Institution: University of Oxford

Unit of Assessment: 10 – Mathematical Sciences

Title of case study:

Influencing Indian Government policy through mathematical modelling of the HIV/AIDS epidemic in India

1. Summary of the impact

Research at Oxford University directly influenced Indian Government policy through its projections of the population of HIV/AIDS sufferers in India under several possible strategic interventions. It formed a central part of the policy documents and presentations of the Indian National AIDS Control Programme (NACP) Planning Team, and was presented to Indian Government officials in 2006 in order to plan the third phase of the control programme, NACP III (2006-2011). The projected HIV/AIDS populations then served as a reference for mid-term evaluations of NACP III in 2009. The study was used to measure the impact of the intervention programs, and acted as a source of reference during the planning of the next phase, NACP IV (2012-17).

2. Underpinning research

After two phases of AIDS control activities in India, the third phase, NACP III, was launched in July 2007. Professor Philip Maini, permanent faculty member of the Mathematical Institute, University of Oxford since 1990, was a key member of an international multidisciplinary research team who developed a mathematical model [1] with the purpose of predicting the number of people living with HIV/AIDS in India to assist the NACP III planning team in determining appropriate strategies for targeting groups during the project period.

As part of the planning of NACP III, Dr Arni Rao (Indian Statistical Institute, Kolkata) was commissioned by members of the NACP Planning Team to provide predictions of the effectiveness of various HIV/AIDS strategies. To complement existing statistical approaches, Dr Rao visited Prof Maini at Oxford University's Centre for Mathematical Biology who provided the necessary mathematical modelling capability for the programme [1]. An example of the results from this modelling is given in Figure 1.

The research involved constructing dynamical models which capture the mixing patterns between susceptibles and infectives in both low-risk and high-risk groups in the population. The aim was to project forward the HIV estimates by taking into account general interventions for susceptibles, targeted interventions among high risk groups, the provision of anti-retroviral therapy, and behaviour change among HIV-positive individuals. The standard compartmental model framework was extended and adapted to account for possible interactions between different categories of risk behaviour amongst male and females, sex workers, intravenous drug users, and blood transfusion recipients. The resulting system of coupled nonlinear ordinary differential equations was extensively analysed by numerical simulation and validated against existing data for disease spread in various states in India. The model parameters were determined by various means including literature searches, fitting of submodels to specific data, and de-convolution methods. A sensitivity analysis of the parameters was also carried out. The model was then interrogated to compare the effects of different control and intervention strategies. The model projections based on the NACP II and III scenarios indicated that prevention programmes which were directed towards the general and high-risk populations, as well as HIV-positive individuals, would be key in determining the decline or stabilization of the epidemic.

