Statistical tests of the assumptions behind Respondent Driven Sampling in a survey of female sex workers in Shanghai

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Introduction

With the exception of sub-Saharan Africa, the HIV/AIDS epidemic remains concentrated in critical sub-populations for which standard survey sampling strategies fail because the target populations cannot be accessed through well-defined sampling frames [18]. These sub-populations have been described as "most at risk" by the UNAIDS/World Health Organization 2008 Report on the Global AIDS Epidemic [19]. From the perspective of public health monitoring, these high-risk groups are often referred to as "hidden populations" because of the difficulty of obtaining representative samples. Examples of these hidden and high-risk populations include intravenous drug users (IDUs), men who have sex with men (MSM), sex-workers (SW) and the sexual partners of these groups. The critical role of such hidden groups in the HIV/AIDS epidemic was recently dramatized in a highly publicized CDC report that revised HIV infection rates within the United States upwards by 40% [3]. In that report, infections amongst just two hidden populations (MSM, IDUs) accounted for 69% of 53,600 new HIV infections in the US during 2006.

Researchers studying hidden populations are typically forced to use non-standard survey techniques such as time-location sampling, network sampling or variants of chain referral sampling [18, 14, 12]. This paper focuses on empirical assessments of the validity of one such

method, Respondent Driven Sampling (RDS). Specifically we examine whether or not critical assumptions required by the RDS methodology are met in the context of a survey of female sex-workers (FSW) in Shanghai. This work is a component of a larger project titled Sexual Behavior, Sexual Networks and STDs in China (Merli, PI) which focuses on the social and behavioral determinants of HIV and other STDs in China, given a background of rapidly changing social norms and behaviors, a rising incidence of STDs and concerns that HIV will soon spread from high risk groups to the general population.

The RDS methodology was first developed by Heckathorn *et al.* [5, 6, 17, 20, 7] as a means of recruiting survey respondents and making point-estimates of the prevalence of discrete characteristics of hidden populations. Typical examples of the characteristics of interest in RDS studies are HIV infection status or behaviors associated with risk of HIV infection. In place of the standard survey methodology of drawing independent selections from a sampling frame, RDS generates a sample of dependent observations by using social connections between respondents. Starting with a small group of seed respondents, respondents are asked to refer new participants to the study in successive waves until a target sample size has been obtained. Because a sample obtained in this manner necessarily reflects properties of the sampling process, the RDS methodology uses information about network sizes and linkages between recruiters and their recruits as a basis for adjusting for sampling biases. From a qualitative perspective, RDS samples are frequently praised by researchers because recruiting respondents through social connections produces a more diverse sample than alternative techniques such as Time Location Sampling (TLS) [4, 13, 16]. From the perspective of quantitative science, the greatest strength of RDS is that it allows researchers to make point-estimates of population proportions in the absence of a sampling frame. The cost of using RDS to make such estimates is that one must be able to make explicit assumptions about critical aspects of the chain-referral process. In this paper we focus on evaluating three of these assumptions.

1. **Non-preferential recruitment**: respondents refer new recruits into the study without preference amongst their acquaintances.

2. **Reciprocity**: relationships between recruiters and recruitees are reciprocal, in other terms the long run probability that a referral occurs between any pair of potential respondents does not depend upon which member of the pair is the recruiter and which is the recruitee.

3. **Rapid mixing**: the chain referral process converges to its stationary distribution so quickly that we may treat the entire sample, with the exception of the initial wave of recruits, as if it arises from this distribution.

These three assumptions imply that the patterns of recruitment found in a RDS survey must follow a restrictive class of statistical models. By comparing the observed pattern of recruitment with the patterns required by these statistical models we develop rigorous statistical tests for whether or not the assumptions required by the RDS methodology are met.

The FSW population in Shanghai provides a particularly valuable context in which to assess the RDS assumptions. This population is typical of the types of the target groups to which RDS has been applied in the sense that prostitution is both illegal and highly stigmatized. Furthermore, sex-work in China occurs in a wide variety of public and semi-public venues such as karaoke bars, coffee shops, beauty and massage parlors, or from the halls of hotels where FSWs contact potential clients by calling their rooms directly [9, 8, 15].

