migrants in Amsterdam”. Participants were asked how many times they travelled to their home country in the last five years and from these data we estimated the number of trips per year per gender. Participants were also asked if they have sexual partners in their home country (a ‘main’ partner and how many ‘other’ partners), and how frequently they used condoms with these partners. Frequency of intercourse between main partners was not asked. Therefore, we calculated the average duration of trips and assumed that individuals having a main partner in their home country have intercourse with this partner twice a week. Hence, the number of sexual acts per trip is equal to twice the average duration (in weeks) of each trip. For instance, Caribbean men reported an average duration of 5.79 weeks per trip to their home country; the number of sexual contacts per trip is then estimated at $2 \times 5.79$.

Effect of cART: Combining data from several European and American Cohorts of individuals on cART, it was estimated that for those on cART aged 20 years, the average life expectancy is 49.4 years [9]. This gives a total life expectancy of at least as long as the sexual lifespan. Also, in the Netherlands it has been shown that for successfully treated individuals, the mortality rates approach those of uninfected individuals [10]. Hence we used a zero excess mortality rate for those on cART ($\mu_{\alpha} = 0$).
References

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Dutch</th>
<th>Africans</th>
<th>Caribbeans</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_k$</td>
<td>Number of main partners per year: Men</td>
<td>0.32</td>
<td>1.00</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>0.32</td>
<td>1.35</td>
<td>0.76</td>
</tr>
<tr>
<td>$\phi_k$</td>
<td>Number of secondary partners per year: Men</td>
<td>0.16</td>
<td>1.44</td>
<td>4.32</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>0.17</td>
<td>0.52</td>
<td>0.82</td>
</tr>
<tr>
<td>$\psi$</td>
<td>Percentage of sexual acts between main partners that are unprotected</td>
<td>88%</td>
<td>57%</td>
<td>74%</td>
</tr>
<tr>
<td>$\xi$</td>
<td>Percentage of secondary partners with whom unprotected intercourse is practiced</td>
<td>43%</td>
<td>24%</td>
<td>33%</td>
</tr>
<tr>
<td>$\alpha_j$</td>
<td>Number of coital acts with main partners per year</td>
<td>107</td>
<td>107</td>
<td>107</td>
</tr>
<tr>
<td>$\hat{\alpha}_j$</td>
<td>Number of coital acts with secondary partners per year</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

* Data sources: $\sigma_k$ and $\alpha_j$ from data from Rutgers-NISSO Group [4,6], $\hat{\alpha}_j$ assumed (see section S4). The other parameters for Dutch natives were estimated from the second PIENTER study [5] and those for migrants from data from the HIV survey among migrants in Amsterdam [3].

* The subscript $k$ denotes gender (male or female) and the subscripts $i$ and $j$ denote ethnicity ($i,j = 1, 2, 3$ for Dutch, Africans, and Caribbeans, respectively).
MODELLING HIV AMONG MIGRANTS

Figure S1. Flow diagram of the course of HIV infection at the individual level. The subscripts denote: $k$ gender (male, female); $i$ ethnicity (Dutch native, African migrant, Caribbean migrant); and $0, 1, 2, 3, 4$ the state of HIV infection.

Figure S2. HIV infections among migrants acquired in or outside the Netherlands. Percentage of new infections in the Netherlands among (a) African migrants and (b) Caribbean migrants who were acquired outside the Netherlands (dark grey) or in the Netherlands (light grey).
Figure S3: Changes of sexual behaviour in the Netherlands. The prevalence of HIV infections in 2022 in different ethnic groups living in the Netherlands (NL): (a) percentage of Dutch natives being infected, (b) percentage of African migrants being infected, (c) percentage of Caribbean migrants being infected, and (d) percentage of the whole adult heterosexual population being infected. The horizontal axis shows the percentage change in the number of main and secondary partners that Africans have in the Netherlands. The three curves were calculated with a 100% increase (solid lines), or 50% increase (dashed lines), or 50% decrease (dotted lines) in the number of partners of Caribbeans in the Netherlands.
**Table S2.** Parameters relating to travelling and sexual behaviour of migrants in their home countrya