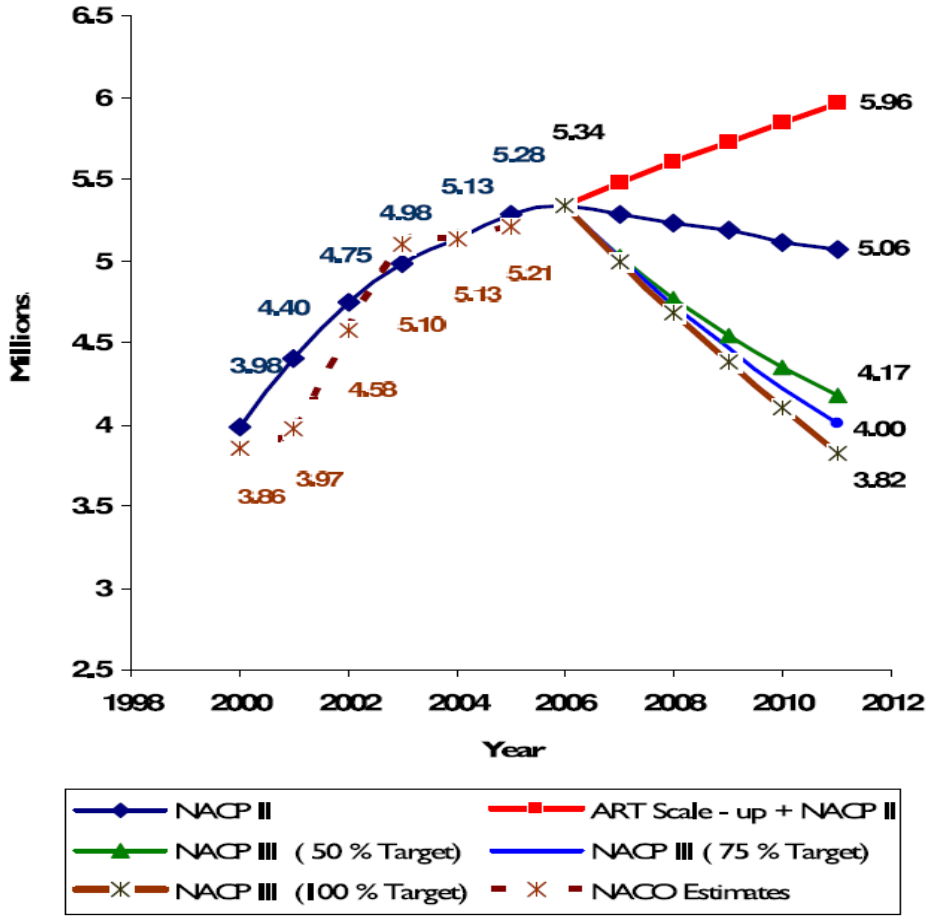

Figure 1. Projections based on the mathematical model for the number of people living with HIV/AIDS. Five sets of projections for HIV estimates, using different strategies, are shown based on revised estimates by NACO released in 2007. Reproduced from Fig 6 [1] and used as Fig 2.7 [2].

3. References to the research

*[1] Rao, A.S.R.S., Thomas, K., Sudhakar, K. and Maini, P.K. (2009), HIV/Aids epidemic in India and predicting the impact of the national response: mathematical modeling and analysis. *Mathematical Biosciences & Engineering* **6**, 4, pp. 779-813. doi: 10.3934/mbe.2009.6.779

The asterisked output best indicates the quality of the underpinning research. Mathematical Biosciences & Engineering is an international refereed journal.

4. Details of the impact

The impact of the research falls into the category of better informed public policy-making and the beneficiaries are the Indian Government and people living with HIV/AIDS in India.

The HIV epidemic has been evolving in India since the first detected case in 1986 and India is among the top three countries in the world in terms of HIV burden. As a result, there has been sustained activity from the Indian Government to implement effective control and prevention strategies. From 1998 to 2005 the number of people living with HIV/AIDS rose from an estimated 3.5 million to 5.206 million with significant variations from state to state. After two initial stages of control activities, NACP III was launched in 2006 for a 5 year period with the goal of reducing new infections by 60-80 percent in different regions in India.

Pathway from Research to Impact:

The research carried out by Maini and his colleagues had a direct impact on the Indian Government strategy for NAPC III. One of the novel features of the modelling approach was to incorporate the effects of preventive measures on people already infected with HIV. For example, the modelling showed that treatment with anti-retroviral therapy could actually increase HIV prevalence because it would prolong the life of those infected with HIV, potentially leading to them passing on the disease. The research considered a number of levels of future responses which were being proposed by the Indian Government, and made predictions about the number of people living with HIV/AIDS in each case.

Maini helped to formulate the model and to lay down the plan of model validation and interrogation, and then assisted in the interpretation of results. In particular two figures (3 and 6) and tabular data in [1] were used for the Strategy and Implementation Plan [A] (and appear explicitly as figures 2.4 and 2.7 in that document) as part of the NACP III for the period 2007-12. Figure 2.7 in [A] is shown above as Figure 1. Through collaborations during the period 2005-2012 Maini's role was pivotal in extending the model building to enable further strategies to be considered which accounted for variations in behaviour on a district level [B], and the effects of anti-retroviral therapy [A], in addition to the published work [1]. A member of the NACP III and IV planning teams (and co-author of [1]) reports [C] that "*The output of these models were used extensively in finalizing the implementation plans for the country.* […] *We are grateful to Professor Maini and Dr Rao for their continued assistance in guiding these policy decisions and their contribution to enabling scenarios to be assessed and results to be evaluated and help those working in these difficult areas*".