FSWs may also work entirely outside of any of these fixed venues by working as escorts who accompany clients for a fixed duration, or as "second wives" of men with money and influential positions, or outside of public view in the street or in parks. This diversity of venues and circumstances under which sex-work occurs in China leads to a high degree of social stratification amongst the population of FSWs which may produce differences in preventive and risky sexual behavior. It is expected that this complex social context will be represented in the pattern of RDS recruitment between social tiers and risk groups. Thus we will be able to evaluate whether or not the RDS assumptions are valid from the point of view an empirical descriptive analysis of the survey data as well as by the use of statistical inference.

Data

Between September and December 2007, the RDS approach was used to recruit female sex workers in Shanghai for a cross-sectional survey of behavioral and socio-demographic factors associated with STD infection. Recruitment for the FSW survey started with 7 seeds selected from the clients of the local CDC offices by survey staff. Seeds were stratified by type of venue, on the hypothesis that type of venue is associated with socioeconomic status and preventive or risky behaviors. Seeds were given three uniquely coded coupons with which they were instructed to recruit up to three survey participants through their social networks. Recruits were in turn instructed to recruit other participants until the target sample size of 520 respondents was reached. All respondents provided informed consent, anonymous interviews and a urine sample for testing of Chlamydia and gonorrhea. Each received 100 Chinese Yuan for the interview and an additional 100 Yuan for each of her successful recruitments. Formative research was conducted prior to the fielding of the survey to assess the appropriate incentive level.

The questionnaires used to measure socio-demographic characteristics and HIV/STD-related risk behaviors were largely based on the RDS module provided by investigators who employed RDS to recruit female sex workers in Vietnam [11] and on the FSW module of the Family Health International Behavioral Surveillance Surveys [10]. An additional set of questions on the reasons for sex work was introduced as part of this study. Recruiters were asked to return to the interview site to collect their incentives. On this occasion they were administered a brief follow-up questionnaire to assess the basic socio-demographic characteristics, place of work, and condom use of their recruits and type and strength of relationship with their recruits. These questions were designed to mirror questions asked of respondents in the main questionnaire so as to provide a check of consistency between reports of recruiters and recruits and assess the reciprocity assumption. Similar questions were also asked of the recruiters network members who turned down the invitation to participate and, as a variation of the usual RDS practice, of members whom she did not invite to participate. Information on respondents entire social network was obtained to shed light on the assumption of non-preferential recruitment.

Analysis

The assumptions required by the RDS methodology imply that the observed patterns of recruitment across any subdivision of the target population will follow a restrictive class of

statistical models. Specifically, suppose that the target population can be divided into two disjoint sub-populations A and $B = A^c$, *i.e* assume that every member of population is in either group A or B and nobody is in both groups. The assumption of rapid mixing implies that observed group transitions will follow a first-order Markov model. What this means is that the probability of transition between or within groups will depend only on the characteristics of the recruiter and recruitee, but will be independent of the characteristics of respondents appearing earlier in the data collection process. For example, if a respondent is a member of group A, then the first order Markov model states that the probability that this respondent will recruit a member of group B only depends on the respective group memberships of recruitee and recruiter. By using classical results on statistical inference for Markov models we can test whether or not there is evidence for or against such a model, and thus we can test whether or not the assumption of rapid mixing assumption is reasonable [1, 2].

In a similar manner, the assumptions of rapid mixing, non-preferential recruitment and reciprocity together imply that the counts of recruitments from group A to group B, and from group B to group A will depend solely on the relative sizes of the two groups and the number of social connections between them. Conditional on the sizes of the groups A and B, this implies that recruitment counts will follow a multinomial model whose means reflect this relationship. As in the case of the Markov model, we use classical inferential techniques to construct statistical tests for violations of this model.

Conclusion

By combining statistical models with an empirical descriptive analysis of our survey data we present an analysis of RDS as a sampling tool for studying the FSW population in Shanghai. Given the current popularity of RDS as a recruitment tool for studying hidden and hard-to-reach populations, we believe that a careful and critical investigation of the assumptions upon which this method is founded must be a routine part of any study using RDS. It is our hope that the analysis presented here will provide a partial template for examinations of the assumptions behind RDS in other contexts.

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