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_{AI}$</td>
<td>Number of trips to home country per year</td>
<td>0.32 0.23 0.32 0.30</td>
<td>[14]</td>
</tr>
<tr>
<td>$\theta_{AI}$</td>
<td>Proportion having a main partner during trip, among those who travel to their own country</td>
<td>18% 7% 4% 6%</td>
<td>[14]</td>
</tr>
<tr>
<td>$\theta_{SI}$</td>
<td>Proportion having secondary partners during trip, among those who travel to their own country</td>
<td>18% 9% 34% 5%</td>
<td>[14]</td>
</tr>
<tr>
<td>$\dot{N}_{AI}$</td>
<td>Number of secondary partners per trip, among those reporting secondary partners during visits to home country</td>
<td>2 1 3.7 1</td>
<td></td>
</tr>
<tr>
<td>$\dot{E}_{AI}$</td>
<td>Percentage of sexual acts between main partners (during visits to home country) that are unprotected</td>
<td>30% 50% 20% 58%</td>
<td></td>
</tr>
<tr>
<td>$\dot{E}_{SI}$</td>
<td>Percentage of sexual acts between secondary partners (during visits to home country) that are unprotected</td>
<td>33% 75% 20% 50%</td>
<td></td>
</tr>
<tr>
<td>$d_{AI}$</td>
<td>Frequency of sexual intercourse between main partners per trip to home country</td>
<td>2x6.85 2x6.41 2x5.79 2x5.13</td>
<td></td>
</tr>
<tr>
<td>$\beta$</td>
<td>HIV prevalence in country of origin</td>
<td>5% 5% 1% 1%</td>
<td></td>
</tr>
</tbody>
</table>

a HIV prevalence in country of origin was estimated from [8,7]. The other parameters were estimated from data from the HIV survey among migrants in Amsterdam [3].

**Table S3.** Parameters relating to HIV, antiretroviral therapy, and the population

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_1$</td>
<td>Probability of transmission per coital act: acute HIV</td>
<td>0.0082</td>
<td>[11]</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>Chronic HIV</td>
<td>0.0007</td>
<td>[11]</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>Pre-AIDS</td>
<td>0.0032</td>
<td>[11]</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>Treated</td>
<td>0.00004</td>
<td>[12,13]</td>
</tr>
<tr>
<td>$\beta_{av}$</td>
<td>Average</td>
<td>0.0012</td>
<td>[11]</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Per capita rate of entering and departing the population</td>
<td>0.018</td>
<td></td>
</tr>
<tr>
<td>$b_1$</td>
<td>Fraction of Dutch being born outside the Netherlands</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>$b_2$</td>
<td>Fraction of Africans migrating to the Netherlands</td>
<td>0.69</td>
<td>[14]</td>
</tr>
<tr>
<td>$b_3$</td>
<td>Fraction of Caribbeans migrating to the Netherlands</td>
<td>0.62</td>
<td>[14]</td>
</tr>
<tr>
<td>$\theta_1$</td>
<td>HIV prevalence among Africans migrating to the Netherlands</td>
<td>3.5%</td>
<td></td>
</tr>
<tr>
<td>$\theta_2$</td>
<td>HIV prevalence among Caribbeans migrating to the Netherlands</td>
<td>3.5%</td>
<td></td>
</tr>
<tr>
<td>$\theta_3$</td>
<td>Average duration of: acute HIV infection</td>
<td>2 months</td>
<td>[11]</td>
</tr>
<tr>
<td>$\theta_4$</td>
<td>Chronic HIV for those untreated</td>
<td>8 years</td>
<td>[16,17]</td>
</tr>
<tr>
<td>$\theta_5$</td>
<td>Chronic HIV until initiation of cART</td>
<td>3 years</td>
<td>[11]</td>
</tr>
<tr>
<td>$\theta_6$</td>
<td>Pre-AIDS stage, if untreated</td>
<td>1.5 year</td>
<td>[11]</td>
</tr>
<tr>
<td>$\theta_7$</td>
<td>Pre-AIDS until initiation of cART</td>
<td>1 month</td>
<td></td>
</tr>
<tr>
<td>$\theta_8$</td>
<td>During chronic HIV, initiate cART before pre-AIDS</td>
<td>0.5%</td>
<td></td>
</tr>
<tr>
<td>$\psi_1$</td>
<td>Rate of stopping cART</td>
<td>0.1/year</td>
<td>[11]</td>
</tr>
<tr>
<td>$\psi_2$</td>
<td>Rate of developing AIDS for those treated</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>$\psi_3$</td>
<td>Rate of developing AIDS for those not treated</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>$\psi_4$</td>
<td>Total number of Dutch natives</td>
<td>11,035,000</td>
<td>[19]</td>
</tr>
<tr>
<td>$\psi_5$</td>
<td>Total number of Africans living in the Netherlands</td>
<td>116,000</td>
<td>[19]</td>
</tr>
<tr>
<td>$\psi_6$</td>
<td>Total number of Caribbeans living in the Netherlands</td>
<td>355,000</td>
<td>[19]</td>
</tr>
</tbody>
</table>

a The subscripts m and f denote gender male and female; the subscript i denotes ethnicity.

b Accounting for 55 years of sexual lifespan (ages 15-69 years).

c Assumption.

d Based on assumption that HIV prevalence among those migrating to the Netherlands is equal to the prevalence among migrants living in the Netherlands.

e For those with chronic HIV infection, this is expressed as the probability to initiate combination antiretroviral therapy (cART) before progressing to pre-AIDS.

f Size of the respective adult population (ages 15-69 years). Male to female ratio is 1:1.