In addition to presentation directly into the NACP the research work was circulated more widely into Indian AIDS prevention activities [eg D,E]. It was presented at a collaborative meeting between the Indian Clinical Epidemiology Network, a network of academic health care researchers across 135 Medical colleges/Institutions in India, and the Indian Statistical Institute, Kolkata, which was providing technical assistance to NACP. It also formed part of a Capacity Building Workshop on Operations Research in HIV/AIDS for the Northeast States during September 2010. The research was further disseminated through activities of the Postgraduate Institute of Medical Education and Research School of Public Health, first at a Technical meeting in June/July 2009, and then in their School of Public Health Impact Study in June 2010, and also at the Indian Council for Medical Research Institute in Kolkata in December 2009.

The direct impact of the research was facilitated by two of the co-authors of [1] who were members of the NACP III planning team. The work formed the cornerstone of documents and presentations produced by this team, including predictions directly from the paper [1], forming a central element of the Strategy and Implementation Plan [A].

Nature and Extent of the Impact

One of the key outcomes from the research was to influence the recommendation in the Strategy and Implementation Plan [A] based around the groups modelled as high risk, specifically commercial sex workers, injecting drug users and men having sex with men. In 2007, the model projections indicated that, should the interventions of NACP II be continued, there would be 2.08 million people living with HIV/AIDS by the end of 2011. This value is very close to the data for 2011 released by the Indian Ministry of Health in 2012 showing the number of people living with HIV/AIDS was 2,088,642. Subsequently the model predictions helped inform the mid-term review of the NACP III plan initiated by the National AIDS Control Organisation (NACO) of the Ministry of Health in 2009. The mathematical model predictions, including using the model to predict AIDS levels at a district level [B], exploited data collected by the NACO from May 2009 until the beginning of 2011. These predictions were presented in 2011 [F] to the Director General of NACO and the Heads of Department and then to the NACO All Stake Holder meeting, and served as a source of reference in developing the follow-on programme NACP IV (2012-17). In particular, a member of the NACP planning team at the time (and co-author of [1]) reports [C] that "*This model was used in quantifying the benefit and impact of different intervention of NACP lll in 2009 and prioritizing the programs for NACP IV during 2012. Different scenarios were considered and presented by the team at meetings of relevant Indian Government Health Department ministers*

with great effect. As a consequence of this input government decided to extend full support for the program during the next 5 years in spite of pressure from many quarters to scale down the interventions due to competing priorities. Resulting policy proved that the planned interventions to be [sic] *very effective with AIDS prevalence in India reducing from 23.95 lakh* [hundred thousand] *in 2009 to current level of 20.89 lakh*."

The success of this modelling study has resulted in Dr Rao being invited to serve on the planning team for AIDS policy for the fourth phase (2012-2017). Maini, who serves the planning team as a consultant, continues to provide crucial input in relation to model formulation and papers presented to government.

5. Sources to corroborate the impact

[A] National AIDS Control Programme, Phase III 2006 - 2011: Strategy and Implementation Plan (2006), which can be found at:

http://aidsdatahub.org/dmdocuments/India_Strategy_and_Implementation_Plan_NACO_Programme_PhaseIII_2006_2011.pdf.pdf

Copy held by the University of Oxford.

[B] District Level Mathematical Modeling of HIV/AIDS in Tamil Nadu, September 2010, submitted to Project Director, AIDS Prevention and Control Project, The Voluntary Health Services, Taramani, Chennai 600113, INDIA. Copy held by the University of Oxford.

[C] Letter from a Member of the NACP III and IV Planning Teams (and co-author of paper [1], current Director of Research at the Oman Medical Speciality Board) confirming the pathway to impact and the significance. Copy held by the University of Oxford .

[D] Copy of email from the National AIDS Control Organisation to Dr Rao requesting he presents the model and its results to the "Dissemination on HIV/AIDS Research 19-21 Jan 2011", held by the University of Oxford.

[E] Copy of email inviting Dr Rao to attend the Advisory Committee Meeting of India Impact Study at NACO on 1 Oct 09, held by the University of Oxford.

[F] Powerpoint presentation by one of the authors of [1] to the Director General of the National AIDS Control Organisation and the Heads of Department, and to the National AIDS Control Organisation All Stake Holder meeting while preparing for NACP IV. Copy held by the University of Oxford.